SITE STABILIZATION
and
CLOSURE PLAN
for
LOW-LEVEL RADIOACTIVE WASTE MANAGEMENT FACILITY
US ECOLOGY, INC.
BEATTY, NEVADA

RADIOACTIVE MATERIALS LICENSE
STATE of NEVADA
NO. 13-11-0043-02

REVISION NO. 1
SEPTEMBER, 1992

USEcology, Inc.
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USEcology

an *American Ecology* company

September 28, 1992

Mr. John Vaden, Manager
Low-Level Waste Project
Bureau of Regulatory Health Services
State of Nevada
505 East King Street, Room 101
Carson City, Nevada 89710

Dear Mr. Vaden:

The purpose of this letter is to file a license renewal application for the Nevada State Health Division Radioactive Material License No. 13-11-0043-02, in accordance with NAC 459.820. Please find attached to this letter two copies of the complete submittal for license renewal as defined in NAC 459.820.

Included as part of this submittal is the Beatty Facility Standards Manual, the Beatty Contingency Plan and the Beatty Operational Procedures. US Ecology is proposing no changes in the operations to be conducted at the Beatty Low-Level Radioactive Waste (LLRW) Disposal Facility and thus feels that these existing documents should remain the same. US Ecology is seeking only to continue current operations beyond 1992. Two changes have been made to the enclosed Facility Standards Manual; the license application date has been revised and the address of American Ecology has been updated.

A revised Site Stabilization and Closure Plan is also included with this submittal. The Site Stabilization and Closure Plan was revised to reflect more recent data, studies and information that has become available. US Ecology is not proposing any technical changes to the State approved 1989 Site Stabilization and Closure Plan for the Beatty LLRW Disposal Facility.

We will be glad to provide any additional copies that you may need during the review process. If there are any additional questions or concerns, please feel free to address them to my attention.

Sincerely,

Richard E. Sauer

Richard E. Sauer
Vice President

RES:njc
Atts.

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The December 1989 "Beatty, Nevada Low Level Radioactive Waste Disposal Facility Stabilization and Closure Plan was approved by Nevada Division of Health. That approved plan is being revised to reflect updated information dealing with geology, site contours, closure costs and long term care funding. Similarily, this Closure Plan is in response to the Facility Lease Agreement Closure requirements and Radioactive Material License Closure requirements.

Lessee agrees to perform the following activities in accordance with the Lease Agreement between US Ecology and State of Nevada, Item XVIII, dated May 1, 1977:

(1) "burial of all radioactive;"

Covered by Objective 2, Section 5.0

(2) "removal of all surface structures and equipment except lighting equipment, fences and gates;"

Covered by Objective 2, Section 5.0

(3) "all equipment and facilities which cannot be released by radiation survey after decontamination will be disposed of, or transported from the Site, as radioactive material;"

Covered by Objective 2, Section 5.0

(4) "backfilling and mounding of all open trenches, without exception, in accordance with radioactive material license requirements;"

Covered by Objective 2, Section 5.0; Objective 4, Section 8.0; and Objective 8, Section 12.0

(5) "reduction of radiation levels to 2 mR/hr at ground level within radioactive burial area;"

Covered by Objective 4, Section 8.0

(6) "plugging and capping water wells and dry wells;"

Covered by Objective 5, Section 9.0

(7) "the East access gate to the radiological burial facility will be sealed shut;"

Covered by Objective 13, Section 17.0

(8) "installing alarms on all remaining gates which will activate in Deputy Sheriff's office in Beatty when gate is opened;"

Covered by Objective 12, Section 16.0

(9) "replacement of faulty or damaged fencing;"

Covered by Objective 13, Section 17.0

(10) "replacement of any illegible or damaged warning signs;" and

Covered by Objective 13, Section 17.0

(11) "final radiation survey and written report to LESSOR which is confirmed by LESSOR.

Covered by Objective 4, Section 8.0

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BEATTY, NEVADA LOW-LEVEL RADIOACTIVE
WASTE DISPOSAL
STABILIZATION AND CLOSURE PLAN

1.0 GENERAL

The "Beatty, Nevada Low-Level Radioactive Waste (LLRW) Disposal Stabilization and Closure Plan," herein referred to as "Closure Plan," is the document that will provide specific site requirements to assure that the facility is closed in accordance with the state of Nevada Radioactive Materials License 13-11-0043-02, Amendment 14 and the Lease Agreement between the state of Nevada, Department of Human Resources and US Ecology, Inc.

The Closure Plan also provides an operational plan to assure that the waste materials which were disposed of during the operational phase of the facility continue to remain in a suitable, stable and safe condition, thus allowing for minimal maintenance on the part of the custodial agent during the custodial care period. Facility closure is an integral part of each radiological work procedure and operational procedure used throughout the operational phase of the facility. Therefore, the prime objective of the environmental monitoring program, receipt and burial procedures, and the procedures utilized to construct, fill, stabilize and cap the burial trenches, is to assure that the individual disposal units, and the facility as a whole, meet the pertinent requirements for the protection of the public during the necessary custodial care period.

2.0 FACILITY CHARACTERISTICS

2.1 Description of Facility

The Beatty LLRW Disposal Facility is owned by the State of Nevada, and is leased to and operated by US Ecology, Inc., which, prior to January 1, 1981, was known as Nuclear Engineering Company, Inc. Operations began at the facility in October 1962. The total acreage leased by the State to US Ecology covers approximately 80 acres, however, only approximately 40 acres are dedicated to the disposal of LLRW. The remaining part is utilized for the disposal of hazardous chemical and toxic wastes under EPA Permit No. NVT 330010000, but is separated from the LLRW disposal facility by a 7-acre, 200-foot-wide, non-disposal-use buffer zone. A topographic map showing the site plan configuration of the two disposal areas and the buffer zone is shown in Attachment 1. The hazardous waste management (RCRA) facility is approximately 33 acres in size and has been licensed since 1970. The HWMF also has been approved for disposal of PCB's since 1978.

The LLRW disposal facility is located in Nye County, Nevada, Latitude N 36°46'09", Longitude W 116°41'23", approximately 11 miles south of Beatty, in the Amargosa Desert. It is surrounded by federally-owned land administered by the Bureau of Land Management (BLM) as rangeland. The ten 1/4, 1/4 sections (40 acre square plots) which abut the site boundary are leased by BLM Recreation or Public Purpose Lease Number Nev. 057750 Renewal, to the state of Nevada for use as a buffer zone. The width of this buffer zone, therefore, is the width of a 1/4, 1/4 section, approximately 1320 feet. A topographic map showing the facility and surrounding area is shown in Attachment 2.

The closing of the LLRW disposal facility and closing of the hazardous chemical waste landfill are not expected to happen concurrently. A different set of regulatory criteria and economic conditions will determine when each facility will undergo closure.

The chemical operations are expected to continue until the permitted area is filled or when economic and regulatory factors adversely affect the economic viability of the chemical disposal operations. The differing factors which affect the two operations make it unlikely that the sites will close concurrently.

2.2 Climate

The US Ecology Beatty facility is located in the Amargosa Desert, an arid basin within the Basin and Range physiographic province of North America. Such basins, in general, experience high evaporative demands and very little precipitation. The amount of snow and rainfall that does take place varies considerably within each basin, and is primarily dependent on elevation.

Summer precipitation takes the form of brief and very localized thunderstorms. Often, conditions on the basin floor are so extreme that rain from these storms is evaporated before reaching the ground. Winter precipitation is more widespread, resulting from frontal systems penetrating eastward from the California coast. Winter rain or snow will account for most, and occasionally all, of the annual total at a given location. Totals from year to year are highly variable, and significant rainfall events, in the hydrogeologic or engineering sense, may take place years or even decades apart.

The specific climatic conditions in the Amargosa Desert at the US Ecology disposal facility are described and discussed extensively by William Nichols (Attachment 3), who analyzed historical data from both Beatty and Lathrop Wells. The Lathrop Wells weather station, at 2680 feet above mean sea level, is 100 feet lower than the general elevation of the disposal facility. The Beatty station, after being relocated in 1972, is now 768 feet higher than the facility. This difference in elevation is reflected in the greater average annual precipitation recorded at the Beatty station. Nichols concluded that, because of the similar elevation of the weather station, and the strong correlation in this climate between precipitation and elevation, the Lathrop Wells data better represented conditions at the US Ecology facility.

At Lathrop Wells, precipitation averages 2.9 inches per year with a range of 1.0 to 5.3 inches. An average daily maximum temperature of 102^{o}F occurs in July, while an average minimum of 28^{o}F is recorded in January. Relative humidity was measured at the facility during the period of Nichols' study, and averaged 23% in summer and 41% in winter. Humidities as low as 9.5% were recorded in early August. Specific humidity, or the actual amount of water present (by weight) for each unit weight of dry atmosphere, averaged 0.6% and 0.3% in summer and winter, respectively. This data suggests that, except for during or just after rains, the relative humidity is mostly temperature dependent, and that the actual atmospheric water vapor content remains uniformly low year-round.

Potential and actual evaporation at the disposal facility were also estimated by Nichols, from both historical data and data collected on site. As would be expected in an arid environment, potential evaporation greatly exceeds precipitation, creating an annual soil moisture deficit. Actual evaporation was calculated at 97% of precipitation, with the remaining three percent representing potential mean annual recharge. This potential is described further in Section 2.5.

The contrast of the climate of the Amargosa Desert with that of more humid areas of the eastern United States is marked. The typical depiction of the hydrologic cycle, especially the components of infiltration, runoff, and stream base flow, is disrupted substantially here by the extreme lack of moisture. An obvious example is the Amargosa River, which, though occasionally carrying storm water runoff south from the Beatty area, has never been observed to flow at the point where it passes 1.5 miles to the southwest of the facility. In fact, no perennial surface water exists within ten miles of the LLRW disposal facility.

The US Ecology waste management facility is unique in its location and in the high degree of natural environmental isolation it provides. Eastern United States waste disposal locations, from which studies have described the processes of precipitation infiltration, leachate production, and groundwater recharge, experience over ten times the annual precipitation falling in the Amargosa Desert. Further, such areas may record four to eight times the specific humidity, much lower average daily temperatures, and approximately one-half the estimated evaporation rate (Nichols, 1986). The fact that the Beatty facility does not exhibit the hydrogeologic processes of facilities in more humid climates makes it an excellent location for waste disposal operations.

2.3 Geology

The Amargosa basin was formed by normal block faulting, which displaced the surrounding strata upward with respect to the crustal block underlying the valley. This widespread structural process formed the characteristic topography of the entire Basin and Range province. Erosion of the uplifted areas, during and after their displacement, has filled the basin with a variety of sedimentary structures. These deposits have reached a depth of 1000 feet in the center of the basin near Lathrop Wells.

The sediments of the valley floor are unconsolidated to partly indurated, and Tertiary to Holocene in age. Deposited as alluvial fans, streambeds, dunes, and lake beds, they exhibit a very wide range of shapes and grain size distributions. The mineralogy of the sediments varies widely as well, reflecting the diversity of their source rocks.

Alluvial fan deposits extend into the basin from the pediment on each side, coalescing to form broad bajadas. At the center of the basin, intermittent prehistoric lakes have deposited extensive clays and silts, which interfinger with the fan deposits at their margins. Between periods of lake bed or playa deposition, and since the end of the Pleistocene, fluvial and eolian processes have dominated deposition in this central area.

Sedimentary, metamorphic, and igneous rocks make up the faultblock mountain ranges to the east, west, and north of the Amargosa basin. These rocks also underlie the younger, unconsolidated sediments in the valley floor. The age of the various sedimentary and metamorphic strata is Precambrian and Paleozoic, while the volcanics present were formed during the Tertiary.

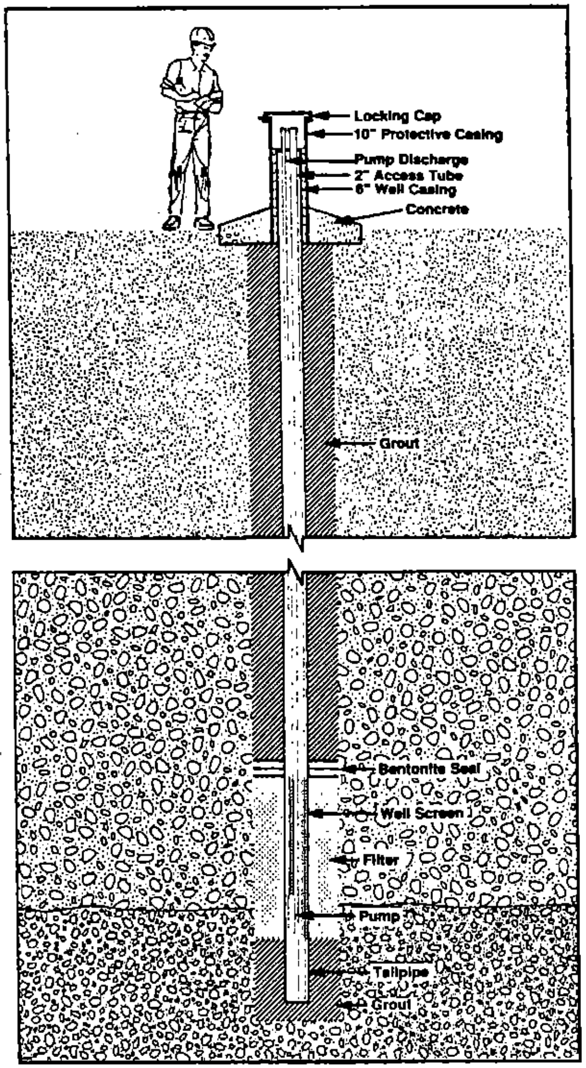
Details of the nature of the unconsolidated strata beneath the facility have been determined from the various borings and well installations which have been made since 1961. Recently, extensive hydrogeologic investigations have been conducted at the Beatty facility to determine the soil properties and hydrologic characteristics. Four exploratory borings were completed on the RCRA facility in 1988. The borings were used to collect soil data and determine aquifer hydraulic properties. This investigation (The Mark Group, April, 1989) was completed with the installation of ten 300 series (Detection Monitoring) wells. For well locations, see Figure 2-1. The 300 series wells are screened in the water table aquifer. Additionally, six 600 series (confined aquifer) monitoring wells were constructed in 1991 (Geraghty & Miller, May 15, 1991). The 600 series wells, screened through the upper 20 feet of the confined aquifer, were constructed to monitor piezometer gradient and groundwater quality.

Two soil borings were drilled at the southwest boundary of the LLRW facility in 1991 (Geraghty & Miller, May 14, 1991). The borings were completed as monitoring wells 001 and 002. Both wells are screened in the water table aquifer and provide water table elevation data and groundwater radiological monitoring.

FIGURE 2-1

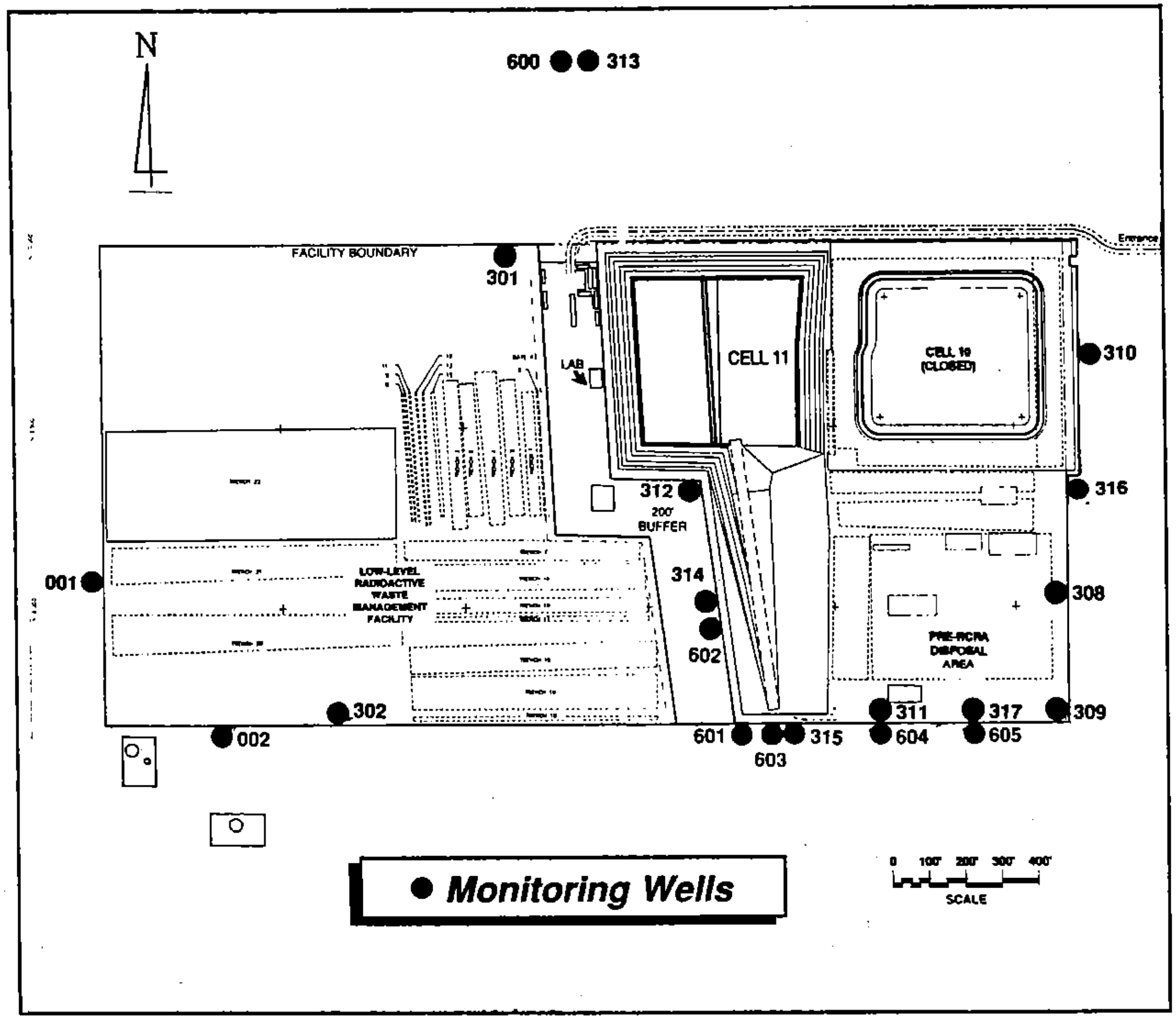
Monitoring Wells

TYPICAL WELL CONSTRUCTION



Well Depths Range From 300' TO 475' Below Surface

WELL LOCATIONS



20 Wells Monitor Groundwater Quality

Stratigraphic information derived from the installation programs shows a sequence of deposits consistent with alluvial fan and playa depositional processes. The deposits from the ground surface to a depth of approximately 300 feet beneath the Beatty facility consists of alluvial deposits. The alluvial soils are predominantly gravelly sands with poorly sorted gravel or sand deposits which occur in discontinuous intervals.

The gravelly sand extends deeper (approximately 350 feet below ground surface) at the south western area of the LLRW facility. The soils are slightly stratified at wells 001 and 002, compared to this interval beneath the RCRA facility. The increased stratification may have resulted from previous fluviation by the Amargosa River.

Generally, the next 60 to 150 feet of deposits beneath the RCRA facility consist of silt, clay and indurated deposits. The fine grained deposits are typical of playa deposits and may change composition relatively quickly with depth.

Silt-clay deposits were observed in borings 001 and 002. The upper surface of the silt-clay unit is relatively flat beneath the northern half of the RCRA facility and appears to deepen to the southwest beneath the LLRW facility.

The drilling investigations indicate that the water table aquifer occurs immediately above or within the silt-clay and indurated sediments. The confined aquifer is observed immediately below this interval in the sandy gravel.

A coarse sandy gravel is observed beneath the silt-clay interval and generally becomes coarser as it extends to depth exceeding 575 feet below ground level.

The deeper gravels, cobbles, and boulders found in each boring represent a higher energy, fluvial environment. Site specific data is therefore consistent with the general depositional pattern assumed for the Amargosa and adjacent valleys.

Some very localized variation due to the coalescing of alluvial fans and intermittent streambed deposition may be imprinted upon this sequence.

2.4 General Hydrology

There are no perennial streams within 10 miles of the facility. A reasonable estimate of the average rainfall rate at the site ranges from 2.5 to 5 inches per year. A conservative estimate of the evaporation rate is 36 inches per year. A comparison of the expected rates of precipitation and evaporation indicates that virtually all precipitation is susceptible to a rapid return to the atmosphere as water vapor. Therefore, the rate of precipitation as well as the pH of the rainfall is not significant. The facility is not located on a flood plain (Attachment 4), shoreland, or a groundwater recharge area, and there is no known hydraulic connection between the site and potential standing or flowing surface water. A cross-section map illustrating the location of US Ecology's facility in relation to the Amargosa Valley features is included as Attachment 6.

The site is located on a rise on an alluvial fan forming the upper end of a long valley within the Amargosa Desert. Site elevations vary from 2787 feet to 2770 feet above mean sea level (MSL). The land continues to slope to the southeast for at least 8000 feet as shown on the USGS quadrangle sheet "Bare Mtn. Nev." Attachment 5). The site is not subject to concentrated storm water flows resulting from extreme rainfall events. Sheet flow which might result from such a storm is diverted away from the site by drainage ditches north and east of the site. These existing diversion features prevent off-site run-on from entering the facility. Within the disposal area any runoff which might be generated by incident precipitation is retained within the below-grade disposal unit. Any future waste management area will be similarly protected.

The peak flow for the 100-year storm for the Amargosa River watershed above the site was routed around the site to determine independently if the site lies within the 100-year flood plain. A conservative approach was taken by assuming that this desert region has experienced between 0.5 and 1.1 inches of rainfall in the previous five days by assuming Antecedent Moisture Condition II, which is commonly used for hydrological analysis of a humid region.

The Amargosa River watershed above the site is 139.7 square miles with a maximum length of 39.05 miles and an average landslope of eleven percent which accounts for mountain slopes and valley slopes perpendicular to the river channels. The drainage area consists of well-drained sands and gravel soils and may be characterized as rangeland with poor hydrological conditions. A Soil Conservation Service (SCS) runoff curve number of 68 was used in the analysis (Attachment 7) to model the hydrological characteristics, soil types, and Antecedent Moisture Condition II. The 100-year, 24-hour point rainfall is 2.6 inches with a runoff over the watershed of 0.43 inches. A 100-year storm hydrograph was developed and the peak flow was found to be 2056 cubic feet per second (CFS) at the site.

The Amargosa River consists of six distinct channels, each with an approximate width of 160 feet as measured from the Bare Mountain topographic map in Attachment 5, across the desert valley which is approximately 4.5 miles wide at the site. The desert drains into these channels or into smaller swales which eventually empty into the channels. The channels have an approximate slope of 0.69 percent which is the same as the valley slope.

The routing analysis assumed that only the six channels shown on the topographic map drained the valley around the site. This is a conservative assumption since the desert contains many smaller channels which would also carry the flow. It was found that the 100-year, 24-hour storm peak flow of 2056 cfs, would be carried into the six channels of the Amargosa River with a flow depth of 0.13 feet. Since the site is at least four feet above the nearest channel, it would not be impacted by the 100-year, 24-hour flow in the Amargosa River. Therefore, the site is not within a 100-year flood plain.

2.4.1 Surface Drainage Features

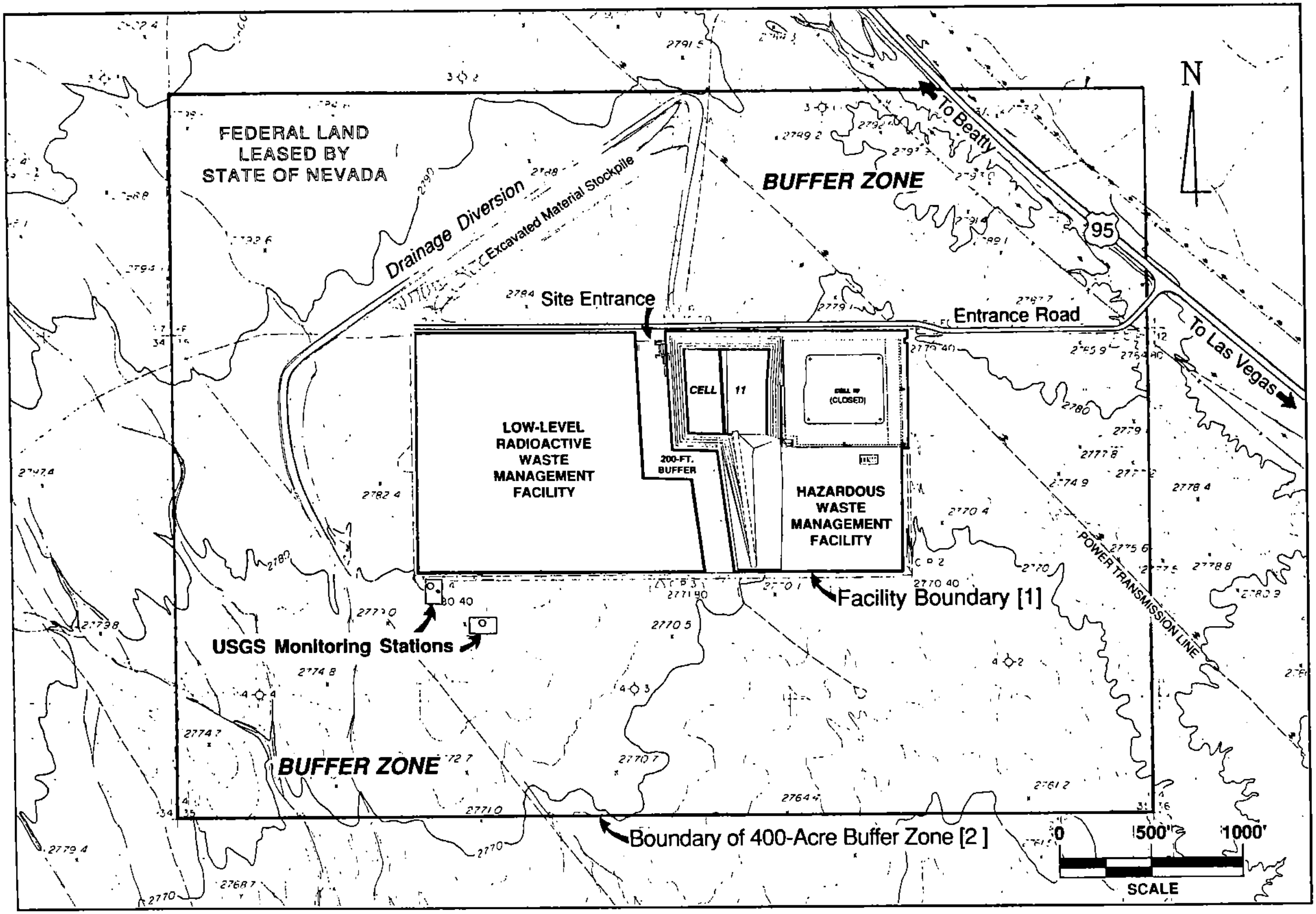
As previously mentioned, the site is located on a rise in the desert formed by an alluvial fan. This rise extends up the valley from the site approximately 4.1 miles forming a drainage area of 1.7 square miles. Drainage from the remainder of the desert and surrounding mountains is provided by the Amargosa River channel and natural drainage swales in the desert and does not impact the site during a 100-year storm.

Run-on control for the 100-year, 24-hour design storm is provided for the 1.7 square mile drainage area. This is provided by a trapezoidal ditch north of the site which diverts the major portion of the drainage area to natural swales west of the site and a smaller triangular ditch along the northern and eastern boundaries of the site to divert the remainder of the drainage area around the site, see Figure 2-2. Design drawings and as-built cross sections of the drainage ditches are included in Attachment 8.

The on-site drainage area inside the run-on protective measures which could presently impact the radioactive waste disposal facility is approximately 56 acres. Runoff estimates for a 100-year, 24-hour design rainfall of 2.6 inches were computed using SCS methods and are found in Attachment 9. Desert soil consists of sands and gravels with good drainage characteristics. Therefore, an SCS classification of "A" was assigned. The land is best modeled as a fallow area with poor hydrological characteristics. Due to the low rainfall, the antecedent

FIGU. .-2

Facility Development Plan



[1] 80-acre disposal site is owned by the State of Nevada and leased to US Ecology,Inc.
[2] All land in the vicinity of the facility is owned by the U.S. Bureau of Land Management. The buffer zone is leased by the State of Nevada.

moisture condition is AMC I. However, for conservatism, AMC II, based upon 0.5 to 1.1 inches of rain in the previous five days was chosen. The resulting Runoff Curve Number (RCN) was determined to be 77 and the resulting runoff over the drainage area was found to be 0.8 inches.

The time of concentration (T_C) was found to be approximately 0.75 hours based upon a RCN of 77, a maximum flow length of 1320 feet and an average land slope of 0.75 percent. Using Northeast Technical Service Center (NETSC) Technical Note-Engineering 20 (Rev. 2) by the SCS, the peak flow of runoff from the site is 27.2 cubic feet per second (CFS). This would convert to approximately 0.49 cfs/acre.

Flow in the three drainage swales previously mentioned has been estimated for a 100-year, 24-hour design storm. In addition, flow depths and velocities have been estimated to characterize the erosion at the site during a storm event.

Swale	Drainage Area	Flow	Flow Depth	Velocity
Western	15 AC.	7.4 CFS	0.32 ft	1.54 ft/sec
Center	18 AC.	8.8 CFS	0.35 ft	1.67 ft/sec
Eastern	23 AC.	11.3 CFS	0.26 ft	1.74 ft/sec

Computations indicate that very little flow will be experienced from runoff at the site, even during a 100-year, 24-hour design storm. Velocities are below the velocity required to cause erosion of surface soils at the site. In fact, the low velocities could lead to some deposition of sediments in the channels. Maintenance of drainage paths at the facility, therefore, is limited to periodic inspection and grading to prevent the accumulation of sediments which might ultimately fill the drainage features at the site.

2.4.2 Runoff from Active Area

The controlled area at the LLRW disposal facility where rainfall might come into contact with waste materials is approximately five acres which is entirely within a below-grade disposal unit up to 50 feet deep (Trench 22). With run-on control measures previously described as well as site grading, the only water that will enter the controlled area will be rain falling within it. Due to the depth of the excavation, potentially contaminated rainwater is completely contained in the trench and no runoff from the controlled area occurs. Any future trenches would be handled similarly.

2.5 Hydrogeology

Numerous reports have been prepared describing the hydrogeologic conditions at the Beatty facility. Included in these reports are boring logs, geologic cross-sections, well pumping tests, infiltration tests, soil studies, and groundwater contour maps. Data from more recent reports have replaced or updated earlier work for the purpose of hydrogeologic evaluation and groundwater monitoring system design, (The Mark Group, April, 1989, Geraghty & Miller, May 14 and May 15, 1991).

2.5.1 Saturated Zone

The degree of continuity of the hydrogeologic components beneath the site may be seen in the cross-sections contained in The Mark Group Report (Drawing 2-2). At each boring location, saturation began near the top of an eighty to one hundred and fifty foot thick sequence of cemented clays, silts, and sands. This was also true at the ten 300 series well locations and at wells 001 and 002. The depth to saturation from the ground surface ranges from near 285 feet on the north side of the site to more than 360 feet on the southwest corner of the LLRW facility (see Attachment 10). The interbedding of clays and cemented silts and sands at these depths serves to separate the water table aquifer from the confined gravel aquifer beneath the confining strategy into discrete hydrogeologic units.

A second aquifer is encountered beneath the cemented materials near a depth of 380 feet. It consists of sandy gravels with some cobbles and boulders, and is over 250 feet thick at the southern boundary of the site. The piezometric level measured in this aquifer occurs near 315 feet below ground surface, indicating a confined condition. The groundwater gradient in both the upper and lower water bearing strata is to the south and southwest, following the trend of the Amargosa Valley. This gradient is consistent with regional data, as reported by Nichols, (USGS, 1985).

The interconnection of the upper saturated units with the lower gravel aquifer was the focus of a series of pumping tests conducted in 1988, (The Mark Group, April, 1989). The conclusion drawn from the test data was that hydraulic interconnection between the two aquifers was not measurable. The uppermost saturated units were hydrogeologically independent of the lower gravel aquifer. For this reason the detection monitoring system was designed to monitor the uppermost portion of the saturated zone.

Attachment 10 is a site plan showing water table contours in early 1992. Groundwater gradients increase to the south beneath the RCRA facility and are generally uniform to the southwest beneath the LLRW facility. All wells and borings drilled to sufficient death have encountered a confined aquifer. A piezometric contour map of the confined aquifer is also provided in Attachment 10. Groundwater flow in the low aquifer is generally to the south-southwest.

Compilation of uppermost aquifer groundwater elevations indicates insignificant changes with time. Hydraulic gradients and flow directions have been, therefore, essentially constant since the detection monitoring system was installed. A recent comprehensive review of existing site characterization data indicated that saturated hydraulic conductivities had been determined on several subsurface core samples obtained from the uppermost aquifer during monitoring well installation (The Mark Group, 1989; Geraghty & Miller, May 14, 1991). The saturated hydraulic conductivity data in these reports were used to calculate flow rates.

Hydraulic conductivities in the upper water-bearing zone range from about 4×10^{-6} to 10^{-9} ft/sec. Hydraulic gradients are of the order of 0.025-0.05 ft/ft in the southeastern part of the facility. Groundwater flow velocity estimates range from less than 0.01 to about 10 ft/yr. The measured hydraulic conductivities are consistent with sample lithologies and are considered representative of the upper water-bearing zone.

Pumping test data from earlier studies (The Mark Group, 1989; Grant & Associates, 1990) indicate that the lower aquifer has a transmissivity ranging from about 1900 to 3000 gpd/ft. Assuming these values are representative of the screened intervals of the 600-series wells, and using gradients derived from Attachment 10, groundwater flow velocity of about 35 ft/yr. is typical of the lower aquifer.

2.5.2 Unsaturated Zone

In addition to geologic logging and the determination of aquifer characteristics, investigations have also examined gas migration potentials in the subsurface (Dames & Moore, 1978), and the potential for precipitation infiltration through the unsaturated zone. The most recent of the unsaturated zone studies was by Nichols, who tracked soil moisture contents at various depths over a two year period. Working from within a 10-meters-deep caisson constructed at the disposal site, Nichols installed thermocouple psychrometers (a moisture measuring device) horizontally, up to .5 meters into the adjacent undisturbed sediments. His conclusion, based on the data collected at the site and on the historical data from Beatty and Lathrop Wells, was that net precipitation infiltration to a depth of 2.4 meters may have occurred on three separate occasions since 1968. Nichols estimated that these pulses of infiltration could result in downward liquid migration to the groundwater table at the rate of 4×10^{-3} cm/year or 1.3×10^{-10} cm/sec. From this value, the travel time of liquid from the bottom of a 75-foot deep trench (Note that LLRW facility trenches are 50 feet deep) to the water table 225 feet below would be 1.7 million years.

The work begun by Nichols was continued, for several years, by Jeffrey Fischer and David Morgan of the USGS. A deeper caisson was constructed, with greatly expanded instrumentation. Psychrometers are now installed to 13 meters into the surrounding sediments, and are sealed and insulated from temperature and humidity changes within the caisson (See Attachment 11). It is assumed that data from the current monitoring facility closely reflects site conditions.

Water potential data collected by the USGS study shows little recharge is moving through the shallow alluvial soils (Fischer, 1990). Generally, the hydraulic gradient indicates upward movement toward the surface. Seasonal reversal of the water-vapor flux may occur to a depth of 8 meters (Fischer, 1990). Rainfall during the 2.5 year study period did not penetrate deeper than about 2 meters. This represents the return to the atmosphere of infiltrated soil moisture, introduced by the infrequent precipitation events described previously. Monitoring of the USGS facility is ongoing under the direction of Brian Andraski. These continuing studies have verified that the water or vapor moving through the soil at the Beatty site is quite low. Additionally, they have shown that in spite of the extremely dry conditions, the amount of water stored in the near surface soil is dependent upon the amount of vegetation present (Andraski, 1992).

2.6 Additional Site Characterization

For the purposes of the pathways analysis to characterize the LLRW area, US Ecology has proceeded with the various modeling activities using the data generated from the completed RCRA site characterization. To provide additional data specific to the pathways analysis, 22 samples collected from the exploratory borings were analyzed to produce moisture tension curves, and to calculate saturated and unsaturated hydraulic conductivities. These 22 samples were collected expressly for this purpose at representative depths in each of the four borings. Each sampling depth also coincided with the sampling intervals used for other analyses, such as mineralogy, bulk density, and moisture content.

To confirm the conclusion regarding the continuity and trend of subsurface features beneath the LLRW area, two additional exploratory borings were drilled and sampled similarly to the four already completed. The locations of the two additional borings are midway between Well 302 and the western property boundary (along the southern boundary of the LLRW area), and at the western boundary of the site (see Attachment 10). Each boring was completed as a groundwater monitoring well; constructed according to the specifications used for the RCRA monitoring system. Both wells are monitoring the uppermost saturated deposits beneath the LLRW area. The final report of the boring and monitoring well installations on the LLRW facility, including analytical results of soil tests, are described in the report by Geraghty & Miller, Inc. May 14, 1991 entitled, "Drilling, Sampling and Installation of Two Monitoring Wells at the US Ecology, Inc. Beatty, Nevada Facility Rad Site".

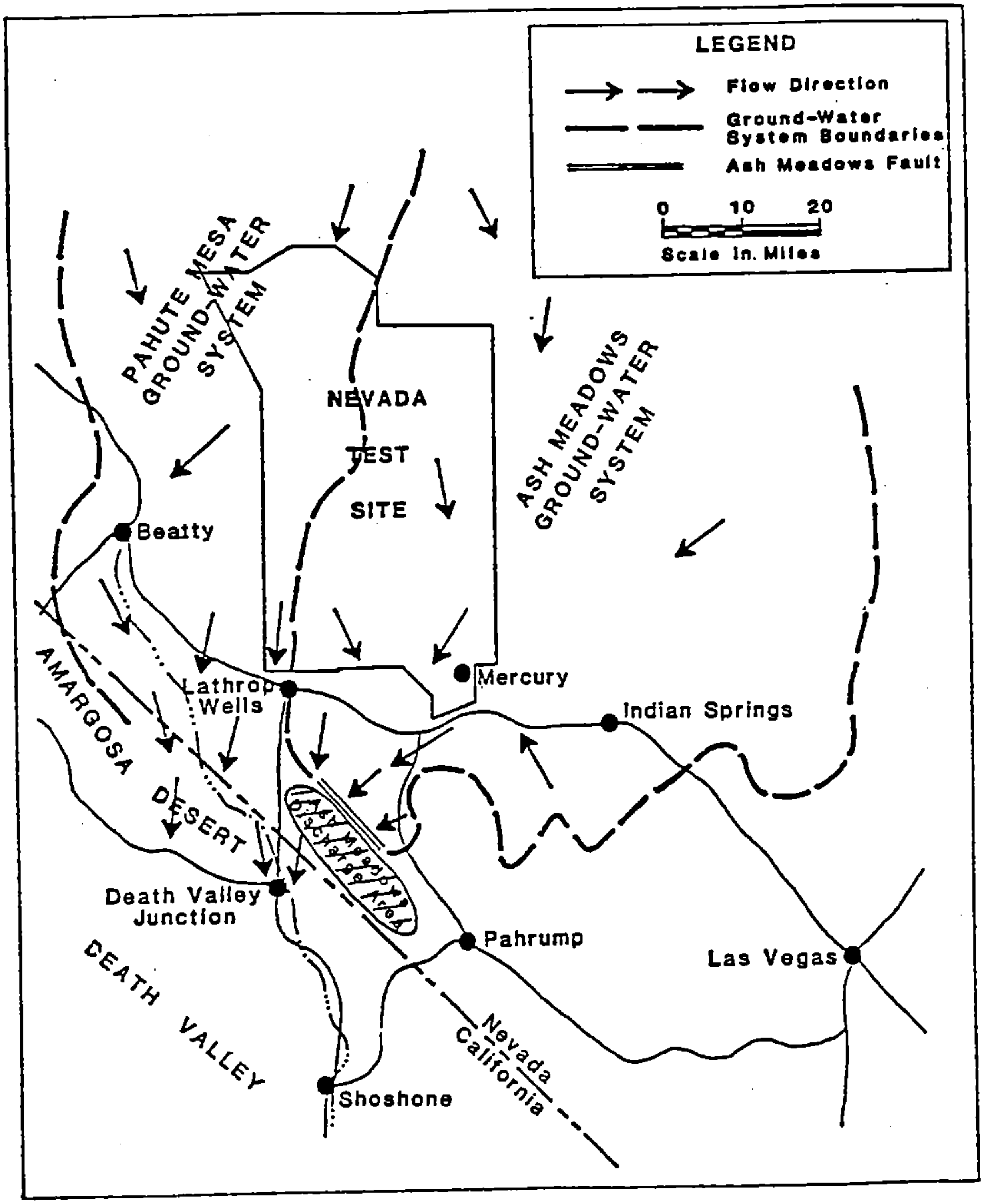
3.0 WATER USE IN THE AMARGOSA DESERT

3.1 Regional Groundwater Flow Patterns

The surficial drainage area of the Amargosa Desert covers about 2600 square miles and is part of two regional groundwater systems (Figure 3-1): (1) the Ash Meadows System consisting of a 7150 square mile area of 10 intermontane valleys and occupying the eastern part of the Amargosa Desert and extensive areas of the Nevada Test Site (NTS) and Nellis Air Force Range (NAFR) east of the NTS and (2) the Pahute Mesa System which occupies western parts of the NTS and NAFR, Oasis Valley, and the western and northwestern parts of the Amargosa Desert (including the Beatty site). These two groundwater systems converge in the Amargosa Desert and probably continue to the south into Death Valley. Summaries of previous work on regional groundwater flow in this part of Nevada can be found in Elliott (1982) and Feeney et al. (1987). Groundwater flow is controlled by alluvium, volcanic rocks, and carbonate rocks. Thick volcanic sequences associated with calderas of the NTS and areas to the west become less significant to the south, and thick carbonate rock sequences are assumed to be present beneath the Amargosa Desert (Feeney et al., 1987).

At Ash Meadows in the eastern Amargosa Desert, discharge from fault-controlled springs has been estimated to be 17,000 acre-feet per year (Walker and Eakin, 1963; Elliott, 1982 and references therein). Evapotranspiration west of the Ash Meadows springs and subsurface flow across the Ash Meadows fault to Death Valley may be other areas of discharge. Recharge to the Spring Mountains has been suggested to account for up to 65% of the springflow at Ash Meadows with underflow from areas of the Ash Meadows Groundwater System to the northeast contributing about 35% of the springflow (Feeney et al., 1987 and references therein).

Amargosa Desert recharge can occur as underflow from adjoining basins, deep percolation of infiltrated precipitation, and deep percolation derived from streamflow infiltration. Recharge



Regional groundwater flow patterns in the Amargosa Desert and vicinity (from Elliott, 1982).

FIGURE 3-1

sources for the western and northwestern Amargosa Desert are apparently numerous and may include: (1) underflow from the carbonate aquifer of the Ash Meadows Groundwater System; (2) underflow from Oasis Valley; (3) Amargosa River infiltration; (4) irrigation return flow; (5) surface discharge from Fortymile and Tonopah Washes; and (6) underflow from Crater Flat. Deep percolation of infiltrated precipitation in alluvial valleys is most likely a very minor recharge component in the Amargosa Desert and probably represents only 0-2% of annual precipitation based on studies and calculations in the desert and adjacent areas (e.g., Crater and Frenchman Flats; Walker and Eakin, 1963; Feeney et al, 1987; Tyler, 1987). Groundwater flow directions in the Amargosa Desert are generally to the southeast and southwest (Elliott, 1982; Feeney et al., 1987).

In the Pahute Mesa Groundwater System, recharge to Pahute Mesa and Gold Flat flows into Oasis Valley. Annual discharge for this system is estimated at 9000 acre-feet, with about 2000 acre-feet being discharged through evapotranspiration in Oasis Valley. About half the groundwater recharged to Oasis Valley flows south and southeast into the Amargosa Desert through the buried sediments of the Amargosa River channel (Elliott, 1982; Feeney et al., 1987). Estimated annual discharge from this groundwater system in the Amargosa Desert is 7000 acre-feet (primarily as pumpage and evapotranspiration). Spring discharge in Death Valley has been estimated at 5000 acre-feet and is due to groundwater flow from both the Pahute Mesa and Ash Meadows Systems.

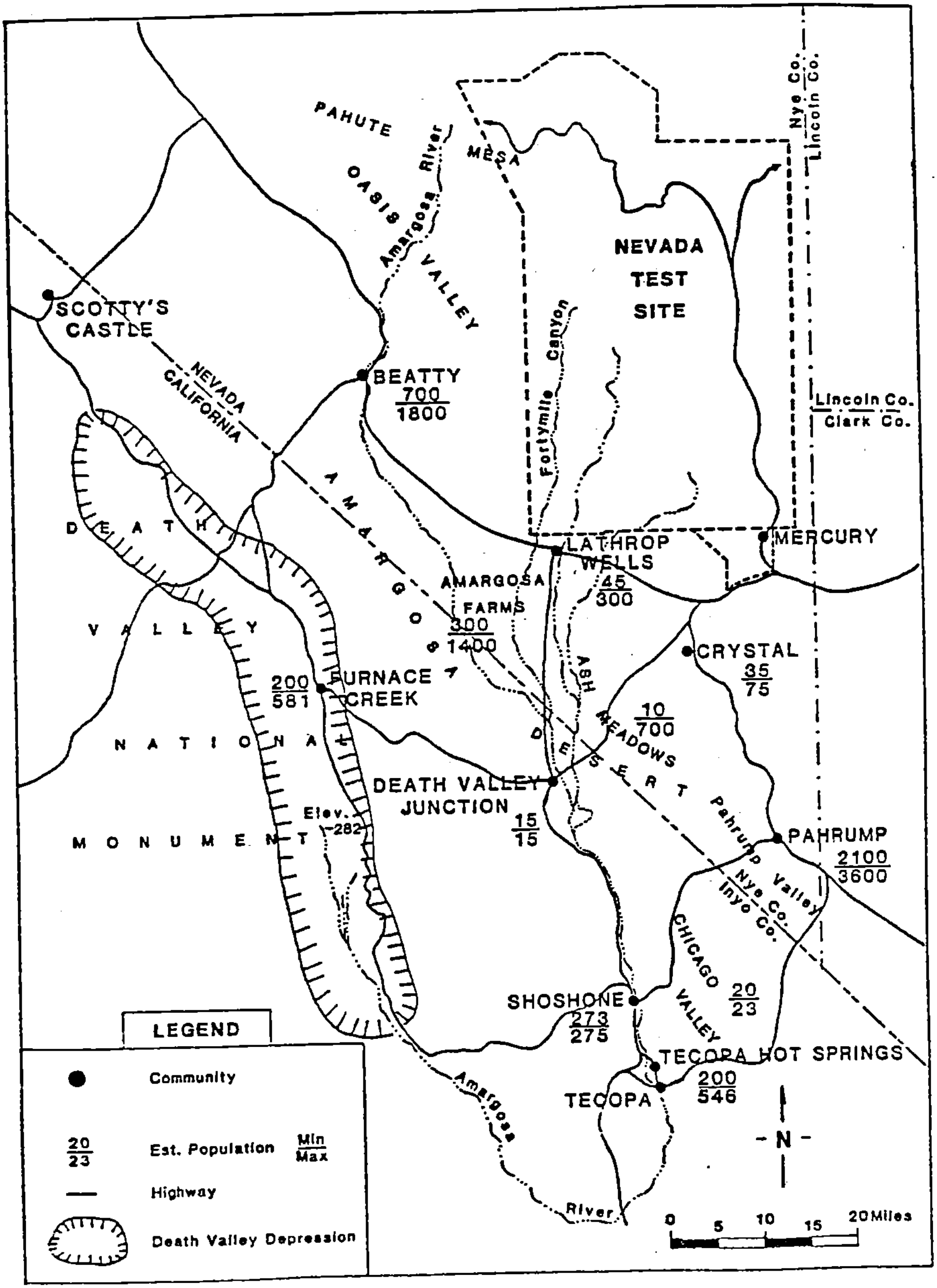
3.2 Water Use

A report on the groundwater resources of the Amargosa Desert was published as "Reconnaissance Series Report 14" by G. E. Walker and T. E. Eakin in 1963. As is true at present, groundwater development was concentrated between Lathrop Wells and Death Valley Junction with more than 100 wells in place for irrigation. Perennial yield was estimated at 24,000 acre-feet/year based on estimated natural discharge. Spring discharge at Ash Meadows accounted for an estimated 17,000 acre-feet, while the remaining 7000 acre-feet of natural discharge was attributed to evapotranspiration and outflow mainly in the southeastern parts of the desert. Walker and Eakin (1963) estimated groundwater storage in the upper 100 feet of saturated alluvial fill in T.15-16S. and R.48-49E. to be about 1.4 million acre-feet. The Walker-Eakin report is still referenced (e.g., Feeney et al, 1987) and used by the Nevada State Engineer's Office-Division of Water Resources.

Demographic surveys of the Amargosa Desert and adjacent areas have been conducted (Elliott, 1982; Richard-Haggard, 1983). Richard-Haggard (1983) summarized various estimates of population growth for Nye, Clark, and Lincoln counties and the Beatty and Pahrump townships of Nye County through the year 2020. The two estimates for Nye County differ by a factor of 1.7 in the year 2000 (10,000 vs. about 17,000). The impact of these estimated population increases on groundwater resources or use was not addressed in these reports.

Groundwater quality in the Amargosa Desert has been discussed by Walker and Eakin (1963) and Elliott (1982). Drinking water sources vary from individual wells at Amargosa Farms and Ash Meadows to urban well systems such as at Beatty to springs at Furnace Creek and Shoshone, California (for location map see Figure 3-2). Chemical analyses of irrigation water (Walker and Eakin, 1963) showed salinity hazards from medium to high and mostly low sodium (alkali) hazard. Elliott (1982) analyzed water samples from 22 locations in the Amargosa drainage basin for inorganic constituents and for H-3, gross alpha, gross beta, gross gamma, Sr-89 and -90, Pu-238 and -239, U-234, -235, and -238, and Ra-226. No concentrations of radionuclides and radioactivity exceeded drinking water standards; however, some naturally-occurring inorganic constituents were above Federal standards.

The U.S. Geological Survey recently published a summary of groundwater conditions in the Amargosa Desert (Kilroy, 1991).



Location of communities and geographic features in the Amargosa Desert area (adapted from Elliott, 1982).

FIGURE 3-2

Hydrographs of wells in the Amargosa Farms area show water-level declines from the 1950s to 1987 of greater than 30 feet in some locations. Nichols and Akers (1985) also found that groundwater use may have exceeded perennial yield in the Amargosa Farms area, since water levels in alluvial wells dropped as much as 27 feet from 1962 to 1984. In the Bare Mountain area (near the Beatty facility), Kilroy reports that contours of water-level altitude cross the mountain front at right angles, suggesting that this area is part of the regional flow system.

A current hydrographic basin abstract of the Amargosa Desert has been obtained from the Nevada State Engineer's Office-Division of Water Resources. The abstract lists permits for wells with the following uses: irrigation, mining and milling, quasi-municipal, commercial, recreational, domestic, municipal, and wildlife. Irrigation wells account for 57% of the total, mining and milling and quasi-municipal (wells supplying more than one house) about 33%, with the remaining uses varying from less than 1 to 4%. Domestic wells are not fully represented in the abstract since permits are not usually required. Approximately 90% of the wells are located in the following areas: T.15S., R.49-50E., T.16S, R.48-49E., T.17S., R.48-53E., and T.18S., R.49-51E. These areas are in the Amargosa Farms-Ash Meadows region between Amargosa Valley and Death Valley Junction. The only other areas represented in the basin abstract are T.12S., R.46-47E., T.13S, R.46E., and T.19S., R.50E. The majority of wells in R.46-47E. are associated with mining activities. A pumpage inventory for 1991 indicated about 7,000 acre-feet of groundwater being utilized mainly by irrigation wells. Estimates of water committed, based on 1985 data, range from 38,000 to 54,000 acre-feet.

3.3 Conclusions

Groundwater development and use in the Amargosa Desert is concentrated in the Amargosa Farms region, primarily for irrigation. This region is a minimum of 13 miles from the Beatty facility. No other operating wells or potential receptors downgradient of the facility are known closer than this. Recharge sources for the Amargosa Farms region are numerous (Kilroy, 1991), including some outside the boundaries of the Amargosa Desert drainage basin. The contribution of groundwater flow from the area of the Beatty facility is probably minor. In fact, discharge of groundwater flowing from the area of the Beatty facility could be as far south as Death Valley.

4.0 VEGETATION AND WILDLIFE

It is well known that plants can both inhibit and promote the mobilization of buried wastes (e.g., Perkins and DePoorter, 1985). The root zone removes soil moisture and the aboveground biomass transpires. Water storage decreases and the potential for deep percolation is reduced. Plants also reduce the potential for wind and water erosion on trench caps. Roots can also absorb trace and radioactive elements that are subsequently translocated into the aboveground biomass. If rooting depths are great, roots can penetrate into burial trenches to accelerate radionuclide movement. Burrowing animals have the potential to access buried wastes and may influence erosion and water balance by changing soil properties (e.g., Hakonson, 1986).

The following sections discuss specific features of northern Mojave Desert vegetation and animal communities that bear on site stability and trench cap performance. Detailed consideration of radionuclide transport and uptake by vegetation and animals will be provided in the environmental pathways analysis and dose model.

4.1 Native Vegetation

The Beatty facility is part of the northern Mojave Desert. Perennial plant species that occur in the vicinity of the Beatty site include: Larrea tridentata (creosote bush), Ambrosia dumosa (bur-sage or burro bush), Krameria parvifolia (range ratany), Acamptopappus shockleyi (goldenhead), Atriplex confertifolia (shadscale), Atriplex canescens (four-winged salt bush), Ephedra nevadensis (mormon tea), Lycium andersonii (desert thorn or wolfberry), and Lycium pallidum (box-thorn). The phenology of Mojave Desert shrubs was studied at different locations on the Nevada Test Site (NTS) (Ackerman et al., 1980), and results are in general relevant to the Amargosa Desert. Winter and early spring rains are more important for growth than the local, infrequent summer rains. As soil moisture is depleted and soil temperatures rise in the summer, some species start to lose their leaves and become dormant. Some species also can have a dormancy period in the winter. In the spring, Ackerman et al. (1980) observed that

Krameria parvifolia was the last species to break dormancy in the Mojave Desert. Shrub species that never shed all their leaves, and are therefore considered evergreens, and are able to grow after spring, summer, or fall rains included Larrea tridentata and the Atriplex species.

Environmental and biological factors have combined in the Mojave Desert to produce a shrub clumping effect. Only about 20% of the soil surface is occupied by clumps of growing plants, while the remaining 80% acts predominantly as a watershed for the vegetated areas. Within the clumps, the soil has become highly structured and fertile, and is as favorable for plant growth as soils in more humid climates. Plant roots in the "fertile islands" extend into the bare areas to potentially utilize the soil moisture of the entire land area (Wallace and Romney, 1980; Wallace et al., 1988). This structuring of the soil surface into highly and poorly productive areas is of major importance to the maintenance of perennial Mojave Desert ecosystems (Wallace et al., 1980e).

Vegetational groupings and soil-plant relationships have been extensively studied at Jackass, Frenchman, and Yucca Flats and at Rock and Mercury Valleys (el-Ghonemy et al., 1980). Although strictly relevant to the transition zone between the northern Mojave and Great Basin deserts, the results are generally applicable to plant species in the Amargosa basin (differences would be primarily related to longitude, elevation, and precipitation patterns). The Larrea tridentata vegetational grouping contained 23 species which are given in Table 4-1 in order of abundance. The L. tridentata grouping is the most widespread and diversified, and is considered the most stable vegetation cover in this area and consequently represents a climax community (El-Ghonemy et al., 1980). El-Ghonemy et al. (1980) also summarized soil characteristics among the different vegetational groupings including pH, soil moisture retention, exchangeable cation percentages, cation exchange capacity, and total phosphorus and organic nitrogen. One important factor in the survival of plants adapted to arid environments is a more rapid decrease in transpiration rates than decrease in photosynthetic rates as soil water potential decreases (Clark et al., 1980). Maximum gas exchange rates in L. tridentata and A. dumosa occur during the early spring months when high soil moisture conditions are present. Romney et al. (1980b) measured physical and chemical properties of soil profiles as a function of depth and horizontally from shrub clumps to bare areas. Soil properties which had higher values under shrubs, but which were not significantly different from bare areas included pH, water-holding capacity, and exchangeable Na. Soil properties that were significantly higher under shrub clumps included soluble cations and anions, exchangeable potassium, cation exchange capacity, organic carbon and nitrogen, available phosphorous, and extractable iron and manganese.

Several edaphic (soil texture, salinity, and soil moisture stress) and climatic (temperature) conditions affecting the distribution and revegetation (See Section 4.2) of perennial shrub species in the Mojave Desert are summarized in this paragraph. Larrea tridentata is known to require good aeration of the root zone and well-drained soils (Romney and Wallace, 1980), does not grow in saline or moderately saline soil, and is capable of small positive net photosynthesis at a soil water potential as low as -65 bars and is thus able to maintain productivity well into the summer (Kleinkopf et al., 1980). A high soil pH may inhibit L. tridentata seedling development and growth (Hunter et al., 1980b) and its distribution suggests that it is not adapted to the colder, wetter climates of the Great Basin desert (Kleinkopf et al., 1980). It has been observed near Rock Valley that L. tridentata does not occur in washes, while Lycium andersonii grows only in washes. Ambrosia dumosa and Lycium pallidum occurs in both wash and nonwash areas. These vegetation patterns could be due to differences in (1) water availability, (2) soil texture, or (3) soluble salt content between wash and nonwash areas (Wallace et al., 1980a). Ambrosia dumosa, Ceratoides lanata, and Lycium pallidum are better adapted to finer-textured soils than L. tridentata or L. andersonii (Romney and Wallace, 1980). The more salt-tolerant Mojave Desert species include A. dumosa, Atriplex spp., and L. pallidum. Atriplex canescens tends to populate low-lying areas (e.g., playas) that have accumulated clay and silt, have saline soils with relatively high moisture content, and that experience winter temperature inversions (Kleinkopf et al., 1980; El-Ghonemy et al., 1980). Results of Hunter et al. (1980a) and Bamberg et al. (1980) indicate that Krameria parvifolia, Yucca schidigera, and Lycium andersonii have long life spans, and natural revegetation of these species onto disturbed sites would be very slow. Atriplex confertifolia apparently has one of the shortest life spans of the shrub species studies. In conclusion, the distribution of vegetation in an area is controlled primarily by three groups of interrelated factors relating to soil fertility, soil salinity, and soil texture and water retention capacity (Wallace et al., 1988).

4.2 Characteristics of Vegetation

4.2.1 Rooting Depths and Other Properties

Information on the rooting depths of native and introduced species is important in site assessment and trench cap performance analysis because of the effects of roots on the quantity and rate of deep percolation of soil moisture and on potential radionuclide uptake. Quantitative data on root depth distribution for plants in the northern Mojave Desert is not extensive. The work of Wallace et al. (1980d) in Frenchman Flat and in Mercury and Rock Valleys will be summarized in the following paragraph.

Wallace et al. (1980d) sampled the root systems of the following perennial plant species: Acamptopappus shockleyi, Larrea tridentata, Lycium andersonii, Lycium pallidum, Ephedra nevadensis, Ambrosia dumosa, Krameria parvifolia, Atriplex canescens, and Atriplex confertifolia. These species include those dominant in the vicinity of the Beatty facility.

Nearly all the root systems were distributed in the first 50 cm of soil. The majority of the below ground biomass was at depths less than 50 cm. Biomass means for the nine species as a function of depth were:

0-10 cm:	39%
0-20 cm:	70%
0-30 cm:	86%
0-40 cm:	95%

Large multiple taproots dominated the root systems in the top 10 cm of the soil, while small roots occurred between 10 and 30 cm. Krameria parvifolia and A. shockleyi were more shallow rooted than other species. These two species have more than 85% of their root systems within the first 20 cm. Data from Rock Valley on depth distribution of the very fine root biomass indicated no difference from roots in general. The depth distribution of winter annual plants was more shallow than for perennial species. The first 5 cm of soil contained 19-31% of the annual plant root biomass. The shallow rooting characteristics of perennial and annual plants in the Mojave Desert can be related to the sparse precipitation and to soil structure.

Foxx et al. (1984a, 1984b) reviewed the literature for rooting depths of western U.S. plant species. They also provide available data on root depth to shoot height ratios, radial root lateral spread to shoot height, and root depth to root lateral spread. Life forms for which data are presented include trees, shrubs, subshrubs, annual forbs and grasses, and perennial forbs and grasses. Relatively few species of importance to the Mojave Desert are represented. The region of southern Nevada occupied by the Amargosa Desert is shown by Foxx et al. (1984b) to have the most shallowly rooting species in the western U.S. Within their Region 1 (including southern Nevada, much of Arizona, southeastern California, southern New Mexico, and western Texas), 75% of the specimens recorded rooted at depths of 92 cm or less. The median root depth for all plants in their survey in sandy soil was 75 cm. Rooting depths of eight native annual grass species, irrespective of region, were within the first 91 cm, with the highest frequency at 30 cm. Data on cumulative rooting depth frequencies indicate that grasses and forbs have more shallow root systems than shrubs.

Foxx et al. (1984a) provide data on rooting depths of species at low-level radioactive waste site at Los Alamos National Laboratory (LANL). Only a few species are relevant to the Mojave Desert and include Salsola kali (Russian thistle) and Yucca spp. Salsola was represented by only one specimen with a rooting depth of 67 cm, while Yucca spp. averaged 112 cm with a range from 30-213 cm. It must be recognized that LANL is in an evaporation-precipitation region with generally deeper-rooting plants than in the Mojave Desert (Foxx et al., 1984b).

Information on Salsola kali and two species similar to ones in the Mojave Desert was obtained by Klepper et al. (1985) for the 200 Area of the Hanford Site. Again, the Hanford Site is in a region with generally deeper-rooting species than in the Mojave Desert (Foxx et al., 1984b). The maximum root depth for Salsola kali was 209 cm, with a mean maximum root depth of 172 cm. The first 50 cm of soil contained 72% of the mean root density for S. kali, with 94% within the top 100 cm. Klepper et al. (1985) also provide measurements of root depth vs. shoot height for Salsola. Ambrosia acanthicarpa (bursage) had a maximum root depth of 180 cm, with 85% of the mean root density at 100 cm or less. One specimen of Atriplex spinosa (spiny hopsage) was measured with a maximum root depth of 195 cm.

For modeling purposes, the seasonal leaf-area index (LAI) is used to estimate plant transpiration and soil evaporation. For Rock Valley shrubs, estimates of LAI are given in Lane (1984). Other data available for Rock Valley perennial species include dry weight of stems, above ground stem biomass/unit area, below ground standing biomass, standing dead plant material, and the proportion of dead wood on living plants (Bamberg et al., 1980; Romney et al., 1980b). Below ground biomass and root:shoot ratios for Larrea tridentata, obtained using C-14 labeled carbon, can be found in Wallace et al. (1980c). It must be noted, however, that annual photosynthetic production in the Mojave Desert ecosystem can change dramatically from year to year as the result of seasonal rainfall and temperature variations (Romney et al., 1980b).

A general review of the influence of plants on soil moisture and of genetic and environmental factors affecting rooting patterns can be found in Perkins and DePoorter (1985). They cite one study showing that root:shoot ratios, and presumably root depths, do not increase with increasing aridity (and decreasing subsurface moisture availability) as was suggested in earlier studies. This is consistent with the shallow rooting depths noted in the Mojave Desert by Wallace et al. (1980d). Perkins and DePoorter (1985) also demonstrated the effectiveness of plants in removing upper soil moisture in field experiments at LANL. The impact of evapotranspiration processes on water storage in soils of the Mojave Desert is illustrated in Wallace et al. (1988). Disturbed bare soils areas showed build-up of soil moisture (but generally to levels below the field capacity) which can reduce water stress during revegetation.

The U.S. Geological Survey study of the geohydrology of the Beatty site documented potential soil moisture movement to a maximum depth of 2.4 m (Nichols, 1987). A recent study examined the water-potential to a depth of 13 m (Fischer, 1990). Liquid movement in the soil did not exceed 2 m in depth during the 2.5 year study period. Below a depth of approximately 9 m, the hydraulic gradient indicates an upward movement.

Tyler (1987) reviewed recharge studies conducted at the NTS. In alluvial basins, analysis of bomb-produced tritium vs. depth demonstrated that since 1952 precipitation has penetrated less than 2.5 m. Tyler offers the hypothesis that 2.5 m is the maximum depth of storage of precipitation. Soil moisture held in storage in the upper 2.5 m of soil would be evaporated and transpired at a rate equal to the yearly precipitation flux into the soil surface. The 2.5 m depth would then represent a soil moisture flow divide. The studies referenced earlier on Mojave Desert plant behavior are consistent with this hypothesis, since rooting depth is limited by the depth of the wetting front and roots do not penetrate far into very dry soils (Klepper et al., 1985).

At the U.S. DOE Low-Level Defense Waste Management site in Area 5 of the NTS, results from infiltration studies in alluvial soils also bear on the shallow-rooted nature of northern Mojave Desert vegetation. Infiltration after both simulated and natural rainfall was studied (Kearl, 1982). The simulated rainfall approximated a 500-year storm event. About 2.5 cm of water was applied in 49 minutes to the study plot. The wetting front reached a depth of only 15 cm, and measurements taken up to 9 days after the event showed no significant moisture content changes at 46 cm depth. Following the natural precipitation event of about 1.1 cm (two storms on two consecutive days), the wetting front was found to be only 10 cm (Kearl, 1982).

4.2.2 Revegetation Rates and Plant Succession

The Radioactive Material License for the Beatty LLRW facility states that stabilization of the site will be such as to minimize the cost of long term care and maintenance. Toward that goal, US Ecology proposes to allow natural revegetation of the trench cap. Recent USGS studies (Andraski, 1992) indicates that the amount of moisture stored in the near-surface soil is dependent upon the vegetation present. The following paragraphs will review recent studies on managed transplantation and husbandry procedures to restore perennial vegetation on disturbed Mojave Desert land, and then will discuss available data on natural revegetation rates and plant succession.

E. M. Romney, A. Wallace, R. B. Hunter, and associates have studied the transplantation and survival of native perennial Mojave Desert shrubs on disturbed land (Hunter et al., 1980a, 1980c, 1980d; Romney et al., 1971, 1987a, 1987b; Wallace et al., 1980b, 1980e, 1988). They discuss terrain manipulation, selection of seed from pioneering shrub species, preservation of existing shrub clumps, supplemental fertilization, irrigation, organic amendments, and transplantation procedures that are needed to effectively restore vegetation. These activities, however, can require extensive resources and time and generally are not compatible with the stipulation on long-term care and maintenance contained in the license.

Wallace et al. (1980e, 1988) have discussed the many problems involved in restoration of desert land. The great variability in the amount and time of distribution of precipitation in the Mojave Desert makes predictions of the success of restoration efforts very difficult. Year-to-year variations in perennial plant phenology and climatic factors could negate any efforts to plant or manipulate native vegetation. To successfully manage a restoration effort, a detailed understanding of plant sociological relationships is needed. Edaphic factors (soil fertility, salinity, and textural variations) must be known for a site. Plant communities often respond to very subtle changes in soil properties which can impact long-term success of restoration activities. Therefore, the local plant ecotypes must be known in detail. Consideration must be given to the photosynthetic mechanisms of various species and the effects of competition. Grazing jack-rabbits (Lepus californicus) and pocket gophers (Thomomys bottae) must be controlled, since they seem to show a preference for transplanted shrubs over nearby native vegetation (Romney et al., 1987a). Restoration work must take into account the relationship between plant species, water supply, and available nitrogen supply. Responses to supplemental irrigation can be difficult to predict as exemplified by the study of Hunter et al. (1980a). Wallace et al. (1988) point out that even successful establishment of new seedlings will not guarantee plant survival. Ongoing surveillance and remedial action may be needed for years. In Rock Valley, Wallace et al. (1980e) showed that only two years out of the six studied were conducive to the establishment of new seedlings. A plan to transplant shrubs must consider the dormancy behavior of each species.

Natural revegetation processes on disturbed land of the northern Mojave Desert may require several decades for a return to the native perennial shrub species (Romney et al., 1971, 1987a; Wallace et al., 1988). The reasons for the slow recovery include the sparse and irregular precipitation and the destruction of the "fertile islands" of undisturbed land. These conditions make it difficult for perennial plant seedlings to become established, and several favorable years in a row are necessary for natural revegetation which tends to come in pulses (Romney et al., 1980a), 1987a). After nearly two decades, denuded areas at Yucca Flat have experienced essentially no recovery of original perennial shrub species (Romney et al., 1971). The higher elevation and greater precipitation at Yucca Flat would tend to accelerate natural revegetation processes relative to the Amargosa Desert.

A disturbed site will evolve through a succession of plant communities. Site-specific information on climax species composition, and on rooting depth and related properties of the different communities can be inferred from the extensive studies on the NTS. Several open alluvial valleys with roughly similar latitude, elevations, and precipitation patterns to the Beatty LLRW disposal facility have been characterized (particularly Rock Valley).

The climax community in the area of the Beatty site is probably dominated by Larrea tridentata and Ambrosia dumosa (by analogy with vegetational grouping studies by El-Ghonemy et al., 1980). However, the initial plant community would most likely be dominated by summer annual species such as Salsola and winter annual plants. Influx of Salsola species within a few years after disturbance of a site has been commonly observed at the Beatty site, at the NTS (e.g. Yucca Flat; Romney et al., 1971; Wallace et al., 1980e) and at other arid and semi-arid locations (e.g., the Hanford Site; McKenzie et al., 1982; Klepper et al., 1985). After establishment of Salsola, areas in the Great Basin desert with higher precipitation than the Beatty site then typically become dominated by mixed grasses (Romney et al., 1971), but this is doubtful in the Mojave Desert. A more likely succession community after Salsola would involve pioneer species that have been shown to be capable of invading bare areas and that may have a role in establishing new fertile islands. These pioneer species are Acamptopappus shockleyi, Lepidium fremontii, Sphaeralcea ambigua, and Atriplex confertifolia (Wallace and Romney, 1980). Of the native perennial shrub species, Krameria parvifolia, Ephedra nevadensis, and Yucca schidigera would probably have the slowest natural re-vegetation rates (Hunter et al., 1980a).

4.3 Characteristics of Wildlife

Burrowing animal intrusion into trench caps, and the effects of grazing animals on vegetation are of concern when assessing site stability. For the most part the concern is with rodents, and in the northern Mojave Desert these include pocket gophers (Thomomys bottae), rabbits (Lepus californicus and Sylvilagus audubonii), kangaroo rats (Dipodomys merriami), and mice (Onychomys torridus and Peromyscus spp.) (Hunter et al., 1980d).

Very limited data on burrowing habits and burrow depth distribution was found in the literature. McKenzie et al. (1982) reviewed published quantitative data on burrowing species to formulate the characteristics of a reference arid low-level waste burial site. Percent distributions of burrow systems for several species are as follows (from Table 3.2-1 of McKenzie et al., 1982):

	Depth interval (m)				
	0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0
Pocket mice and Kangaroo rats	50	40	5	5	0
Pocket gophers	85	15	0	0	0

Hakonson (1986) demonstrated the effectiveness of gravel and cobbles in inhibiting pocket gopher burrowing. The large mass of the cobbles and the noncohesiveness of the gravel prevented burrows from either being built or maintained. The Beatty site soils and sediments that are be used to construct the trench cap contain up to 60 wt.% gravel+cobbles (Law Engineering, 1981; Converse Consultants, 1984; Mark Group, 1988).

Rodents can also damage newly established plants. Jackrabbits can prune plants aboveground, while pocket gophers can destroy plants by eating roots (Hunter et al., 1980c; Romney et al., 1987b; Wallace et al., 1988). Mitigation of rodent problems will be provided after closure by the perimeter fence. The current fence around the site seems to limit animal activity to predominantly jackrabbits. Fencing has been shown to be effective in reducing animal grazing problems during the restoration of native perennial shrub species (Hunter et al., 1980d; Romney et al., 1987b).

4.4 Summary/Conclusions

The sparse and irregular precipitation of the northern Mojave Desert has resulted in the development of a land surface structure characterized in the undisturbed state by small "fertile islands" consisting of shrub clumps separated by large areas of poorly productive soil. Disturbance of a site destroys this structure and results in very slow revegetation by native perennial plant species. Restoration of disturbed land by man requires considerable time and effort using transplantation and husbandry procedures, and its success is dependent on a multitude of interrelated factors many of which are not controllable. Natural revegetation processes would most likely result in a succession of plant communities with rapid influx of Salsola species, probably followed by a more gradual replacement by pioneer perennial plant species. After several decades, establishment of a climax community of perennial shrub species would be expected. Information on rooting depths of species within these communities, although not comprehensive, suggests that the climax shrubs would be the deepest-rooted. As much as 95% of the below ground biomass of these shrubs in areas of the NTS were within the top 40 cm of the soil, and most Mojave Desert species root within 1 meter of the surface. This behavior is consistent with vadose zone recharge studies which indicate potential storage of precipitation within 2-2.5 m of the surface. Limited quantitative data on burrowing animals suggests that 90-100% of burrow systems would be confined to 1 meter or less and most likely none would be below 2 meters. This is consistent with the shallow rooting depths noted above. A trench cap plus soil overburden of greater than 10 feet, and at least 15 feet for trench 22 and future trenches, would seem to afford protection against root penetration and animal intrusion into buried wastes at the Beatty facility. More detailed considerations of the effects of plants and animals on site performance is provided in the Environmental Pathways Analysis and Dose Model.

For informational purposes, a list of vegetation species found in the areas surrounding the site in approximate order of abundance is included as Table 4-1.

TABLE 4-1

LARREA TRIDENTATA VEGETATIONAL GROUPING

Species	Common Name
Larrea tridentata	creosote bush
Ambrosia dumosa	bur-sage or burro bush
Lycium andersonii	desert thorn or wolfberry
Grayia spinosa	spiny hopsage
Acamptopappus shockleyi	goldenhead
Krameria parvifolia	range ratany
Oryzopsis hymenoides	Indian rice grass
Atriplex confertifolia	shadscale
Ephedra nevadensis	Mormon tea
Ceratoides lanata	winterfat
Yucca schidigera	Mojave yucca
Atriplex canescens	four-winged salt bush
Mendora spinescens	
Lycium pallidum	box-thorn
Sphaeralcea ambigua	desert mallow
Yucca brevifolia	Joshua tree
Ephedra funerea	
Lepidium fremontii	
Hymenoclea salsola	cheesebush
Dalea fremontii	
Dalea polyadenia	
Cactus sp.	
Thamnosma montana	

NOTES: From Table 1 of El-Ghonemy et al., 1980; species are relevant to study areas in Jackass, Frenchman, and Yucca Flats and in Mercury and Rock Valleys; species listed in approximate order of abundance (greatest to least).

5.0 OBJECTIVE 1

"To assure that all waste forms and types have been buried in accordance with the conditions of the license."

5.1 Response:

5.1.1 General

All waste has been and will continue to be buried in accordance with the applicable regulatory requirements in existence at the time of burial. To support the burial requirements, manuals and procedures have been and will continue to be issued in the future, as appropriate, to give the necessary radiological and operational guidance to US Ecology personnel. Present guidance and documentation requirements are contained in the Beatty Facility Standards Manual, Nevada State Board of Health Radioactive Materials License No. 13-11-0043-02, and the Beatty Operating Procedures (BOP's). State of Nevada management audits and radiological control and safety audits are performed periodically to ensure operations are conducted as required. US Ecology has also monitored its compliance with license, regulatory and procedural objectives through its own quarterly management audits, radiological control and safety audits and frequent site inspections.

5.1.2 License

Copies of the subject licenses, amendments, reference letters, manuals and procedures are retained at the facility; to wit:

A. Atomic Energy Commission (AEC) and its successor agency, Nuclear Regulatory Commission (NRC) License, and correspondence relating to the license.

B. Nevada State Board of Health Radioactive Material License No. 13-11-0043-02, and correspondence relating to the license.

C. US Ecology's Facility Standards Manual and Beatty Operating Procedures.

5.1.3 Records Involved in Receipt of Waste

Prior to shipment and acceptance of a waste shipment for disposal at the site, a Radioactive Waste Shipment and Disposal Manifest (RSM) must have been completed by the generator in its entirety.

A vehicle radiological survey is performed by a qualified radiological control and safety technician to ensure compliance with all applicable federal and state regulations and company requirements. Documentation of these surveys is required by the company's License No. 13-11-0043-02, Facility Standards Manual and Beatty Operating Procedures.

Other documents required by the Nevada License are reviewed for completeness and accuracy prior to acceptance of a shipment for disposal. If applicable to the waste to be shipped, a certificate of compliance for the shipping container and/or a DOE/NRC-741 form for a shipment involving source or special nuclear material may be necessary.

5.1.4 Records/Audit

The following records are maintained at the corporate office and at the facility for review by the State, NRC, and the company's chief radiological control and safety officer (CRC&SO).

A. Radioactive Waste Shipment and Disposal Manifest (Manifest)

A review of the manifest files indicates that these forms have been received/reviewed by a qualified individual since October 1962. The form has been revised over the years but the information is basically the same, (i.e., isotope activity, radiation levels, etc.). Since October 1962, the number of the trench the waste was buried in has been recorded. These records are filed by generator. All other associated documentation concerning the waste shipment will have the same sequential receipt number.

B. Vehicle Survey

Records involving vehicle surveys for radiation and contamination levels date back to October 1962. These reports are also filed by date.

C. Burial Reports

Burial reports have been submitted on a monthly basis to the state and date back to the November 1962 report. Copies of these reports are filed by the month/year by the company.

D. DOE/NRC 741 Forms

Nuclear Materials Transaction (SNM) NRC-741 forms dating back to January 1980 indicate the generator, cubic footage, millicuries, grams of SNM and weight of source material, as required by 10 CFR 70.

E. Audits

Quarterly audits performed by the CRC&SO are filed chronologically beginning in 1962. US Ecology Quarterly Management Audits are conducted quarterly and also are filed chronologically.

F. Accident Reports

An accident report is generated when an accident occurs at the facility. These reports indicate the type of accident, personnel involved and what actions were taken. Reports of this nature date back to 1976.

G. Quarterly Site Inspection

A quarterly site inspection is performed by site radiological control personnel and is documented as required by the licenses. These inspection reports began in 1962. The report forms have been revised during subsequent years, but basically require the same information.

5.1.5 Radiological Control and Safety Audits

The radiological control and safety audits are performed by the CRC&SO or his designee. Audit procedures require that this audit review, at a minimum, the areas of personnel dosimetry, training, emergency drills, radiological control procedures, decontamination procedures, radiological surveys, instrumentation calibration, radioactive source control, security and environmental monitoring.

5.1.6 Management Audit Summary

Quarterly management audits cover the following items: safety, equipment status, security, receipts and disposal of waste, inspection of closed trenches, environmental monitoring and surveillance conditions, trench construction, personnel administration, training, etc.

In conclusion for Objective 1, all necessary procedures for waste receipt, handling and documentation are included in US Ecology's Facility Standards Manual and Beatty Operating Procedures. These are reviewed annually and revised, if necessary. Therefore, all waste buried at the facility has been and will be in compliance with applicable federal and state regulations and all license conditions, both past and present. Audits performed by the AEC, NRC, State, CRC&SO and US Ecology management, to date, have confirmed such compliance.

6.0 OBJECTIVE 2

"To dismantle, decontaminate as required, and remove all structures, equipment and materials that are not to be transferred to custodial agency."

6.1 Response:

6.1.1 Site Structures

Structures not required by the custodial agency will be removed from the facility after they have been surveyed for compliance with release for unrestricted use. If radiation levels are above the unrestricted use level, then structures will be decontaminated or demolished and placed in the operating disposal area. If buildings or trailers are removed from the site, no disposal cost will result as structures so removed will be decontaminated at US Ecology's expense. Materials resulting from the decontamination of buildings or equipment will be placed in the operating disposal area.

Presently the only structure located within the restricted area of the LLRW disposal facility is a small prefabricated building located at the restricted area control point. This building is used as a personnel frisking station.

This structure is considered by US Ecology to be the only existing building which could become contaminated and which may require decontamination during the closure period. Materials resulting from any necessary decontamination of this building will be placed in the operating disposal area.

6.1.2 Decontamination

Decontamination of site equipment or structures, if surveys indicate they are above unrestricted use release levels, will be performed in accordance with the NRC Regulatory Guides, guideline 1.86. This will ensure that the equipment meets all of the unrestricted release criteria. Decontamination operations will be conducted in accordance with US Ecology's Facility Standards Manual, and all pertinent Beatty Operating Procedures.

In lieu of decontamination, any contaminated equipment or structure can be removed and disposed of in the active portion of the trench. The facility offices and change rooms are outside of the controlled area and will not require disposal as radioactive material. Potential contamination is minimized by a strict monitoring program and by controlling access from the trench disposal area. The controls being utilized now will be continued, thereby keeping the building in a non-contaminated condition. By doing this, decontamination to the limits specified in Regulatory Guide 1.86 would be minimal prior to unrestricted release at closure.

6.1.3 Equipment and Materials

Without a specific request and subsequent agreement, no materials, equipment or supplies will be transferred to the custodial agency. Contamination will be the primary factor for choosing the method for disposal of equipment and materials. Contaminated or unsalvageable items will be disposed of in the operating disposal area. Salvageable items will be removed from the site at no cost to the custodial agency after radiological control personnel have decontaminated and surveyed in accordance with NRC Regulatory Guide 1.86, US Ecology's Facility Standards Manual and applicable Beatty Operating Procedures.

6.1.4 Cost Evaluation

A. Partial Closure

Partial closure of the landfills has been routinely accomplished in the past by placing final cover as the layered waste reached the three-foot cut-off level. Trench 22 and all succeeding trenches, will be closed utilizing an eight-foot below grade cut-off level, as required by our present license.

B. Ultimate Closure

Upon facility closure, the unclosed area of landfill surface will be limited to the area of the last few days' receipts because of routine partial closure as described above. After all waste, building rubble and contaminated equipment have been buried all remaining trench space shall be backfilled.

After the final landfill cell has been closed in accordance with license requirements, the entire radioactive waste trench area will be capped with a minimum seven-foot thick cap (minimum 10 feet above buried waste). The cap will be a minimum of seven feet above grade at the perimeter, and slope upward at a minimum 1% slope to a ridge near the center. The cap outslopes will be graded to a 4 horizontal:1 vertical slope. The proposed cap will be constructed basically in accordance with Drawings No. NV-119-TRE-001, -002, and -003, included as Attachment 12. The first phase (Drawing NV-119-TRE-002) includes capping of the previously filled trenches while Trench 22 is still in operation. The major portion of this cap has been placed as shown on the facility topographic map, Attachment No. 1. The capping for Trench 22 will be completed after the trench has been filled, (Drawing NV-119-TRE-001).

Any future trenches would be capped in accordance with Drawing No. NV-19-TRE-003.

Upon completion of the cap, all trench monuments will be relocated by engineering survey.

During ultimate closure the entire site will be inspected and such conditions as follows will be checked:

1. Drainage ditches and swales are free of debris and sediment;

2. The cap is graded to promote runoff and is free of erosion;

3. No depressions or swales are present that could pond water; and

4. Grading to prevent accumulation of sediments or erosion of drainage pathways has been maintained.

C. <u>Monuments</u>

The monuments marking closed trenches will be similar in construction, and will contain the same information as that furnished on the monuments already marking Trenches 1 through 21. After construction of the seven foot cap is complete, all monuments shall be relocated by engineering survey. Since more detailed information is included in site records, and since accurate location of underground features can be quickly re-established by surveying in the recorded coordinates of the corners of those features, the monuments serve as a redundant checkpoint. A more complete description of the trench monuments can be found in Section 14.1 of this closure plan.

D. <u>Conclusion</u>

At closure, all surface structures, if any, will be removed from the controlled area except lighting equipment, fences and gates.

The estimate for closure and site stabilization are shown in Section 19.0.

7.0 OBJECTIVE 3

"To document the status of arrangements for orderly transfer of site control and for long-term care by the custodial agency."

7.1 Response:

The state of Nevada and US Ecology, Inc., entered into a twenty year lease with renewal option dated May 1, 1977, for approximately 47 acres (this acreage included the radioactive site and a 200-foot buffer zone) of land located in the NW 1/4, NE 1/4; NE 1/4, NW 1/4 of section 35, TWP 13 South, Range 47 East M.D.B.&M to be developed and utilized as a LLRW disposal facility. US Ecology's lease has the provision for one ten-year (10) extension.

The primary agreement by and between the parties which formalizes the implementation and continuation of institutional control is the aforementioned May 1, 1977, lease as amended. A copy of this lease has been appended as Attachment 13. This document clearly defines the state of Nevada's commitment to and time of assumption of institutional control. It is assumed that the state of Nevada's institutional control activities will be carried out in full compliance with the tenets and provisions of 10 CFR 61, et seq.

The May 1, 1977, lease agreement, as amended, clearly delineates the responsibilities of the parties in regard to the operation, closure and post-closure of the LLRW disposal facility which is owned in fee simple by the state of Nevada. As examples of the dispositive articles contained in the lease, Article XVIII, entitled "Closure Requirements," imposes responsibility upon US Ecology to perform the specific closure obligations as delineated in that provision. Article XIX, entitled "Responsibility Following Termination," expressly vests sole responsibility for all the materials buried at the LLRW disposal facility with the state of Nevada upon facility closure, or in the event of default by US Ecology.

The Bureau of Land Management (BLM) is not a part to the May 1, 1977, facility lease, as amended, nor does it have any regulatory association with the LLRW disposal facility. Therefore, the responsibilities as set forth in the lease and facility licenses do not contemplate any activity on the behalf of the BLM.

The BLM has only an ancillary role regarding the LLRW facility. This role is confined to the leasing of 400 acres to the state of Nevada as described in a lease entered June 20, 1982, by and between BLM and the state of Nevada. This acreage is immediately contiguous to the LLRW facility, and is described as follows:

Mount Diablo Meridian
T. 12 S., R. 47 E.
sec. 26, S1/2 S1/2;
sec. 35, S1/2N1/2, NE1/4NE1/4, NW1/4NW1/4

This lease is for a period of 25 years with a rental fee of $300.00 per each five year period. The lease also contains references to an option held by the state of Nevada to purchase this property during the term of the lease. The lease document itself conveys no regulatory or other authority to BLM in regard to the adjacent LLRW disposal facility, nor does it obligate the state to purchase the presently leased property. A copy of this June 20, 1982, lease is attached as Attachment 14. US Ecology is not privy to further arrangements, if any, currently existing between the state of Nevada and the BLM.

An estimate has been prepared determining the funds required, based upon present day costs, to fund site closure, stabilization and custodial care. Details of these costs may be found in Section 19.0.

Per letter dated July 9, 1992 from Mr. Ron Lange (Administrative Services Officer, Department of Human Resources), the state has accrued a fund of $5,292,589 as of June 30, 1992. At an interest rate of 2% above inflation, and without the potential additional revenue from the expected disposal of future waste and at the rate of disbursement projected in the closure cost estimate, the state will have a surplus of $20,632.293 in the fund at the end of the 100-year perpetual care and maintenance period. Details of the analysis may be found in Attachment 15. US Ecology has concluded that even a conservative state investment would yield an interest rate of 2% above inflation of any given period. Thus, given all the circumstances, it would appear that the anticipated total funding will meet the needs for site closure, post-closure and custodial care.

In accordance with the explicit terms of the May 1, 1977, lease, as amended, it is US Ecology's belief that its responsibilities for operation and maintenance of the LLRW disposal facility shall be properly terminated upon the performance of the closure activities as identified in the lease, or any licensure documents which are not in conflict therewith and have been duly promulgated in accordance with the applicable laws, rules and regulations of the state of Nevada. The designation of an eighteen-month period for closure and stabilization is based on the fact that historically trench cap or other types of subsidence have not been a material concern and the absence of groundwater, coupled with the extremely arid climatic conditions, allow for a relatively short, yet still comprehensive, period to ensure all closure activity objectives have been met. Documentation of the favorable geohydrological and climatic conditions present at the LLRW disposal facility is extensive and available in the public record.

8.0 OBJECTIVE 4

"To assure the direct gamma radiation from buried waste shall be essentially background at the site boundary."

8.1 Response:

8.1.1 Shielding

The application of fill material during burial and the placement of fill material between the waste and grade provide for a substantial amount of shielding material. The trenches have at least three (3) feet of fill material between the waste and grade. Beginning with trench number 22, waste will be placed up to a point allowing a minimum of eight (8) feet of soil between the last layer of disposed waste and the ground surface. The fill material is composed of predominantly SiO_2 (sand), a very dense material, which affords very substantial shielding. The shielding value of SiO_2 in reducing gamma radiation by a factor of 10 is calculated to be approximately 10 to 20 inches. A first approximation of the shielding value of SiO_2 was estimated utilizing the basic exponential attenuation law which describes the attenuation of a plane monodirection gammas source by an absorber:

$$I = B\, I_o e^{-uX}$$

where

I = Intensity of gammas, after passing through X thickness of absorber, at the point of interest. (photons/cm^2.s)

B = Buildup factor used to correct for radiation that is scattered from the absorber to the point of interest.

u = The linear attenuation coefficient which is the product of the mass attenuation coefficient and the density of the absorber (cm^{-1}).

X = thickness of the material in cm.

I_o = The intensity of the gammas entering the material (photons/cm^2.s)

The buildup factor is dependent upon the thickness and composition of the absorber and the energy of the gammas. The trench fill material and trench caps are predominantly sand with a density range of 1.7 to 2.2 g/cm^3. The photons emitted from radionuclides in the waste have energies ranging from less than 0.01 MeV to approximately 1.7 MeV with an average of about 0.5 MeV. The values for the mass attenuation coefficients for gammas with an energy range of 0.5 to 1.7 MeV and SiO_2 with densities of 1.7 to 2.2 g/cm^3 would vary from 0.04825 to 0.0874 cm^2/g. The resultant linear attenuation coefficients would vary from 0.082 cm^{-1} to 0.185 cm^{-1}. The buildup factor, used to correct for underestimated gamma intensity based upon uncollided flux approximations, was calculated based upon Taylor's work with the Goldstein-Wilkins calculations (Taylor, 1954).

The tenth value layer, the amount of sand required to reduce the gamma intensity to one-tenth the initial value, was calculated using an infinite slab source equation described in Fitzgerald (Fitzgerald, 1967). The range of calculated values for the tenth value layer is 25-50 cm or about 10 to 20 inches.

Therefore, after application of the additional seven-feet thick cap, radiation levels will be reduced to approximately a millionth of the original intensity. This amount of shielding will assure that radiation levels at the fenceline will be essentially background.

8.1.2 Trench Surveys

During the operational and closure periods, all closed and capped trenches shall be surveyed for direct gamma radiation as described in Section 8.1.4. A detector with micro-r per hour (ur/hr) sensitivity will be utilized for this type of survey. Any readings determined to be above the operational value of 0.5 mR/hr shall require the application of additional fill material in order to decrease the direct gamma radiation readings to approximately background. All trenches closed during the closure period will be surveyed after cap completion.

Surveys of filled trenches shall be performed on a quarterly basis when the trench caps are routinely inspected for subsidence or cracking. All cap surveys shall be conducted as walking surveys as presented in Section 8.1.4.

8.1.3 Survey Procedures for Trench Caps

This section sets forth the guidelines to be implemented by the facility radiological control and safety officer (FRC&SO) or his designee or the custodial agency when performing the gamma surveys and inspections on closed trenches.

A. Instrumentation

All surveys shall be performed utilizing a Ludlum Model 19 Micro R meter or meter of equivalent sensitivity. Instruments shall be calibrated at six (6) month intervals. The requirements of US Ecology's Facility Standards Manual and BOP 61 shall be followed during the operational phase, closure phase, post-closure phase and are recommended for the custodial period.

B. Surveys/Inspections

Radiological surveys and inspections of trench caps shall be performed by radiological control personnel. These surveys are to be performed during the operational life of the facility, during closure phase, and post-closure phase and are recommended for the custodial period. The general requirements for these surveys are as follows:

1. Operational Phase

During the operational life of the facility (i.e., that period of time when low-level radioactive waste is being disposed of), trenches which have been closed and capped shall have an initial survey as described below. Subsequent surveys and inspections shall be performed on a quarterly basis.

2. Closure and Site Stabilization

During the closure phase of the facility, (i.e., that 18 month period of time when the final site closure and site stabilization activities are being carried out) a trench cap survey and inspection will be performed.

An eighteen month period for closure and site stabilization should be more than sufficient to complete these tasks and monitor the site's security. Little maintenance is necessary for an arid site with favorable geology. There is no need for mowing or pumping leachate as with a humid site.

Minor subsidence or other maintenance needs that may arise can be attended to during the semi-annual inspection and maintenance trips during the custodial period.

3. Custodial Period

During the custodial period of the facility, trench cap surveys and inspections are recommended to be performed on a semi-annual basis.

C. Records

Records of the trench cap surveys and inspections during the operational period, the closure and site stabilization periods will be maintained at the facility.

8.1.4 Survey Procedures

A. The following guidelines shall be followed during the operational and closure periods when performing the trench cap survey.

1. Trenches that are closed and capped during the operational and closure periods shall be surveyed within two months of the date the newly filled trench is capped. All other trenches shall be surveyed such that 25 percent of each trench is surveyed quarterly and all capped trenches are completely surveyed annually as follows:

(a) A post at least five (5) feet tall shall be placed at each trench corner.

(b) A five (5) foot wide path shall be surveyed along the length of the trench. This shall be repeated every twenty (20) feet along the width of the trench until the edge of the trench is reached. The first path surveyed during the first quarter of each year shall be from the northeast to northwest corner post of each trench. The second quarter's first path shall begin five (5) feet south of each trench's northeast and northwest corner post; third quarter, then (10) feet; fourth quarter, fifteen (15) feet.

(c) Surveys shall be documented on a scaled map of each trench (where one inch equals twenty (20) feet) marked in a grid pattern where each square equals five (5) square feet.

B. The initial survey performed to close a trench must provide 100 percent survey coverage. The individual performing the survey should be able to survey two and one half (2 1/2) feet to each side thereby covering a five (5) foot width with each pass.

C. Readings should not exceed the baseline values (within instrument accuracies); however, if readings are greater than baseline, additional trench capping material will be placed on those areas until such time as the levels are found to be at approximately baseline values.

D. The following will be used when performing the trench cap surveys during the custodial care period at the Beatty, Nevada, Low-Level Radioactive Waste Facility.

1. The grid systems as outlined in (A) above shall be utilized by personnel performing these surveys.

2. Radiation surveys will be taken with a calibrated and functional Ludlum Model 19S or instrument of equivalent sensitivity. Maximum radiation levels shall be recorded for each trench on separate diagrams.

The procedure as stated above is recommended for use during the custodial period. These surveys should be performed on an annual basis using the grid system outline in (A) above.

The radiation surveys will be used to guarantee that all active areas of the site have a radiation level of 2 mr/hr or less per the 1977 lease requirements. Any areas found above that reading will be backfilled as required by the lease.

A final radiation survey report will be included in those documents turned over to the state as the custodial agency.

9.0 OBJECTIVE 5

"To assure and be able to demonstrate that the rate of increase of radionuclides through air, ground, and surface water pathways are at or below acceptable levels. Acceptable levels of water are those set forth in NAC 459 (or 10 CFR 20 of Appendix A, at the site boundary, and EPA drinking water limits at the nearest water supply. Acceptable levels for air are those found in NAC 459 (or 10 CFR Part 20, of Appendix A)."

9.1 General:

This response discusses the type and extent of environmental monitoring needed at the site in the closure and stabilization period.

The current environmental monitoring plan will be revised during closure to reflect a reduced sampling and assessment regimen as outlined below. The plan will include the recommended action levels for indicator parameters, e.g. concentration of radionuclides in air, water, soil and vegetation.

9.2 Environmental Monitoring Plan

The Beatty site has hydrogeologic and climatologic conditions that are favorable to the minimization of waste transport to the environment. Coupled with the waste disposal methods employed at the facility, the environmental monitoring requirements during the closure and stabilization phase will not be intensive.

9.3 Air Sampling

Air sampling performed on a daily basis during operations has not indicated any detectable radionuclides above ambient background. Therefore, it is highly unlikely that once all waste materials are disposed and the trench is capped that any air releases would result.

A 24-hour air sample will be collected and analyzed on a quarterly basis during the closure and site stabilization period. The air sample shall be analyzed by gamma spectrometry, for total uranium and isotopic plutonium. Records will be maintained by the CRC&SO of the air monitoring results for inspection for an indefinite period.

Records of all calculations, including factors and constants, used for obtaining the final air concentration shall be maintained indefinitely by the CRC&SO.

A record of all routine and special calibrations of air flow or volume metering devices, including primary or secondary standards used, methods employed and estimates of accuracy of the calibration metering device shall be maintained indefinitely by CRC&SO.

The air concentration data shall be reviewed and evaluated, obtained, by the CRC&SO to assess trends, the potential for ceeding action levels, estimating annual exposures via the transport pathway, and the validity of results compared with sample size and minimum detection level.

The action levels are those concentrations in air listed in Table II, Column 1, Section 459.334 "Table of Concentrations in Air and Water Above Natural Background," Chapter 459 of the Nevada Administrative Code.

9.4 <u>Soil and Vegetation Sampling</u>

Surface soil samples shall be taken semi-annually in the spring and fall during closure and site stabilization. The samples shall be taken from undisturbed soil within an area of 12" x 12" x 1". Soil samples shall be analyzed for total uranium, isotopic plutonium and by gamma spectrometry. Additional soil sampling and analysis shall be performed whenever trench surveys demonstrate an elevation in ambient radiation that is significantly above the baseline levels established during operations and closure. Soil sampling and analysis shall also be performed subsequent to any trench cap repairs or modifications. Maps shall be maintained indefinitely by the CRC&SO that show the location of soil samples.

Vegetation samples shall be taken semi-annually in the spring and the fall during closure and site stabilization. The samples should include only new growth and shall be analyzed for total uranium, isotopic plutonium and by gamma spectrometry. Whenever possible the vegetation samples should include samples from filled and capped trenches. Maps shall be maintained indefinitely by the CRC&SO that show the location of vegetation samples.

Data from the soil and vegetation monitoring will be compared with the predictions of the dose/pathway analysis. Positive indications of radionuclides that are not naturally occurring shall result in additional sampling. Records of the soil and vegetation monitoring shall be reviewed, evaluated and then maintained indefinitely by the CRC&SO. The CRC&SO's evaluation shall include an assessment of trends in the data, the validity of results compared with sample size and minimum detection level and comparison with the dose/pathway analysis as appropriate.

9.5 Groundwater Sampling

The Beatty site contains a dry waste inventory. The potential for liquid migration from the trenches to the underlying water table is extremely low due to the minimal recharge. Maximum liquid downward migration rates from the surface have been calculated to be on the order of 4 $cm/10^3$ years (Nichols, 1985). More recent data indicates that there is no net downward transport of liquid below 9 meters (Fischer, 1990). Ambient water quality moving under the site has not appeared to be impacted by the US Ecology site operations.

In accordance with the terms of the lease, US Ecology will remove those wells that the state deems are not needed for purposes of monitoring upon facility closure.

Groundwater monitoring will be performed during the site closure and stabilization periods, semi-annually on wells 001, 002, 301, and site water well. Well 001 is located approximately 325 feet east of the southwest corner of the facility. Well 002 is located southwest of Trench 22 approximately 410 feet north of the southwest corner of the facility. Samples from these wells will be analyzed for gross alpha, gross beta, gamma emitting radioisotopes, and tritium. Any indication of levels significantly above background or increasing trends will result in additional analyses to determine specific alpha and beta emitters. If analysis indicates that migration of radionuclides could be occurring, additional confirmatory sampling will be performed. Verification of migration will result in immediate notification to establish that limits in NAC Chapter 459 have not been exceeded.

9.6 Data Review and Evaluation

Data from the environmental monitoring program will be screened to identify values that deviate greatly from other data or appear to be inaccurate. Outliers will be investigated for validity by reviewing laboratory results, sample collection practices and vendor reported minimum detection level.

Laboratory vendors shall be required to report all data with an estimate of the total uncertainty associated with the analysis. Questionable results will be thoroughly evaluated with respect to all available information that may lead to the conclusion that the contaminate was or was not detected. Trend analysis will be performed to determine whether the concentration of a contaminant is increasing, decreasing, or remaining stable with time, relative to background and/or historical data.

9.7 Dose Model and Pathways Analysis

The Pathways Analysis was submitted to the State, March 30, 1989 and illustrates how the site is to perform during the closure, stabilization and perpetual care and maintenance periods in maintaining releases below acceptable levels. The Pathway Analysis and Dose Model states that radiological exposure from the surface water, biotic intrusion, gaseous migration, atmospheric and groundwater pathways are insignificant. The calculated dose to a maximum exposed individual is well below the performance objectives of NAC 459.8155(1).

The reassessment of the original Pathway Analysis was completed by James L. Grant & Associates, Inc., March 14, 1991 entitled "Reassessment of Beatty Pathways Analysis Beatty Low-Level Radioactive Waste Disposal Facility." The purpose of the report was to re-assess the original Pathways Analysis based upon the new data acquired from drilling the two monitoring wells, 001 and 002. The conclusion of the analyses was, "Travel times calculated in this report do not differ significantly from previously reported results, and would not lead to projected concentrations of radionuclides significantly different from those presented in the March 1989 Pathways Analysis."

A follow-up analysis titled "Study Conducted by James L. Grant & Associates, Inc. to Determine the Effects of the New Beatty Source Term on the US Ecology Dose Model and Pathway Analysis dated March 1989" was completed and submitted to the state on December 30, 1991. In summary, this report stated that the original Environmental Pathways Analysis and Dose Model March, 1989, is still a conservative representation of the pathway of migration analysis for the Beatty LLRW facility.

10.0 <u>Objective 6</u>

"To document that all trench bottom elevations are above the water table level, taking into account the history of seasonal fluctuation since record keeping began."

10.1 Response:

Groundwater beneath the site ranges from a depth of approximately 300 feet to 360 feet, whereas, the deepest trench constructed to date is approximately 50 feet deep. It is not conceivable that groundwater at this depth will ever come in contact with buried waste as seasonal fluctuations in the ground water table amount to a few feet at most. (See Section 3.0)

11.0 OBJECTIVE 7

"That all site generated conditions that caused positive environmental samples in the past, including any evidence of unusual or unexpected rates or levels of radionuclide migration in or with groundwater, are analyzed and corrected."

11.1 General:

Objective 5, Section 9.0 describes the procedures to be followed in the event a positive environmental sample is encountered. The facility's environmental samples are recorded and filed. Those samples that have required investigation due to possible increases in isotopic concentration are noted with an indication of what actions were taken in confirmation or correction. These records will be turned over to the custodial agency at closure.

In accordance with Article XVIII, Section 6 of the 1977 lease, US Ecology agrees to remove all wells that are not needed for purposes of monitoring upon facility closure..

US Ecology has established in the Beatty Facility Standards Manual, Tables 6.1 and 6.2, action levels which initiate corrective or mitigative action.

The action levels have, during past and present operations, permitted evaluation of analytical results to ensure compliance with license, state and federal limits.

The tables stipulate steps required to be taken when a sample exceeds an action level. This includes the collection of additional samples to identify the isotope contributing to the activity and, if deemed necessary, monitoring to determine the extent of migration.

11.2 Analysis Review

In September, 1982, analysis of a groundwater sample indicated an elevated level of tritium. The sample had a tritium concentration of 24 nCi/L and was listed on the vendor analytical report as customer identification #44 which is normally associated with Well 301, the upgradient well. Subsequent samples from Well 301 were less than the minimum detection level until March 3, 1983 when a sample had 0.14 $\pm$ 0.07 nCi/L of tritium. Because of the large uncertainty, 50 percent, it is likely that this measurement is due to a statistical variation in the background. Analysis of groundwater for tritium from the vendor, Teledyne, has always shown a minimum detection level of 1.0 nCi/L.

The most significant tritium concentrations have been measured in site well 302. Tritium concentrations in site well 302 were less than detectable until October 1982 when a peak of 410 nCi/L was measured. A plateau of 35-79 nCi/L of tritium existed until May 1983. From that time a gradual reduction in the concentration occurred until February 1986 when the concentration was less than the minimum detection level of 0.5 nCi/L. There has been only one groundwater sample with detectable tritium from well 302 since February 1986. This occurred in a October 1986 sample, 0.6 $\pm$ 0.3 nCi/L. This measurement is not very significant statistically and may not indicate the presence of tritium. All other groundwater samples of well 302 from February 1986 through October 1988 have been less than the minimum detection limits, 0.5 nCi/L.

A precise reason for the presence of tritium in site well 302 can not be made. Hypothetical causes for the presence of tritium in the groundwater include the following:

1. Tritiated water has migrated down to the groundwater from the disposed waste;

2. Contamination of the samples has occurred at some point during the collection, shipping, storage, or analysis of the samples;

3. The wells were spiked with tritium.

Each of these three hypotheses will be discussed in turn including the evidence supporting and conflicting with each hypothesis.

Data collected over the past three years by the U.S. Geological Survey adjacent to the Beatty site suggest that transport of contaminants through the undisturbed alluvium is minimal. Previous measurements from 1975 through 1985 support a maximum water migration rate downward of 4 $cm/10^3$ years. (Nichols, 1985) A U.S. Geological Survey has suggested in more recent studies (Fischer, 1990) that 4 $cm/10^3$ years is optimistic and that there is no downward transport below 9 meters.

The U.S. Geological Survey has postulated that much of the water flow may actually occur as vapor flow which does not carry dissolved radionuclides except for volatile molecular compounds of hydrogen, oxygen and carbon. Water-potential gradients give preliminary indications that flow through interconnected pore spaces may change seasonally to a depth of approximately 8 m. The hydraulic gradient appears to be upward below 9 m (Fischer, 1990).

The moisture retention characteristics of sediment samples from borings at the Beatty facility (see Section 2.6) have been measured from which unsaturated hydraulic conductivities have been calculated. These conductivities were used, assuming unit hydraulic gradients, to estimate vadose zone fluxes and radionuclide travel times to the saturated zone. This is part of the Environmental Pathways and Dose Model analysis that was submitted to the State, March, 1989. It considered the potential for liquid migration to the groundwater and vapor migration through the final cap to the surface. This analysis refutes the hypothesis that the tritium measured in groundwater at the Beatty site is due to transport and diffusion from disposed tritium.

The second hypothesis cannot be supported because the tritium concentration was significantly positive over a relatively long period of time. During that time period several different individuals have collected and shipped samples and four different commercial analytical laboratories have been employed to measure the tritium concentration. It is highly improbable that contamination would have occurred during every sampling round under these circumstances.

The third hypothesis, spiking of the well with tritium is possible. The opening to the wells were not secured until late in 1983. Anyone with access to the site could have spiked the well. In addition, the ropes used to lower bailers into the wells have been contaminated during sampling. The presence of tritium in the groundwater samples and the behavior of tritium concentration in the groundwater are the strongest evidence that the wells were spiked. Data from shallow land disposal sites show multiple concentration peaks with the increases and decreases in concentration superimposed over a long-normal distribution baseline. The tritium concentration in well 302 shows only one peak with a regular and gradual decrease.

Another site condition, trench excavation and backfill may change the vertical variability of the soil and may influence water potential. Soil-water monitoring is in progress at experimental disposal trenches located adjacent to the Beatty facility. Recent data collected from this study indicates infiltrated waters have not exceeded 1 m below the surface of the trenches and, as much as 84 percent of the infiltrated water had been depleted by evaporation (Andraski, 1991). Soil-water content of the deeper backfill and undisturbed soil have remained relatively constant (Andraski, 1991). Present climate conditions, low precipitation and high evaporation rates, limit the infiltration waters.

This study and those conducted by Fischer confirm the results of the earlier studies. Water is not a potential transport mechanism from the waste trenches to the 352 foot depth of well 302. This also supports the hypothesis that the well may have been spiked.

Additionally, the supporting evidence for this conclusion consists of the following:

- o Tritium analysis from recently constructed wells 001 and 002 have not shown high concentrations.
- o The rope used to raise and lower the sampling bailer became contaminated;
- o Contamination in the groundwater from disposed waste would not have contaminated the walls of the well;
- o The tritium concentration showed only one peak with a gradual drop-off in concentration over the next year. The tritium concentration was below detection limits in 3.3 years. Typically, groundwater contaminated with radionuclides from land burial demonstrates a multitude of peaks intermittent with low or background concentrations;
- o The present geohydrological data results in a calculated minimum travel time to the groundwater of about 2 million years. Even if the tritiated water moved 1,000 times faster than that measured at the site it would take 2,000 years. There has not been sufficient time for waste to have migrated to the groundwater;
- o After the wells were capped and secured no more tritium concentration peaks occurred. This is highly irregular behavior for contamination in groundwater.

12.0 OBJECTIVE 8

"That the trenches are stabilized such that settlement of the trenches is reduced to minimal rates."

12.1 Response:

Final closure of the burial trenches will be accomplished by covering the site with seven feet of soil. A conceptual plan drawing of this cover is included as Attachment 12. This type of cover will have many benefits, including minimizing infiltration into the disposal trench, the extra weight of the soil will have a surcharging effect on the waste thereby causing early consolidation of waste, provide protection against burrowing animals and root penetration, prove a barrier against inadvertent intruders and creating a self healing cap.

The entire closed trench area encompassing approximately 26.4 acres will be covered with site soil. This area may be expanded if a future trench is constructed south of Trench 20. The cap will be constructed by placing soils to a minimum depth of seven feet above pre-1962 elevations over the entire disposal area. With the three feet of soil already placed above the waste, a minimum of ten feet of soil will be between the waste and the top of cap. In order to provide drainage, the cap will be sloped up at approximately 1% to 4% from the perimeter to a ridge in the center of the area. The outslopes from the perimeter will then be sloped at 4 horizontal:1 vertical to provide for stable slopes. These shallow slopes will provide for good runoff of the from the cap yet be resistant to wind and water erosion. The majority of the initial phase of the cap has been constructed. This phase (Draw- ing NV-119-TRE-002) includes capping of the old trenches while Trench 22 is still in operation. The next phase for cap construction will be completed after Trench 22 has been filled (Drawing NV-119-TRE-001). Any future trench caps would be constructed in accordance with Drawing NV-119-TRE-003.

12.2 Landfill Settlement

In 1984 a study was conducted by James L. Grant & Associates to be utilized as a synthetic/clay liner system waiver request for future disposal cells at the RCRA facility. A portion of that study investigated trench cap subsidence. This study is also applicable for the radioactive disposal trenches since the trench depths, disposal methods and backfill/waste ratio are similar. The results of Grant's study is summarized below.

Settlement of trench covers may occur as a result of several potential factors. Settlement may occur as a result of consolidation or readjustment of the host formation. This would occur if the host formation were compressible or weak. Loads imposed by the trench contents would cause the foundation of the trench to settle, and this settlement, if it were severe enough, could be reflected to the trench cover. Similar settlement could occur by the compression of a component of the trench, such as a liner, if the component were thick enough to cause significant settlement. At the Beatty site, the host formation is comprised of dense, partially cemented materials that are dry. These materials generally are dense, and have unit weights larger than the waste that will be placed in the trench.

Because of the dense, dry nature of the host soils, any settlement that may occur would result from elastic deformation. This settlement would occur almost concurrently with the imposition of the load, and thus would not influence the long-term performance of the trench cover. Because of the character of the foundation materials, significant settlement of the foundation is not anticipated. Settlement that does occur will be limited further by the loading history of the foundation, which has been preloaded to loads comparable to or larger than the load imposed by the completed trench.

Because the waste at the Beatty site is disposed of in a dense, partially cemented, dry soil, the majority of the settlement of the trench covers that may occur will result from primary and secondary consolidation of the waste. Primary consolidation results from the elastic deformation of a material in response to a change in stress within the mass. Secondary consolidation in soils results from the same readjustment, but occurs over a long period because of the rheologic factors that may control the rate of stress changes. Generally, the factor that controls the rate of secondary consolidation is the rate of internal drainage of the soil mass. Consolidation of sands is essentially all primary, because the sands allow rapid dissipation of excess pore water pressures generated by the imposed load. Clays may have long periods of secondary consolidation because their low permeability prevents the rapid dissipation of the excess pore water pressure.

Studies of simulated disposal trenches conducted by the USGS adjacent to the Beatty facility have also provided structural monitoring and subsidence. These studies indicate 80 to 90 percent of subsidence within the trench occurred during construction. Total subsidence for both trenches, stacked-drums and randon-drum placement, was about 6mm and generally occurred within the six months following construction (Andraski, 1990). Drum placement (random vs. stacked) did not influence subsidence of the trench covers. Maximum soil loss attributed to deflation was 7mm (Andraski, 1990).

Sowers has studied the behavior of municipal landfills under loading, and has determined that consolidation of the waste materials can be attributed to four mechanisms. These mechanisms are:

1. Consolidation of void ratio reduction;

2. Biochemical decomposition;

3. Physiochemical changes;

4. Ravelling of soils into large voids.

Sowers found that the settlement of a landfill had two distinct phases, similar to those found in the settlement of soils. The first, or primary phase, occurs contemporaneously with the imposition of the load, and results from the adjustment of the waste materials to a changed stress regime. Sowers found this phase of the settlement to be completed within a short period after the load was placed. After the period of primary consolidation, the period of secondary consolidation of the waste begins. This consolidation results from the effects of the first three mechanisms described above. Sowers found that both phases of consolidation could be described by the equations that describe the respective phases in consolidation of soils. In the case of waste consolidation, the settlement parameters are functions of the composition of the waste, the density of the waste, and the conditions within the waste trench that affect the rate of waste decomposition.

The landfills studied by Sowers had void ratios ranging from about 2 for well-compacted fills to as much as 15 for uncompacted fills. These landfills typically contain about 80% waste and 20% backfill. On the basis of field studies of short and long-term consolidation of these landfills, Sowers has developed the following relations for the primary and secondary consolidation of landfills.

Primary consolidation

$$de = -C_c * \log [(s+ds)/s]$$

Secondary consolidation

$$de = A * \log (t2/t1)$$

where

d_e is the change in void ratio

C_c is a compression index related to the void ratio and organic content

s is the initial stress

ds is the stress due to the added load, and

A is a function of the void ratio of the landfill and the conditions under which decomposition of the waste occurs.

For low organic content fills, C_c is equal to 0.125e. A is a function of void ratio, and is equal to values between 0.03e and 0.09e. The lower value is appropriate for conditions unfavorable to decay, and the higher value for favorable conditions. Intermediate values are used for intermediate conditions. Initially, an aerobic environment favors decomposition, but decomposition requires water, and the very dry environment at the Beatty site may inhibit decomposition. Sowers notes that decomposition has been arrested in the laboratory by keeping fills dry in plastic bags.

The above relations can be used to calculate potential settlement at the Beatty Chemical site, but it must be recognized that the conditions for which the relations were derived are more severe than at Beatty. Aspects of the Beatty site that differ from those studies by Sowers include:

1. Approximately twenty-five percent of trench contents is waste, the remainder is soil backfill. The landfills studied by Sowers had about the reverse composition;

2. Backfill is compacted by tracking with a large dozer, and further compacted by routing traffic over the buried waste. Some landfills studied by Sowers also were compacted, and

Sowers noted the beneficial effects of compaction on limiting long-term settlement.

The Beatty waste also differs in composition from the municipal waste studies by Sowers. The fraction of paper, cloth and lawn and garden refuse was estimated by Sowers to be between 20 and 60 percent. This waste is not present in significant quantities in the Beatty waste stream.

The density of the Beatty waste also is higher than the wastes studied by Sowers because the fraction of waste in the Beatty trench is less than in the municipal landfills. Sowers notes a minimum void ratio of about 2 for well compacted fills. This value is for municipal landfills where about 75% of the volume of the fill is waste. Assuming that the void ratio of the backfill is about .35, and that the Beatty waste is similar to the municipal waste, then the void ratio of the materials in the Beatty trench would be about 0.69. Thus the void ratios that Sowers worked with are at least about 2.9 times as large as those of the Beatty materials. Settlement at Beatty should be correspondingly less.

These differences relate to the relative compressibility of the Beatty waste relative to that of municipal waste. Although the differences cannot be quantified, it is clear that the waste disposed at Beatty is less compressible and less degradable than municipal waste. Therefore, settlement estimates made by the relations developed by Sowers should be conservatively large.

Estimates of settlement of the trench covers as a result of primary and secondary made using the Sowers relations are.

Primary consolidation - 0.65 feet. This estimate assumes a value of C_c in the low range of values reported by Sowers, and assumes that the load imposed is created by a 10 foot thick cover weighing 125 pounds per cubic foot. The waste was assumed to weight 100 pounds per cubic foot. The cover is assumed large enough that attenuation of the added stress does not occur over the depth of the trench. Settlement only of the waste is considered. Foundation settlement is not included. The waste was assumed in equilibrium prior to applying the cover. This assumption is reasonable because the primary consolidation occurs quickly and the trench is filled slowly.

Secondary consolidation - 0.5 feet at 50 years after closure. This estimate assumes that secondary consolidation occurs during the filling of the trench, and that the average time of consolidation is 10 years when the trench is closed. A value of "A" of 0.09e was used. This value is appropriate for situations where conditions are favorable for decomposition. Lower values probably are appropriate at the Beatty site because of the dryness of the waste. The result obtained from the Sowers equation was divided by 2.9 to account for the smaller fraction of waste in the Beatty trench.

Because primary consolidation is small, and occurs immediately after application of the load, it is not significant to the long-term performance of the trench cover. Secondary consolidation also is small enough that it should not adversely affect the long-term performance of the cover. Slopes on the trench cover are sufficient to maintain drainage with settlements of 0.5 feet, and this settlement, over the area of the trench cover, should not disrupt the integrity of the cover.

The settlement discussed above represents the majority of settlement that may occur in the Beatty trench. Mechanisms that may be important in other situations are not applicable to the Beatty site. Liquefaction occurs when loose, saturated sands are subjected to vibrating loads. The materials in the trench are dense, dry sands, and are not subject to liquefaction. Subsidence also can occur as a result of creep in unconfined soils. The waste in the trench is confined by the dense host formation. Consequently, this mechanism is not credible at the Beatty site.

Sowers notes that settlement by ravelling cannot be predicted. Ravelling results from the movement of soil within the trench into large voids. Ravelling is enhanced by changing moisture conditions in the trench, and by the movement of infiltration through the waste. The Beatty site is operated to minimize voids, and moisture conditions within the trench are relatively constant. Because of the arid setting of the site, significant infiltration into the trench does not occur. These conditions indicate that ravelling should be minimal at the site.

Performance objectives require that disposal trenches be stabilized to minimize settlement. Closure procedures previously discussed minimize settlement after closure by consolidating waste and minimizing void space to a practical level. However, a certain amount of future settlement can be expected due to natural and expected mechanisms. Previous experience, even with trenches closed under less stringent closure requirements, indicates that settlement has been minimal.

Though US Ecology believes that windblown sand will tend to fill surface depressions, the integrity of the cap is safeguarded by inspections on a semi-annual basis during the custodial period and follow-up maintenance on the caps, if necessary. Surveillance and occasional maintenance is a security requirement for the custodial period after post-closure. This factor is the basis for the federal requirement for transferring of the responsibility to either the state or federal government rather than an individual or company.

13.0 OBJECTIVE 9

"That conditions for erosion, water infiltration into trenches, loss of site or trench integrity due to such factors as groundwater, surface water, and wind are eliminated."

13.1 Infiltration

Due to the low annual precipitation (average 2.5 to 5.0 inches), most direct precipitation over the facility area infiltrates and then evaporates, leaving little water available for surface runoff. Thus, surface water runoff or water erosion commonly does not occur at the facility as described in Section 2.4 of this plan. Water infiltration is not expected to penetrate deeper than about nine to thirteen meters below the ground surface.

Preliminary findings at the USGS study site located at the Beatty facility indicate that below approximately nine meters the soil moisture gradient is upward towards the surface. (Fischer, 1990). Additionally, soil-water monitoring is in progress at the experimental USGS trenches located adjacent to the facility. Recent data indicates infiltrated water does not exceed 1 m below grade (Andraski, 1990). As much as 84% of this infiltrated water is depleted by evaporation. Soil water content of the deeper backfill and undisturbed soil has remained relatively constant (Andraski, 1990); although, USGS has shown that the moisture stored in the near-surface soil may be dependent upon the vegetation present.

Interim trench caps are constructed of in situ, granular material and are not designed to prevent but rather to retard moisture infiltration. Most rainfall that occurs at the site infiltrates the ground surface. However, because of the dry condition of the soils, the water will not penetrate too deeply into the ground before evaporation and transpiration return the moisture to the atmosphere. Minimization of infiltration into the present and future cells will be provided by constructing this cover of at least eight (8) feet of site soil and compacting by passing over the lifts with heavy construction equipment.

Upon closure of the facility, additional soil will be used to cover the entire radioactive disposal trench area to a minimum depth of seven feet. This final cap will be graded to an approximate 1% to 4% slope, as shown on drawings NV-119-TRE-001, -002, and -003 with 4 horizontal:1 vertical sideslopes. The cap will provide added infiltration storage capacity for water to be returned to the atmosphere via evaporation, before encountering waste.

13.2 Surface Water Erosion

The resistance to cap erosion is achieved by using mild slopes and constructing the cap with site soils, which are well-graded materials and contain a percentage of gravel and cobble size particles. In 1987 a study was conducted by James L. Grant and Associates to determine the amount of erosion that could be expected on trench caps constructed of site soils at the Beatty facility. The method of analysis used in the Grant study was The Modified Universal Soil Loss Equation (MUSLE).

The basic Universal Soil Loss Equation (USLE) is the best and most widely used method for predicting average annual soil loss from sheet, rill and interrill erosion. This equation relates soil erosion to rainfall characteristics, soil characteristics, land slope and slope length, vegetative cover and erosion control practices. The USLE predicts gross erosion, which is sediment produced by a combination of rill and interrill erosion. The USLE does not account for significant deposition.

The MUSLE is a modification consisted of replacing the rainfall factor in the USLE with a parameter describing the energy of storm water runoff. In the Grant (1987) study, the conclusion was that over a 1000-year period the total erosion on top of the cell cover would be .1 inches and .9 inches on the steeper side slopes.

The results obtained in the Grant study are for a trench which has steeper slopes than those designed for the cap over the closed radioactive material trenches. After substituting the shallower radioactive material trench cap slopes into the MUSLE it was found that over a 1000-year period the expected erosion on top of the cap would be .02 inches and .9 inches on the steeper side slopes. These results illustrate the excellent rainfall erosion protection that is provided by utilizing site soils and shallow slopes for cap construction.

13.3 Wind Erosion

In 1989 a study was conducted by US Ecology to determine the minimum thickness of trench caps required at the Beatty facility based upon wind erosion resistance, (Attachment 16). The method utilized by the Army Corps of Engineers was selected in that it uses wind characteristics along with soil and vegetation factors to predict soil loss.

The results of this study conclude that a minimum thickness of 16.2 inches of site soil will be necessary to insure an adequate gravel cover will remain after 500 years. As stated in this plan, the site will be capped with a minimum 7 feet of soil; increasing the cover over the waste to at least 10 feet. The area that will be most prone to erosion will be in the center of the cap where the thickness will be the greatest, approximately 12 feet above grade. An adequate cover will remain even for this conservative analysis.

13.4 Groundwater

Groundwater at the facility is at a depth of approximately 300 feet below the facility. The deepest trench to date is Trench 22 with a depth of 50 feet. This equates to groundwater being approximately 250 feet below the bottom of the deepest trench. At these depths groundwater will not come into contact with buried waste.

13.5 Floodplain

The facility is not in a 100-year floodplain, as shown on National Flood Insurance Program flood insurate rate map for Nye County, Nevada, Community-Panel number 320018 0152B (Attachment 4). It is located on a rise on an alluvial fan forming the upper end of a long valley within the Amargosa Desert. Site elevations vary from 2787 feet to 2770 feet above mean sea level. The land continues to slope to the southeast for at least 8000 feet as shown on the United States Geological Survey (USGS) quad sheet "Bare Mtn. Nev." The average annual rainfall is estimated to be between 2.5 and 5 inches. The facility is not subject to concentrated storm water flows resulting from extreme rainfall events. Sheet flow which might result from such a storm is diverted away from the site by diversion ditches. These existing diversion ditches prevent off-site run-on from entering the facility.

Due to the arid nature of the facility, the depth of the water table below the disposal units, the sandy nature of the cap, and gentle slopes of caps coupled with gravel protection, natural conditions, even over a substantial period of time, pose a minimal danger to cap integrity.

13.6 Catastrophic Events Analysis

The site closure plan includes final capping of the site with the cap elevated from 7 to 14 feet above grade and sloped to drain. Soil and rock are used to construct the permanent components of the disposal facility cap. These materials are not subject to significant deterioration during the life of the facility and can withstand an abnormal event. The disposal unit cap is designed such that repairs would consist of repairing subsidence features using on-site soils and the regrading of surface drainage swales on the cover.

Abnormal events that could create a need for maintenance include erosion by wind or water and earthquakes. The facility is designed to withstand all credible erosion without loss of function

(Section 13.2 and 13.3), so the occurrence of such events should not create a need for immediate maintenance. Earthquakes, as the analysis below indicates, also would not cause loss of trench cap integrity, but may cause subsidence needing repair.

As stated in the Beatty Hazardous Waste Management Facility RCRA Part B permit application, no record exists of any historic earthquake epicenter in the Beatty area since 1800. However, to evaluate long-term seismic effects on trench cover integrity, relationships between earthquake return period and horizontal acceleration for the southern Great Basin can be used. For a return period of 10,000 years, the acceleration would be about 0.3g.

During an earthquake, trench backfill could be densified leading to subsidence. Knowing the density of backfill and the maximum density (minimum void ratio) of a soil caused by an earthquake of a given magnitude, estimates of subsidence can be made. A soil at a higher density (or lower void ratio) than that resulting from an earthquake would not densify.

A typical value for the density of trench backfill at the Beatty Low-Level Radioactive Waste (LLRW) Facility is 108 pounds per cubic foot (pcf). This is equivalent to a void ratio of 0.54. The void ratios and densities of soil after an earthquake with a horizontal acceleration of 0.3 g. would be 0.74 to 0.86 or 9-95 pcf. These conditions represent soils that are lower in density (higher in void ratio) than the original trench backfill. As a consequence, significant trench subsidence by an earthquake is predicted not to occur.

The Beatty LLRW Site Stabilization and Closure Plan (Dec., 1988) contains an analysis of trench cover subsidence as a result of waste form degradation and settlement. The dry, dense, partially cemented nature of site sediments indicates that the majority of trench cover subsidence will occur from primary and secondary consolidation of the waste. The analysis presented in the plan demonstrates that long-term performance of the trench cover will not be significantly affected by waste consolidation. Liquefaction as a mechanism for trench cover failure is not credible at the Beatty site.

Long-term geochemical alteration of site sediments is restricted to normal weathering and soil-forming processes and would have no impact on trench cover integrity.

Site failure scenarios that would result in increased radionuclide releases or direct exposure to an individual were analyzed on a qualitative basis.

Direct Exposure

The Beatty cells that are closed have from of 3 to 8 feet of soil between the waste and grade. These caps have reduced the direct radiation to approximate background levels. With the placement of an additional 7 to 14 feet of material above the in-place caps, erosion of this material would be required just to return to the present site direct radiation readings. This does not seem plausible for any credible catastrophic event.

Earthquakes have the potential to cause subsidence within the cell. As the above analysis demonstrates, a credible earthquake would not result in subsidence to the extent that waste would be exposed however, even if it were exposed, repairs would be possible.

Radionuclide Release

The potential for radionuclides to migrate from the cell to the groundwater are possible only if the amount of moisture present within the cells increases. Cover failure followed by a potential precipitation event would increase the leachate present within the cell and possibly release radionuclides to the vadose zone for possible migration to the groundwater.

The infiltration rate used in the pathways analysis and dose model for the Beatty site (0.5 mm/yr) resulted in radionuclide doses to a hypothetical individual at the site boundary that was less than 7.2 percent of the regulatory limit.

Sensitivity calculations indicate that different infiltration rates would produce proportional changes in the well radionuclides concentrations and the resultant doses. This means that a tenfold increase in infiltration, resulting in the same radionuclide solubility as was used in the model, would result in an approximate tenfold increase in dose. Also, this infiltration would have to be maintained for one year to equate to the yearly dose calculated in the model. This dose would still be below the regulatory limit in NAC 459.8155(1). Potential precipitation events and trench cover failure modes that would result in infiltration at or above the above scenario do not seem plausible.

13.7 <u>Mitigating Actions</u>

Environmental monitoring and survey data of potential pathways for transport of radionuclides from the facility including groundwater, surface water, air and biotic samples will be collected as described in Sections 8 and 9 of this Plan. Data will be reviewed by the Corporate Radiological Control and Safety Officer. The purpose of the review will be to: 1) assure that limits set forth in NAC Chapter 459 are not exceeded; 2) identify trends associated with the data and evaluate the causes; and 3) assure that migration of radionuclides off-site does not occur. Review will involve comparison with normal background as well as administrative action levels and state of Nevada limits.

Any data indicating that releases have occurred through a pathway will result in increased monitoring of that pathway and any other pathways that may as a consequence be affected. Information gained from such data will be used in conjunction with preoperational and operation data to determine the severity of any release and to estimate through dose calculations the health consequences of the release. The Division will be notified of any data which indicates that a release has occurred. Possible mitigating actions which could be taken to both stop the release and reduce or eliminate any dose to the public are discussed below. Implementation of specific mitigating actions will be undertaken with the approval and concurrence of the Division.

Groundwater Pathway

The groundwater pathway involves migration of contaminated water through the vadose zone and into a drinking water aquifer into which an off-site well may be drilled. Groundwater monitoring is accomplished by sampling from indicator wells 001 and 002 and upgradient well 312. Samples will be collected semi-annually and analyzed for tritium, gross alpha, gross beta, and gamma emitting radioisotopes.

Data will be analyzed to identify the existence of trends and variation from normal background levels as well as conformance with applicable state regulations. If trends or elevated activity are found, additional sampling will be performed and the surveillance frequency will be increased with the review and concurrence of the Division. The site will be inspected to assure the integrity of the trench caps and drainage channels, and repairs will be made as needed. A supplementary monitoring plan will be proposed to the Department for purposes of further characterization of the contaminant plume. Any such plan would be subject to review and approval of the Division prior to implementation.

If increased monitoring or dose projections indicate that NAC Chapter 459 limits are being approached, other actions will be taken to reduce or eliminate radiological exposure. Examples of such action are:

1. Increased surveillance to identify and repair any deficient trench caps;

2. Increase density of cap vegetation;

3. Modify or repair water diversion dikes;

4. Re-cap trenches as necessary to reduce water infiltration.

Surface Water Pathway

The surface water pathway involves transport of radioactivity to an off-site location by surface water run-off. Due to the low probability and unpredictable nature of severe precipitation events around the site, monitoring of this pathway is difficult to achieve. However, if precipitation occurs in large amounts such that the trench caps appear to have been breached, environmental samples (surface water and soil) will be collected as available. Samples will be analyzed for gross alpha, gross beta and gamma emitters.

If surface water samples are available, they will be additionally analyzed for tritium. Repairs to the trench caps will be made with the concurrence of the Division. If environmental samples indicate concentrations of radioactivity above normal background, other samples will be collected to verify and determine the extent of the contamination. Upon verification of contamination, a plan for additional monitoring and mitigating actions will be submitted to the Division. Objectives of the plan will incorporate ALARA principles and compliance with NAC Chapter 459.

Some possible mitigating actions to achieve the above defined objectives include:

1. Increased surveillance of the site, especially during or after severe rain events to evaluate the effectiveness of the surface controls and identify any potential problems.

2. Remediate and repair damage to trench caps and drainage channels.

All mitigating actions would be performed with the concurrence of the Division.

Atmospheric Pathway

The atmospheric pathway involves possible exposure to individuals from:

1. Radioactive particles that have been uncovered and are transported through resuspension, and

2. Release of gases disposed at the site or generated during decomposition of the wastes.

Air samples will be collected and analyzed on a quarterly basis as described in Section 9.3. Analysis will be performed to determine concentrations of total uranium, plutonium and specific gamma emitters.

Results will be analyzed and compared to normal background and investigated for trends. Elevated results would require notification of the Division as well as increased monitoring to further characterize the release. Dose calculations would be performed, if necessary to verify compliance with NAC Chapter 459. A plan for mitigating actions to reduce exposure ALARA would be submitted and implemented with the approval of the Division. Such actions might include:

1. Increased surveillance of trenches and repair as necessary to circumvent erosion.

2. Re-capping or repair of trenches as needed to contain wastes and prevent further erosion.

3. Monitoring of off-site vegetation and surface water supplies for contamination.

4. Survey and decontamination of areas off-site as necessary.

Direct Exposure Pathway

The direct exposure pathway involves exposure to an inadvertent intruder from direct gamma radiation. Monitoring of this pathway will be performed in accordance with Section 8.1.3 of the Closure Plan. All survey data will be documented so that comparison with background and trend analysis can be performed. Surveys will provide a second function of assuring that trench cap integrity is maintained since any subsidence will be observed during the walkover. Any significant subsidence will be documented and reported to the Division. Repairs will be made to reduce exposures ALARA and maintain compliance with NAC Chapter 459.

Other mitigating actions which might be taken to reduce exposure ALARA include:

1. Repair or replacement of fences to prevent entry by inadvertent intruders;

2. Posting of warning signs at required intervals along the fence. Surveillance of the fence will be performed to ensure that the signs are in place and that they are legible;

3. Increases surveillance as necessary to monitor the status of the site caps and activities around the site.

Biotic Pathway

The biotic pathway involves transport of wastes to the soil surface via plant and animal intrusion. Contamination could then be transported off-site. Monitoring of this pathway will be achieved through the collection of soil and vegetation samples as well as surface water samples as discussed above. Soil and vegetation samples will be collected and analyzed biannually as described in Section 9.4. Analysis will be performed to indicate total uranium, isotopic plutonium and specific gamma emitting isotopes

Results will be compared with background concentrations established during the site pre-operational and operational activities. Verification of elevated activity or trends will result in notification of the Division, as well as submission of a plan for proposed mitigating actions to ensure that doses are maintained ALARA and in compliance with NAC Chapter 459.

In addition to the mitigating actions which were previously discussed under the surface water and atmospheric pathways, the following actions might be taken:

1. Removal of deep rooted plants from the site;

2. Repair of areas breached by vegetation or animal activities;

3. Increased surveillance of the site to allow for early detection of improper vegetation types or animal activities.

Upon verification of the existence of radionuclides in pathways which might result in doses to individuals off-site approaching those limits set forth in NAC Chapter 459, a full review of all possible mitigating actions will be performed. This review will entail analyses to determine state-of-the-art methodologies for reducing or eliminating exposure due to the affected pathway.

Alternative courses of action based on this review will be prioritized and submitted to the Division for approval prior to implementation of mitigating actions.

14.0 OBJECTIVE 10

"To demonstrate that trench markers are in place, stable and keyed to bench marks, and that identifying information is clearly and permanently marked."

14.1 Response:

14.1.1 Completed and capped disposal areas are marked with monuments bearing plates inscribed with the identifying information required by the licenses. Survey records tying these monuments and the disposal area corners to established federal control systems will be transferred to the custodial agency after closure. Trenches have been fixed by engineering surveys and plotted on the US Ecology, Inc., site map. An updated facility map with a complete list of trench coordinates tied into the U.S. General Land Office (U.S.G.L.O.) Section Survey will be provided to the custodial agency at closure.

14.1.2 Records pertaining to the replacement of destroyed markers are being maintained by the facility. These records will also be provided to the custodial agency at closure.

14.1.3 It is assumed that the trench markers will last during the entire custodial care period. The monuments placed at each end of the trench should be stable and legible over a 50-year time period due to the lack of water erosion in this area. Rainfall, ranging from 2.5 to 5.0 inches per year, does not provide enough moisture for appreciable corrosion to occur. The lack of moisture in the soil also prevents a freeze/thaw cycle which could dislodge the monument from its permanent position. Experience with an arid facility for over 30 years also indicates that erosion and corrosion of these types of materials are minimal. Also, the likelihood of a monument being dislodged by equipment during the custodial period is remote, and this would be the most likely factor to damage the monument. The brass plate is attached to the concrete monument with four expansive sleeve bolts; one bolt in each corner of the plate. The brass plate is engraved with letters 10/1000 inches deep.

14.1.4 The trench markers utilized are solid concrete blocks, approximately 12 inches thick, 12 inches wide and 36 inches long. Necessary information is inscribed on a brass plate approximately 4 inches x 6.5 inches, 1/8 inch thick and bolted to the marker. The brass plates have inscribed on them the following information: trench number; depth, length and width of the trench in feet; opening and closing month and year; byproduct material in curies; source material in kilograms; special nuclear materials in grams; the total volume of waste buried in cubic feet; and the coordinates of the trench corners. Monuments bearing this information have been placed at each end of all 21 closed trenches.

In addition, there is a "special projects area" which has a monument at each end which lists the following information: depth, width and length of area in feet; opening and closing month and year; byproduct material in curies; source material in kilograms; special nuclear materials in grams; and the total volume of waste buried in cubic feet.

15.0 OBJECTIVE 11

"To assure that the custodial agency will receive complete records of site maintenance and stabilization activities, trench elevations and locations, inventory, and monitoring data for use during custodial care in the event there is a need to take unexpected corrective measures or to interpret data."

15.1 Response:

Those records required by the custodial care agency, generated during the operational phase of the facility, will be inventoried as necessary prior to closure and during closure. The following records are deemed appropriate for transfer to the custodial agency:

A. Radioactive Waste Shipment and Disposal Manifest;

B. Burial reports required by the radioactive materials license;

C. Environmental monitoring results and any documentation of required corrective actions. US Ecology has performed environmental analyses of soil, vegetation and water samples since 1962. This data is available at the facility and will be transferred to the custodial agency;

D. Quarterly trench inspection and maintenance records;

E. Isotopic data is available for waste received covering the life of the facility;

F. Current plot plan, indicating all disposal areas and facilities;

G. Trench monument data (redundant record);

H. Copies of applicable Manuals and Procedures;

I. License files and license correspondence files.

Copies of the monthly isotopic report are currently on file with the state. Records indicated above will be furnished as computer print-outs, microfiche, microfilm or raw data, as appropriate, at the time of transfer to the custodial agency.

16.0 <u>OBJECTIVE 12</u>

"To assure that a buffer zone has been established surrounding the site which is sufficient to provide space to stabilize slopes, incorporate surface water management features, to assure that future excavation of adjoining areas will not compromise trench or site integrity, and to provide working space for unexpected mitigating measures in the future."

16.1 Response:

The area surrounding the site is leased by the state of Nevada from the BLM for use as a buffer zone. This is approximately 1320 feet wide as shown on the topographic map in Attachment 2 and as described in Attachment 14. Additionally, the state is considering the purchase of the BLN land for a permanent buffer zone.

In addition, site operations voluntarily allow a 20-foot-wide tract between the trench boundary and the facility boundary.

17.0 OBJECTIVE 13

"To provide a secure passive site security system (e.g., a fence), that will require minimum maintenance."

17.1 Response:

The east access gate to the radiological disposal facility will be sealed shut in a manner which will not allow it to be used (either welded or bolted in the closed position). The remaining gate will be locked and fitted with a suitable alarm to be activated in the deputy sheriff's office in Beatty, Nevada, when the gate is opened. When this alarm is triggered, an officer will be dispatched to the facility to investigate, unless the deputy sheriff's office has been notified by an authorized party of an entry at that time. The determination of parties authorized to enter the facility will be by the custodial agency or its representative. US Ecology, Inc., will have direct access control to the facility while actively operating and/or maintaining the facility.

Life of the perimeter fence is based upon US Ecology's observation at the site which indicate a useful life of at least 50 years under desert conditions. The fence is an eight (8) foot high chain link topped with barbed wire. The posts are set ten (10) feet center to center and are set in a portland cement grout mix.

Warning signs, which are placed along the fence approximately every 50 feet, will be replaced when they become illegible or damaged.

18.0 OBJECTIVE 14

"That a surveillance program, to assure the objectives of the decommissioning plan have been met, is established. This shall include a groundwater, surface water and air quality monitoring system."

18.1 Response:

It is recommended that the present facility environmental monitoring program (including vegetation, soil, groundwater, and air quality) be modified to ensure that the requirements of Section 9.0 of this document are met.

Radiation survey air sampling and counting equipment will continue to be calibrated and maintained under the same frequency as during the operational phase (i.e., semi-annually). Parts and/or equipment will be replaced if it is determined that (a) the system cannot be repaired or (b) cost to repair exceeds the cost to replace the equipment.

Routine radiological surveys of equipment and facilities, by the radiological control personnel, for removable contamination and fixed radioactivity will be conducted as part of the Radiological Control and Safety Program. The general requirements for these surveys are as follows:

18.1.1 Removable Contamination

Surveys for removable contamination will be performed by wiping the surface being surveyed with an absorbent material using moderate pressure and then counting any collected radioactivity on the absorbent material (smears). The absorbent material utilized for the survey may vary depending on the abrasive nature of the surface being surveyed. The number of smears taken for a particular survey will vary with the size, type of smear used, and condition of the surface (i.e., abrasive, damp, dirty, etc.). An acceptable technique for taking a smear from an accessible surface will be to make an "S" pattern over the surface being surveyed, starting the smear at the normal extended arm's length and drawing it toward the body. The area covered by a smear will also be a function of the physical condition of the surface being surveyed and the type of smear being used, but will generally be from 100 to 300 square centimeters.

Smears suspected of having alpha contamination will be checked for alpha activity by counting in an instrument capable of detecting alpha radiation.

18.1.2 Fixed Radioactivity

Fixed radioactivity surveys are gamma surveys and are sometimes referred to simply as "radiation" surveys. The technique used in taking these surveys will depend on the item being surveyed. The detector probe is usually held at waist height when doing general area surveys or the probe is held one inch from the object for a direct survey. Any survey instrument which has been calibrated for, and reads out in "mr/hr", "R/hr" or "uR/hr" is acceptable for radiation surveys. Beta gamma friskers may be used for low-level radiation surveys. If levels are less than 300 cpm above background with background less than 300 cpm less than 0.1 mr/hr may be recorded. Whenever a different probe is utilized on a survey meter, the calibration will be checked.

18.1.3 Contamination Limits

The contamination limits to be utilized will be taken from 49 CFR 173.443 as described below. These limits are used because the major portion of the disposal site activities which may be associated with contamination, (vehicle receiving, DOT containers, decontamination and vehicle release) are governed by DOT regulations.

Surfaces which are surveyed directly with an Eberline HP-210, and HP-190 detector or equivalent, may be considered free of beta-gamma contamination if no readings greater than 100 counts per minute above background are detected, provided the background is less than 300 counts per minute.

Removable (non-fixed) radioactive contamination is considered significant if the level of contamination when averaged over any area of 300 square centimeters of any surveyed surface exceeds any of the following:

Contaminant	Maximum Permissible Level Ci/cm^2	dpm/cm^2
Natural or depleted uranium and natural thorium:		
Beta - gamma........................	10^{-5}	2200
Alpha..............................	10^{-5}	220
All other beta-gamma emitting radionuclides.............................	10^{-5}	220
All other alpha emitting radionuclides.....	10^{-6}	22

(1) In assessing surface contamination, a sufficient number of measurements must be taken in the most appropriate locations so as to yield a representative assessment of the contamination situation. The average amount of removable (non-fixed) radioactive contamination may be determined by wiping the surface with an absorbent material, using moderate pressure, and then measuring the activity on the wiping

material. If the measured activity per square centimeter does not exceed 10 percent of the levels prescribed above, it may be assumed that those levels have not been exceeded. Other measurement methods of equal or greater efficiency may also be utilized.

19.0 FACILITY CLOSURE COSTS

Facility closure costs for the Beatty site are divided into two sections. The first section addresses the various costs of closing the facility. These include backfilling the remaining trench volume, environmental monitoring and constructing the minimum seven feet thick above grade cap. The second section includes costs for the one-year site stabilization period. These costs include maintenance and environmental monitoring.

For cost accounting, closure of the Beatty LLRW facility is assumed to take place on December 31, 1992. Should the site accept waste past 1992, the maintenance fund would increase.

It has been estimated that upon facility closure all of the necessary building removal and landfill closure can be accomplished in six months. Following this period, US Ecology personnel will be present at the facility to conduct routine environmental monitoring and monitoring of site stabilization for an additional year. During this period records will be compiled for transfer to the custodial agency.

Each year during the closure, stabilization and post-closure periods, US Ecology has included a contingency allowance of $5,000. In addition, two fence replacements have been included and to fund any unforeseen events that require capital, a contingency of $150,000 is included in year 10, $250,000 in year 50 and $500,000 in year 100.

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N E V A D A R A D C L O S U R E C O S T S

nvrpcm

CLOSURE PREIOD (6 MONTHS)		
LEGAL		$36,000
PERSONNEL		
MANAGER	$12,500	
ASSIT. MANAGER	$10,000	
RSO	$17,500	
TECH	$16,250	
LABOR(1)	$11,750	
CLERICAL	$4,375	
subtotal	$72,375	
LOH @ 45%	$32,569	
TOTAL LABOR COST		$104,944
OFFICE		
UTILITIES	$600	
PHONE	$2,400	
MISC OFFICE	$1,200	
TRAVEL	$4,400	
VEHICLE	$1,350	
MISC	$6,000	
TOTAL OFFICE COST		$15,950
MICS EQUIPMENT	$12,000	$12,000
CORP. AUDIT (2 days/qtr)		
AIR TRAVEL	$1,600	
ROOM/BOARD	$240	
VEHICLE RENTAL	$180	
TOTAL CORP. AUDIT COST		$2,020
ENVIR. MONITORING		
GROUNDWATER	$1,920	
VEGETATION	$1,968	
SOIL	$1,960	
TLD's	$170	
AIR	$258	
TOTAL ENVIR. MON. COST		$6,276
BUILDING DECON	$200	$200
EQUIPMENT DECON	$500	$500
LANDFILL CLOSURE (PROJECTED as of 12/31/92)		
TRENCH BACKFILL	$145,455	
137,222 cy @ $1.06/cy		
7 ft cap	$146,694	
138,391 cy @ $1.06/cy		
RELOCATE FENCE	$52,248	
2800 lf @ $18.66		
GATE ALARM SYSTEM	$3,000	
RELOCATE TRENCH MONUMENTS	$1,200	

SITE ENGR. SURVEY		$5,000	
AERIAL PHOTO/MAPPING		$7,500	
TOTAL LANDFILL CLOSURE COST			$361,098
CONTINGENCIES		$2,500	$2,500
TOTAL CLOSURE COSTS			$541,488
STABILIZATION PERIOD (MONTH 7 through MONTH 18)			
PERSONNEL	effort		
MANAGER	50%	$25,000	
ASSIT. MANAGER	50%	$20,000	
RSO	100%	$32,500	
TECH	0%	$0	
LABOR(1)	100%	$23,500	
CLERICAL	0%	$0	
subtotal		$101,000	
LOH @ 45%		$45,450	
TOTAL LABOR COST			$146,450
OFFICE			
UTILITIES		$1,200	
PHONE		$4,800	
MISC OFFICE		$1,200	
TRAVEL		$6,600	
VEHICLE		$2,700	
MISC		$12,000	
TOTAL OFFICE COST			$28,500
MICS EQUIPMENT		$3,408	$3,408
CORP. AUDIT (2 days/qtr)			
AIR TRAVEL		$3,200	
ROOM/BOARD		$480	
VEHICLE RENTAL		$360	
TOTAL CORP. AUDIT COST			$4,040
ENVIR. MONITORING			
GROUNDWATER		$3,840	
VEGETATION		$3,936	
SOIL		$3,920	
TLD's		$340	
AIR		$516	
TOTAL ENVIR. MON. COST			$12,552
CONTINGENCIES		$5,000	$5,000
TOTAL STABILIZATION PERIOD COSTS			$199,950
STATE ADMINISTRATION (CLOSURE & STABILIZATION PERIOD, 18			
PERSONNEL			
ON-SITE INSPECTOR DURING CLOSURE		$21,632	
1040 hrs @ $20.80/hr			
RAD HEALTH SUPERVISOR DURING CLOSURE		$15,000	
& STABILIZATION PERIOD quarter time			
520 hrs/yr @ $40,000/yr			

CLERICAL DURING CLOSURE $5,625
& STABILIZATION PERIOD quarter time
520 hrs/yr @ $15,000/yr
ADMINISTRATIVE AID DURING CLOSURE $6,250
& STABILIZATION PERIOD one month/yr
173 hrs/yr @ $50,000/yr
subtotal $48,507
LOH @ 60% $29,104
TOTAL LABOR COST $77,611

OFFICE SUPPIES $2,000/yr $3,000

TRAVEL
ASSUME 1 SITE VISIT/QTR, 2 DAYS EACH
600 MILES/TRIP @ $0.25/MILE $900
PER DIEM @ $60/DAY $720
TOTAL TRAVEL COST $1,620

TOTAL STATE ADMINISTRATION COSTS $82,231

S U M M A R Y of C L O S U R E & S T A B I L I Z A T I O N

TOTAL CLOSURE COSTS	$541,488
TOTAL STABILIZATION PERIOD COSTS	$199,950
TOTAL STATE ADMINISTRATION COSTS	$82,231
TOTAL	$823,669

POST-CLOSURE PERIOD (98.5 yr PERIOD)

ASSUMPTIONS: MONITORING & MAINTENANCE UNDER THE CONTROL
CUSTODIAL AGENCY. WORK WILL BE PREFORMED BY THE CUSTODIA
AGENCY OR THIER CONTRACTOR.
LABOR RATE ARE MARKED UP 250% FOR CONTRACTOR OVERHEAD &

LABOR
RAD TECH
2 men @ 10 days/yr @ $20/hr $788,000
MAINTENANCE
2 men @ 4 days/yr @ $15/hr $236,400
TOTAL LABOR COST $1,024,400

MICS. EQUIPMENT $126,080 $126,080
4 days/yr @ $195/day PLUS $500 mob/demob

ENVIR. MONITORING per yr $/yrs

GROUNDWAT	@4	$960	$94,560	
VEGETATIO	@6	$984	$96,924	
SOIL	@7	$980	$96,530	
TLD's	@16	$85	$8,369	
AIR	@1	$129	$12,707	
CONSUMABLES @ $500/yr			$49,250	
TOTAL ENVIR. MON. COST				$358,339

FENCE REPLACEMENT (@ years 25 & 75) $216,456 $216,456
5800 LF @ $18.66/replacement

MICS. MATERIALS	$98,500	$98,500
CONTINGENCIES		
ANNUAL BASE OF $5,000/yr	$492,500	
@ YEAR 10 $150,000	$150,000	
@ YEAR 50 $250,000	$250,000	
@ YEAR 100 $500,000	$500,000	
TOTAL CONTINGENCIES COST		$1,392,500
STATE ADMINISTRATIVE PERSONNEL		
RAD HEALTH SUPERVISOR DURING CLOSURE	$164,798	
& STABILIZATION PERIOD 2 wks/yr		
87 hrs/yr @ $40,000/yr		
CLERICAL DURING CLOSURE	$61,799	
& STABILIZATION PERIOD 2 wks/yr		
87 hrs/yr @ $15,000/yr		
ADMINISTRATIVE AID DURING CLOSURE	$205,998	
& STABILIZATION PERIOD 2 wks/yr		
87 hrs/yr @ $50,000/yr		
subtotal	$432,595	
LOH @ 60%	$259,557	
TOTAL LABOR COST		$692,152
OFFICE SUPPIES $500/yr	$49,250	$49,250
TRAVEL		
ASSUME 1 SITE VISIT/YR, 2 DAYS EACH		
600 MILES/TRIP @ $0.25/MILE	$14,775	
PER DIEM @ $60/DAY	$11,820	
TOTAL TRAVEL COST		$26,595
TOTAL POST-CLOSURE COSTS		$3,984,272

SUMMARY of CLOSURE, STABILIZATION & POST-CLOSURE COST

TOTAL CLOSURE & STABILIZATION COSTS	$823,669
TOTAL POST-CLOSURE COSTS	$3,984,272
TOTAL	$4,807,941

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Geohydrology of the Unsaturated Zone at the Burial Site for Low-Level Radioactive Waste Near Beatty, Nye County, Nevada

By WILLIAM D. NICHOLS

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Geohydrology of the Unsaturated Zone at the Burial Site for Low-Level Radioactive Waste Near Beatty, Nye County, Nevada

By William D. Nichols

Abstract

Low-level radioactive solid waste has been buried in trenches at a site near Beatty, Nev., since 1962. In 1976, as part of a national program, the U.S. Geological Survey began a study of the geohydrology of the waste-burial site to provide a basis for estimating the potential for radionuclide migration in the unsaturated zone beneath the waste-burial trenches. Data collected include meteorological information for calibration of a long-term water-budget analysis, soil-moisture profiles, soil-water potentials, and hydraulic properties of representative unsaturated sediment samples to a depth of about 10 meters (m).

The waste-burial facility is in the northern Amargosa Desert about 170 kilometers (km) northwest of Las Vegas, Nev. The region is arid; mean annual precipitation at Lathrop Wells, 30 km south of the site, is only 7.4 centimeters (cm). The mean daily maximum temperature at Lathrop Wells in July, the hottest month, is 37 °C. The site is underlain by poorly stratified deposits of gravelly or silty sand and sandy gravel, and thick beds of clayey sediments. The total thickness of valley-fill deposits beneath the site is about 175 m; the unsaturated zone is about 85 m thick. Volumetric soil moisture to depths of 4 m ranges from 4 to 10 percent but commonly is in the range of 6 to 8 percent. Soil-water potential, measured to depths of 3 to 10 m, ranged from −10 to −70 bars. Unsaturated hydraulic conductivity computed from laboratory analyses of representative samples ranges from 10^{-13} to 10^{-4} centimeters per day (cm/d).

Evaporation studies over a 2-year (yr) period were used to calibrate a numerical procedure for analyzing long-term precipitation data and estimating annual water budgets during the 15-yr period 1962–76. This analysis (1) demonstrated that a potential exists for deep percolation (greater than 2 m), despite high annual evaporation demands, and (2) provided predictions of the time of year and the antecedent conditions that enhance the probability of deep percolation. Soil-moisture profiles obtained monthly over an 18-month (mo) period demonstrate that deep percolation does occur. Soil-moisture conditions antecedent to an observed deep-percolation event, and the time of year when the percolation occurred, support the interpretations based on long-term meteorological records.

Calculation of downward moisture movement through the waste-trench backfill material, on the basis of simplified assumptions, suggests that moisture could have penetrated as much as 6 m below land surface from 1963, when the oldest trenches were closed, to 1980, but that the moisture requirement for such penetration far exceeded the amount of moisture actually available. Steady-state downward movement of moisture at depths greater than 10 m and beneath the waste-burial trenches would be on the order of 4 cm per 1,000 yr, assuming a steady flux rate of 1×10^{-5} cm/d.

INTRODUCTION

The disposal of radioactive waste has been a problem for more than 30 years (yr). Disposal methods until 1962 included both land burial at federally operated facilities and sea disposal by several privately owned companies. Opposition to sea disposal led the Atomic Energy Commission in the late 1950's to designate several land-disposal sites for burial of low-level radioactive solid waste[1] generated by private industry. The first of these commercially operated burial grounds opened near Beatty, Nev., in 1962, and by 1971 a total of six sites (four east of the Mississippi River and two in the west) had been licensed.

Earth containment (burial) has been and still is considered the most viable method for disposing of radioactive solid waste. In general, however, the acceptability of any disposal method depends on its effectiveness in preventing radioactivity from becoming a public hazard. The effectiveness of burial as a disposal method thus depends on the chemical and physical form of the waste, the waste

---

[1] The term "low-level radioactive waste" has carried a changing and imprecise definition over the years. Currently, it generally means waste that does not fit the definition of high-level waste and in which the concentration of transuric elements is less than 10 nanoCurie per gram. It consists, in part, of miscellaneous solid materials that have been irradiated and contaminated through use as well as products of reactors and fuel reprocessing plants.

containers, the engineered containment mechanisms, the character of surrounding earth materials, and the hydrologic and geologic environment. Although burial removes the radioactive waste from the surface environment, it subjects the waste to possible influences of water infiltration and movement, erosion, plant uptake, animal penetration, and human activity. Probably the greatest threat to burial-ground integrity is water infiltration and movement, because radionuclides can migrate from the burial location either by dissolution in soil water or ground water, or through exposure by erosion and dissolution in surface water.

On the basis of the recognized threat posed to buried radioactive waste by water infiltration and movement, it has been suggested that certain areas of the arid west could provide locations where little or no water would move into or out of buried waste and, thus, maximum reliance could be placed on the natural system to provide containment (National Research Council, 1976, p. 67). It also has been suggested that more latitude in waste form might be possible and that reliance on engineered containment could be minimal at these locations (Battelle Memorial Institute, 1976, p. 24.48). Although these may be valid assumptions, insufficient data were available to reasonably demonstrate the effectiveness of geologic and hydrologic conditions in the arid zone to isolate buried radionuclides from the environment for the long period of time required for some of them to decay to innocuous levels.

Purpose and Scope

The U.S. Geological Survey in 1975 began a new national program in the area of low-level-radioactive-waste disposal. The general purpose of the program, designed to be a 5-yr endeavor, was to develop geohydrologic guidelines that can be used to establish technical criteria for selecting, evaluating, licensing, and operating new waste-burial sites. The commercial burial facility for low-level radioactive solid waste operated by U.S. Ecology, Inc. (formerly Nuclear Engineering Company), near Beatty, Nev., was one of five sites to be studied. The study at this site began in October 1976. The specific purpose of the investigation at this waste-burial facility was to determine, for current climatic conditions, the potential for downward movement of soil water in the unsaturated zone, thus providing a means for estimating the potential for and rate of downward transport of radioactive solutes or leachates. Additionally, actual movement of radionuclides was to be determined, if possible, by obtaining sediment samples from the zone directly beneath the waste-burial trenches into which contaminants might have migrated.

The investigation included the following activities:

1. Collection of meteorological data for site-specific evaporation studies, to be used in turn to estimate long-term relations between precipitation, evaporation, and deep percolation on the basis of National Weather Service data;
2. Monitoring of soil-moisture profiles for evidence of deep percolation;
3. Monitoring of soil-water potential to determine the magnitude of this potential at depth and the depth at which transient soil-water changes are dampened out;
4. Determination of unsaturated hydraulic conductivity of representative soil samples in the laboratory; and
5. Estimation of the rate and magnitude of deep soil-water percolation.

Detailed plans were also developed to obtain sediment samples from beneath waste-burial trenches for laboratory determination of radionuclide content and calculation of migration rates after the waste-burial trenches were closed. These plans were suspended indefinitely after analysis of the data contained in this report indicated that in the past 17 yr, infiltrating precipitation has not percolated to the reported depth of the older waste-burial trenches.

Location

The waste-burial facility is on the Amargosa Desert 17 kilometers (km) southeast of Beatty and 169 km northwest of Las Vegas in Nye County, Nev. (fig. 1). It lies about 32 km east of Death Valley, Calif., in the northern half of section 35, T. 13 S., R. 47 E., Mount Diablo baseline and meridian. The eastern border of the radioactive-waste burial area is about 900 meters (m) west of U.S. Highway 95.

Geographic Setting

The Amargosa Desert in the area of the waste-burial site is a northwest-trending valley about 13 km wide (figs. 1, 2; pl. 1). It is bounded on the northeast by Bare Mountain and on the southwest by the Grapevine Mountains and the Funeral Mountains. The head of the valley, about 19 km northwest of the waste-burial site, is formed by the Bullfrog Hills. The desert extends from the Bullfrog Hills about 80 km southeast to the Spring Mountains and about 80 to 90 km south-southeast to the Greenwater and Resting Spring Ranges. The altitude of the valley floor decreases from about 1,100 m above sea level in the northwest to nearly 600 m at the southeastern end near Death Valley Junction. The waste-burial facility is 847 m above sea level.

The floor of the northern Amargosa Desert is a sparsely vegetated, seemingly flat surface. Actually, it is moderately dissected by abandoned or little used shallow dry washes, all draining to the southeast. These washes have led to the development of an irregular and gently undulating surface that is not obvious when viewed from ground level. The apparent flatness of the desert floor is caused by the general accordance of the tops of low ridges separating the shallow dry washes.

Immediately southeast of the waste-burial site, and west of U.S. Highway 95, is a low southeast-trending ridge that extends for a distance of about 3 km (fig. 2). The northeast-facing slope of the ridge is steeper and more deeply dissected by washes and rills than the southwest-facing slope, which gradually descends westward to the general level of the desert floor within a distance of about 0.8 km from the ridge crest. Part of the northeast-facing slope has been destroyed or modified by construction of U.S. Highway 95 and by a secondary drainage system of unknown age that may have developed in historical times because of the presence of either the highway or the railroad that occupied the same position before the highway was constructed. Erosional remnants northeast of both the highway and the secondary drainage channels indicate that the northeast-facing slope descended to the level of the alluvial fans bounding Bare Mountain over a distance of about 0.4 km from the present ridge crest (figs. 2, 3). Detailed examination of this anomalous feature strongly suggests that it is an erosional remnant of an older depositional surface that is being supported by a locally developed caliche layer about 1 m below the surface of the ridge crest.

Previous Work and Acknowledgments

The only previous report dealing specifically with the waste-burial site is a report prepared by the U.S. Geological Survey (Clebsch, 1962) at the request of the Atomic Energy Commission at the time the facility was being established. Geologic investigations of a general nature in the northern Amargosa Desert include studies by Cornwall and Kleinhampl (1961, 1964), Cornwall (1972), and Byers and others (1976a, 1976b). A study of the hydrogeologic framework of the south-central Great Basin by Winograd and Thordarson (1975) marginally includes the area of the waste-burial facility. Walker and Eakin (1963) discuss the geology and ground water of the Amargosa Desert, but most of the data are for the southern part of the desert.

The author received the cooperation and assistance of many people and organizations during the course of the study. The cooperation of the Bureau of Consumer Health Protection Services, Nevada State Health Division, whose inspectors control activities at the waste-burial facility, was appreciated. The cooperation of U.S. Ecology, Inc., operators of the facility, is gratefully acknowledged. The author wishes to specifically thank William Jones and Steven Carpenter, site managers, and the other members of the work crew at the waste-burial site for their assistance and cooperation during the study.

Many other individuals helped at various stages of the investigation, and without their assistance the project would not have been completed. Mr. and Mrs. John Lisle and Patricia Thayer, of Beatty, served as observers for the meteorological instrument station at the study site and diligently serviced the equipment every other day. Donald H. Schaefer, U.S. Geological Survey, supervised installation of the instrument shaft and neutron probe access tubes. Other U.S. Geological Survey personnel, including Douglas K. Maurer, R. Nyle Pennington, Susan J. Mathews, and David B. Wood, provided field assistance during the course of the study; Robin G. Brown assisted full time during the last 15 mo of the study and largely managed and controlled the acquisition, processing, correction, and publication of the meteorological and related data collected for the investigation; Alex M. Sturrock, Jr., provided invaluable assistance and guidance on the collection and interpretation of meteorological data for evaporation calculations; both he and Henry M. Moore also provided equipment and field repair expertise when required; John B. Robertson provided timely and much needed support during the latter stages of the study; technical assistance on unsaturated zone hydrology was provided by E.P. Weeks, C.D. Ripple, Jacob Rubin, and E.G. Lappala; and, finally, Emily L. Mathews, student aide, digitized about 21 mo of multichannel daily meteorological data on analog charts comprising more than 17,000 data values per day; her persistence and perseverance are gratefully acknowledged.

GEOLOGIC SETTING

Consolidated Rocks

The Amargosa Desert is bounded, in large part, by mountain ranges composed of lower Paleozoic carbonate and clastic sedimentary and metasedimentary rocks (pl. 1). The valley floor is presumably underlain at depth by rocks of these same types. Rocks of Precambrian and Cambrian age crop out in part of the Funeral Mountains along the western side of the valley (Chapman and others, 1973; Streitz and Stinson, 1974). The Bullfrog Hills at the north end of the valley and the Grapevine Mountains on the northwest are composed mostly of Tertiary sedimentary and volcanic rocks but include small outcrops of Precambrian schist and gneiss (Cornwall and Kleinhampl, 1964). Tertiary volcanic rocks also are present in several of the ridges between the southern end of Bare Mountain and Lathrop Wells on the east side of the valley.

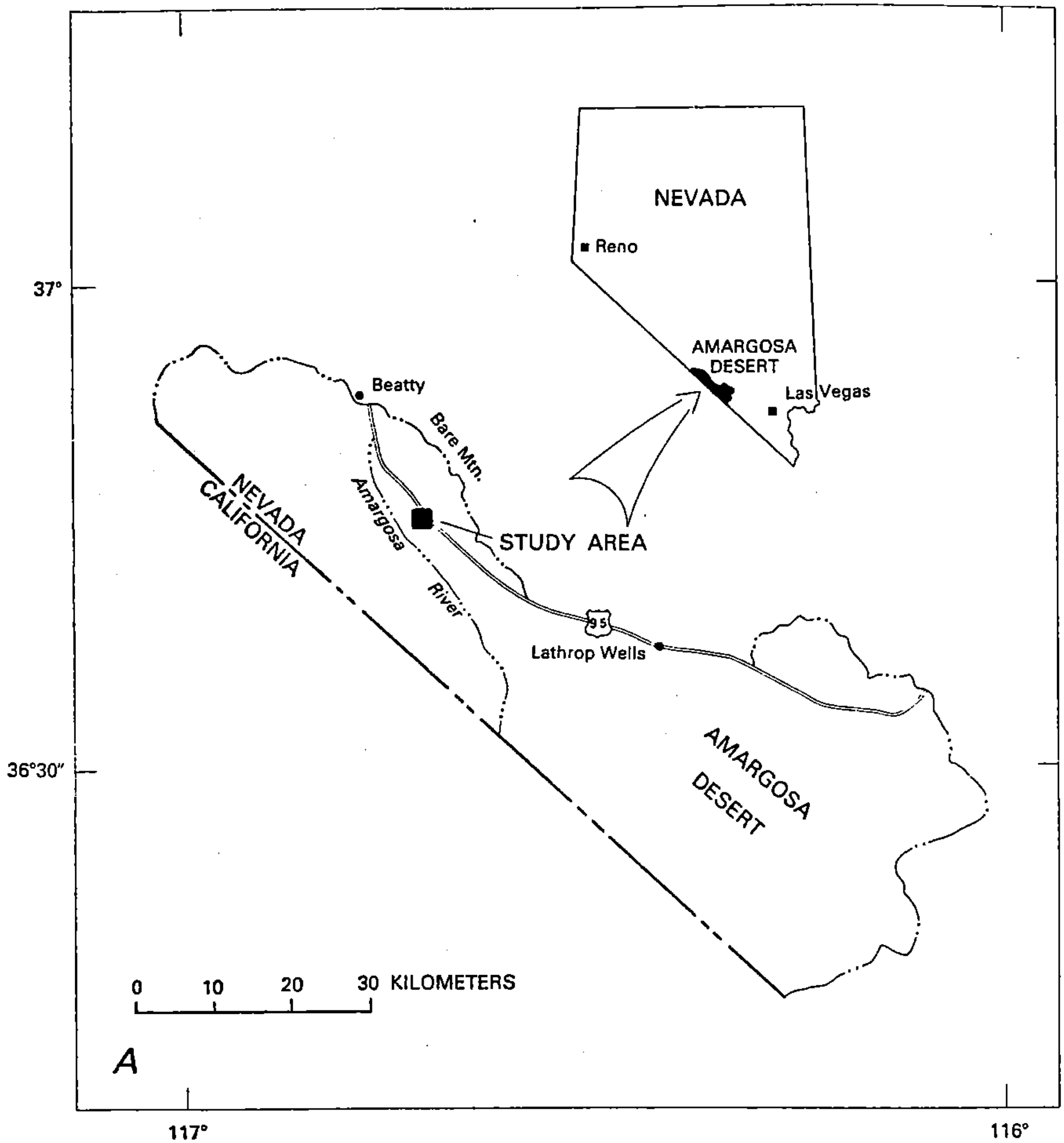

Figure 1A. Location of study area.

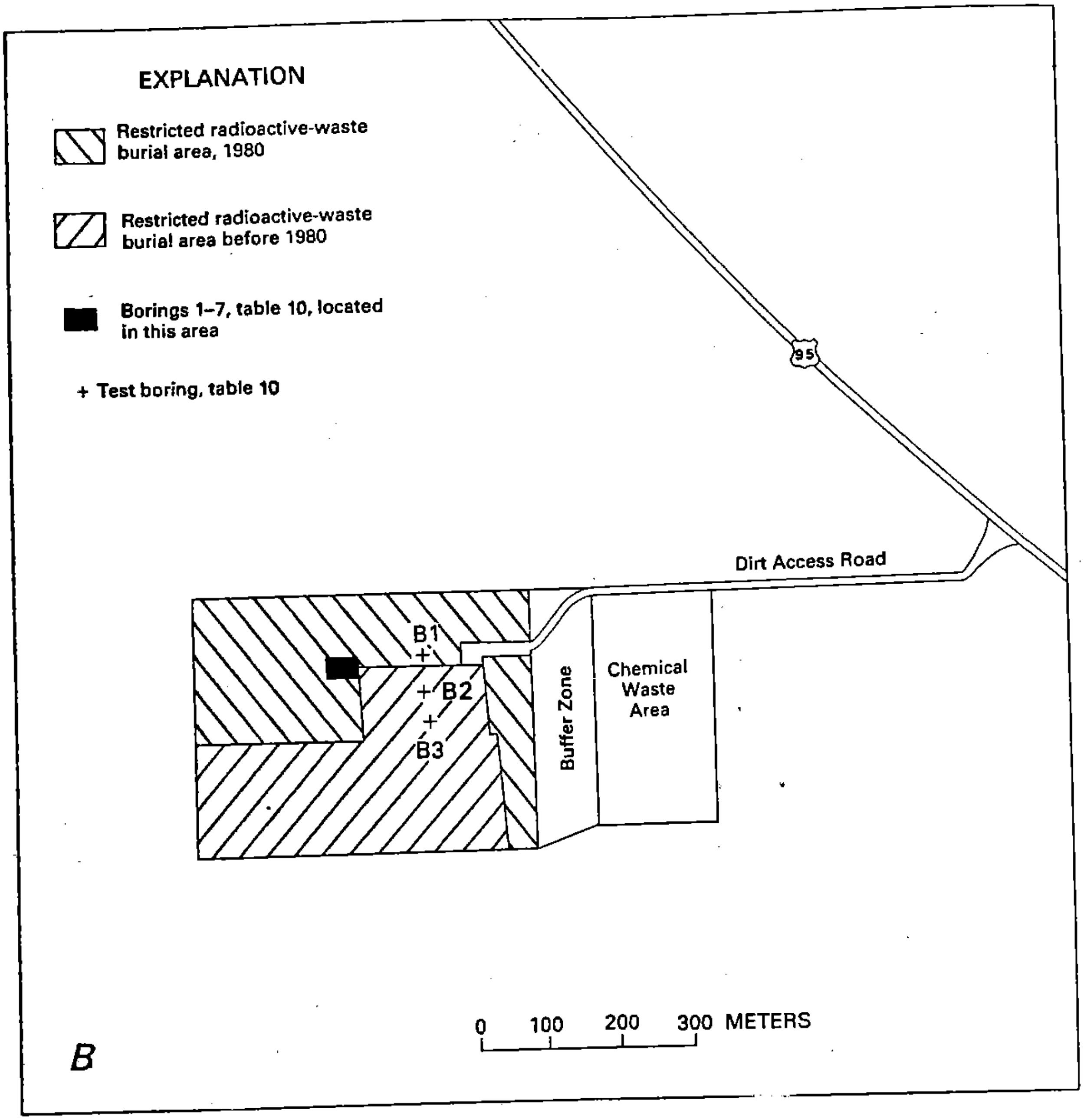

Figure 1*B*. Detail of waste-burial site.

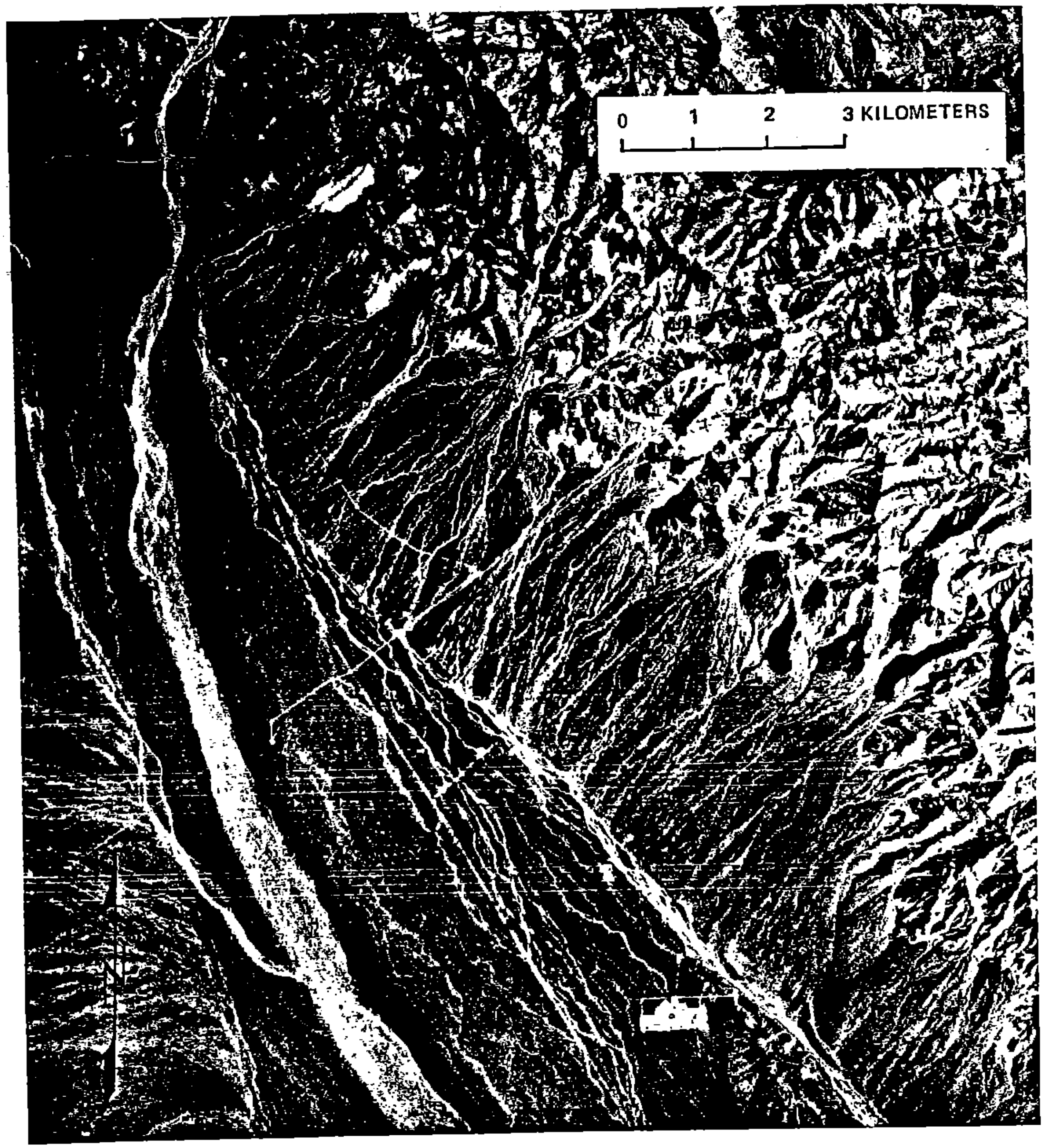

Figure 2. Aerial photograph of part of the northern Amargosa Desert, showing Bare Mountain (right), dry channel of the Amargosa River (light band from top left to bottom center), Amargosa Narrows (top left), and waste-burial site (light area to right of center near bottom). (Photograph taken June 6, 1976.)

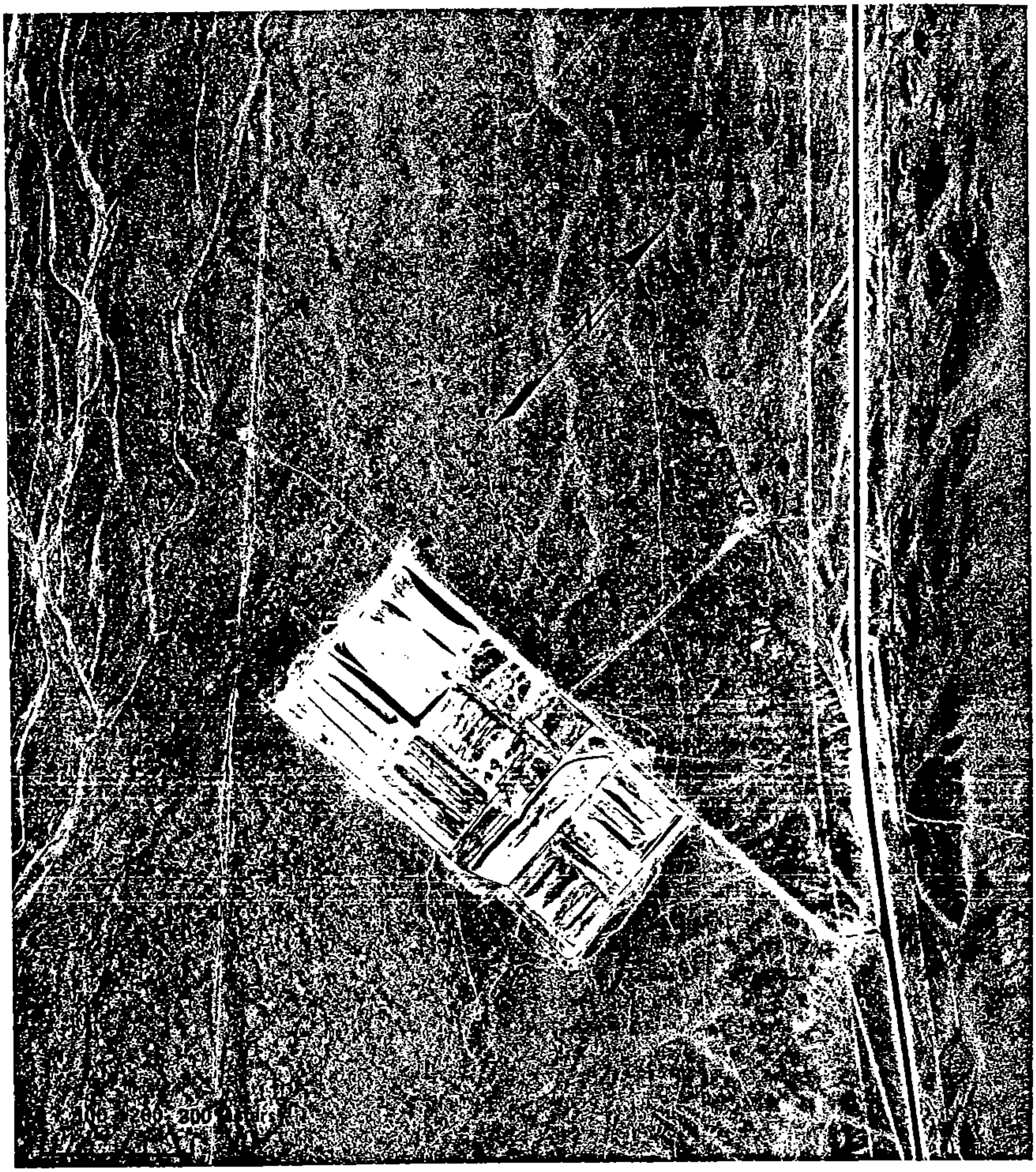

Figure 3. Aerial photograph of the waste-burial site, September 24, 1980. (U.S. Department of Energy photograph, northern Amargosa Valley, no. 297.)

The geologic structure of the region surrounding the Amargosa Desert is complex. The major structural features include large-scale normal and thrust faults. Many of the surrounding mountain ranges are bounded by normal faults producing the typical Basin and Range structure shown by the topography of the area. Within the surrounding ranges the rocks are folded and for the most part intensely faulted by small-scale thrust, tear, normal, and strike-slip faults. Superimposed on this highly complex pattern of folding and faulting are several shear zones, including the Las Vegas Valley shear zone which extends northwestward to Mercury, Nev., just southeast of the Amargosa Desert, and shear zones in Death Valley and the Amargosa Desert (Winograd and Thordarson, 1975).

More detailed discussion of the geology in the area of the northern Amargosa Desert can be found in reports by Cornwall (1972) and Byers and others (1976b).

Unconsolidated Deposits

The Amargosa Desert is underlain by unconsolidated to weakly indurated deposits of Tertiary and Quaternary age. These include alluvial-fan deposits, fluvial deposits of sand and gravel, and freshwater or brackish-water playa deposits. Fluvial sediments, playa deposits, and dune sand of Pleistocene and Holocene age are present locally. The unconsolidated sediments are at least 170 m thick in the northern part of the desert, more than 295 m thick farther south near Lathrop Wells, and 240 m thick in the vicinity of Death Valley Junction (Walker and Eakin, 1963).

Stratigraphy

The best information available on the subsurface stratigraphy of the valley-fill deposits beneath the waste-burial site is a driller's log and sample descriptions for a well drilled at the site. The log and sample descriptions from a report by V.P. Gianella (consulting geologist, written commun., 1961) are given in tables 16 and 17 at the end of this report. The log and descriptions indicate that the materials penetrated by the well are, for the most part, a poorly sorted mixture of boulders, gravel, sand, silt, and clay. The driller's log (table 16), which is summarized in figure 4, is not entirely in agreement with the geologist's sample descriptions (table 17). Some of the unit boundaries are taken from the driller's log and are not noted or otherwise indicated on the geologist's log.

Generally, the sediments penetrated by the well can be divided into thick sequences of poorly sorted coarse-grained and fine-grained materials, probably representing fanglomerate and debris flows, interbedded with sequences of clay and clay with gravel. There also are several intervals of clayey limestone or calcareous clay.

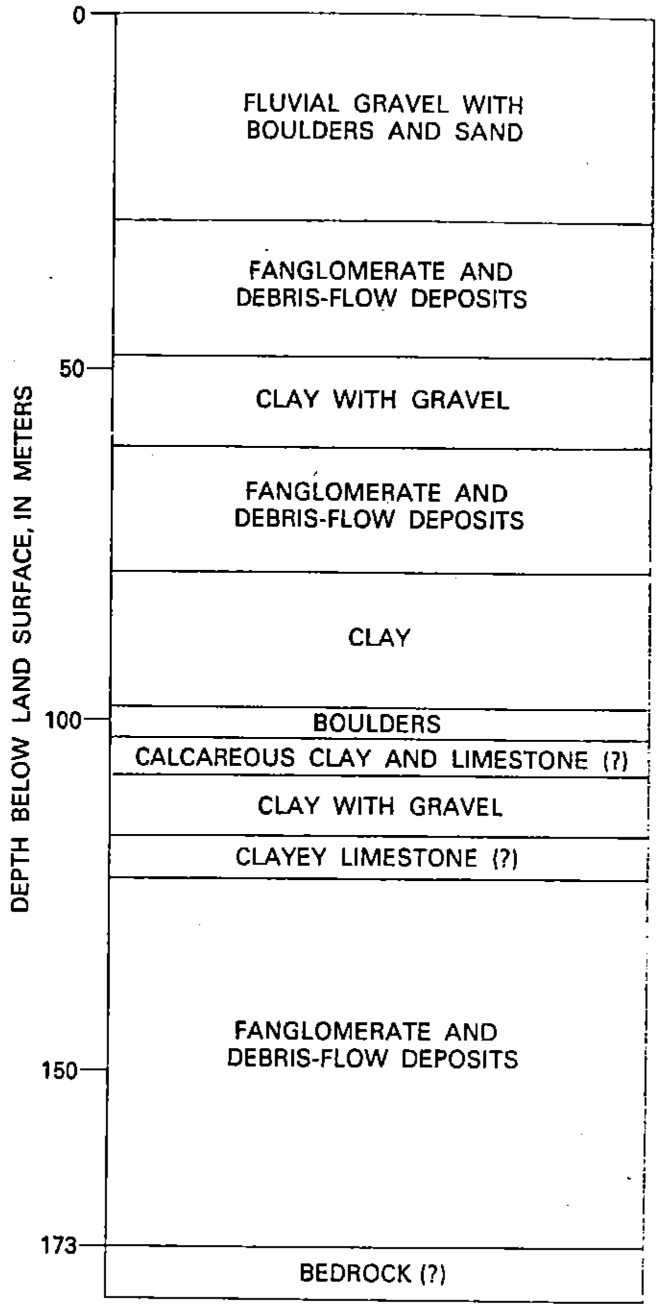

Figure 4. Summary log of U.S. Ecology, Inc., well at waste-burial site.

Descriptions of the samples collected from the well (table 17) strongly suggest that deposition of clastic sediments in this part of the valley has long been influenced principally by down-valley surface-water movement rather than by lateral infilling by extension of the bounding alluvial fans. Sample descriptions of material to a depth of 30 m suggest that the sediments are largely fluvial deposits associated with the Amargosa River. Below 30 m, lake- and debris-flow deposits predominate and volcanic gravel is less pervasive. Quartzite and schist are referred to more frequently in this part of the log, suggesting greater influence of lateral infilling by the building of alluvial fans. Nevertheless, the dominance of gravel derived from volcanic rocks throughout the section indicates that the most likely source of inflow to the valley was somewhere along the northern boundary of the desert or farther upstream in the upper reaches of the Amargosa River or its ancestral drainage.

Surface drainage appears to have ponded several times in the northern Amargosa Desert. The intervals of clay or clay and gravel are too thick to represent debris flows. Additionally, the clay and gravel at 49 m underlie a large part of the northern end of the desert (see below). The sequences of calcareous clay and limestone also represent a lacustrine depositional environment.

The areal extent of the fine-grained deposits shown in figure 4 has not been determined by test drilling. The thickness of clay and gravelly clay intervals on the driller's log suggests that these units may be traceable over a considerable area. A reconnaissance seismic reflection survey was made over part of the northern Amargosa Desert to determine the areal distribution of the clay and gravel bed in the interval 49 to 62 m. The results of the survey are shown in figure 5. The thickness of a deeper clay bed (80 to 99 m below land surface) suggests that it too may be an areally extensive deposit and of more than local significance. The calcareous clay or clayey limestone(?) (marl?) at 103 and 117 m may also be areally extensive and may represent deposition in freshwater or brackish-water lakes.

Thickness

The well drilled at the waste-burial site may have penetrated bedrock at about 173 m, so the unconsolidated deposits are at least that thick. A reconnaissance gravity survey made during this study, together with gravity data given by Healey and Miller (1962, 1965), provide some indirect information on possible thickness of the valley fill in the northern part of the Amargosa Desert. A gravity anomaly map (fig. 6) based on all available data suggests that bedrock is relatively shallow under the waste-burial site and for some distance northwest and southeast of the site. Two profiles across the Amargosa Desert, one near the burial site and one about 6.4 km northwest (fig. 7), were drawn to show the thickness of valley fill on the basis of the gravity data. A maximum thickness of about 600 m is suggested for the deeper parts of the basin. The interpretation of the relatively shallow depth to bedrock at the burial site on the basis of gravity data is supported partly by the well log discussed above and partly by the presence of a small bedrock knoll 1.6 km east-southeast of the waste-burial site and just west of U.S. Highway 95. This knoll is about 2.5 km west of the nearest outcrop on Bare Mountain. Several other bedrock knolls are present, about 5 km southeast of the waste-burial site and west of the highway. These outcrops are also within the area of the interpreted bedrock high.

Structure

The alluvial fans along the west side of the north end of Bare Mountain have been cut by faulting (fig. 2, pl. 1), probably during the late Quaternary. The fault, which is a sinuous to arcuate normal fault, can be traced from near the south boundary of Beatty through the Amargosa Narrows and southward for about 9.5 km. It lies to the east of and parallel to U.S. Highway 95 (fig. 2). The greatest offset seems to be at a point about 1.7 km south of the narrows, where the fault-scarp height is about 22 m.

Recent studies suggest that movement along the fault is older than 10,000 yr but younger than 50,000 yr (W.J. Carr, U.S. Geological Survey, oral commun., 1980). The fault scarp cuts alluvial-fan deposits that are considered to be 50,000 yr old and in places does not cut, or is covered by, alluvial-fan deposits that are considered to be not more than about 10,000 yr old. Additional studies, using the approximate relationship between fault-scarp slope angle and scarp age as developed by Wallace (1977), produced conflicting results (A.J. Gordon, consultant, written commun., 1980). At one location, the slope angle is consistent with an approximate age of 10,000 yr; at several other locations, the slope angle suggests an age of about 5,000 yr. The younger age is not consistent with the local Quaternary geology and may be the result of caliche layers retaining the slope at a steep enough angle to imply an erroneously young age.

Nowhere does the fault exhibit composite or multiple scarps. This suggests that movement occurred as a single event, or as a series of smaller events over a geologically short time. Composite or multiple scarps, in contrast, would suggest mean recurrence intervals of movement on individual faults on the order of thousands of years (Wallace, 1977).

The fault probably extends along the entire southwest side of Bare Mountain and is probably the main bounding fault for the mountain block. About 1 km east of the waste-burial site, some type of tectonic disruption of the unconsolidated sediments is suggested by interrupted, but not offset, older erosional surfaces, truncated depositional surfaces, and disarranged minor drainages. However, little to no surface evidence of vertical movement exists, except for the bedrock knob about 1.6 km east-southeast of the waste-burial site.

This bedrock knob lies west of the southeastward extension of the fault trace projected from its last surface expression about 8 km to the northwest. At this point the bedrock exposure is immediately west of U.S Highway 95,

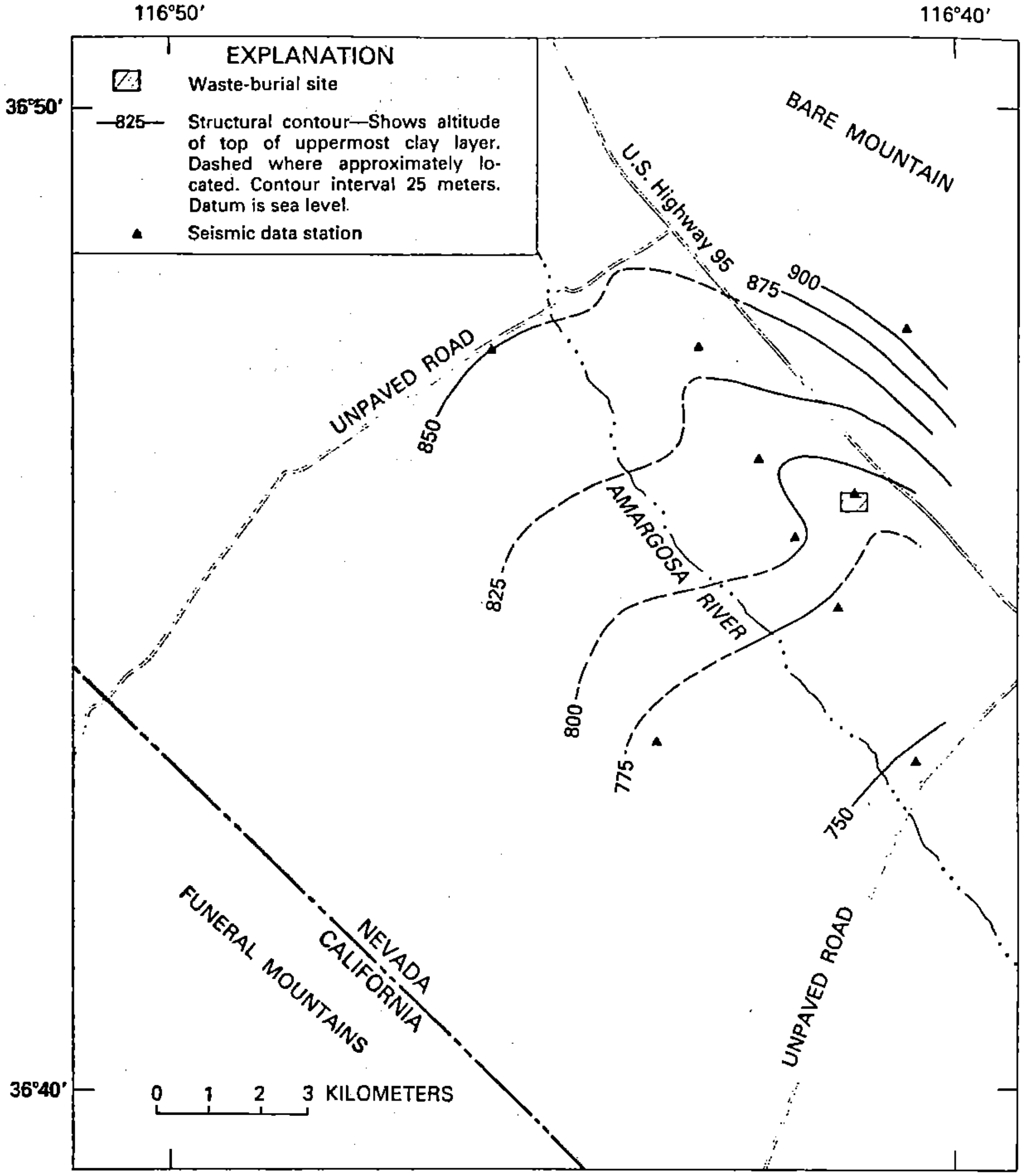

Figure 5. Approximate altitude of top of uppermost clay layer, northern Amargosa Desert.

and the projected fault trace would be about 300 m east of the highway. This implies a relative movement on the fault in this area opposite to that at the north end of Bare Mountain, where the downdropped area is to the west. Faulting along this segment of Bare Mountain probably is more complicated than farther north and requires more detailed field studies.

HYDROLOGIC SETTING

The waste-burial site is located in the drainage basin of the Amargosa River, which is part of the Death Valley hydrographic area. The terminus of the dry channel of the Amargosa River is at the southern end of Death Valley, but no flow has been observed along that part of the river in historic times. The ground-water system beneath the site probably flows toward Ash Meadows, to the southeast, but may also flow toward the south and southwest beneath the Funeral Mountains and into Death Valley. Ground water in the Ash Meadows area also eventually discharges toward Death Valley. Thus, both the surface-water and ground-water systems beneath the waste-burial site eventually terminate in Death Valley.

Table 1. Annual maximum discharge at U.S. Geological Survey gaging station on Amargosa River south of Beatty, calendar years 1964–79[a]

Date	Discharge (m^3/s)
July 26, 1964	~0.71
September 7, 1965	~.57
1966	No flow
August 30, 1967	120
February 10, 1968	2.6
February 24, 1969	453
August 15, 1970	~.002
1971	No flow
1972	No flow
February 11, 1973	.51
1974	No flow
September 10, 1975	12
February 1976	~2.8
June 1977	~.05
March 1, 1978	~18
1979	No flow

[a] No flow during most or all of each year.

Surface-Water Runoff

Precipitation is sparse in the area, averaging less than 10 cm a year, but surface runoff is even more rare. No perennial streams exist within about 16 km of the waste-burial facility. The dry bed of the Amargosa River is the principal drainage channel. Perennial flow in this channel is maintained by springs in the upper reaches of the Amargosa River north of Beatty, and the flow usually has disappeared beneath the surface within about 3 km downstream from Beatty. The dry channel of the Amargosa passes about 3 km west of the waste-burial site.

No records or observations of flow in the Amargosa River at the latitude of the waste-burial site are available. Records of flow about 3 km south of Beatty since 1964 are available and are summarized in table 1. Commonly, these flows last for only a few days following a major storm over the drainage basin upstream from the gaging station; there is no flow most of the year. Most measurements on the Amargosa River south of Beatty record peak flow from a crest-stage gage or from slope-area measurements. Several of the events recorded at this gage probably produced sufficient discharge for surface flow to have reached as far south as the latitude of the waste-burial site, a distance of about 14 km along the river channel from the gage south of Beatty. On March 1, 1978, a flow of about 18 cubic meters per second (m^3/s) was recorded at the gage south of Beatty. On the same day, flow was also observed by the author about 8 km south of the gage, at a road crossing in the SW¼ of sec. 18, T. 13 S., R. 47 E.; the estimated flow there was in the range of 1–3 m^3/s. The southern extent of this flow was not determined, but it may have continued the additional 6 km required to reach the latitude of the waste-burial site. Two previous events recorded at the gage near Beatty probably provided flow opposite the waste-burial site: On August 30, 1967, a discharge of about 120 m^3/s was determined from slope-area measurements at the gage, and on February 24, 1969, a discharge of about 450 m^3/s was determined, also from slope-area measurements.

Secondary drainage features that may be of some significance are two dry streambeds that trend roughly parallel to U.S. Highway 95 (figs. 2, 3). Both drainages split from the main channel of the Amargosa about 4 km south of the Amargosa Narrows. One dry channel trends south-southeast and passes about 0.6 km west of the waste-burial site between the waste-burial site and the main channel of the Amargosa. It rejoins the main channel of the Amargosa about 6 km south of the site. The other dry channel trends southeast along the east side of the highway, passes about 1 km east of the waste-burial site, and has several small tributary channels that appear to drain the southwest slope of Bare Mountain. This channel largely disappears on the desert floor about 13 km southeast of the site. Both channels are probably overflow bypass channels developed during a high discharge event of the Amargosa River.

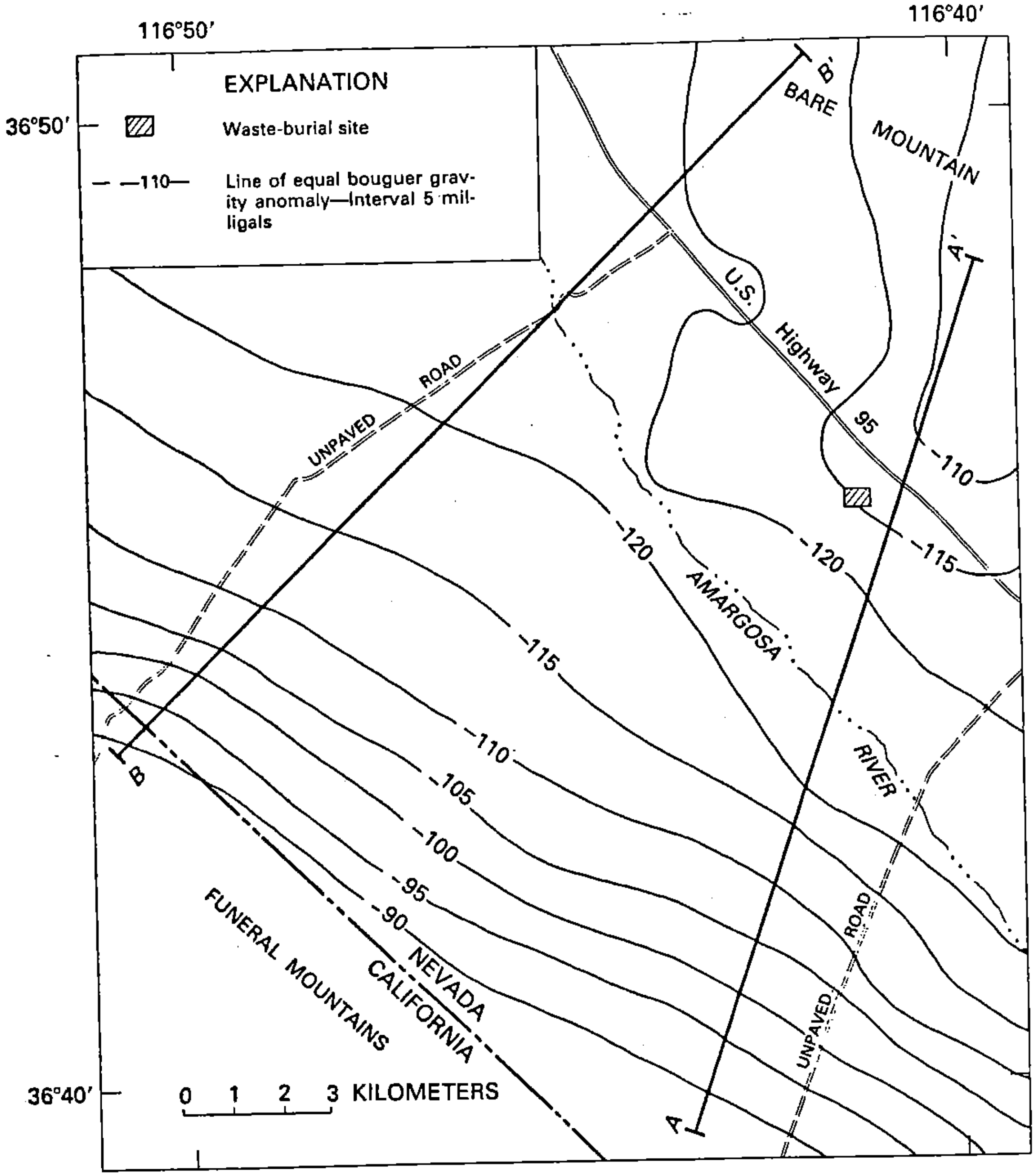

Figure 6. Bouguer gravity anomalies of the northern Amargosa Desert. Data from Douglas K. Maurer (U.S. Geological Survey, written commun., 1979). Shows location of profiles *A-A′* and *B-B′* (fig. 7).

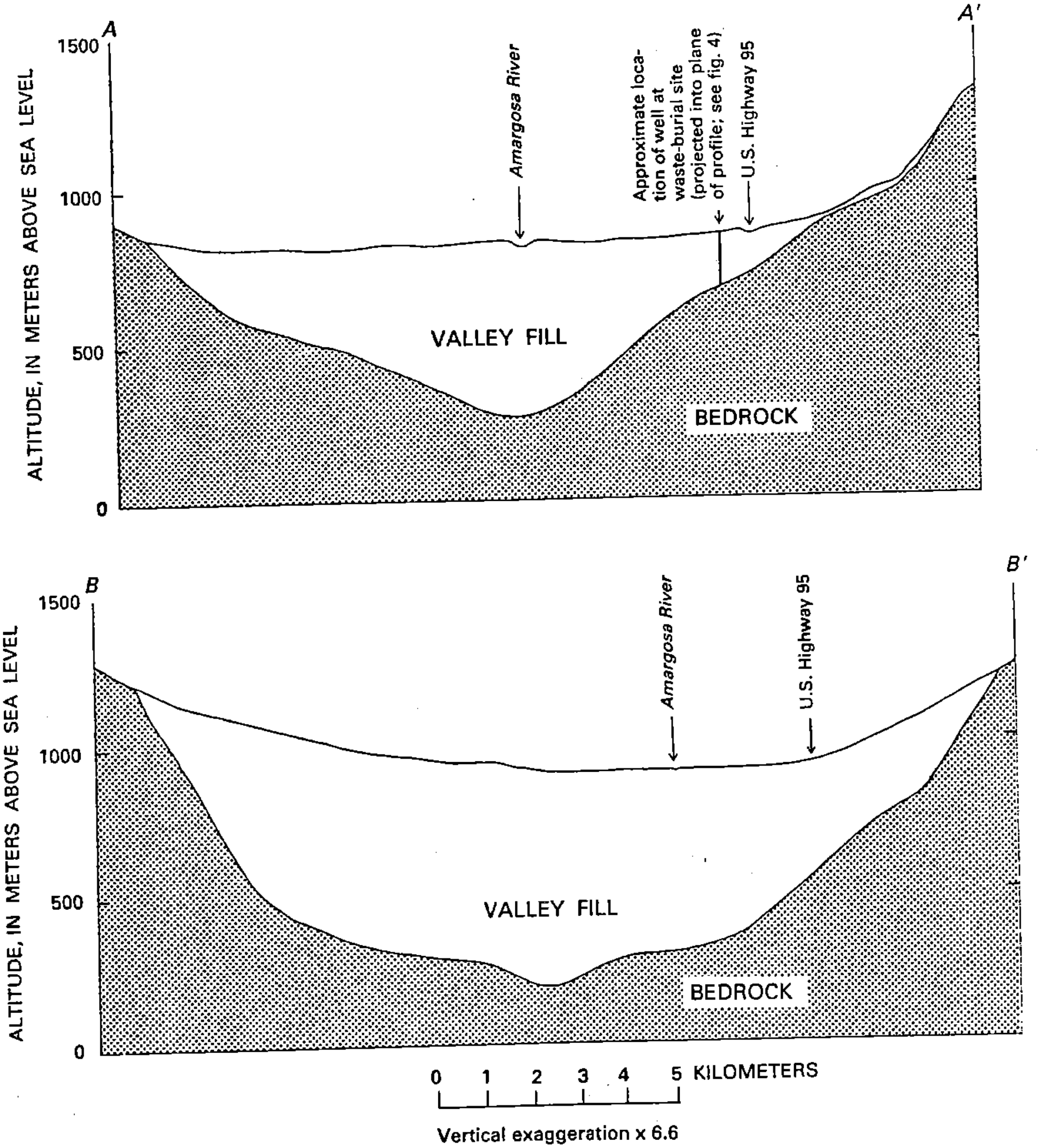

Figure 7. Profiles along lines *A–A'* and *B–B'* in figure 6, showing approximate depth to bedrock on the basis of gravity data.

Table 2. Water-level data for wells in vicinity of waste-burial site

Site number (pl. 1)	Name	Altitude of land surface (meters above sea level)	Well depth (meters)	Depth to water	
				Meters	Date
1	Nuclear Eng. Co.[a]	850	175	85.9	7-12-62
2	W. Dale[a]	795	147	77.1	7-12-62
3	Rose's Station[b]	775	--	63.4	1905

a From Walker and Eakin, 1963.
b From Ball, 1907.

On aerial photographs, minor local surface-drainage channels appear to pass through the area occupied by the waste-burial site. However, no surface runoff was observed or reported during the course of the study.

Unsaturated Zone

The unsaturated zone is of special significance in this study because it is through this zone that any radionuclides leached from the waste-burial trenches must pass before reaching the saturated zone; only then can the radionuclides be transported elsewhere (unless they are exhumed by erosion). The unsaturated zone in this part of the Amargosa Desert is at least 60 m thick and locally is nearly 90 m thick.

The soil-moisture content and soil-water potential of the unsaturated zone are not generally known. Data collected during this study at the waste-burial site suggest moisture contents of 4 to 10 percent by volume in the upper 6 m, except during the winter months when the moisture content of the top 0.5 to 1 m may be as high as 15 to 18 percent following a heavy rain. Studies of similar alluvial material at Jackass Flats, 32 km east of the waste-burial site, indicated moisture contents of 5 to 8 percent by volume (Clebsch, 1962). Infiltration experiments at Jackass Flats suggested that downward movement of soil moisture below the top 0.5 m did not occur until the soil attained about 50 percent saturation; this requires a volumetric soil-moisture content of between 15 and 20 percent.

The magnitude and range of soil-water potential is even less well known. Some measurements were made at the waste-burial site during the course of this study and are discussed in detail later in this report. Measured potentials ranged from a few millibars negative pressure in the near-surface sediments following rainfall events to several bars negative pressure in the same sediments during the dry summer months. At depths of 3 to 10 m, soil-water potential is in the range of 20 to 60 bars negative pressure. These values are consistent with laboratory soil-water potentials determined for these types of sediments and the observed moisture-content range (Mehuys and others, 1975).

Ground-Water System

Few wells have been drilled in the northern Amargosa Desert, and, consequently, the occurrence of ground water in the area is poorly known. Based on studies at the Nevada Test Site and in the southern Amargosa Desert, two major aquifers probably underlie the area: a valley-fill aquifer and an aquifer in the underlying Paleozoic bedrock, which together constitute the ground-water system. Three wells, located in Tps. 13 and 14 S., R. 47 E., Mount Diablo baseline and meridian, are the only sources of subsurface data northwest of Lathrop Wells. These wells are listed in table 2 and shown on plate 1.

Knowledge of the ground-water system beneath the waste-burial site is based almost solely on the information obtained from the drilling and testing of a well at the waste-burial site in 1961. The data obtained from this well suggest the presence of a principal water-bearing zone in the valley-fill deposits in the depth interval 99 to 103 m below land surface (fig. 4). Another, less productive zone exists from 132 to 173 m. This zone may be in hydraulic continuity with the water-bearing bedrock aquifer that is presumed to underlie the valley fill.

The deepest aquifers beneath the study area are those in the bedrock underlying the valley fill. No data are available for these aquifers beneath this part of the Amargosa Desert. Considerable information on the bedrock aquifers has been developed for large areas east and southeast of the disposal site, including the southern Amargosa Desert (Winograd and Thordarson, 1975). The most widespread bedrock aquifer is in the Cambrian to Devonian carbonate-rock sequence, which is presumed to underlie the study area because of its presence in Bare

Mountain. Less widespread and occasionally of only local significance are aquifers in Tertiary welded and bedded tuffs, several of which may underlie the valley fill of the northern Amargosa Desert. Water in these aquifers moves primarily through fractures and, in the carbonate-rock aquifer, through solution openings. Recharge to these aquifers probably is supplied by underflow from outside the Amargosa drainage basin. The source area of this recharge is not known.

The deepest aquifer in the valley fill, extending from 132 to 173 m below land surface, is assumed to immediately overlie the bedrock aquifer. The well drilled at the waste-burial site was originally perforated only in the interval from 138 to 173 m. The water level was 93 m below land surface; this is 39 m above the presumed top of the aquifer, suggesting confined conditions for the aquifer in this area.

The upper aquifer in the valley fill between 99 and 103 m also may be confined and is directly beneath the well-defined confining layer that extends from 62 to 99 m below land surface (fig. 4). Following a brief test of the deepest valley-fill aquifer, the well casing was slotted from 91 to 136 m depth so that it is now open to the entire interval from 91 to 173 m. The water level in the well rose to 86 m below land surface, which is 13 m above the presumed top of the upper aquifer. This represents a composite head for the whole thickness of valley-fill aquifers beneath the waste-burial site and indicates that the head in the upper aquifer is higher than that in the lower one.

Plate 1 shows the generalized configuration of the potentiometric surface for valley fill beneath the northern and central Amargosa Desert. The contours, slightly modified from those of Walker and Eakin (1963, pl. 3), are based on the assumption that ground-water flow beneath the northern part of the desert is to the southeast—that is, downvalley toward the Ash Meadows area. A similar interpretation was made by Winograd and Thordarson (1975, pl. 1). The basic assumption of downvalley flow is, however, not necessarily correct. The location of the three wells (pl. 1, wells 1, 2, and 3) used as altitude control for water-level contours in the northern part of the desert is such that the wells do not really define the direction of the gradient. It is possible that the gradient is toward the south or even the southwest.

The present interpretation of the direction of ground-water flow implies a recharge area to the north and northwest, perhaps the Sarcobatus Flat-Pahute Mesa area (see pl. 1). Some water in the valley-fill aquifer discharges to Alkali Flat, near Death Valley Junction; the rest may enter the carbonate-rock aquifer and eventually discharge to Death Valley, possibly along the Furnace Creek fault zone bounding the Funeral Mountains on the west. Hunt and others (1966) noted the similarity in chemical composition between ground water in the Ash Meadows area and spring discharge along the northeast side of Death Valley.

CLIMATE

Radioactive waste is buried at the facility near Beatty at depths of 6 to 15 m in an unsaturated zone that is about 85 m thick. A number of geologic and hydrologic processes that govern and affect the movement of water into and through this zone must be recognized and understood if we are to understand the potential for radionuclide migration beneath the site. Among these are the hydrologic processes controlled by the climate in the area of the waste-burial site.

The climatic factors of rainfall, temperature, solar radiation, and evaporation interact under bare-soil conditions, such as those that exist at the waste-burial site, in a complex manner with the geohydrologic factors of soil moisture, soil-water potential, and unsaturated hydraulic conductivity to determine the amount and movement rate of water percolating through the unsaturated zone. The only water that might come in contact with, leach, and transport radionuclides from the buried waste is that derived from precipitation falling directly on the backfill in the waste-burial trenches. The amount of water that infiltrates and percolates downward, and the depth and rate at which it moves, depend largely on the amount and intensity of precipitation, evaporation demand, and pre-existing soil-moisture conditions. To clarify the hydrologic processes in the shallow unsaturated zone at the waste-burial site, each of the controlling parameters is examined in considerable detail. The following discussion defines the areal climatic factors of precipitation, temperature, and evaporation, which in turn characterize recharge-inducing rainfall events and set an upper limit on the potential recharge from local sources. Transpiration demands are not considered in the following analysis and discussion of significant precipitation because the waste-burial site is kept cleared of vegetation; only the evaporation losses from bare soil are applicable. If plant-growth requirements are added to bare-soil evaporation, deep percolation of precipitation would be doubtful. Site-specific conditions of soil moisture and soil-water potential are discussed in a later section of this report.

Precipitation

The waste-burial site is situated in one of the most arid parts of the United States. Mean annual precipitation in the area varies from 11.4 centimeters (cm) at Beatty (altitude, 1,005 m), 17.4 km north of the site, to 7.4 cm at Lathrop Wells (altitude, 817 m), 30 km southeast of the site.

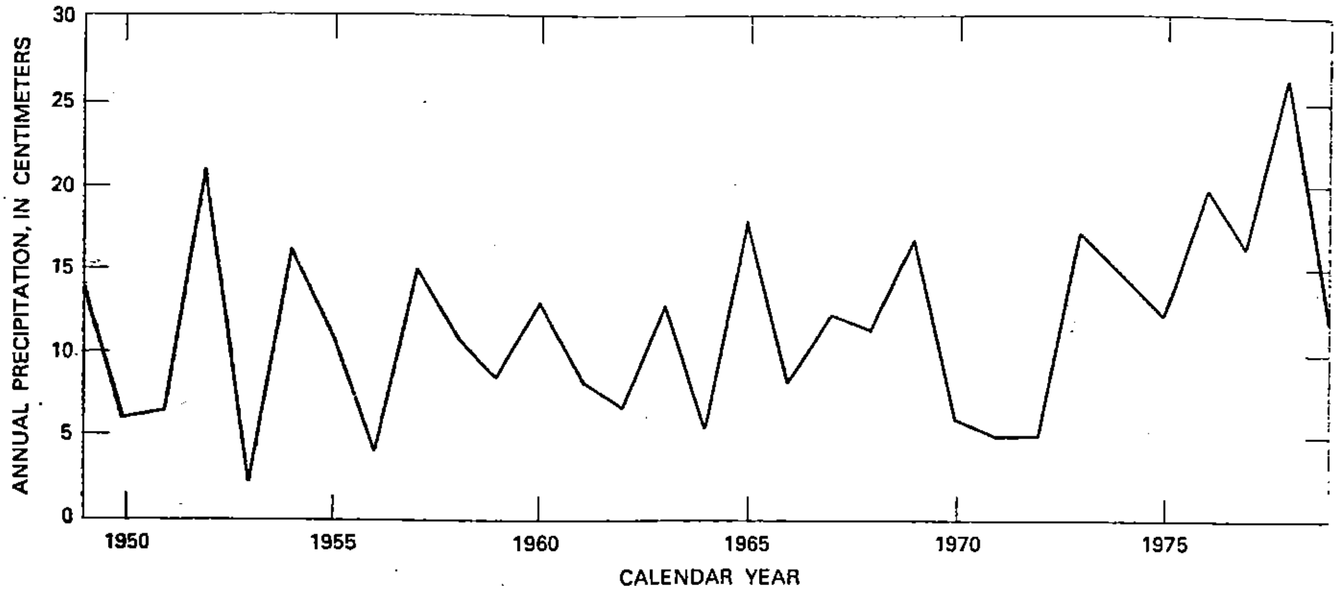

Figure 8. Annual precipitation at Beatty, 1949–79.

Annual precipitation varies considerably from one year to the next. During the time period 1949–79 at Beatty (fig. 8), it ranged from 1.8 cm in 1953 to 26.3 cm in 1978. During the same time period at Lathrop Wells, recorded annual precipitation (the record is discontinuous) ranged from 2.4 cm in 1962 to 13.4 cm in 1957.

Precipitation can occur during all months of the year, but the amount varies considerably with season; most falls during the winter months. Mean monthly precipitation at Beatty and Lathrop Wells during the period 1949–79 is shown in figure 9. Winter precipitation originates from the west and is commonly associated with transitory low-pressure systems that usually cover large areas. It is almost always in the form of rain. Snow is uncommon at Beatty and rare on the Amargosa Desert, and it persists on the ground for no more than a few hours. Summer rainfall occurs predominantly during convective storms that may yield intense rainfall over small areas. On several occasions during late August or in September, tropical storms have come inland from the Pacific Ocean, crossing the California coast between San Diego and Los Angeles, and moved northeast across southern Nevada. Such a storm in August 1977 produced nearly 5 cm of rain in 24 hours (hr) at Beatty.

More important than total or mean annual rainfall as a source of potential recharge to the unsaturated zone is the magnitude, intensity, and timing of a single precipitation event. For a given precipitation event to have potential recharge significance, it must exceed evaporative demands during the following days and also be able to satisfy and exceed the existing soil-moisture deficit. Precipitation events during summer months, when evaporative demands are high and surface soils are extremely dry, are unlikely to result in recharge. Alternatively, precipitation may occur when evaporative demands are low, such as during the cool winter months, and when the soil-moisture deficit is small, as would be the case following a series of closely spaced rainfall events. Precipitation intensity is also a factor influencing infiltration. High-intensity rainfall commonly results in less infiltration and more runoff. Rainfall intensity is not considered in this analysis because (1) the necessary data were not available, and (2) winter storms, which are of greatest importance to deep percolation, are generally of low intensity (but long duration) compared with high-intensity summer convective-storm precipitation.

An analysis of single-rainfall-event magnitude and frequency has been made using data from the National Weather Service stations at Beatty and Lathrop Wells. Conditions at Lathrop Wells are more like those at the waste-burial site because of similarities in topographic setting and altitude, but the precipitation record there is shorter and much less complete than the record at Beatty. The major undesirable feature of the Beatty weather-station site with respect to the waste-burial site is the difference in altitude—1,005 m at Beatty versus 847 m at the waste-burial site. Nevertheless, most of this analysis relies on the more complete record from the station at Beatty; data from the station at Lathrop Wells is compared

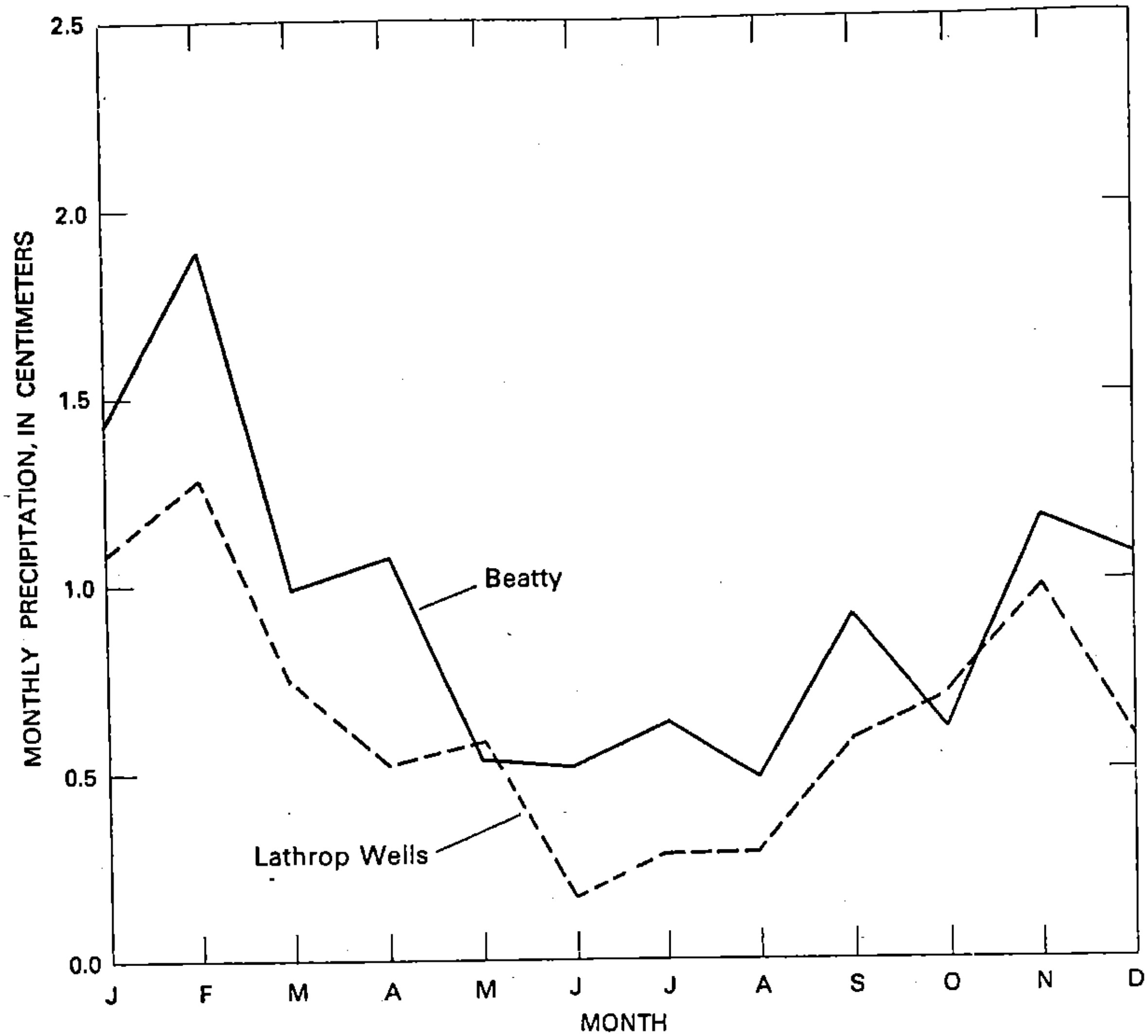

Figure 9. Mean monthly precipitation at Beatty and Lathrop Wells, 1949–79. Data for Lathrop Wells are based on incomplete record.

and contrasted with that from Beatty for those years for which the record is complete.

Analysis of the frequency and magnitude of individual precipitation events in southern Nevada is complicated by a number of factors. Studies by Weedfall (1963) and Quiring (1965) demonstrated that precipitation in the region is a function of both altitude and longitude. The weather station at Beatty was 158 m higher in altitude than the waste-disposal site during the period 1948–72. In 1972, the station was moved to a new location that is 234 m higher than the previous location. The station at Lathrop Wells is 190 m lower in altitude than the waste-burial site. Much of the record at Lathrop Wells for the period 1949–77 is missing, thereby complicating any analysis dealing with number of events. Years with partial record are not included in the following analysis; thus,only 16 yr of complete record could be compared with the data from the Beatty station.

The number of precipitation events in different magnitude categories is given in table 3 for Beatty and in table 4 for Lathrop Wells. The amount of rainfall recorded during a 24-hr period is considered to represent a discrete rainfall event, which is not strictly correct because a given storm may span more than 1 day. The potential effect of this approach to defining rainfall events would be to reduce the number of large rains and increase the number of smaller rains. Examination of the dates and magnitudes of daily precipitation, however, suggests that this approach has not significantly affected the analysis.

Daily precipitation at Beatty producing 2.5 cm or less accounted for 98 percent of the total number of daily events recorded from 1949 to 1979. Daily precipitation of

Table 3. Classification of 24-hr precipitation data at Beatty, 1949–79, by magnitude of event

[cm, centimeters]

Calendar year	Total precipi-tation (cm)	Cumulative precipi-tation (cm)	Number of events in each class				
			Class 1 (0.01 to 0.60 cm)	Class 2 (0.61 to 1.25 cm)	Class 3 (1.26 to 2.50 cm)	Class 4 (2.51 to 3.75 cm)	Class 5 (3.76 to 5.0 cm)
1949	13.79	13.79	32	1	2	1	0
1950	6.04	19.83	9	3	1	0	0
1951	6.60	26.43	14	5	0	0	0
1952	21.23	47.66	21	15	1	1	0
1953	1.75	49.41	13	0	0	0	0
1954	16.36	65.77	16	0	6	0	1
1955	10.95	76.72	16	6	2	0	0
1956	4.24	80.96	8	0	1	0	0
1957	15.01	95.97	25	6	3	0	0
1958	10.74	106.71	18	4	2	0	0
1959	8.61	115.32	9	4	2	0	0
1960	13.00	128.32	11	7	0	1	0
1961	8.36	136.68	12	4	1	0	0
1962	6.78	143.46	18	2	1	0	0
1963	12.70	156.16	13	3	4	0	0
1964	5.36	161.52	17	2	0	0	0
1965	18.62	180.14	25	4	5	0	0
1966	8.18	188.32	14	1	2	0	0
1967	12.39	200.71	17	5	2	0	0
1968	11.30	212.01	8	4	2	0	1
1969	16.59	228.60	10	5	4	1	0
1970	7.62	236.22	7	3	0	1	0
1971	5.03	241.25	2	1	2	0	0
1972	5.18	246.43	3	0	1	1	0
1973	17.07	263.50	30	9	2	0	0
1974	14.73	278.23	20	6	3	0	0
1975	12.29	290.52	28	1	0	0	1
1976	19.86	310.38	14	8	2	2	0
1977	16.36	326.74	16	4	1	1	1
1978	26.34	353.08	31	8	7	0	0
1979	11.96	365.04	34	4	2	0	0
Total	365.04	--	511	125	61	9	4
Percentage of total events	--	--	71.9	17.7	8.6	1.3	0.5
Average annual	11.77	--	16	4	2	<1	<1

0.6 cm or less is by far the most common size of event, accounting for nearly 72 percent of the total. The potentially significant storms (from a recharge standpoint) that produced more than 2.5 cm accounted for about 2 percent of the events during the period of analysis—only 13 events in 31 years. Of those, nine produced rainfall of 2.51 to 3.75 cm and four produced rainfall of 3.76 to 5.0 cm. Interestingly, 5 of the 13 major precipitation events occurred after the station was moved in 1972. Table 5 gives the date and magnitude of each of the major events.

A noticeable increase in precipitation was recorded at the Beatty weather station following 1972 when the station was moved to a location 76 m higher than the previous site. The increase in both cumulative precipitation and cumulative number of events of 0.6 cm or less after 1972 is shown in figures 10 and 11. The probable effect of moving the station to a higher altitude is suggested by the data shown on both graphs.

The seasonal distribution of daily precipitation events of several different magnitudes that are less than or equal to 2.5 cm at Beatty is shown in figures 12 and 13. These storms typically account for 70 to 90 percent of the annual rainfall. Exceptions to this arise when a large storm occurs during a year of low annual rainfall such as

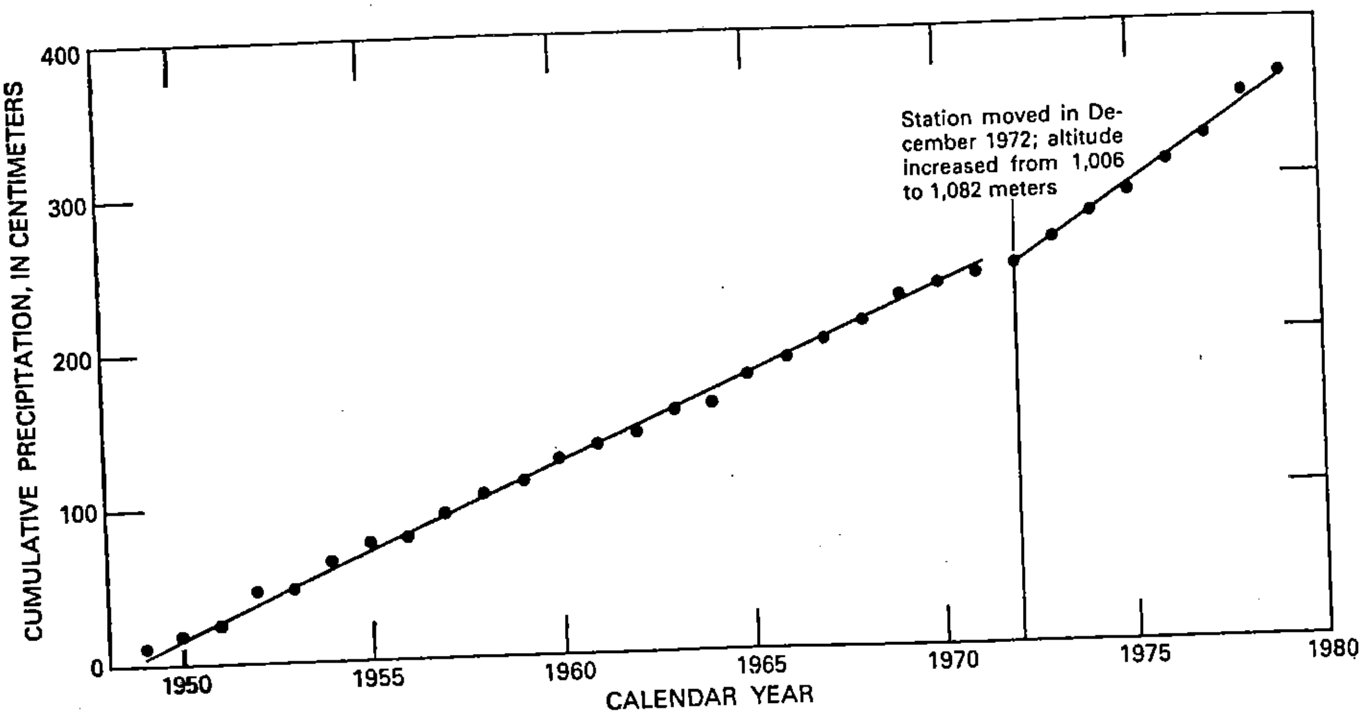

Figure 10. Cumulative precipitation at Beatty, 1949–79.

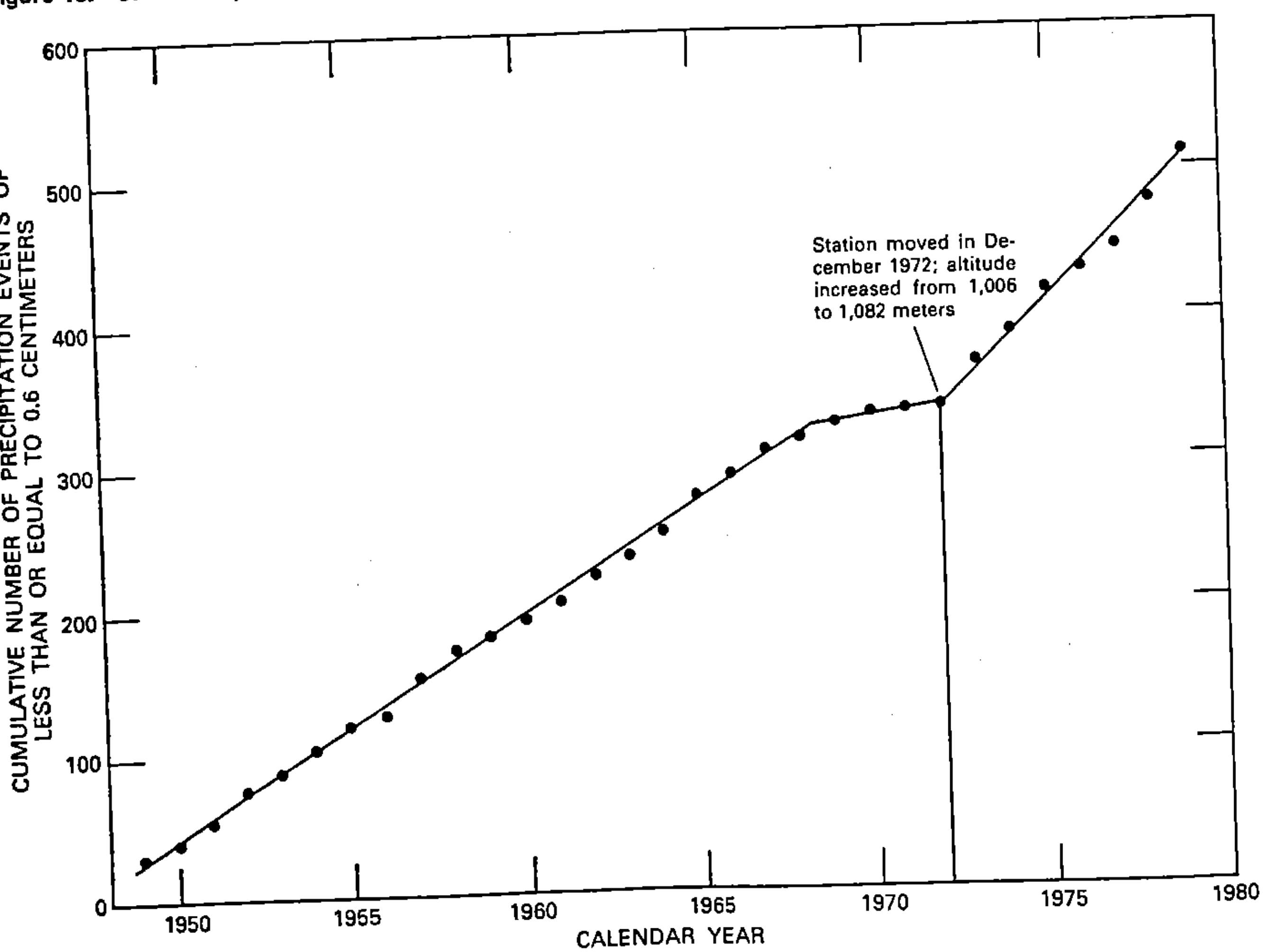

Figure 11. Cumulative number of precipitation events of 0.6 cm or less at Beatty, 1949–79.

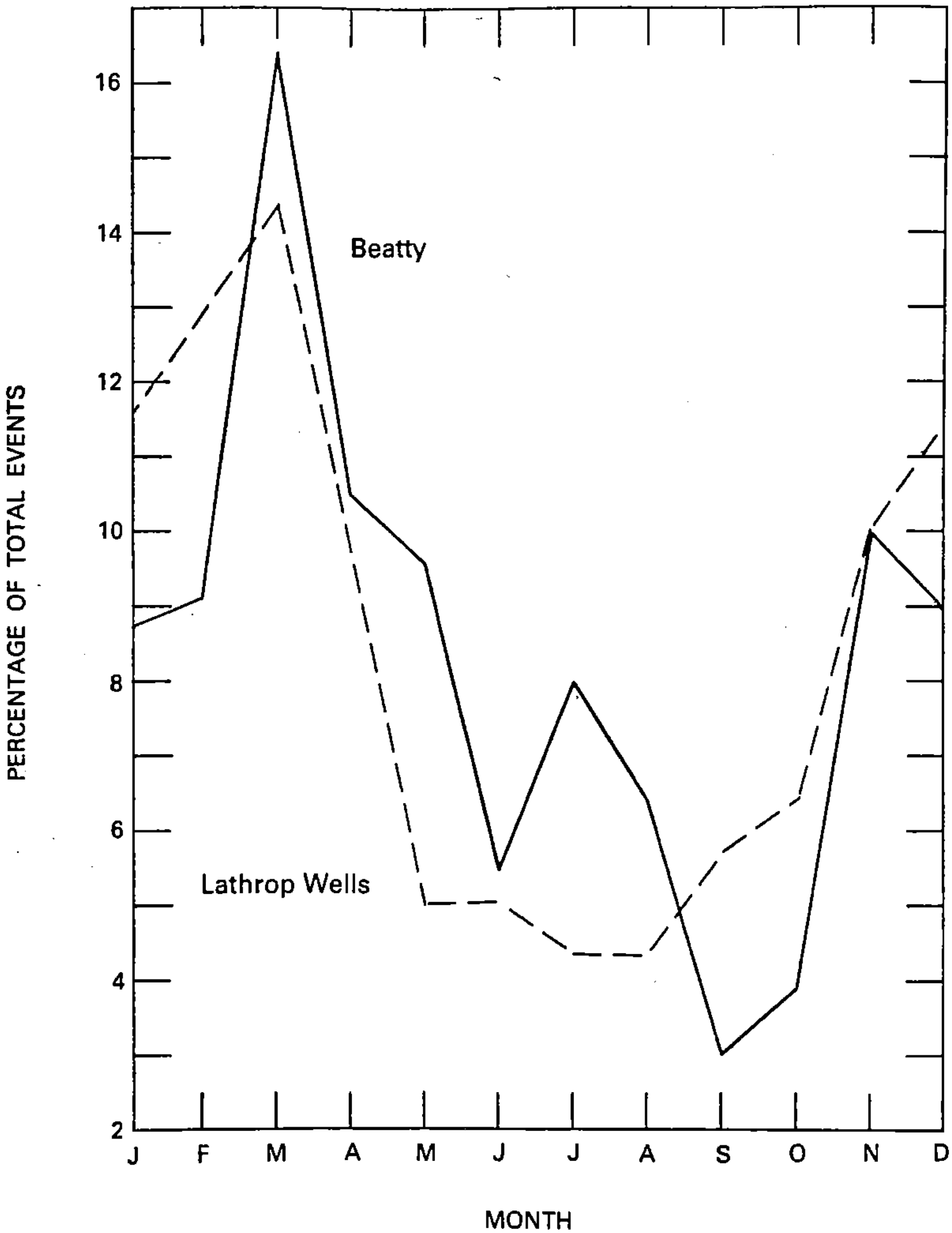

Figure 12. Monthly distribution of precipitation events of 0.6 cm or less at Beatty and Lathrop Wells, 1949–76.

Table 4. Classification of 24-hr precipitation data at Lathrop Wells, 1949–77, by magnitude of event

[cm, centimeters]

Calendar year[1]	Total precipitation (cm)[2]	Cumulative precipitation (cm)	Number of events in each class: Class 1 (0.01 to 0.60 cm)	Class 2 (0.61 to 1.25 cm)	Class 3 (1.26 to 2.50 cm)	Class 4 (2.51 to 3.75 cm)	Class 5 (3.76 to 5.0 cm)
1949	11.99	11.99	4	3	1	2	0
1950	3.40	15.39	1	0	2	0	0
1951	2.79e	18.18	4	1	1	0	0
1954	11.61	29.79	8	3	2	1	0
1955	6.78	36.57	4	4	1	0	0
1956	3.05	39.62	4	2	0	0	0
1957	13.39	53.01	6	5	4	0	0
1958	11.43	64.44	12	8	1	0	0
1962	2.44	66.88	5	0	1	0	0
1971	3.58	70.46	9	2	0	0	0
1972	7.95	78.41	15	2	0	1	0
1973	11.10	89.51	25	3	2	0	0
1974	8.00	97.51	15	2	2	0	0
1975	5.26	102.77	7	3	1	0	0
1976	10.97	113.74	9	2	1	0	1
1977	11.3e	125.04	--	--	--	--	--
Total	125.04	--	128	40	19	4	1
Percentage of total events	--	--	66.7	20.8	9.9	2.1	0.5
Annual average	7.82	--	8	2	1	<1	<1

1 Period of full-year record only.
2 Estimated values indicated by "e."

1972. A greater frequency of occurrence of small events (less than or equal to 0.6 cm) in July and August as compared with June, September, and October (fig. 12) probably reflects increased convective-storm activity during these 2 mo.

Precipitation frequency and magnitude at Lathrop Wells is more nearly like that at the waste-burial site than is the frequency and magnitude at Beatty. Missing records at Lathrop Wells between 1949 and 1977 have resulted in only 16 yr of usable data for the 30-yr period, and the longest span of continuous record is the 6 yr from 1971 through 1976. These 16 yr of data are compared with the same 16 yr of record from Beatty.

Precipitation events of 0.6 cm or less are the most common type at Lathrop Wells, as they are at Beatty, accounting for 67 percent of the events recorded during the 16 yr of record (table 4). Daily precipitation of 2.5 cm or less accounted for 97 percent of the total number of rainfall events during the 16 yr being considered. The seasonal distribution of daily precipitation events of 2.5 cm or less at Lathrop Wells is shown in figures 12 and 13. In most years, these rains account for all the precipitation recorded at Lathrop Wells. The pattern is similar to that at Beatty, but there are fewer small rainfall events (0.6 cm or less) in July and August and more rainfall events producing 0.61 to 2.5 cm in March and April.

The total precipitation at Lathrop Wells amounted to 69 percent of the total recorded at Beatty during the 16 yr of concurrent record. The number of small storms (0.6 cm or less) at Lathrop Wells amounted to only 51 percent of the number of small storms at Beatty. The number of events producing 0.6 to 2.5 cm of rain at Lathrop Wells was 74 percent of the number of events of the same size at Beatty. The number of potentially significant precipitation events, those producing more than 2.5 cm of rain, was nearly the same at the two stations during the 16 yr being examined—five at Lathrop Wells and six at Beatty. Table 5 gives the date and magnitude of these events at Lathrop Wells. The event on November 6, 1960, is not included in table 4 because the records for that year are incomplete, but it is included in table 5 for comparison with events of similar size at Beatty.

Table 5. Date and magnitude of 24-hr precipitation events exceeding 2.5 cm at Beatty and Lathrop Wells, 1949–79

Date	Precipitation, in centimeters	
	Beatty	Lathrop Wells
February 27, 1949	3.71	3.56
May 18, 1949	(a)	3.25
March 15, 1952	2.54	(b)
November 11, 1954	4.06	2.67
November 6, 1960	3.25	2.85
February 10, 1968	4.19	(b)
November 7, 1969	2.54	(b)
February 21, 1970	2.69	(b)
October 4, 1972	3.05	3.30
September 9, 1975	4.39	(c)
February 7, 1976	3.23	4.85
February 9, 1976	(c)	4.85
September 10, 1976	3.07	(c)
May 9, 1977	3.33	(c)
August 17, 1977	4.45	5.72 (2.25")

a Missing record.
b Station not in operation.
c Precipitation less than 2.5 cm.

Temperature

Temperature is an indicator of the evaporative demands in the area at any given time and provides a guide to potential evaporation. Temperature also tends to show more areal uniformity over longer periods of time than precipitation, so that average temperature values have greater meaning than do average values of precipitation.

The seasonal distribution of mean monthly temperature at Beatty is shown in figure 14. The mean annual maximum daily temperature for the period 1949–79 is 25 °C. The mean annual minimum daily temperature is 6 °C, and the mean annual mean daily temperature is 15 °C. The mean daily maximum temperature exceeds 32 °C from June through September. The hottest month is July, with a mean daily maximum temperature of 37 °C; the mean daily minimum temperature for this month is 17 °C. Average daily minimum temperatures fall below 0 °C during December, January, and February. The coldest month is January, with a mean daily minimum temperature of −3 °C; several days in early January have long-term mean daily minimum temperatures below −5 °C.

The temperature distribution and ranges at Lathrop Wells (fig. 15) are similar to those at Beatty (fig. 14). The mean annual maximum daily temperature is 27 °C, the mean annual minimum is 8 °C, and the average annual mean daily temperature is 18 °C. The warmest month is July, having a mean daily maximum temperature of 39 °C and a mean daily minimum of 20 °C. The mean daily maximum temperature exceeds 32 °C from June through September. The coolest month is January, with a mean daily minimum temperature of −2 °C and a mean daily maximum of 14 °C. The average daily minimum temperatures drop below 0 °C during December, January, and February.

These temperature distributions and extremes are significant from the standpoint of evaporation demands. The warmest temperatures occur in the summer months, when precipitation is sparse and small rainfall events dominate. Evaporation demands are greatest during these months. The coolest months are the winter months, when much of the yearly rainfall occurs and when most of the major potentially significant precipitation events take

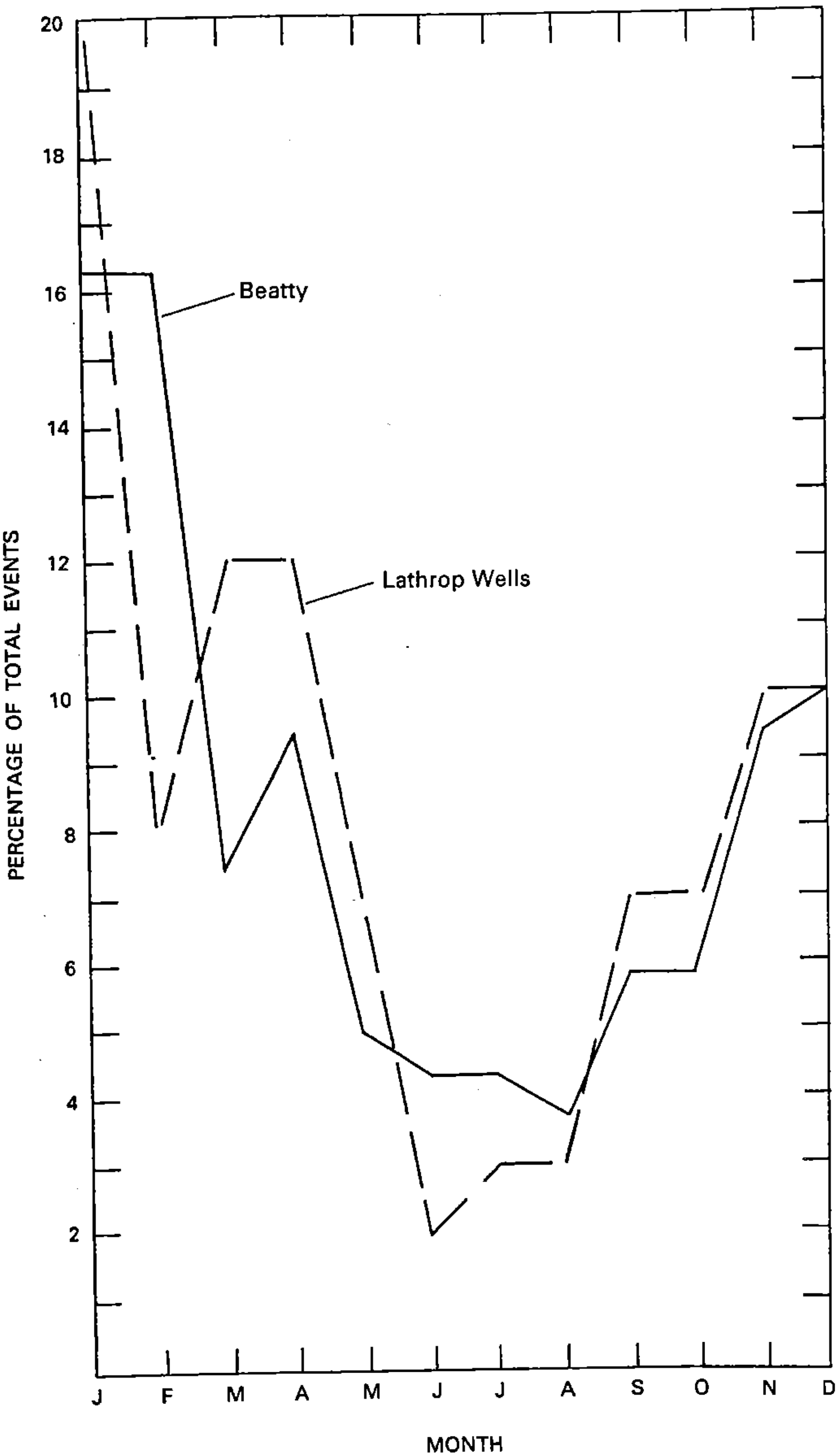

Figure 13. Monthly distribution of precipitation events of between 0.61 and 2.5 cm at Beatty and Lathrop Wells, 1949–76.

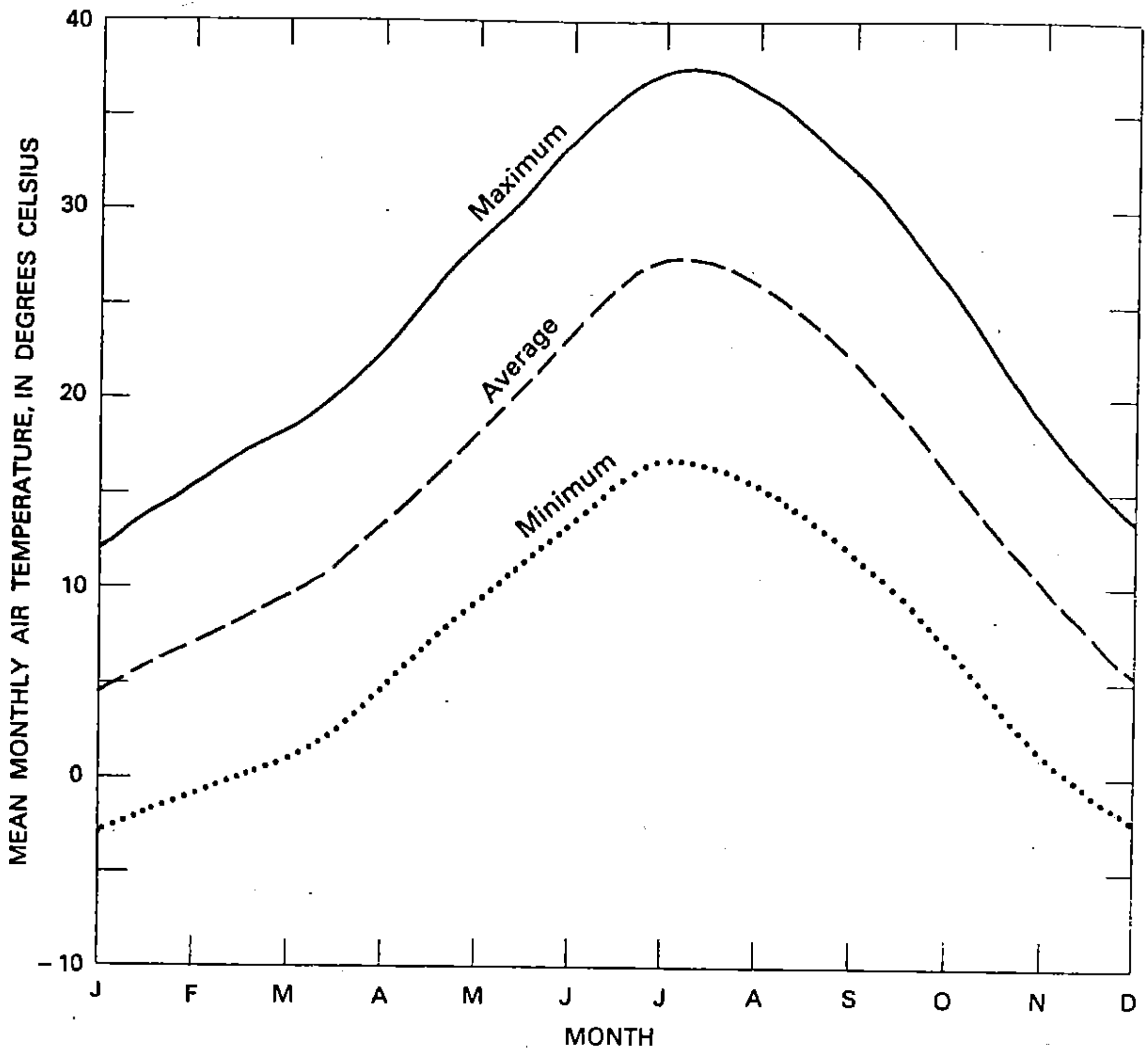

Figure 14. Mean monthly maximum, average, and minimum air temperatures at Beatty, 1949–76.

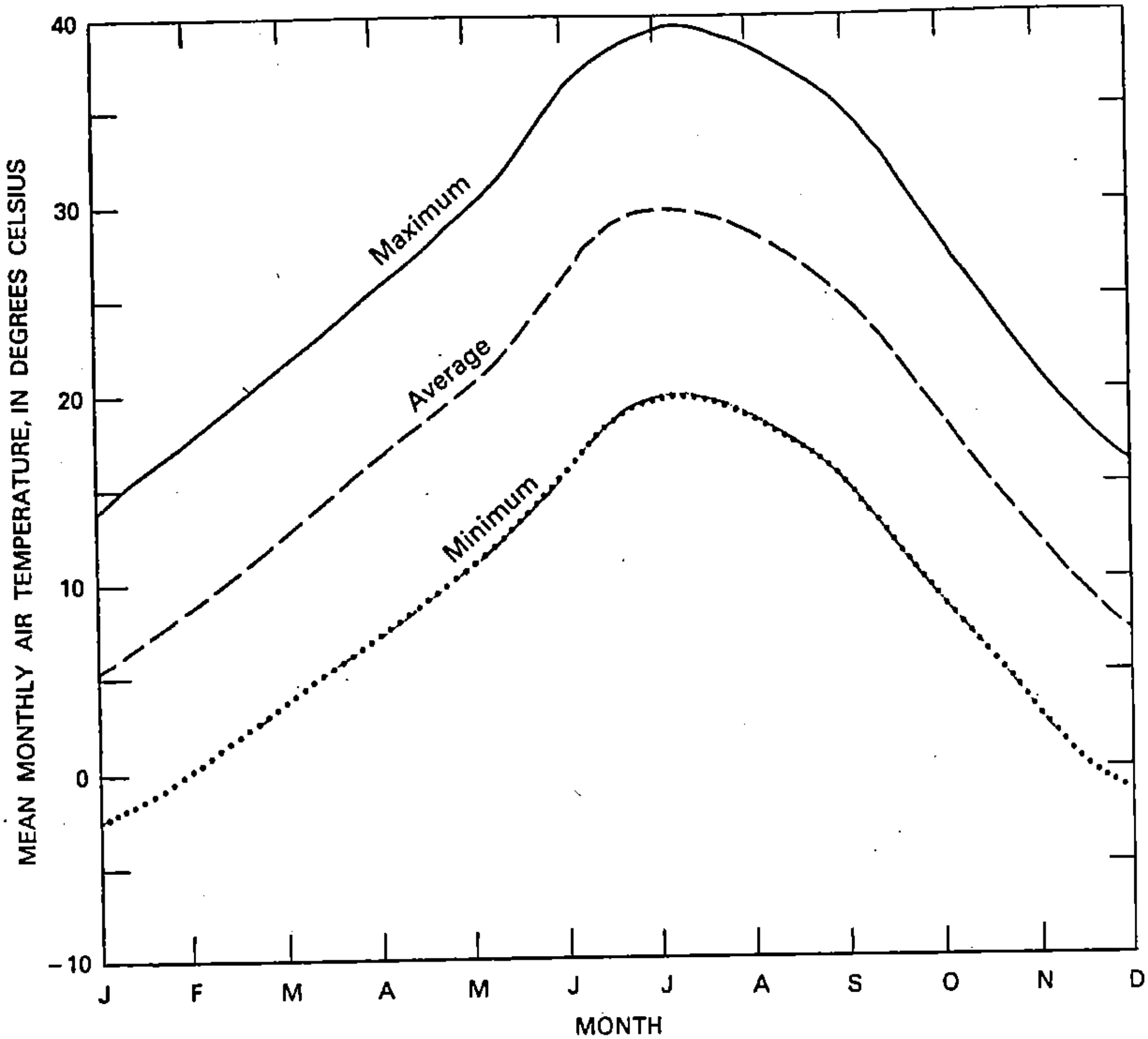

Figure 15. Mean monthly maximum, average, and minimum air temperatures at Lathrop Wells, 1949–76.

place. Evaporative demands are low during these months, and if enough precipitation falls to satisfy the soil-moisture deficit built up during the preceding summer, there is the potential for deep percolation.

Evaporation

Evapotranspiration, rather than just evaporation, is more commonly considered in investigations of this type because of the need to consider not only water lost directly from the soil by evaporation, but also moisture lost by plants through transpiration. Only evaporation is considered here, however, because the waste-burial site is kept cleared of vegetation and water is lost to the atmosphere only through evaporation from bare soil.

Many discussions of evaporation consider only pan evaporation or potential evaporation, usually because actual evaporation data are not available. Pan-evaporation and potential-evaporation rates can be useful guides to actual evaporation in some instances, but they are poor indicators in such an arid climate. Pan evaporation occurs at the potential, or energy-limiting, rate. As long as water is available, evaporation at this maximum rate will continue, and the purpose of the evaporation pan is to provide a continuous supply of water. Potential evaporation also is a measure of evaporation at the energy-limiting rate, but, rather than being measured directly, it is computed using climatic data. Pan evaporation in this part of Nevada probably exceeds 250 cm a year. Measured pan evaporation at Boulder City, 183 km southeast of the waste-burial site, is about 280 cm per year.

A number of equations have been developed to compute potential evaporation and potential evapotranspiration using a variety of meteorological or climatic data. Most equations have been developed to compute potential evapotranspiration from cropped surfaces using readily available meteorological data. Those equations developed for calculating potential evaporation from bare soil commonly require meteorological data that are not readily available, particularly in remote areas. Equations to estimate actual evaporation also require data that commonly are not available.

During the course of this investigation, meteorological data (described below) were collected at the study site for use in evaporation studies. Several equations were used to calculate actual evaporation for selected time periods of 5 to 15 days. Several other equations were employed to estimate long-term potential and actual evaporation on the basis of 28 yr of precipitation and temperature data from the Beatty weather station. The details of these computational procedures are discussed later in this report. The intent of an in-depth study of evaporation is not to calculate a precise annual total for a particular year or an accurate water balance for the area for an extended period, but rather to screen the available climatic data for the area since 1949 for potential "recharge-inducing" events on the basis of reasonable long-term estimates of evaporation. Because virtually no runoff occurs at the waste-burial site, the difference between precipitation and evaporation, once the soil-moisture deficit is satisfied, is considered to be the recharge that can percolate deep into the unsaturated zone. This approach to estimating long-term evaporation allows a reasonable upper limit to be set on the amount of recharge that might have occurred since the waste-burial facility was established in 1962, and it also identifies the times and conditions under which the recharge would have taken place. This approach is discussed in greater detail later in this report.

Mean monthly potential evaporation at Beatty from 1961 to 1976 is shown in figure 16. It ranges from 4 cm in December to 33 cm in July. The seasonal distribution can be compared with that of precipitation (fig. 9). Annual potential evaporation at Beatty for 1961 through 1976 is shown in figure 17. It ranges from 132 cm to 214 cm and averages 190 cm over the 16 yr. A comparison of the evaporation data in figure 17 and precipitation data in figure 8 clearly demonstrates the limited usefulness of potential-evaporation computations in constructing a water balance. In contrast to the monthly potential evaporation, estimated monthly actual evaporation from bare soil at the waste-burial site ranges from 0.4 cm in December to slightly less than 1.1 cm in February (fig. 18). The pattern of estimated actual evaporation is significantly different from that of potential evaporation. Maximum estimated actual evaporation occurs in February, when rainfall is most common and water is most readily available, and it generally declines through the rest of the year to a minimum in December. Mean annual estimated actual evaporation is 9 cm and ranged from 2 to 16 cm for the 16-yr period.

The precipitation record upon which these evaporation estimates were based is a modification of the record from the Beatty station. Comparison of the records from Beatty and Lathrop Wells indicates significantly fewer rainfall events in the size category 0.6 cm or less at Lathrop Wells than at Beatty, but Beatty has the more complete record as required for the analysis. Accordingly, the number of precipitation events recorded at Beatty that were equal to or less than 0.6 cm was reduced by 33 percent by arbitrarily deleting every third rainfall event of that size, which in turn resulted in a mean annual precipitation of 10 cm for the 16 yr of analysis, a reasonable average for the location of the waste-burial site. For the 16-yr period, the cumulative amount of estimated actual evaporation equaled 97 percent of cumulative precipitation. Likewise, the mean annual value for estimated actual evaporation equaled 97 percent of the

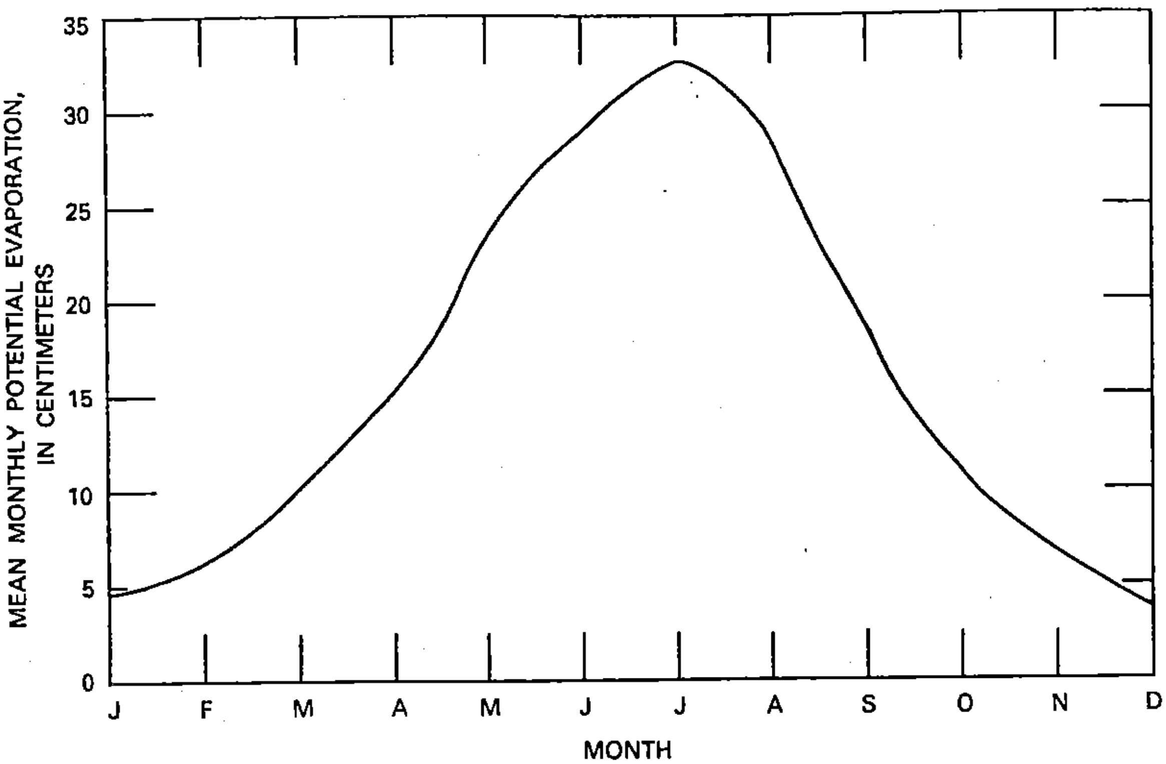

Figure 16. Mean monthly potential evaporation at Beatty, 1961–76.

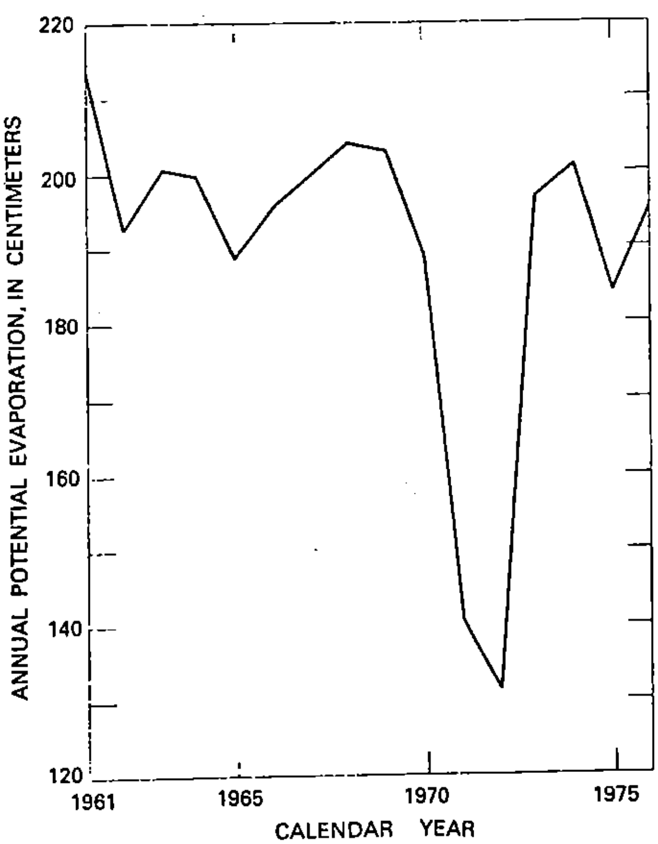

Figure 17. Annual potential evaporation at Beatty, 1961–76.

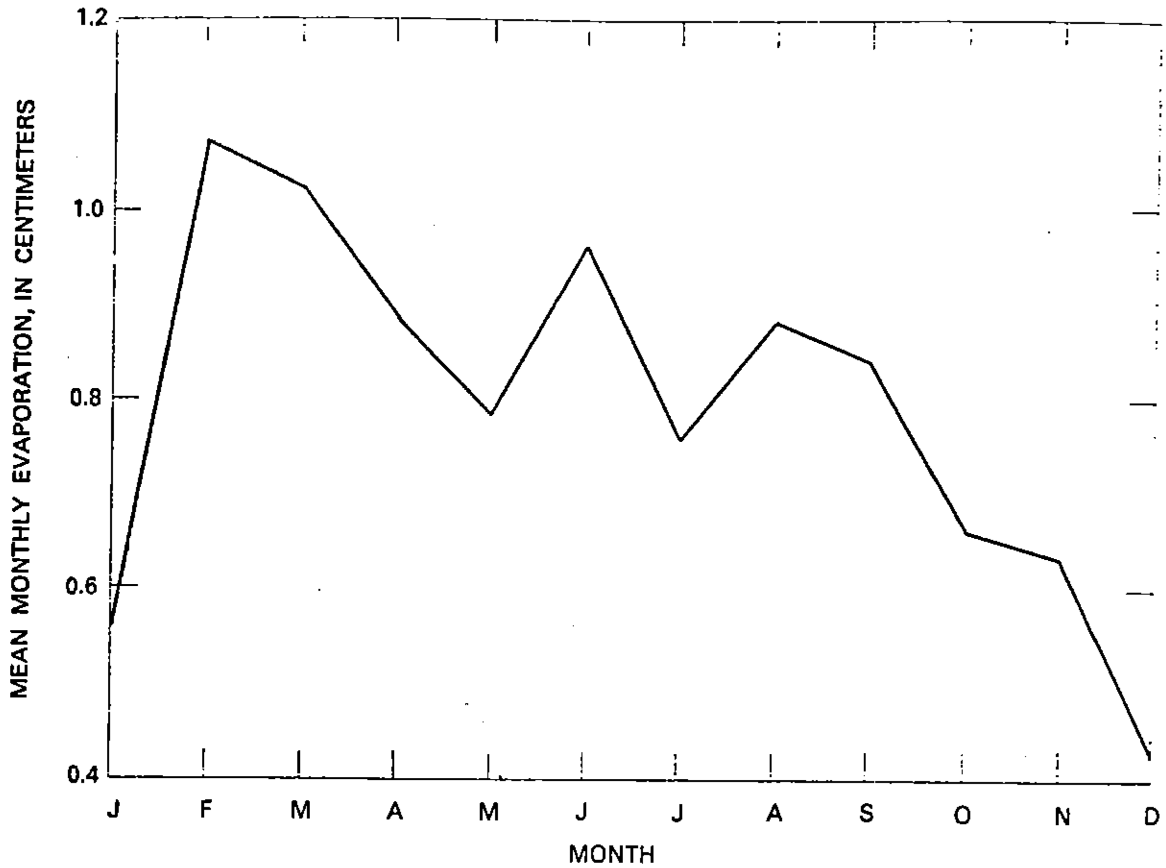

Figure 18. Estimated mean monthly actual evaporation from bare soil at waste-burial site, 1961–76.

mean annual rainfall. The remaining 3 percent (or 0.3 cm), which is within the limits of accuracy of the estimate, would represent potential mean annual recharge.

GEOHYDROLOGY OF THE UNSATURATED ZONE AT THE WASTE-BURIAL SITE

Geohydrologic studies at the waste-burial site have been confined to a detailed investigation of the top 10 m of the unsaturated zone. The intent is to provide a better basis for determining the potential for infiltration and deep percolation of precipitation; only deeply percolating rainfall can leach and transport radionuclides from the buried waste. Micrometeorological data (R.G. Brown, U.S. Geological Survey, written commun., 1985) were collected to better characterize the precipitation and evaporation conditions at the site. Soil-moisture profiles to a depth of 3.5 m were obtained monthly for a 15-mo period. Soil-water potential and soil temperature to a depth of 10 m were obtained over a 37-mo period.

Evaporation and the Potential for Recharge

Evaporation Studies

Micrometeorological data collected at the waste-burial site include (1) short-wave incoming solar radiation, (2) net radiation, (3) air and wet-bulb temperature at 1 and 0.5 m above land surface, (4) soil-heat flux, (5) soil temperature, and (6) precipitation. Data on windspeed and wind direction and reflected short-wave radiation were collected for a short time. The micrometeorological data were originally intended for use in calculating a rigorous water budget for the study site, but instrument failures leading to significant record gaps and the relatively short period of data collection (2 yr) for such a variable climate necessitated the use of other methods. Consequently, the data were used to calibrate a water-balance model developed by E.P. Weeks (U.S. Geological Survey, written commun., 1980) for estimating a long-term water budget.

Briefly, the model is used to compute, on days with precipitation, a value for daily potential evaporation which in turn is subtracted from the precipitation value. Precipitation in excess of potential evaporation is then assumed to replenish soil-moisture depletion; when the soil-moisture deficit is satisfied, the remaining moisture from precipitation is considered to be recharge. On days without precipitation, or when precipitation is less than the computed daily potential evaporation, the computed "actual" evaporation is subtracted from soil-moisture storage and the deficit increases accordingly. The major problem, then, is in computing a daily "actual" evaporation. An approach reported by Ritchie (1972) is used in the water-balance model for this application.

Estimated actual evaporation from bare soil is calculated in two stages. The first is a constant-rate stage in which evaporation is limited only by the supply of energy to the soil surface (termed the "energy-limiting" stage). The second stage is a falling-rate stage in which evaporation is limited by hydraulic properties of the soil and by climatic conditions (the "soil-limiting" stage). This approach allows evaporation to proceed at the energy-limiting, or potential, rate until the water content of the near-surface soil has decreased below a threshold value, at which time evaporation takes place at the soil-limiting rate.

Potential evaporation in the model is computed by the Jensen-Haise equation (Jensen, 1973, p. 73, 74), which was developed for well-watered crops with full cover in the Western United States; although not strictly applicable to the present situation, the equation is believed to give the best approximation for the available data. Potential evaporation, using the Jensen-Haise equation, is given by

$$E_{TP}=C_T\,(T-T_x)\,R_s, \qquad (1)$$

where

E_{TP}= potential evapotranspiration as defined for alfalfa, in centimeters per day,
C_T= temperature coefficient (see below),
T= mean air temperature, in degrees Celsius,
T_x= intercept of the temperature axis (see below), and
R_s= solar radiation, in calories per square centimeter per day.

The temperature coefficient is given by the equation

$$C_T=\frac{1}{C_1+C_2C_H}, \qquad (2)$$

where

C_1= 38−2(A/305), in degrees Celsius,
A= altitude, in meters above sea level,
C_2= 7.6 °C, and
$C_H=\frac{50 \text{ millibars}}{e_2-e_1}$, in which e_2 is the saturation vapor pressure at mean maximum temperature for the warmest month and e_1 is the saturation vapor pressure at mean minimum temperature for the warmest month, both in millibars.

The temperature-axis intercept is given by

$$T_x=-2.5-[0.14(e_2-e_1)T/P]-A/550, \qquad (3)$$

where

T= temperature, in degrees Celsius, and
P= pressure, in millibars.

Long-term data on daily temperature from the National Weather Service station near Beatty and long-term average solar radiation from Las Vegas (fig. 19), 185 km southeast of Beatty, are used to solve the Jensen-Haise equation. The equation may underestimate potential evaporation from bare soil because it was developed to estimate potential evapotranspiration from an alfalfa reference crop. The leaf canopy of alfalfa is sufficiently dense to absorb most of the solar radiation before it reaches the soil surface. This is not especially critical in the present application because evaporation at the potential rate is considered to occur only on days when there is precipitation, and at Beatty this happens, on average, 20 days/yr. Evaporation on nonprecipitation days is the dominant factor. Use of the term "evaporation" henceforth should be understood to mean actual evaporation.

Estimated evaporation from bare soil on days without precipitation was calculated at the soil-limiting rate, provided the water available for energy-limiting evaporation, assumed to be 1 cm, had been exhausted. Following Black and others (1969), Ritchie (1972) computed the cumulative evaporation since the beginning of soil-limiting, or stage 2, drying with the following equation

$$\Sigma E_{s_2}=Ct^{1/2}, \qquad (4)$$

where

E_{s_2}= evaporation rate from bare soil during stage 2 drying, in centimeters per day,
C= coefficient dependent on climate and the hydraulic properties of the soil, in centimeters, and
t= time since the beginning of stage 2 drying, in days.

Black and others (1969) defined the coefficient C as

$$C=2(\theta_i-\theta_0)(D/\pi)^{1/2}, \qquad (5)$$

where

θ_i= initial water content at time t=0, in centimeters,
θ_0= water content at the surface at $t>0$, in centimeters, and
D= soil-water diffusivity, in square centimeters per day.

Ritchie (1972) assumed that C is independent of climate and is a function of soil hydraulic properties only, but

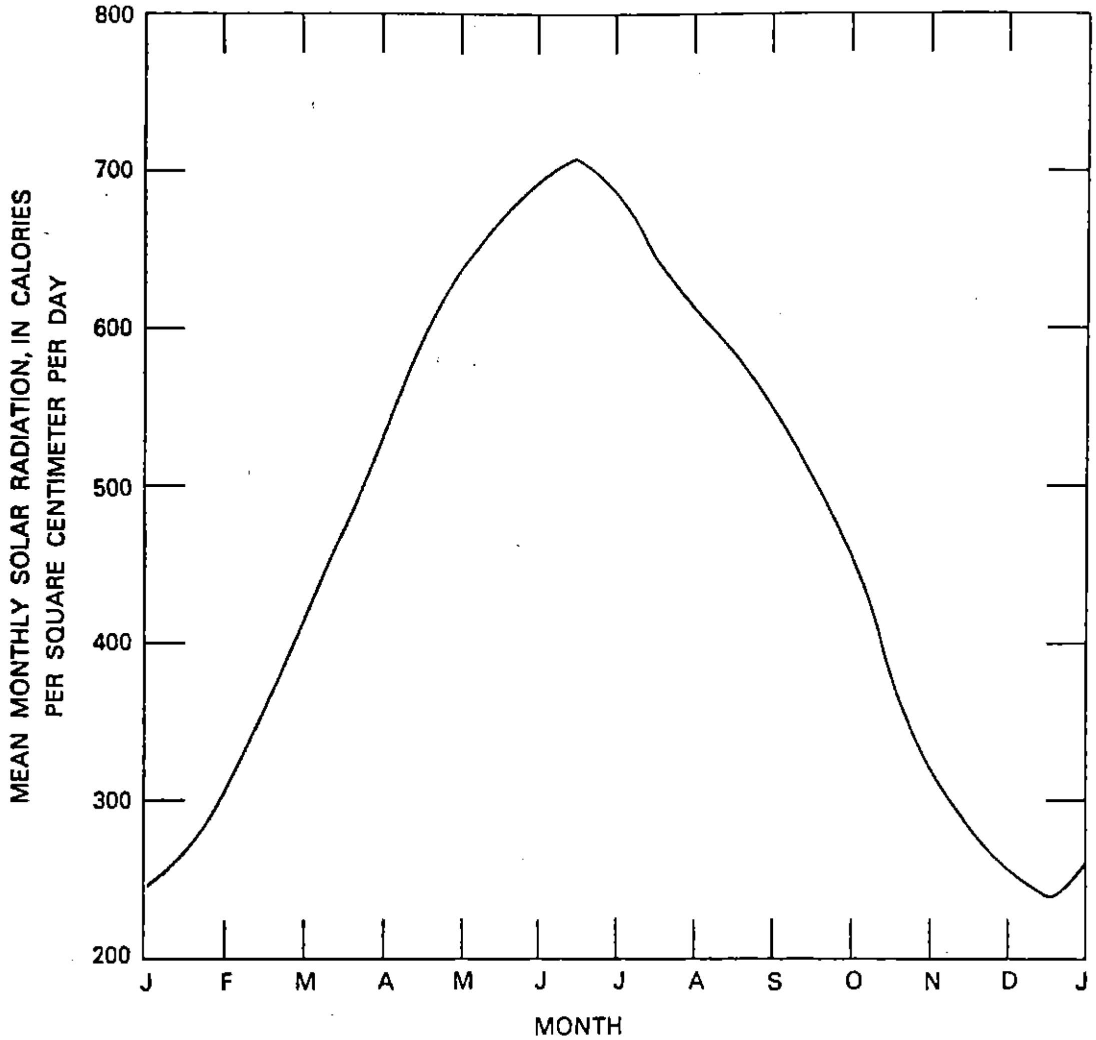

Figure 19. Mean monthly solar radiation at Las Vegas, 1955–75.

Jackson and others (1976) show that *C* also can be correlated with temperature using the normalized temperature dependence of water-vapor diffusion in soil, and thus is a function of climate (represented by temperature) as well as soil properties. Analysis of the parameter *C*, using data collected at the waste-burial site during this investigation, is in accord with the conclusions of Jackson and others (1976), as is shown below.

Data were selected for two time periods to investigate the parameter *C*. The periods July 21 through August 2, 1979, and January 31 through February 13, 1980, were selected for their representation of seasonal extremes. In both periods, rainfall occurred on the first day. The data are given in table 6.

Daily evaporation rates were computed using the energy-balance equation

$$LE = R_n - H - G, \qquad (6)$$

where

LE= the latent heat flux, in calories per square centimeter per day (E=evaporation rate, in centimeters per day, and L=latent heat of vaporization, in calories per gram),

R_n= net radiation,

H= sensible heat flux, and

G= soil-heat flux, all in calories per square centimeter per day.

Rearranging terms (Wilson and Rouse, 1972) so that H is divided by LE, gives

$$LE = (R_n - G)/(1 + H/LE), \qquad (7)$$

where $H/LE = \beta$, which is the Bowen ratio. Both R_n and G can be readily measured, and β can be determined by

$$\beta = \gamma(\Delta T/\Delta e), \qquad (8)$$

Table 6. Meteorological data for waste-burial site during July 21 through August 2, 1979, and January 31 through February 13, 1980

[R_n=net radiant energy of all wavelengths, in calories per square centimeter per day; T_1=air temperature at 1 meter, T_{w1}=wet-bulb temperature at 1 meter, T_2 = air temperature at 0.5 meter, and T_{w2}=wet-bulb temperature at 0.5 meter, all in degrees Celsius; G=soil-heat flux, in calories per square centimeter per day]

Date	R_n	T_1	T_{w1}	T_2	T_{w2}	G
1979[a]						
July 21	313.8	25.3	19.3	25.6	19.5	6.0
22	285.6	28.2	18.0	28.7	18.3	37.8
23	286.2	31.1	17.9	32.2	18.5	48.0
24	258.6	31.3	17.0	32.1	17.0	40.8
25	253.8	32.2	16.9	33.0	17.3	32.4
26	228.6	32.5	15.9	33.4	16.3	27.0
27	221.8	32.3	15.6	33.0	15.9	18.0
31	228.6	30.5	14.4	31.4	14.8	18.6
Aug. 2	208.8	31.6	14.1	32.2	14.4	15.0
1980						
Jan. 31	37.2	6.8	4.0	7.0	3.9	-9.6
Feb. 1	98.4	9.3	5.2	9.4	4.9	21.0
2	79.2	11.4	6.7	11.5	6.7	19.8
3	33.0	11.0	6.8	10.9	6.6	-1.2
4	78.0	12.7	7.0	12.8	6.8	18.6
5	40.8	11.7	6.0	11.8	6.0	7.2
6	67.8	14.0	6.0	13.9	5.9	18.6
7	1.8	9.9	3.6	10.1	3.5	-6.6
8	72.0	10.0	3.0	10.1	3.1	2.4
9	74.4	6.3	0.9	6.2	0.5	4.2
10	57.0	6.0	0.8	6.0	0.3	5.4
11	81.0	6.5	1.0	6.4	0.8	13.8
12	-37.8	5.5	0.5	5.6	0.6	-36.6
13	-96.0	5.5	3.3	5.4	2.5	-15.0

[a] No data available for July 28-30 and August 1.

where

γ= psychrometric constant, in millibars per degree Celsius,

ΔT= difference in air temperature between two vertical measurements at a given time, in degrees Celsius, and

Δe= difference in vapor pressure between two vertical measurements at a given time, in millibars.

The temperature difference, ΔT, between two levels is measured. Δe is calculated from wet-bulb temperature measurements as follows (Wilson and Rouse, 1972):

$$\Delta e=(S'+\gamma)\Delta T_w-\gamma\Delta T \qquad (9)$$

where

S'= slope of the curve for saturation vapor pressure versus wet-bulb temperature at the mean wet-bulb temperature (that is, de_s/dT at $\overline{T}_w$), and

ΔT_w= difference in wet-bulb temperature, in degrees Celsius.

Finally, the evaporation rate, E, is determined by dividing the energy-balance equation by the latent heat of vaporization, L, which leads to

$$E=(R_n-G)/L\rho_w(1+\beta), \qquad (10)$$

where

L= 595.9−0.545T (T=air temperature, in degrees Celsius),

E= evaporation rate, in centimeters per day,

L= latent heat of vaporization, in calories per gram, and

ρ_w= density of water, in gram per cubic centimeter.

Evaporation computed by this equation is given in table 7.

Table 7. Evaporation at waste-burial site during July 21 through August 2, 1979, and January 31 through February 13, 1980
[All values in centimeters]

Date	Evaporation: Bowen-ratio equation	Evaporation: Best fit curve, figures 20 and 21	Cumulative evaporation from best fit curve, figures 22 and 23
1979			
July 21	0.2526	0.2440	0.2440
22	.1808	.1850	.4290
23	.1670	.1600	.5890
24	.1348	.1385	.7275
25	.1232	.1225	.8500
26	.1102	.1085	.9585
27	.0997	.0960	1.0545
28	--	.0860	1.1405
29	--	.0780	1.2185
30	--	.0700	1.2885
31	.0603	.0640	1.3525
Aug. 1	--	.0580	1.4105
2	.0519	.0530	1.4635
1980			
Jan. 31	.1598	.1600	.1600
Feb. 1	.1497	.1420	.3020
2	.0063	.1260	.4280
3	.0442	.1140	.5420
4	.1196	.1020	.6440
5	.1050	.0920	.7360
6	.0839	.0840	.8200
7	.0260	.0720	.8920
8	.0782	.0650	.9570
9	.1034	.0590	1.0160
10	.0865	.0540	1.0700
11	.0977	.0485	1.1185
12	--	.0440	1.1625
13	.0426	.0420	1.2045

Calculated daily evaporation was plotted (figs. 20, 21) and a smooth curve fitted, by eye, to the data points. Revised (or estimated) daily evaporation was obtained from this curve (table 7). Stage 2 evaporation was assumed to have begun on the first day of each of the periods analyzed. In fact, even though rain preceded the period of analysis, stage 1, or energy-limiting, evaporation may not have taken place. The transition from stage 1 to stage 2 evaporation as described by Ritchie (1972) was not observed in the plot of cumulative evaporation as a function of time (figs. 22, 23).

The cumulative evaporation values were then plotted as a function of the square root of time (figs. 24, 25), following the example of Ritchie (1972, fig. 4), and a straight line was fitted to the data; in fitting the line, greatest weight is given to cumulative evaporation values toward the end of the selected time period. The slope of this straight line is equal to C in Ritchie's equation. The value for the June–August period is equal to 0.41 cm, and the value for the January–February period is equal to 0.32 cm. These are well within the range of values for C reported by Ritchie (1972) but higher than the temperature-dependent values suggested by Jackson and others (1976, fig. 2). Jackson and his coworkers (1976) calculated C values for five sets of evaporation data and plotted them as a function of temperature. The data

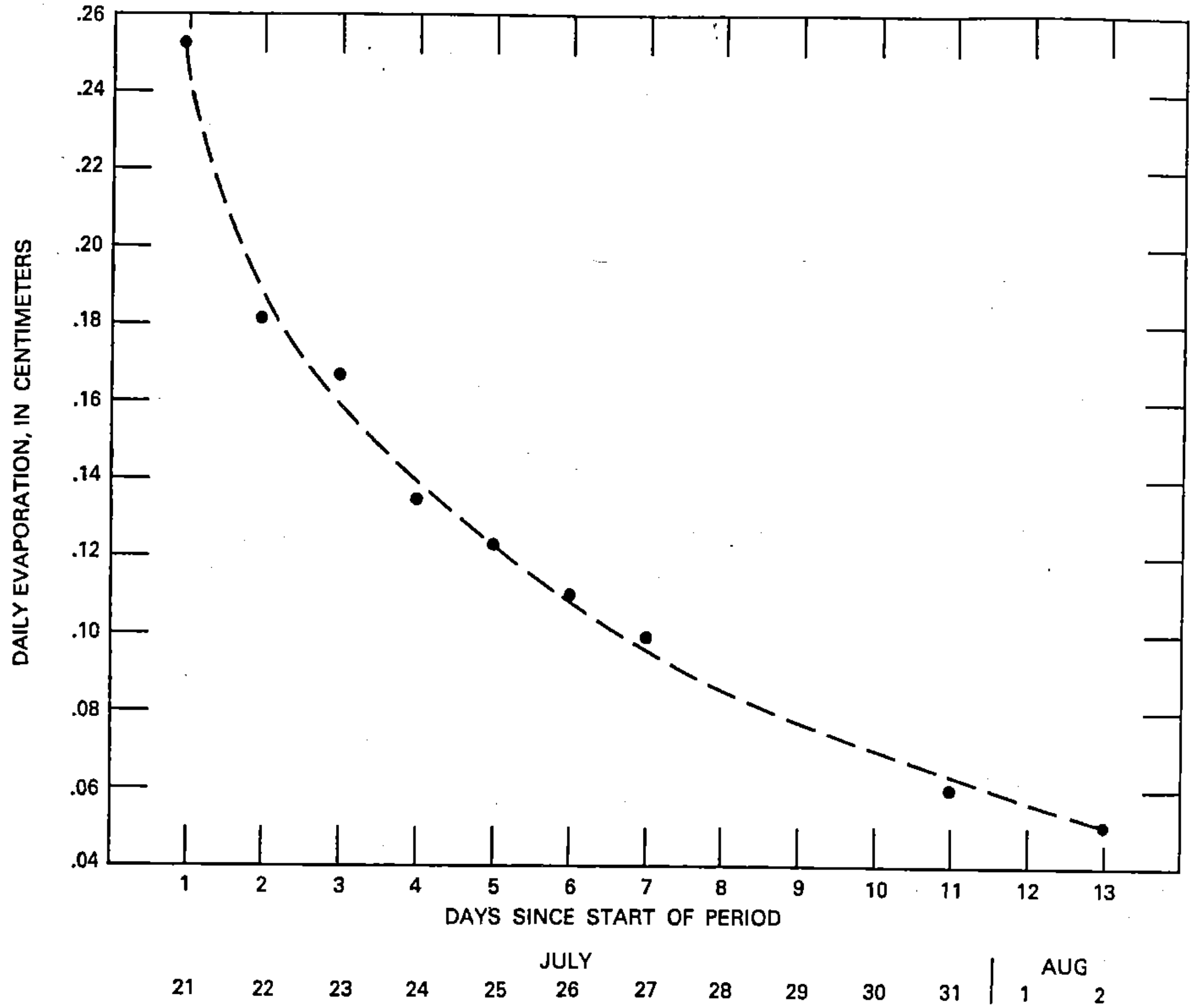

Figure 20. Calculated daily evaporation at waste-burial site, July 21 through August 2, 1979. Dashed line is "visual best fit."

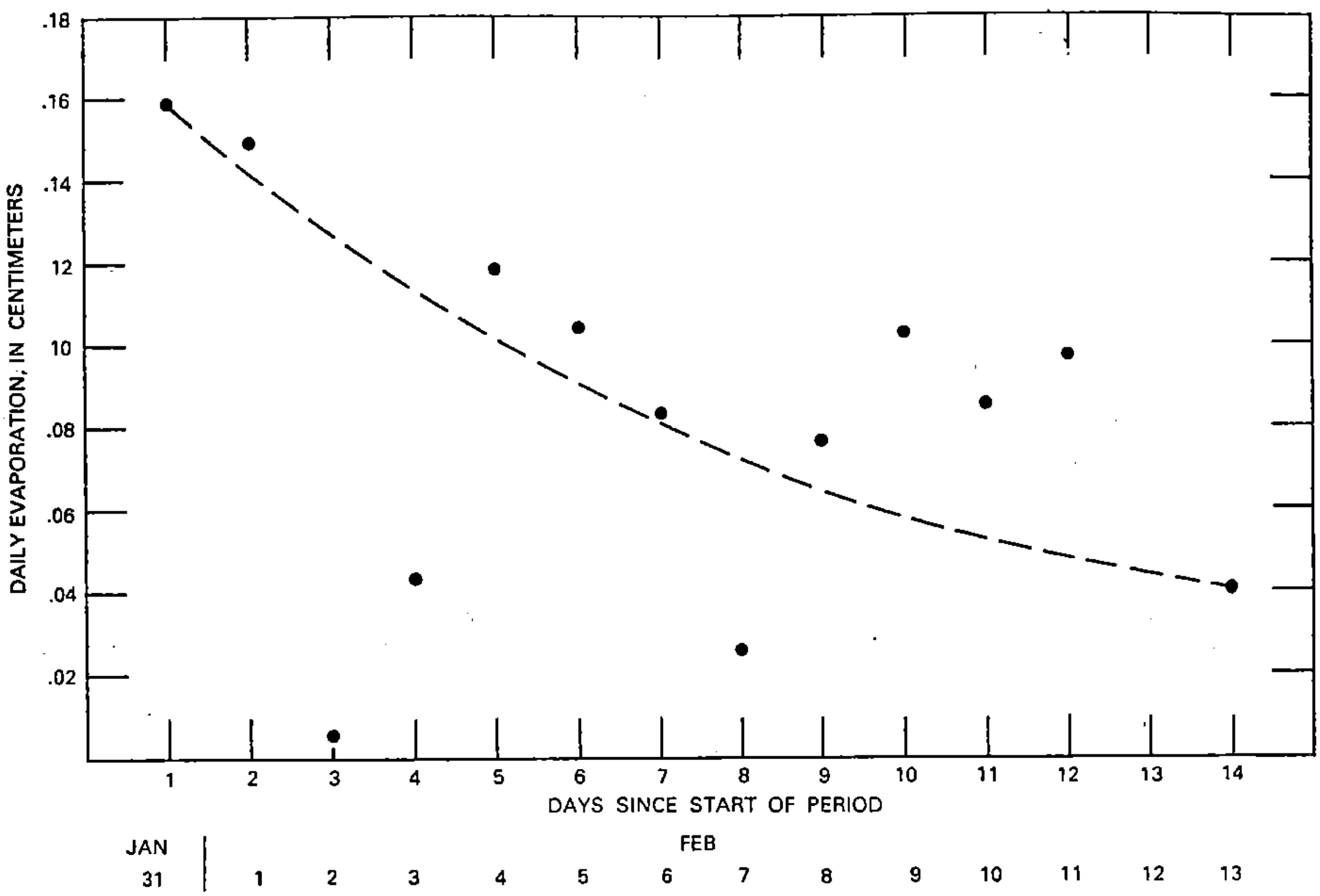

Figure 21. Calculated daily evaporation at waste-burial site, January 31 through February 13, 1980. Dashed line is "visual best fit."

points all fall very close to the curve of the calculated normalized temperature dependence of water-vapor diffusion in soil. This curve is shown in figure 26, and the *C* values calculated from data collected at the waste-burial site are plotted for comparison.

Estimates of Long-Term Evaporation

Long-term evaporation was calculated with the water-balance computer program using several different values for the coefficient *C*. None of the solutions was entirely satisfactory. The program was then modified to allow for the seasonal variation of *C* as a function of mean daily temperature. An equation determined for the curve in figure 26 from Jackson and others (1976) was used initially. The coefficients computed with this equation-calculated too little evaporation and a maximum soil-moisture deficit that was considered too small on the basis of available soil-moisture field data. A new equation was obtained by an upward shift of the curve of Jackson and others (1976) toward the range of *C* values obtained from field data at the waste-burial site. This curve is shown by the dashed line in figure 26.

The water-balance model, like the procedures of Ritchie (1972) and Jackson and others (1976), has been tested only for agricultural conditions and has not been applied to an arid area such as the Amargosa Desert. In this investigation, the model is not used to calculate a precise annual evaporation and water budget for the area, but rather to screen the available climatic data for the area since 1961 for potential recharge events. By varying the value of *C* and the threshold soil-moisture deficit within reasonable limits, the precipitation events that might lead to recharge can be identified and their possible significance with respect to potential radionuclide migration can be assessed.

Table 8 gives the computed annual evaporation for three different values of *C*. The "low" estimate of evaporation is for the low values of *C* from Jackson and others (1976), as indicated by the solid line in figure 26. The "high" and "intermediate" estimates of evaporation are for the high and intermediate values of *C* based on the dotted and dashed curves, respectively, in figure 26. The *C* values obtained from data collected at the waste-burial site are closer to the curve used in obtaining the high estimates. The major difference between the high and intermediate estimates is in the evaporation calculated for 1968 and 1976.

Implications Regarding Recharge

The analysis suggests that recharge could have occurred in February 1968, March 1973, and February 1976. The 1968 event seems to have been the result of two factors: (1) above-average and frequent rainfall in 1967 and (2) a heavy storm in February 1968. The pattern and magnitude of precipitation in 1967 (table 9) kept soil-moisture depletion at a moderate level throughout 1967 and into early 1968, so that when intense rain (5.46 cm at Beatty) fell on February 9 and 10, 1968, a great potential existed for deep percolation. The computed potential recharge in 1968 was about 2.2 cm.

A different sequence of events in 1972 and 1973 led to computed potential recharge in March 1973. Very little rain fell throughout 1972, resulting in a fairly significant soil-moisture deficit by year's end. However, a series of storms, which produced an estimated 2.2 cm of rain in January, 4.6 cm in February, and 4.5 cm in March 1973, resulted in a computed potential recharge of 0.5 cm.

Conditions in 1975–76 leading to potential recharge were similar to those for 1967–68. Moderate rains during the last 4 mo of 1975 held the soil-moisture deficit to an intermediate level. Then, a series of storms extending from February 6 through February 10 produced an estimated 7.5 cm of rain, including 3.2 cm on February 7. These rains were enough to satisfy the soil-moisture deficit and still provide a computed potential recharge of about 2.6 cm.

These calculations of long-term evaporation and recharge, though only estimates, strongly suggest that the potential for recharge, or deep percolation, exists in the area of the waste-burial facility. The calculations also define the types of events and conditions that might eventually lead to deep percolation. Obviously, such a simplistic approach does not accurately simulate the interrelation of precipitation, evaporation, infiltration, and deep percolation, but it does provide a reasonable qualitative framework for further theoretical studies. Note, however, that if vegetation is present, recharge is unlikely. Filled and decommissioned waste-burial sites commonly are landscaped with native or other vegetation that, under the conditions at the site near Beatty, would provide a major buffer to deep percolation.

Water Content and Soil-Moisture Profiles

Detailed field investigations of soil-moisture content and soil-water potential were made at the site from 1978 to 1980. These studies concentrated on the upper 4 to 10 m of the undisturbed stratigraphic sequence. Similar studies on a disturbed sequence of material representative of trench backfill were not made because of the lack of a suitable site.

The shallow subsurface stratigraphy is relatively uniform beneath the area covered by the waste-burial site. Briefly, a thin gravel pavement on the ground surface is underlain by a very fine silty sand that extends from land surface to a depth of about 0.75 m. This is underlain by a coarse sandy gravel, with cobbles, from 0.75 m to about 2.5 m, which is in turn underlain by a dense, poorly

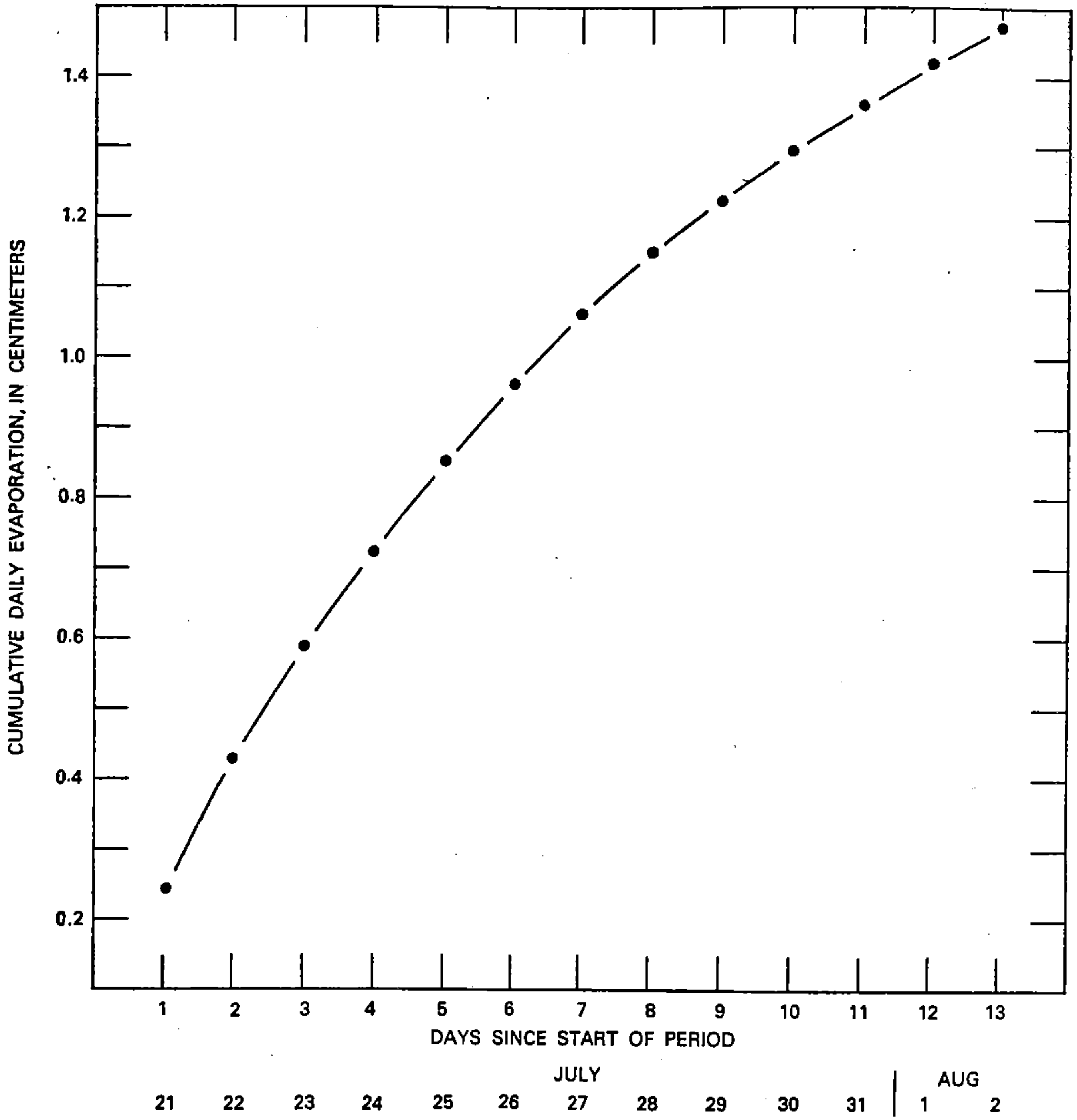

Figure 22. Cumulative daily evaporation at waste-burial site, July 21 through August 2, 1979.

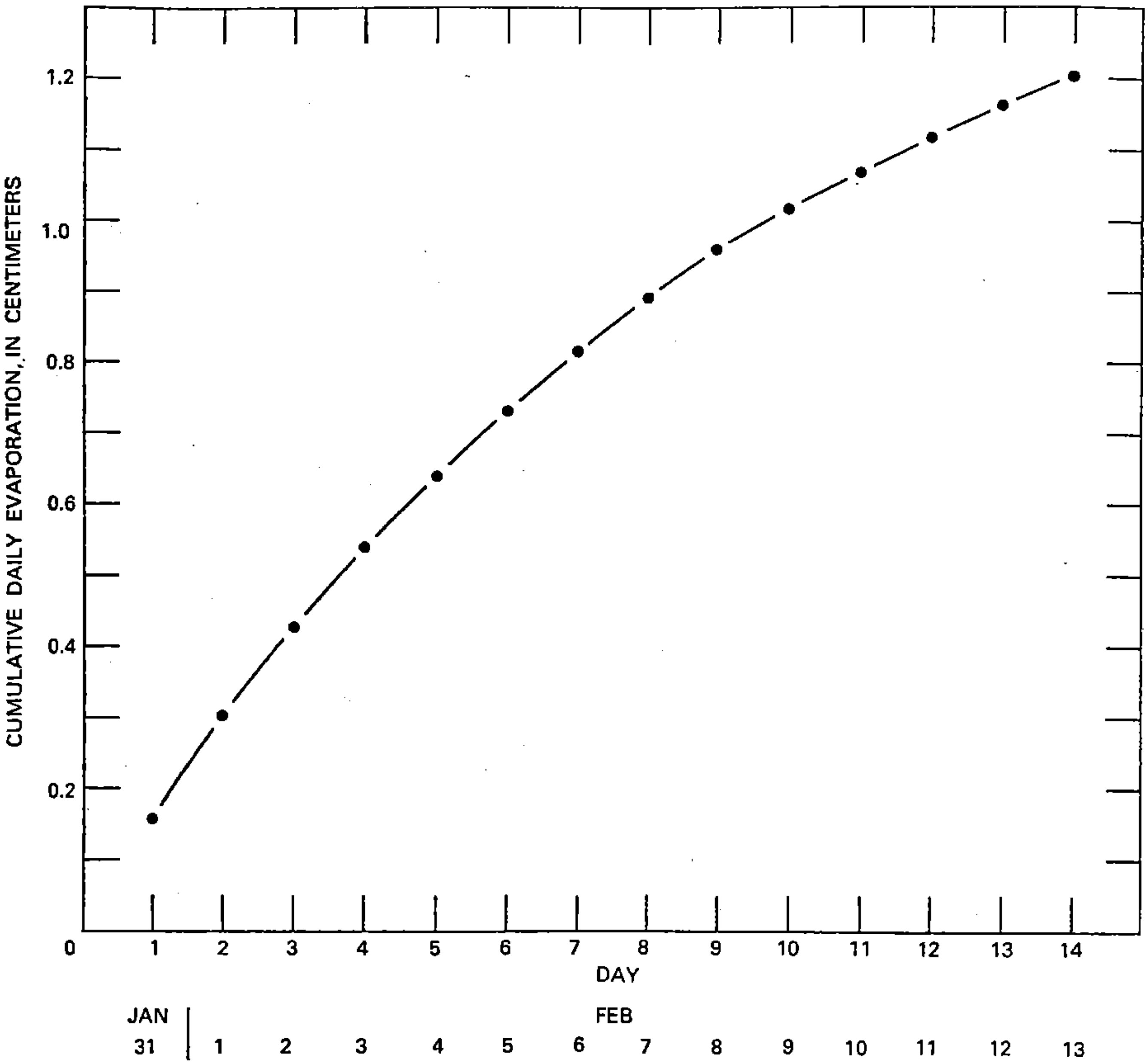

Figure 23. Cumulative daily evaporation at waste-burial site, January 31 through February 13, 1980.

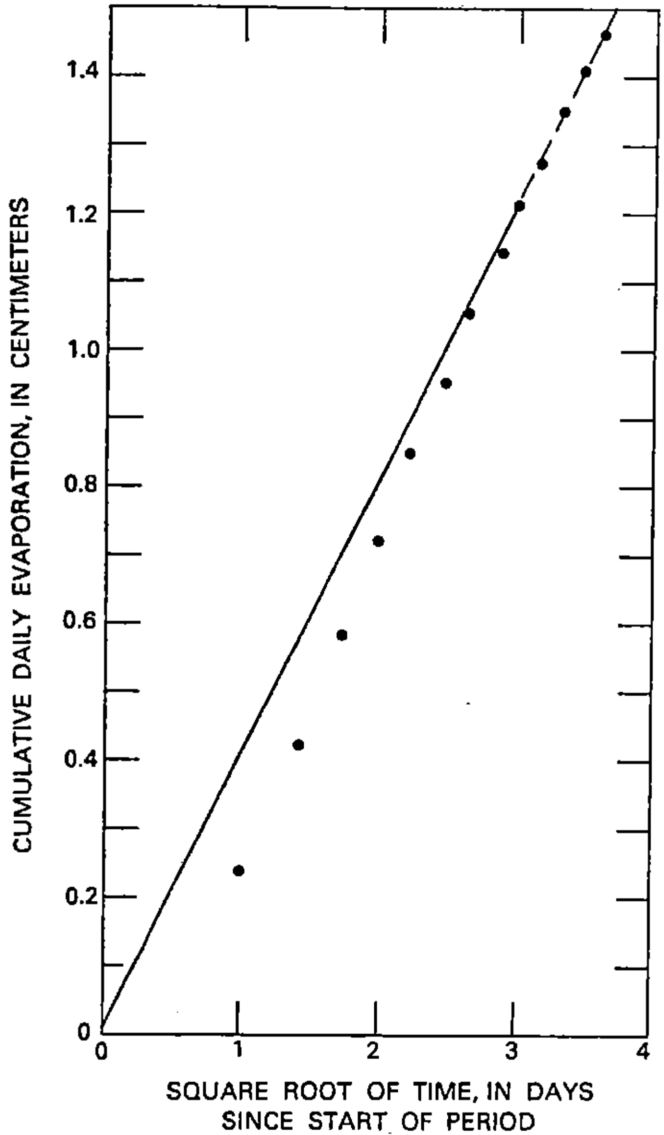

Figure 24. Cumulative daily evaporation versus square root of time, in days since start of period, July 21 through August 2, 1979.

cemented sand to silty sand, with some gravel, cobbles, and a few boulders, from 2.5 m to about 10 m. The stratigraphy below this depth is uncertain, but observations in one trench excavated to 15 m indicate a 1-m-thick layer of coarse sandy gravel, similar to that seen from 0.75 to 2.5 m, underlain by the same type of sediments seen in the interval from 2.5 to 10 m. This sequence is shown diagrammatically in figure 27.

Volumetric water content has been determined for core samples collected to depths of 11 m (table 10), and neutron soil-moisture profiles have been obtained to depths of 3.8 m (fig. 28). Water content to a depth of 0.5 m ranged from 4.5 percent, following lengthy dry spells, to 18 percent after heavy winter rains. The water content of the sediments below 0.5 m is fairly constant, ranging from about 6 to 10 percent. There was no change observed in water content of sediments below 2 m from February 1979 to May 1980.

Cores were collected during the drilling of a deep instrumentation shaft and neutron access holes. The cores were used to determine volumetric water content, using standard oven-drying techniques, to obtain general information on moisture content, and to calibrate the neutron moisture-meter (Troxler, model 104A[2]) used in obtaining moisture profiles. Water content of the samples is given in table 10.

Thin-walled aluminum access tubes for the neutron probe were installed to a depth of 10 m in August 1977. Attempts to obtain moisture-profile logs from these holes

[2] The use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

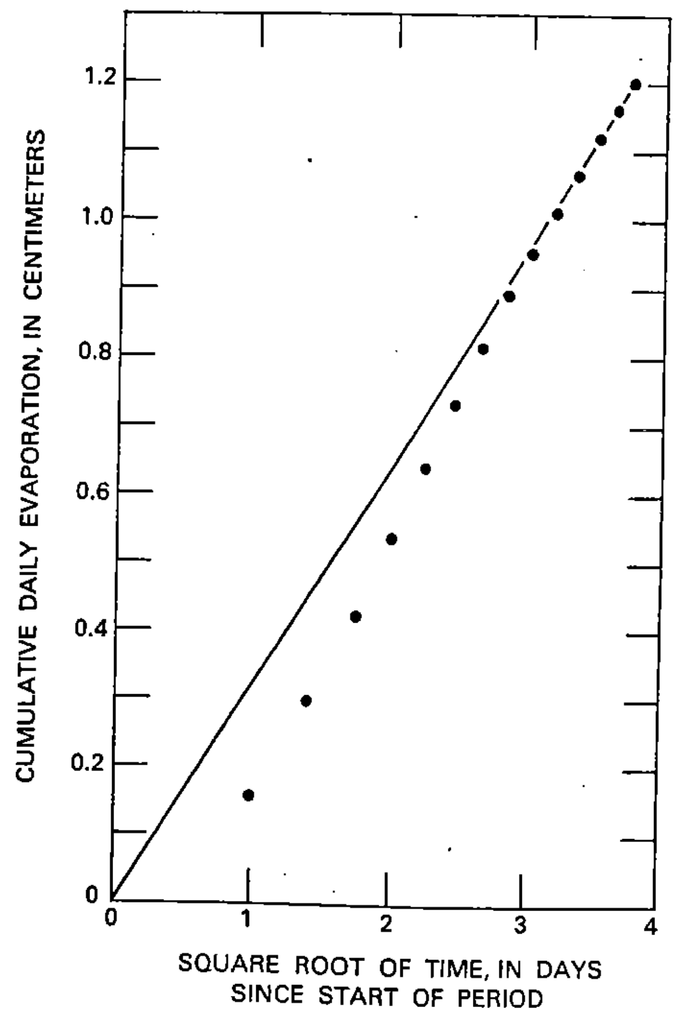

Figure 25. Cumulative daily evaporation versus square root of time, in days since start of period, January 31 through February 13, 1980.

in February 1978 disclosed that all three tubes had been damaged during installation. Replacement tubes to a depth of 3.5 m were installed in January 1979. Profiles were obtained on a nearly monthly schedule until May 1980. Selected profiles are shown in figure 28.

Comparison of the profiles for February 27, 1979, and February 26, 1980 (fig. 28*D*), indicate a downward redistribution of moisture to a depth of about 2 m—nearly to the base of the coarse sandy gravel layer (fig. 27). The change in moisture content between 0.9 and 2.4 m is equivalent to about 0.9 cm of water and represents a total change in water content of 7.9 percent. Examination of several pairs of moisture-content profiles for shorter time periods (not shown) indicates that most of the downward redistribution had occurred by May 1979 (fig. 28*A*) and that the greatest change took place between April 12 and May 23. Additional downward movement took place between May 23, 1979, and February 26, 1980 (fig. 28*B*). However, between February 26 and May 28, 1980, the moisture profile changed little if any below 0.6 m (fig. 28*C*), the approximate depth to the top of the coarse sandy gravel layer. No change of water content below 2.4 m was observed from February 1979 to May 1980.

Considered in the light of the precipitation record from January 1979 to May 1980 (R.G. Brown,

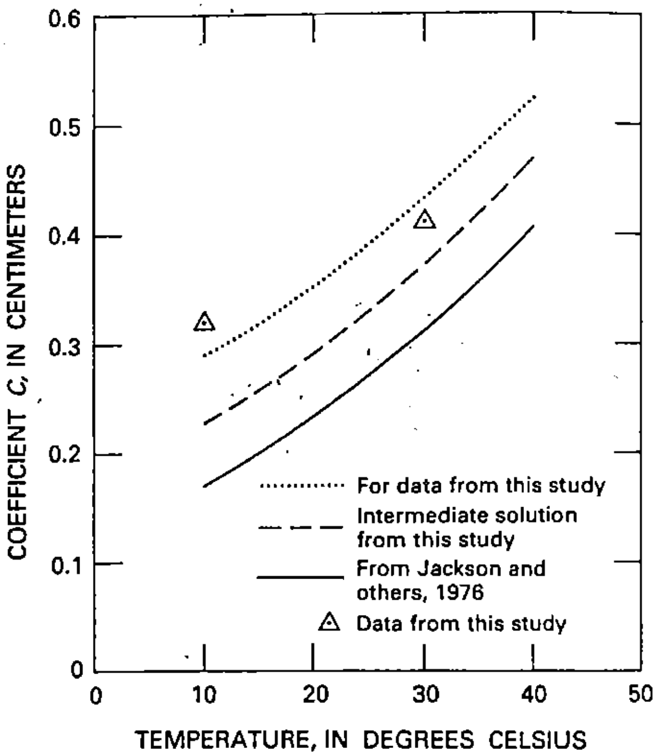

Figure 26. Temperature dependence of the coefficient *C*.

Table 8. Estimates of annual evaporation and potential annual recharge at waste-burial site for three ranges of the coefficient *C* (fig. 26)
[All values in centimeters]

Year	Annual precip-itation	Low			Intermediate			High		
		Annual evaporation	Annual recharge	SMD[1]	Annual evaporation	Annual recharge	SMD[1]	Annual evaporation	Annual recharge	SMD[1]
1961	6.91	8.86	1.17	4.19	8.19	0.00	4.83	6.68	0.00	4.77
1962	6.07	7.11	.00	5.23	8.20	.00	6.96	8.26	.00	6.96
1963	12.24	9.94	.00	2.93	9.77	.00	4.49	10.16	.00	4.87
1964	3.05	5.37	.00	5.25	5.05	.00	6.95	5.47	.00	7.30
1965	13.39	9.40	.00	1.26	9.23	.00	2.79	10.43	.00	4.34
1966	7.21	6.97	.54	1.56	6.86	.00	2.43	7.15	.00	4.28
1967	11.10	12.57	.00	3.02	11.27	.00	2.60	12.97	.00	6.15
1968	11.30	10.54	1.79	4.05	11.77	2.18	5.26	10.36	.00	5.20
1969	14.53	11.84	1.56	2.92	13.17	.00	3.89	13.97	.00	4.65
1970	6.71	7.85	.07	4.14	6.61	.00	3.08	5.80	.00	3.37
1971	2.24	1.45	.00	3.35	2.32	.00	3.89	2.25	.00	3.74
1972	.61	2.79	.00	5.53	2.06	.00	5.34	2.88	.00	6.01
1973	16.33	13.66	.78	3.65	15.26	.50	4.77	15.90	0.40	5.98
1974	12.60	11.15	.30	2.50	12.12	.00	4.29	12.74	.00	6.12
1975	9.37	7.90	.00	1.02	8.63	.00	3.55	9.00	.00	5.74
1976	18.75	14.71	5.23	2.21	16.26	2.57	3.64	17.70	.29	4.99

[1] SMD = Soil-moisture deficit at end of calendar year.

Table 9. Estimated monthly precipitation for selected years at waste-burial site
[All values in centimeters]

Month	1967	1968	1972	1973	1975	1976
January	0.89	0.00	0.00	2.21	0.00	0.00
February	.00	6.27	.00	4.65	.20	7.54
March	.00	.91	.00	4.55	1.32	.00
April	2.41	.86	.00	.00	.56	.84
May	1.37	.00	.00	1.47	.03	.05
June	.74	1.80	.00	.36	.00	.58
July	.00	.56	.00	.00	.20	3.68
August	1.83	.13	.38	.86	.00	.00
September	1.24	.00	.00	.00	5.54	4.42
October	.00	.63	.00	1.04	.43	1.60
November	2.62	.00	.23	.89	.58	.03
December	.00	.13	.00	.30	.51	.00

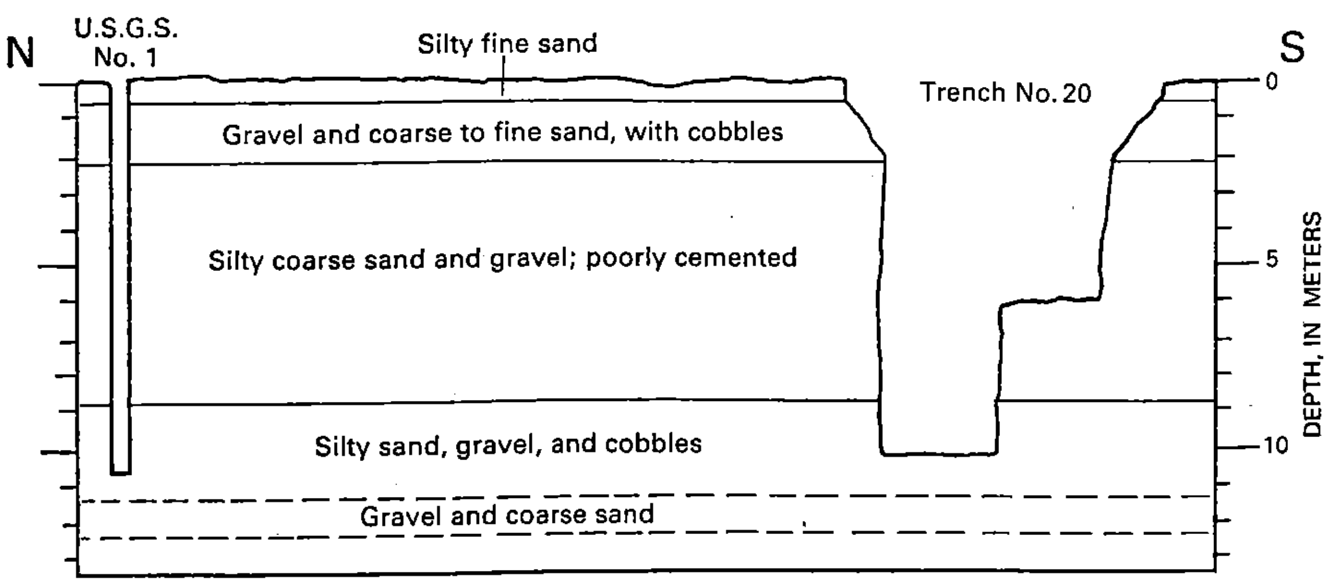

Figure 27. Diagrammatic geologic section of shallow unconsolidated deposits at waste-burial site. Vertical exaggeration=7×.

U.S. Geological Survey, written commun., 1985), the deep percolation that had occurred by May 1979 resulted from the following sequence of events: precipitation in January 1979 restored much of the antecedent soil-moisture deficit, so that the heavier rainfall of late March, which exceeded the seasonal evaporation demands, produced percolation below 0.6 m. Enough moisture was available from these rains to permit downward movement from the fine-grained near-surface sediments into the coarser sediments below 0.6 m. Additional downward redistribution continued from May 1979 to February 1980.

The results of soil-moisture studies made at the waste-burial site support the conclusions of the long-term evaporation studies, namely that given the correct circumstances of precipitation occurrence, evaporation demands, and soil-moisture deficit, deep percolation can take place. The sequence of events leading to the observed deep percolation is not unlike that postulated from long-term evaporation modeling. Precipitation in 1978 was 26.34 cm at Beatty and 23.35 cm at the waste-burial site, more than twice the long-term annual average. This was followed by a significant storm in January 1979 (4.62 cm) and several significant storms in late March 1979 (2.52 cm). The net result was that the March precipitation provided enough moisture to allow downward percolation during the succeeding months.

Soil-Water Potential

Attempts were made during the investigation to obtain in-place measurements of soil-water potential using thermocouple psychrometry. A vertical shaft, 1.5 m in diameter and 10 m deep, was drilled and cased with steel pipe. Windows measuring about 20 by 40 cm were cut into the casing at 1-m intervals to provide access to sediments along the shaft sidewall. The shallowest window was cut at 3 m because slumping and collapse of the upper 2.5 m during drilling of the shaft caused too much ground disturbance to permit collection of reliable data for undisturbed conditions.

The theoretical basis for the psychrometric measurement of soil-water potential has been discussed by Rawlins (1966, 1972) and by Van Haveren and Brown (1972). The measurement of soil-water potential in soil samples in the laboratory using psychrometers has been discussed by Campbell and Wilson (1972), and their field use in a desert environment has been described by Moore and Caldwell (1972). Porous-cup thermocouple psychrometers used during this study were implanted in the sidewall of the 10-m shaft. An access hole 1.3 cm in diameter was drilled horizontally into the sidewall sediments a distance of 45 to 50 cm. Once the psychrometer was emplaced, the access hole was backfilled. Drilling

Table 10. Volumetric water content of core samples from waste-burial site[1]
[Moisture contents in percent; "--" indicates lack of data]

Boring number	Depth, in meters														
	1.0	1.2	1.5	2.0	2.4	2.7	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0
1	--	--	--	7.3	--	--	7.1	7.9	7.9	8.8	6.6	4.9	5.4	8.5	7.6
2	--	--	--	9.7	--	--	7.3	8.2	6.5	7.9	9.4	6.0	--	9.0	--
3	4.1	--	--	--	--	--	8.4	--	--	--	9.4	--	--	--	--
4	--	--	--	7.8	--	--	--	6.6	--	8.9	--	5.1	--	--	--
4A	--	--	6.3	--	--	10.7	11.6	8.3	9.0	--	--	--	--	--	--
5	--	--	6.7	--	--	7.7	8.5	8.2	7.0	--	--	--	--	--	--
6	--	--	5.9	--	--	--	9.5	9.1	--	--	--	--	--	--	--
7	--	7.6	--	--	7.6	--	9.7	--	--	--	--	--	--	--	--
B1	--	--	8.0	--	--	--	9.3	--	6.1	3.9	--	--	--	--	--
B2	--	--	6.7	--	--	--	7.1	--	5.7	4.8	--	--	4.6	--	--
B3	--	--	--	--	--	--	6.9	--	--	7.2	--	--	--	--	--
Average	4.1	7.6	6.7	8.2	7.6	9.2	8.5	8.0	7.0	6.9	8.4	5.3	5.0	8.7	7.6

[1] Measurements made by W. D. Nichols and D. H. Schaefer.

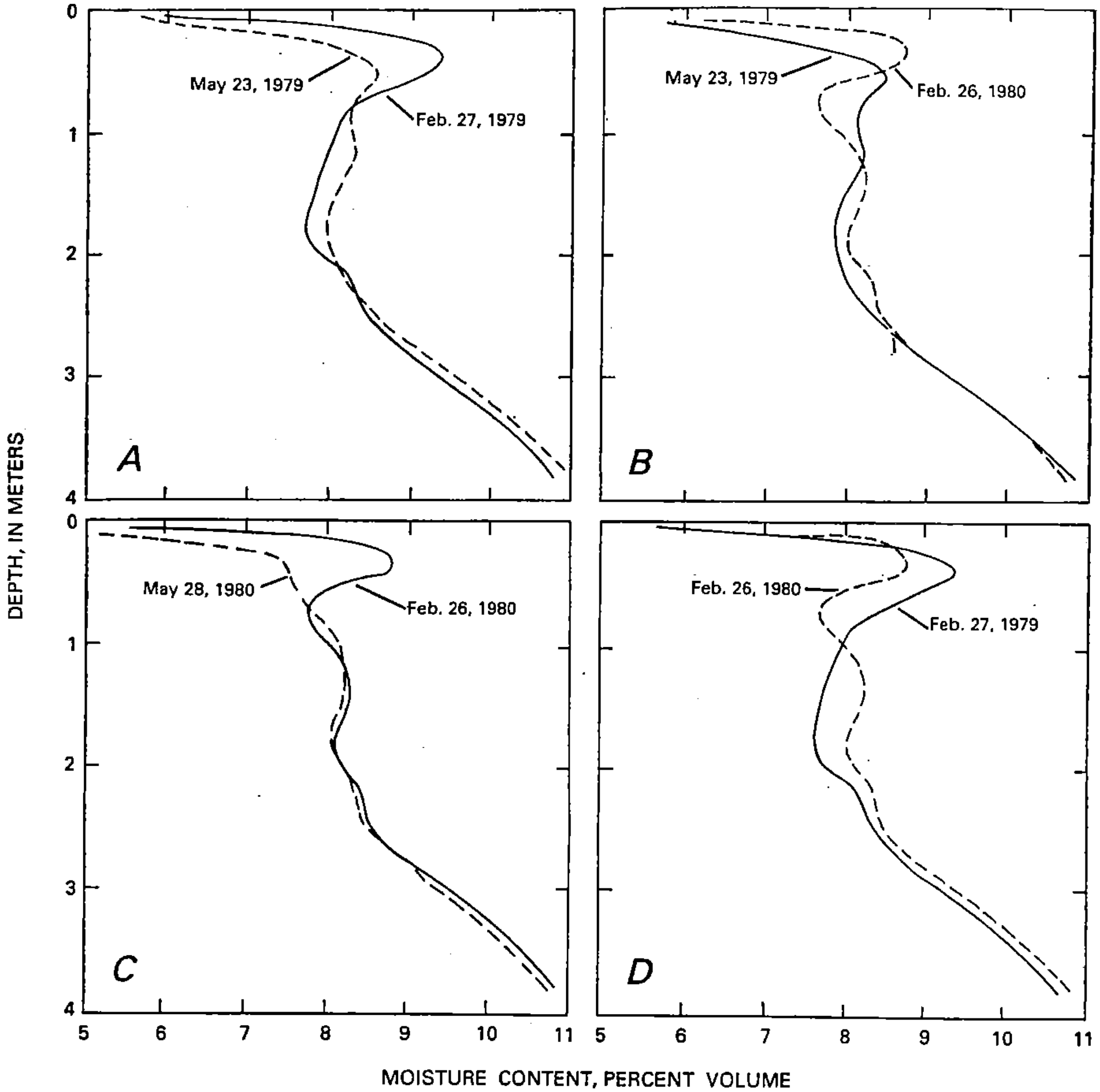

Figure 28. Comparative soil-moisture profiles, showing net changes in moisture content between the following dates: (*A*) February 27 and May 23, 1979; (*B*) May 23, 1979, and February 26, 1980; (*C*) February 26 and May 28, 1980; and (*D*) February 27, 1979, and February 26, 1980.

farther than about 50 cm was difficult because of the large gravel (diameters as great as 3 cm) commonly encountered at all locations. In fact, psychrometers could not be emplaced at depths of 8 and 9 m because of the coarseness and unstable character of the materials there.

The most reliable data were obtained from the psychrometers at 3, 6, and 10 m. Plots of these data are shown in figure 29. Cyclical fluctuations are indicated at depths of 6 and 10 m. The soil-water potential at 6 m also exhibits a trend of decreasing potential during the period of measurement, whereas at 10 m an increase is suggested. The soil-water potential at 3 m shows a slight increase over the period of measurement but does not exhibit a clear pattern of cyclical fluctuations.

Of particular interest is the magnitude of soil-water potential at all three depths. The soil-water potential generally was in the range of −40 to −60 bars, except for late 1979 to early 1980 at the 10-m depth, when the soil-water potential was in the range of −10 to −15 bars. Even this decrease in soil-water potential does not imply any significant change in moisture conditions. A change in soil-water potential from −50 to −15 bars can occur with an increase in volumetric water content of less than 1 percent, and probably less than 0.5 percent.

Hydraulic Properties of Sedimentary Deposits

Determination of the hydraulic properties—specifically the unsaturated conductivity—of sedimentary materials such as those at the waste-burial site was difficult, and the results are questionable. The very coarse deposits encountered make sample collection difficult and nearly preclude collection of representative samples. Laboratory methods and instrumentation for determining unsaturated conductivity versus water content or unsaturated conductivity versus matric potential, particularly in the range of very low moisture content and at potentials more negative than −5 bars, generally have not been applied to such coarse heterogeneous materials. Nevertheless, an attempt was made to determine the relationship among matric potential, water content, and unsaturated conductivity for the three major stratigraphic units found at the waste-burial site (that is, the very fine silty sand from 0.0 to 0.75 m, the coarse sandy gravel and some cobbles from 0.75 to about 2.5 m, and the dense silty sand with some gravel and cobbles below 2.5 m.

Undisturbed core samples were collected at 0.15, 4.0, and 9.0 m, and disturbed bulk samples were collected at 1.0 and 2.75 m. Two cores were collected at each of the cored sample depths, but the materials from each of the two cores (except at 9.0 m) were combined to provide sufficient quantities for analysis. Analyses could not be accomplished on whole samples because of the presence of gravel (table 11). The method of Mehuys and others (1975) was used to determine the hydraulic properties for the fraction of the sample smaller than 2 millimeters (mm) in diameter and then corrected to a "whole-soil" basis. The analyses were made by Gaylon S. Campbell of Washington State University, and the following discussion is based largely on his report (written commun., 1980).

An approximate moisture-release curve was determined for each soil depth sampled. Emphasis was given to the very dry end of the curve because hydraulic properties in the range of −20 to −50 bars are most closely related to conditions at the waste-burial site. Multiple samples for a single depth were combined for these measurements because of the difficult and time-consuming nature of the technique. The total soil-water potential of each composite sample was measured using a thermocouple psychrometer (Campbell and others, 1966). Water content

Table 11. Mass of grain-size fractions greater than and less than 2 mm for soil samples from waste-burial site

[Data from Gaylon S. Campbell, Washington State University, written commun., 1980]

Depth (meters)	Sample number	Fraction >2 mm (grams)	Fraction <2 mm (grams)	Percentage >2 mm[1]
0.15	1	10.5	106.8	9
.15	2	1.3	96.3	1
1.0	1	2,087	2,393	47
1.0	2	2,616	1,757	60
2.75	1	2,572	1,096	70
2.75	2	1,814	1,298	58
4.0	1	56.9	58.2	49
4.0	2	25.1	74.3	25
9.0	1	269.7	343.3	56

[1] Calculated as follows: 100(>2 mm)/[(>2 mm)+(<2 mm)].

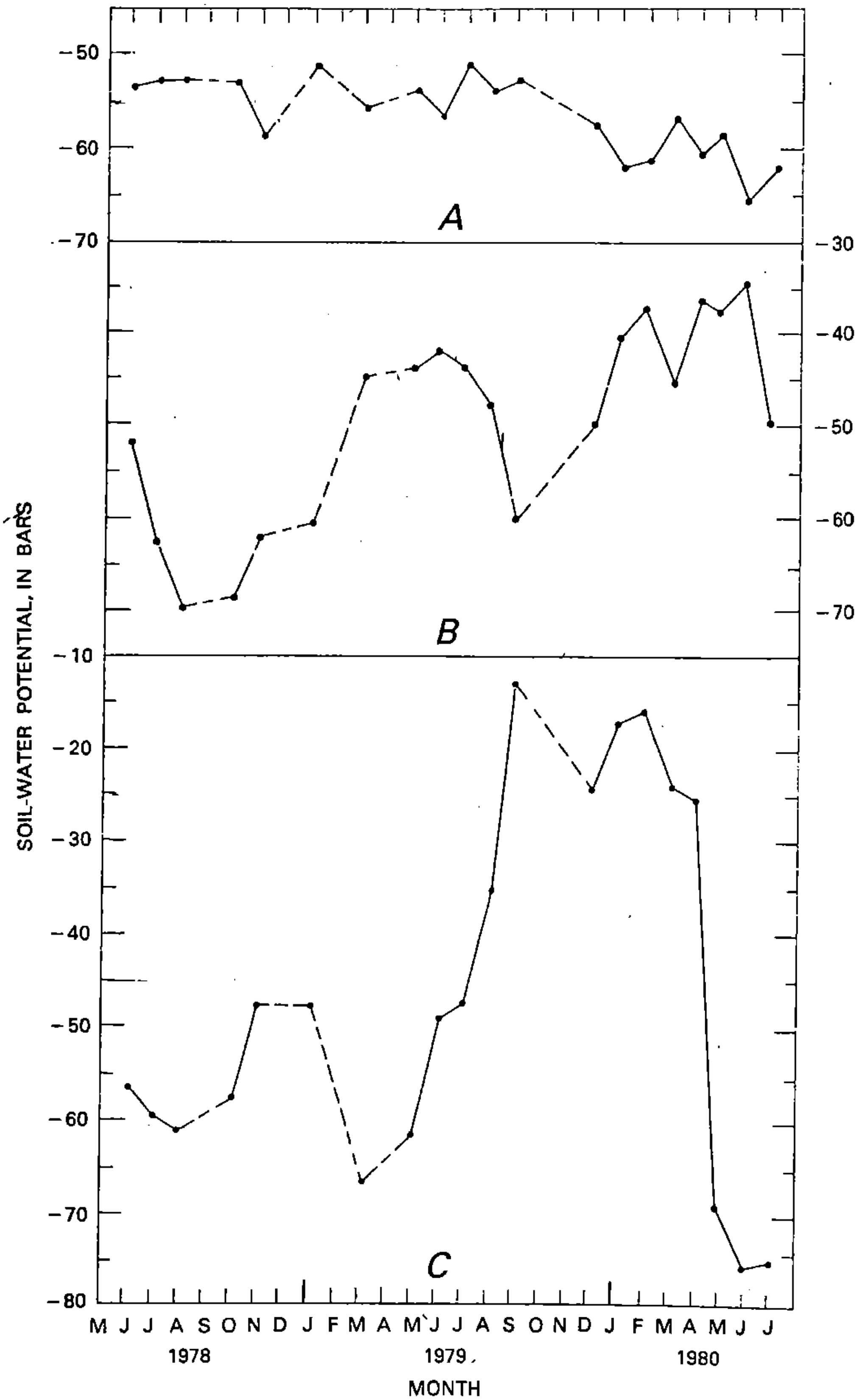

Figure 29. Measurements of soil-water potential, May 1978 to June 1980, for depths of (*A*) 3, (*B*) 6, and (*C*) 10 m. Data points more than 1 mo apart are connected by dashed line.

Table 12. Laboratory-measured moisture characteristics of soil samples from waste-burial site[1]

[cm, centimeters. Data from Gaylon S. Campbell, Washington State University, written commun., 1980]

Depth (meters)	W_1	h_1 (cm) [see footnote 2]	W_2	h_2 (cm) [see footnote 2]	Osmotic water potential at saturation (cm)
0.15	0.030	41.6×10^3	0.065	0.8×10^3	0.3×10^3
1.0	.032	35.9×10^3	.053	3.6×10^3	1.3×10^3
2.75	.030	48.0×10^3	.049	3.9×10^3	$.8 \times 10^3$
4.0	.079	9.1×10^3	.143	1.3×10^3	1.6×10^3
9.0	.075	24.3×10^3	.117	1.3×10^3	—

[1] W_1 and W_2 indicate gravimetric water content of size fraction less than 2 millimeters at potentials h_1 and h_2.

[2] All potentials are negative.

was determined gravimetrically by drying for 24 hr at 105 °C. Initial measurements indicated that salts were present in the samples in sufficient concentration to affect measurements of matric potential at low water content, so the samples were leached with distilled water before the final measurements were made. Electrical conductivity of the leachate from each sample was measured to provide an estimate of the osmotic component of the soil-water potential. Table 12 gives the results of water-content and water-potential measurements made on the sample fraction smaller than 2 mm in diameter.

The data given in table 12 were used to find the constants a and b for the following equation (Hillel, 1971, p. 63):

$$h = aW^{-b}, \tag{11}$$

where h is the matric potential, in centimeters of water, and W is the gravimetric water content, in grams per gram (g/g), at the given potential. These constants computed for the less-than 2-mm fraction, together with the corrected value of the constant a for the "whole soil," are given in table 13. Values of air-entry potential were calculated for each sample. By assuming that the bulk density of the less-than-2-mm fraction was about 1.2 grams per cubic centimeter (g/cm³), a value of saturated water content (for the <2 mm fraction) of 0.42 g/g was determined. Combining the following equation (Campbell, 1974):

$$h = h_e(W/W_s)^{-b}, \tag{12}$$

where

h_e= air-entry potential, in centimeters,
h= matric potential, in centimeters,
W= water content at h, in grams per gram,
W_s= saturation water content, in grams per gram, and
b= constant,

with equation 11, we obtain

$$h_e = aW_s^{-b}, \tag{13}$$

from which the air-entry potential is obtained. The values of air-entry potential used are not the actual values that would be observed for the whole-soil sample; instead, they represent extrapolated values for the finer-than-2-mm fraction. Similarly, the whole-soil values for saturation water content do not represent the actual saturation water content of these gravelly soils. Values of h_e and W_s are given in table 13.

Unsaturated hydraulic conductivity at a given water content or at a known matric potential can be determined from the following equations (Campbell, 1974):

$$k = k_s\,(W/W_s)^m \tag{14}$$

and

$$k = k_s\,(h_e/h)^n, \tag{15}$$

where

k= unsaturated hydraulic conductivity and
k_s= saturated hydraulic conductivity, both in centimeters per day,
n= 2+3/b, and
m= 2b+3.

Both equations require that the saturated hydraulic conductivity be known. It can be measured in a conventional

Table 13. Calculated moisture-characteristic parameters for soil samples from waste-burial site[1]

[mm, millimeters; cm, centimeters; g/g, gram per gram. Data from Gaylon S. Campbell, Washington State University, written commun., 1980]

	a (centimeters)				
Depth (meters)	Fraction <2 mm [see footnote 2]	Whole sample [see footnotes 2, 3]	b	h_e (cm) [see footnote 2]	W_s for whole sample (g/g) [see footnote 4]
0.15	6.9×10^{-4}	5×10^{-4}	5.1	0.06	0.40
1.0	5.5×10^{-3}	2×10^{-4}	4.6	.3	.19
2.75	7.8×10^{-4}	4×10^{-6}	5.1	.07	.15
4.0	2.2	5×10^{-1}	3.3	38	.26
9.0	9.5×10^{-4}	4×10^{-6}	6.6	.3	.18

[1]Symbols: a and b, constants in equation $h = aW^{-b}$; h_e, air-entry potential; W_s, gravimetric water content at saturation.

[2]All values are negative.

[3]Calculated as follows: a(whole sample) = a(<2 mm fraction) x $(1-WR)^b$, where WR is the mass ratio of stones to total sample.

[4]Calculated as follows: W_s (<2mm fraction) x $(1-WR)$, where WR is as defined in footnote 3.

manner or can be calculated by measuring the rate of advance of a wetting front in the dry soil. Bresler and others (1978) have shown that

$$k_s=0.27f^4, \qquad (16)$$

where

k_s= saturated hydraulic conductivity, in centimeters per second, and

$f= dx/d(t^{1/2})$, which is the slope of the line relating the wetting-front position and the square root of time.

The results of both methods are given in table 14. The sample from 9 m was from a cemented layer for which the conductivity was measured by shaping a sample to fit a 5-cm tube and sealing the sample in the tube for a conventional permeameter measurement.

The principal interest in the present application is in estimating an approximate value of unsaturated conductivity for the materials below 2 m in the soil-water potential range of −20 to −50 bars. Combining equations 13 and 14, a single expression,

$$k=k_s\{[(h_e/a)^{-1/b}]/W_s\}^m, \qquad (17)$$

can be used to calculate unsaturated conductivity at any selected value of soil-water potential. Values of unsaturated conductivity in the range of −5 to −50 bars of soil-water potential, based on the data given in tables 14 and 15 and equation 17, are listed in table 15 and shown in figures 30, 31, and 32.

The computed values of unsaturated hydraulic conductivity appear to be too small, but few other data for stony soils at such low water contents and large negative potentials are available for comparison. The study by Mehuys and others (1975) is one of the few to consider stony soils in arid environments. Their experiments included samples of stony soil from Rock Valley in southern Nevada, and their calculated values of unsaturated conductivity for this soil are in the range of 10^{-4} to 10^{-6} centimeters per day (cm/d) at potentials of −5 to −50 bars. This is up to seven orders of magnitude larger than the values computed by Campbell (written commun., 1980) for materials at the waste-burial site (figs. 30–32). Direct comparison of values may be difficult, however, because only 38 percent of the Rock Valley soil was greater than 2 mm in diameter, whereas most of the samples from the waste-burial site contained more than 49 percent of the coarse-grained fraction. The higher percentage of coarse-grained material will result in smaller unsaturated conductivity values for the whole soil. Consequently, the values of unsaturated conductivity obtained during this study will be considered reasonable until more data for these types of soils become available.

Table 14. Measured and calculated values of saturated hydraulic conductivity and other parameters for soil samples from waste-burial site[1]

[Data from Gaylon S. Campbell, Washington State University, written commun., 1980]

Depth (meters)	Sample number	Centimeters per day: k_s [see footnote 2]	Centimeters per day: k_s [see footnote 3]	Centimeters per day: k_s, corrected [see footnote 4]	n	m
0.15	1	$1.7x10^2$	$1.7x10^1$	$1.7x10^1$	2.6	13
.15	2	$8.5x10^1$				
1.0	1	$3.4x10^2$				
1.0	2	$2.5x10^2$	$1.7x10^2$	$8.5x10^1$	2.7	12
2.75	1	$2.5x10^3$				
2.75	2	$6.8x10^3$	$4.2x10^3$	$1.7x10^2$	2.6	13
4.0	1	$6.8x10^2$	$5.9x10^2$	$4.2x10^2$	2.9	10
9.0	1	$1.7x10^0$	--	$1.7x10^0$	2.5	16

[1]Symbols: k_s, saturated hydraulic conductivity; n and m, exponents in equations $k = k_s(W/W_s)^m$ and $k = k_s(h_e/h)^n$, where k is the unsaturated hydraulic conductivity.

[2]Measured using standard permeameter techniques.

[3]Inferred from rate of wetting-front advance.

[4]Computed as follows: (k_s) x (mass ratio for fraction <2 mm).

Table 15. Unsaturated hydraulic conductivity for depths of 2.75, 4.0, and 9.0 m at waste-burial site

[Hydraulic conductivities in centimeters per day. Data from Gaylon S. Campbell, Washington State University, written commun., 1980]

Potential (bars)	Depth, in meters: 2.75	Depth, in meters: 4.0	Depth, in meters: 9.0
-5	$5.47x10^{-11}$	$2.18x10^{-4}$	$1.20x10^{-10}$
-10	$9.35x10^{-12}$	$2.56x10^{-5}$	$2.24x10^{-11}$
-15	$3.32x10^{-12}$	$7.81x10^{-6}$	$8.37x10^{-12}$
-20	$1.59x10^{-12}$	$3.27x10^{-6}$	$4.17x10^{-12}$
-25	$9.05x10^{-12}$	$1.66x10^{-7}$	$2.43x10^{-12}$
-30	$5.86x10^{-13}$	$9.57x10^{-7}$	$1.56x10^{-12}$
-35	$3.84x10^{-13}$	$6.00x10^{-7}$	$1.07x10^{-12}$
-40	$2.73x10^{-13}$	$4.00x10^{-7}$	$7.77x10^{-13}$
-45	$2.02x10^{-13}$	$2.80x10^{-7}$	$5.83x10^{-13}$
-50	$1.54x10^{-13}$	$2.03x10^{-7}$	$4.52x10^{-13}$

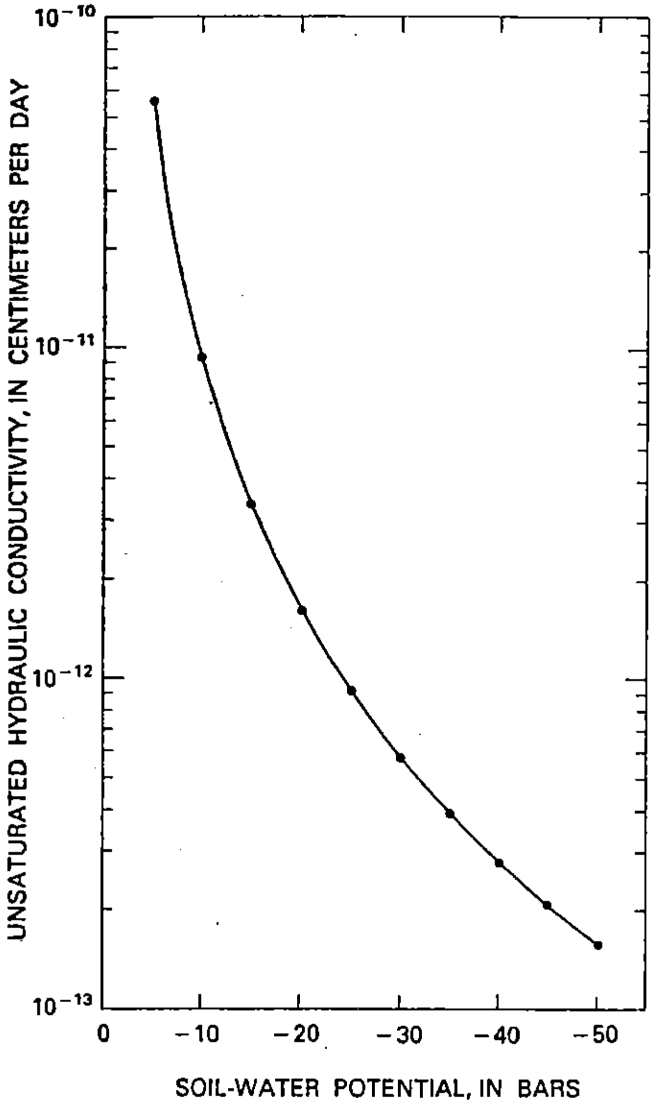

Figure 30. Calculated unsaturated hydraulic conductivity versus soil-water potential for sample from 2.75 m.

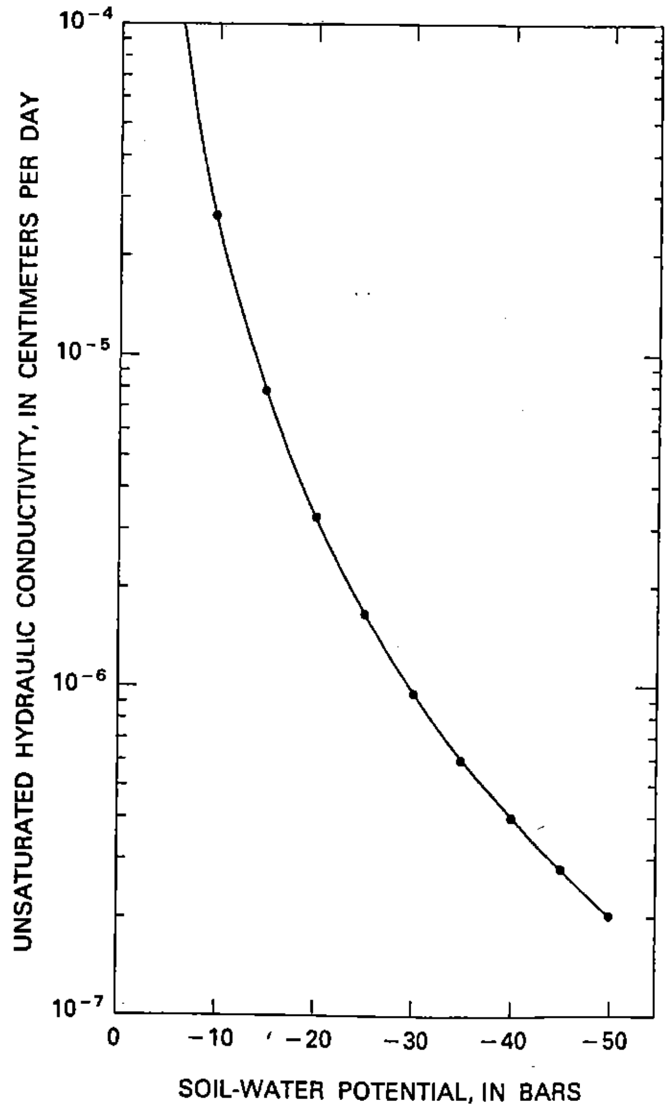

Figure 31. Calculated unsaturated hydraulic conductivity versus soil-water potential for sample from 4.0 m.

IMPLICATIONS REGARDING RADIONUCLIDE MIGRATION

Detailed studies of meteorological data and soil-moisture movement in the natural stratigraphic sequence at the waste-burial site demonstrated that deep percolation can occur, given the required antecedent conditions. The depth of downward moisture movement observed from February 1979 to February 1980 was controlled largely by the coarse-grained layer from about 0.75 to about 2.5 m. This layer served as a natural capillary barrier to unsaturated flow (Corey and Horton, 1969; Frind and others, 1976; Rancon, 1980). A capillary barrier is formed when unsaturated fine-grained sediments overlie unsaturated coarse-grained sediments. The downward movement of soil moisture is retarded at the contact between the two layers. Movement into the coarse sediments does not occur until the saturation level in the overlying fine-grained sediments becomes such that gravitational forces exceed interstitial tension forces. Such a barrier does not exist in the backfill material encompassing the radioactive-waste containers in the waste-burial trenches. The trench backfill is a heterogeneous mixture of the sediments removed during trench construction. It still is considered a stony soil, but the hydraulic characteristics are a composite of the characteristics given in tables 12 and 13. Regardless of the exact character of the backfill material, no capillary barrier overlies the existing trenches and nothing is present to retard moisture movement to depths greater than the 2.4 m observed during this study.

The hydraulic properties of the trench backfill are expected to vary from place to place, but they probably are not too different from the properties of the samples listed in tables 12 and 13 or the properties reported by Mehuys and others (1975) for the Rock Valley stony soil. A reasonable range of unsaturated hydraulic conductivity for matric potentials in the range of −5 to −50 bars might be from about 1×10^{-3} cm/d to perhaps as little as 1×10^{-8} cm/d. Volumetric water content might be somewhat greater at depth in the trench backfill; in the absence of field or laboratory data, an estimated range of water content of 5 to 12 percent might be reasonable. Soil-water potential in the backfill is not known, but, on the basis of the measurements shown in figure 29, it is expected to be in the range of −5 to −25 bars.

Conditions of steady-state unsaturated flow are unlikely in the trench backfill material. Large potential gradients are likely near the wetting fronts of successive deep percolation events. Such fronts are not expected to occur more frequently in the trench backfill than in the undisturbed sediments, but the depth of percolation likely will be greater because of the absence of a natural capillary barrier. (Even this infrequent deep percolation could be reduced by constructing capillary barriers over the waste trenches.) Under the circumstances, an estimation of unsaturated flow rates in the trench backfill is speculative at best. The rate might be as high as 10 cm/d near wetting fronts, where potential gradients are steep, but such rates would not continue to significant depths, or for significant lengths of time.

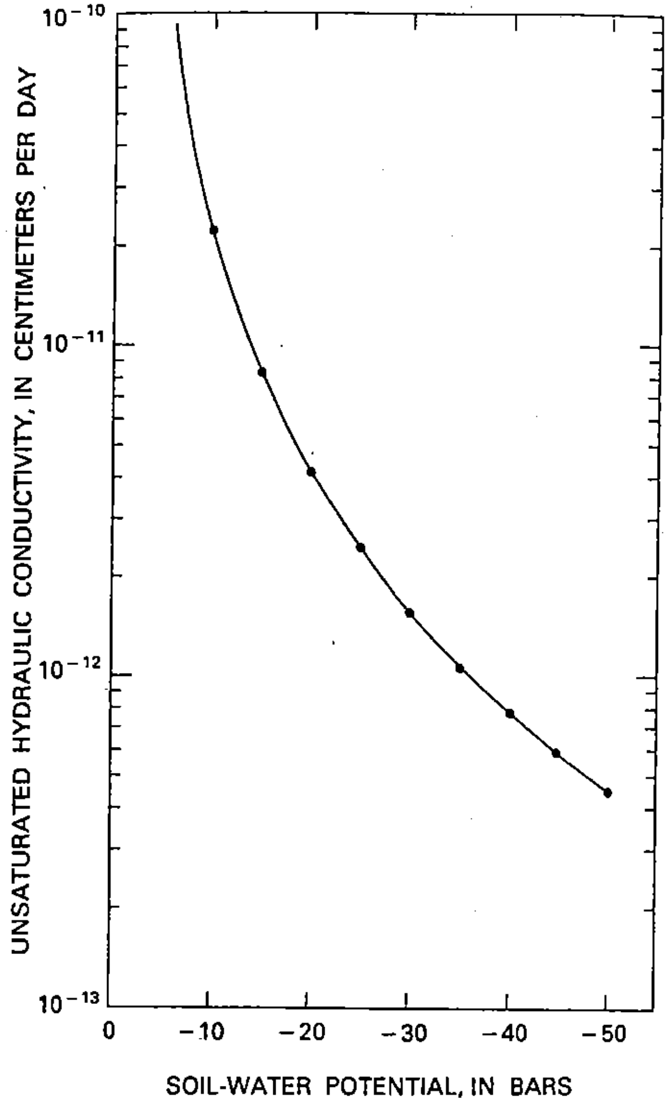

Figure 32. Calculated unsaturated hydraulic conductivity versus soil-water potential for sample from 9.0 m.

A detailed analysis of the hydrodynamics of transient flow in the trench backfill is complicated not only by lack of knowledge regarding hydraulic characteristics of the backfill but also by uncertainty regarding discontinuities introduced by the presence of waste containers. Other hydrologic discontinuities that either promote or inhibit the movement of moisture include settling fractures that extend to land surface, settling fractures that do not extend to land surface, void spaces that originate during the backfill process, and void spaces that develop from collapse of waste containers at some time following burial. Given all these complications and uncertainties, a simplified analysis that assumes ideal conditions is useful to the extent that it could provide a means for estimating possible limiting conditions.

An unsaturated hydraulic conductivity of 1×10^{-5} cm/d and a soil-water potential gradient, $\partial\psi/\partial Z$, of 10,000 cm/cm would give a transient flux rate of 0.1 cm/d. Assuming that (1) this condition was imposed at land surface when the oldest trenches were closed in 1963 and 1964 and (2) the supply of moisture at land surface was sufficient to allow for the continued downward movement of a wetting front at the rate of 0.1 cm/d, the wetting front would have reached a depth of about 6 m during the 18-yr period 1963–80. This depth of penetration is comparable to the reported depth of the older trenches. The volume of water needed to sustain such a flux is not easily determined without more information on the material and hydraulic properties of the trench backfill. Even the minimum volume of water, based on the flux rate of 0.1 cm/d, totals 120 cm^3/cm^2, an amount far in excess of the deep percolation that can reasonably by expected on the basis of the analysis presented earlier in this report. This would suggest that precipitation infiltrating through the trench caps since 1963 has not yet percolated deep enough to reach the bottom of the waste-burial trenches.

Movement of moisture in the region of steady unsaturated flow is expected to be extremely slow in the area of the waste-burial facility. The depth at which steady flow finally occurs is not known; soil-water potential data collected for this study indicate that transient effects may still exist at a depth of 10 m. The steady flux rate is speculative, but a value on the order of 1×10^{-5} cm/d in undisturbed sediments may be reasonable. This implies a moisture movement rate of about 4 cm per 1,000 yr, which in turn would represent the maximum rate of radionuclide transport (disregarding diffusion and dispersion) in the liquid phase in the zone of steady unsaturated flow beneath the waste-burial trenches.

SUMMARY OF ANALYSIS AND CONCLUSIONS

Detailed analysis of climatic conditions and precipitation patterns in the northern Amargosa Desert from 1949 to 1976 demonstrates that most of the precipitation falls in the cool winter months when evaporative demands are at a minimum. Meteorological data collected at the waste-burial site during the present study were used to calibrate a long-term water-balance model based on National Weather Service data. The model was then used to determine when and under what conditions, between 1962 and 1976, deep percolation might have occurred. This approach suggests that deep percolation—that is, percolation to a depth greater than 2 m—might have occurred in 1968, 1973, and 1976. Examination of the precipitation record for the 12 to 16 mo before each occurrence of predicted deep percolation defined the necessary antecedent conditions.

A similar sequence of precipitation events and soil-moisture conditions occurred in 1978 and early 1979. Soil-moisture profiles collected from February 1979 to June 1980 provided documentation of deep percolation to a depth of about 2 m during the late spring of 1979, as a result of these events. These data provide conclusive evidence of deep percolation in areas of bare soil. Considering the small volume of water involved (only 0.9 cm in 1979), deep percolation is not likely if vegetation is present.

Soil-water potential was monitored with thermocouple psychrometers to a depth of 10 m. The most reliable data were obtained at depths of 3, 6, and 10 m. Seasonal-type fluctuations were observed at all three depths but are most pronounced at 6 and 10 m. Measured soil-water potential ranged from −10 to −60 bars. These large changes in potential do not imply any significant change in moisture content; a decrease in negative potential from −50 bars to −15 bars can result from an increase in volumetric water content of less than 1 percent.

The unsaturated hydraulic conductivity of representative samples of the shallow subsurface sediments was determined using laboratory data and empirical relationships given by Hillel (1971) and Campbell (1974). The computed values of unsaturated hydraulic conductivity range from 10^{-13} to 10^{-4} cm/d. These values appear to be too small, but few other data for stony soils at such low water contents and large negative potentials are available for comparison.

A simplified analysis of transient unsaturated flow in the trench backfill material demonstrates the probable slow rate of migration of radionuclides in response to the movement of water under natural conditions. The analysis assumes an unsaturated hydraulic conductivity for the backfill of 10^{-5} cm/d and a gradient of 10^4 cm/cm; the resulting transient flux rate would be 0.1 cm/d. Assuming that (1) this flux condition was imposed when the oldest trenches were closed in 1963 and 1964 and (2) the flux rate was maintained at land surface, the wetting front would have reached a depth of 6 m in the 18-yr period 1963–80. This depth of penetration is comparable to the reported depth of the oldest trenches. However, the volume of water needed to sustain this flux rate, while not easily determined, is estimated to be several orders of magnitude greater than the volume of water expected to be available for deep percolation on the basis of long-term water-balance determinations. Steady flux rates in the unsaturated zone beneath the waste-burial trenches and below a depth of 10 m may be on the order of 10^{-5} cm/d, which implies a moisture movement rate of about 4 cm per 1,000 yr. Disregarding transport by diffusion and dispersion, this value would represent the maximum rate of radionuclide movement in the liquid phase, under steady, unsaturated conditions.

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TABLES 16 AND 17

Table 16. Driller's log for well at waste-burial site[1]

Depth (meters)	Material
0.0-0.6	Silt. Probably wind-blown dust.
.6-1.5	Coarse gravel with some silt.
1.5-9.1	Coarse gravel with some boulders.
9.1-13.7	Fine gravel with large boulders. Boulder bed at 13.7 meters.
13.7-30.5	Coarse gravel with some boulders and sand.
30.5-31.0	Boulders in coarse gravel.
31.0-32.6	Bouldery clay.
32.6-35.6	Bouldery clay; about half clay.
35.6-44.8	Small gravel with brown sandy clay.
44.8-45.1	Boulders in brown sandy clay.
45.1-47.8	Boulders with some clay.
47.8-49.0	Boulders and gravel in orange clay.
49.0-52.1	Orange clay.
52.1-55.1	Reddish-orange clay.
55.1-60.6	Cored in bentonitic red and orange clay. No core recovery.
60.6-61.5	Cored. No core recovered. Brown clay from bit.
61.5-62.8	Cored. No core recovered. Considerable brown clay from bit.
62.8-71.6	Clayey gravel, with boulders, brown clay, and small gravel at 71.6 meters.
71.6-78.6	Fine clayey gravel. Pinkish clay.
78.6-80.8	Gravel and boulders with but little clay.
80.8-83.5	Brown and yellow clay with some gravel.
83.5-85.3	Cored. Recovered 1.8 meters of light brown clay.
85.3-92.0	Brown clay with occasional boulders.
92.0-93.9	White and brown bentonitic clay with layers of bright-yellow clay.
93.9-98.5	Brown swelling clay with some gravel. Mostly clay from 80.8 to 98.1 meters.
98.5-98.8	Boulders in brown sandy clay.
98.8-99.4	Yellow clay.
99.4-103.6	Boulders but with little clay. Possible water zone.
103.6-106.4	White to brown clay. White argillaceous carbonate rock altered to clay.
106.4-108.5	White carbonate rock. Largely altered to clay from 108.2 to 108.5 meters.
108.5-112.1	Bouldery brown clay.
112.1-112.8	White clay, brown clay, and small gravel.
112.8-117.0	Dark volcanic boulders with brown bentonitic sandy-clay.
117.0-123.7	White carbonate rock somewhat altered to clay.
123.7-129.5	Greenish-brown clay, some boulders.
129.5-132.6	White carbonate rock and white clay.
132.6-135.6	Boulders in red clay.
135.6-142.3	Hard boulders with gravel in dark-red clay. Volcanic rocks.
142.3-144.5	Boulders and clay. Red clay at 143.9 meters.
144.5-148.7	A variety of boulders with but little clay. A possible source of water.
148.7-153.0	Hard boulders in brown and red sandy clay.
153.0-161.2	Pinkish-brown clay with sand and occasional boulders.
161.2-166.1	Boulders in pink and light-brown clay. Some sericitic rock.
166.1-168.5	Boulders in clay. Some rounded gravels.
168.5-172.8	Boulders in brown clay. Yellow clay and small gravel at 171.0 meters.
172.8-175.0	Light gray metamorphic rocks. Large boulders or possibly basement rock.

1 V. P. Gianella, consulting geologist, written communication, 1961.

Table 17. Description of samples obtained from well drilled at waste-burial site[1]

Depth (meters)	Description
0.0-0.6	Silt. Probably wind-blown dust.
1.5	Coarse gravels and silt. Volcanic rocks, andesite, basalt, and rhyolite.
3.0	Dominantly volcanic rocks, some quartz.
7.6	Volcanic gravel with some quartz and chalcedony.
20.4	Volcanic gravels. Somewhat altered and silicified.
30.5	Gravels of volcanic rocks.
32.6	Mostly gravels of volcanic rocks and some quartz.
35.6	Volcanic gravel, partly well-rounded.
44.2	Largely rhyolitic gravel. Some quartzite.
44.8-45.1	Gravels of volcanic rocks and quartzite.
48.7	Volcanic rocks, altered volcanic rocks, and some quartz.
52.1	Two-thirds volcanic rocks and about one-third schist, with some well-rounded pebbles.
55.2	Volcanic rocks, quartzite, schist, quartz, and chalcedony. A few well-rounded pebbles.
61.6	Pebbly orange clay from coring bit. Well-rounded pebbles of volcanic rocks. (Note change to volcanics with no sedimentary or metasedimentary rocks.)
62.8	Light brown clay from coring bit with about 5 percent sand.
68.3	Cuttings dominantly volcanic rocks with some quartzite and chalcedony.
76.2	Fine clayey gravel. Gravel chiefly of volcanic rocks with some quartzite, schist, and quartz.
81.4	Yellow to light-brown clay.
84.1-84.4	Light-brown clay from core barrel. Contains little sand.
85.3	Brown sandy clay from core barrel. Contains about 10 percent fine to coarse sand. Some grains are well rounded.
93.3	White, brown, and yellow bands of bentonitic clay. Contains a little gravel from volcanic rocks.
105.5	White to brown bentonitic clay with boulders. Cuttings are mostly white and pink silicified felsitic rock.
108.5	White altered rock with white clay--a carbonate rock, probably an impure freshwater limestone. Also cuttings of dark-colored limestone, volcanic rocks, and some quartzite.
117.0-117.3	White clayey rock continuous from 108.5 meters. Much white clay. Cuttings are from a white clayey-carbonate like that in sample No. 23.
135.6	Dark red sandy clay cuttings of dark volcanic rocks. Some small rounded pebbles of dark gray volcanic rock. Some gray schist, quartzite and occasional quartz. A marked change from sample No. 24.
142.3	Volcanic boulders in light-colored red clay. Cuttings of dark red volcanic rock and some gray quartzite. Some rounded gravels.
144.2	Cuttings of light- and dark-colored volcanic rocks. Very little red volcanic rocks as at 142.3 meters. Some schist and quartz. Many small rounded pebbles.
146.9	Cuttings of light and dark volcanic rock. Some light-colored volcanics, quartzite, and quartz. Rounded pebbles.
147.5	Cuttings like those from 146.9 meters.
153.0	Gravel and red clay. Mostly dark red volcanics, with some rhyolite and rounded pebbles.
155.7	Volcanic rocks, schist, and other metasediments. Fine gravel embedded in red clay.
158.2	Light-colored volcanic rocks with much schist and quartzite.
161.2	Dark pink clay recovered from bit. The clay contains about 5 percent fine sand grains of schist, quartzite, and quartz. Some grains are well-rounded.

Table 17. Description of samples obtained from well drilled at waste-burial site[1]—Continued

Depth (meters)	Description
161.5	Light and dark volcanic rock, quartzite, quartz, and some schist.
163.1	Cuttings are mostly quartzite and schist, with little volcanic rock.
166.4	Cuttings consist of about equal amounts of light and dark volcanic rocks, schist, and quartzite.
167.0	Light-brown clay with pebbles. Volcanic rocks, schist, and well-rounded pebbles.
168.2	Cuttings of light and dark volcanic rocks, schist, and quartzite.
172.2	Reddish clay with pebbles of schist and some volcanic rocks.
172.5	Schist and quartzite predominate, with some volcanic rocks.
174.9	Mostly sericitic schistose rock. Either large boulders or possible basement rock.

[1] V. P. Gianella, consulting geologist, written communication, 1961.

METRIC CONVERSION FACTORS

International System (metric) units of measure used in this report may be converted to "inch-pound" units by using the following factors:

Multiply	By	To obtain
Centimeters (cm)	0.3937	Inches (in)
Centimeters per day (cm/d)	0.3937	Inches per day (in/d)
Cubic meters per second (m^3/s)	35.31	Cubic feet per second (ft^3/s)
Grams	0.03527	Ounces
Grams per cubic centimeter (g/cm^3)	62.43	Pounds per cubic foot (lb/ft^3)
Kilometers (km)	0.6214	Miles (mi)
Meters (m)	3.281	Feet (ft)
Millimeters (mm)	0.03937	Inches (in)

For temperature, degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) by using the formula F=[(1.8)(°C)]+32.

ALTITUDE DATUM

The term "National Geodetic Vertical Datum of 1929" replaces the formerly used term "mean sea level" to describe the datum for altitude measurements. The geodetic datum is derived from a general adjustment of the first-order leveling networks of both the United States and Canada. For convenience in this report, the datum also is referred to as "sea level."

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RUNOFF ESTIMATE FOR 100-YR, 24-HR STORM
LOW-LEVEL RADIOACTIVE WASTE DISPOSAL FACILITY
BEATTY, NEVADA

PARAMETERS:

1) Contributing Drainage Area = 56 Acres = 0.0875 SQ. MI.

2) 100-YR, 24-HR RAINFALL = 2.60 INCHES

3) Longest Flow Path Through Site = 1320 FT. (ℓ)

4) Average Land Slope = 0.75 percent

5) For worst case, use AMC II condition
(0.5 to 1.1 in. of rain in previous 5 days)

6) Due to construction, land characterized as fallow, poor hydr. cond.

For parameters 5) and 6), Runoff Curve No. (RCN) = 77

<u>COMPUTE TIME OF CONCENTRATION (T_c)</u>

$$L \text{ (LAG)} = \frac{\ell^{8} (S + 1)^{7}}{1900 (Y)^{5}}$$

$$S = \frac{1000}{RCN} - 10 = \frac{1000}{77} - 10 = 2.98$$

$$L = \frac{(1320)^{8} (3.98)^{7}}{1900 (.75)^{5}} = 0.50 \text{ HRS}$$

$$T_c = L/0.6 = \frac{0.5}{0.6} = 0.83$$

<u>RUNOFF</u>

QRCN = 77 = 0.80 IN. OF RUNOFF FOR 2.6 IN. RAIN.

<u>COMPUTE PEAK FLOW OF RUNOFF</u>

REF: SCS ENGR 20 (REV 2)

PK. = (DA) (Q) (CSM)
USE CHART T_c = 0.75 HRS, T_T = 0 HRS.

CSM = 389

PK FLOW = (0.085) (0.80) (389) = 27.2 CFS

FOR 56 ACRES, THIS EQUATES TO 0.49 CFS/AC.

COMPUTE PEAK FLOW OF RUNOFF

REF: SCS ENGR 20 (REV 2)

PK. = (DA) (Q) (CSM)
USE CHART T_c = 0.75 HRS, T_T = 0 HRS.

CSM = 389

PK FLOW = (0.085) (0.80) (389) = 27.2 CFS

FOR 56 ACRES, THIS EQUATES TO 0.49 CFS/AC.

ROUTE FLOW THROUGH THE THREE DRAINAGE SWALES WHICH PROVIDE DRAINAGE TO THE SOUTH

WESTERN DRAINAGE SWALE

DRAINAGE AREA APPROX. 15 ACRES
FLOW (Q) = (15 AC) (0.49 CFS/AC.) = 7.4 CFS

BY MAP INSPECTION, SWALE APPROX 15' WIDE (b). ASSUME VERT SIDESLOPES. SLOPE OF SWALE (STEEPEST FOR VELOCITY DETERM.) = 0.6 PERCENT (S) USE MANNING COEFFICIENT (R) = 0.035 TO SAND/GRAVEL SURFACE

$$Q = \frac{K^1}{n} \quad b^{2.667} S^{0.5}$$

$$K^1 = \frac{Qn}{b^{2.667} S^{0.5}} = \frac{(7.4)\ (.035)}{(15)^{2.667}\ (.006)^{.5}} = 0.00246$$

D/b = 0.0216 INTERPOLATED FROM TABLE 7-11, HANDBOOK OF HYDRAULICS, King & Brater

FLOW DEPTH (D) = (0.0216) (15) = 0.32 FT.

AREA (A) = 15 (0.32) = 4.8 FT^2
FLOW VELOCITY (V) = Q/A = 7.4/4.8 = 1.54 FT/SEC

CENTER SWALE

DRAINAGE AREA = 18 ACRES
Q = (18) (0.49) = 8.8 CFS
b = 15 FT. (APPROX.)
S = 0.7 PERCENT
R = 0.035

$$K^1 = \frac{(8.8)\ (.035)}{(15)^{2.667}\ (0.007)^{.5}} = 0.00281$$

D/b INTERPOLATED FROM TABLE 7-11 = 0.0234

D = (15) (0.0234) = 0.35 FT.
A = (15) (0.35) = 5.25 FT^2
V = 8.8/5.25 = 1.67 FT/SEC

EASTERN SWALE

DRAINAGE AREA = 23 ACRES
Q = (23) (0.49) = 11.3 CFS
b = 25 FT (APPROX)
S = 1 PERCENT
R = 0.035

$$K^1 = \frac{(11.3)\ (0.35)}{(25)^{2.667}\ (0.01)^{.5}} = 0.000739$$

D/b = 0.0104

D = 0.0104 (25) = 0.26 FT
A = (25) (0.26) = 6.5 FT^2
V = 11.3/6.5 = 1.74 FT/SEC.

Table 2.21 Definition of Antecedent Condition.

Condition	General Description	5-day Antecedent Rainfall in inches: Dormant Season	Growing Season
I	Optimum soil condition from about lower plants limit to wilting point	<0.5	<1.4
II	Average value for annual floods	0.5-1.1	1.4 - 2.1
III	Heavy rainfall or light rainfall and low temperatures within 5 days prior to the given storm	>1.1	>2.1

Table 2.22 Factors for Converting CN's to Antecedent Condition

Curve Number For Condition II	Factor to Convert Curve Number for Condition II to Condition I	Condition III
10	0.40	2.22
20	0.45	1.85
30	0.50	1.67
40	0.55	1.50
50	0.62	1.40
60	0.67	1.30
70	0.73	1.21
80	0.79	1.14
90	0.87	1.07
100	1.00	1.00

From SCS-TR-55
Retyped for Clarity

9.2

Table 9.1.--Runoff curve numbers for hydrologic soil-cover complexes

(Antecedent moisture condition II, and $I_a = 0.2\ S$)

Land use	Cover: Treatment or practice	Cover: Hydrologic condition	Hydrologic soil group: A	B	C	D
Fallow	Straight row	----	77	86	91	94
Row crops	"	Poor	72	81	88	91
	"	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	"	Good	65	75	82	86
	" and terraced	Poor	66	74	80	82
	" " "	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	" and terraced	Poor	61	72	79	82
		Good	59	70	78	81
Close-seeded legumes 1/ or rotation meadow	Straight row	Poor	66	77	85	89
	" "	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	"	Good	55	69	78	83
	" and terraced	Poor	63	73	80	83
	" and terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	"	Fair	25	59	75	83
	"	Good	6	35	70	79
Meadow		Good	30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		----	59	74	82	86
Roads (dirt) 2/		----	72	82	87	89
(hard surface) 2/		---	74	84	90	92

1/ Close-drilled or broadcast.
2/ Including right-of-way.

From SCS NEH-4 Hydrology

CN 77

RUNOFF FOR INCHES OF RAINFALL

(Curve No. 77)

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03
1	0.05	0.07	0.10	0.14	0.18	0.22	0.26	0.30	0.34	0.39
2	0.45	0.50	0.56	0.62	0.68	0.74	0.80	0.86	0.93	1.00
3	1.07	1.14	1.21	1.28	1.35	1.43	1.50	1.57	1.65	1.73
4	1.81	1.89	1.97	2.05	2.13	2.21	2.29	2.37	2.45	2.53
5	2.62	2.70	2.79	2.87	2.96	3.04	3.13	3.22	3.30	3.39
6	3.48	3.56	3.65	3.74	3.83	3.92	4.00	4.09	4.18	4.27
7	4.36	4.45	4.54	4.63	4.72	4.81	4.90	5.00	5.09	5.18
8	5.27	5.36	5.45	5.55	5.64	5.73	5.82	5.92	6.01	6.10
9	6.19	6.29	6.38	6.47	6.57	6.66	6.76	6.85	6.94	7.04
10	7.13	7.23	7.32	7.42	7.51	7.60	7.70	7.79	7.89	7.98
11	8.08	8.18	8.27	8.37	8.46	8.55	8.65	8.75	8.84	8.94
12	9.03	9.13	9.23	9.32	9.42	9.51	9.61	9.71	9.81	9.90
13	10.00	10.09	10.19	10.28	10.37	10.47	10.57	10.67	10.77	10.86
14	10.96	11.06	11.15	11.25	11.35	11.44	11.54	11.64	11.73	11.83
15	11.93	12.03	12.12	12.22	12.32	12.41	12.51	12.61	12.71	12.80
16	12.90	13.00	13.10	13.19	13.28	13.38	13.48	13.58	13.67	13.77
17	13.87	13.97	14.07	14.17	14.26	14.36	14.46	14.55	14.65	14.75
18	14.85	14.95	15.05	15.15	15.24	15.34	15.44	15.54	15.64	15.73
19	15.83	15.93	16.03	16.12	16.22	16.32	16.42	16.51	16.61	16.71
20	16.81	16.91	17.01	17.10	17.20	17.30	17.40	17.50	17.60	17.69

TE: Runoff value determined by equation $Q = \frac{(P-0.2\,S)^2}{P + 0.8\,S}$

REF: [illegible] Hydrology Guide

EXAMPLE: 4.50 inches rainfall = 2.21 inches runoff.

DISCHARGE TABLE IN CSM/INCH OF RUNOFF FOR 24 HOUR - TYPE 2 DISTRIBUTION

TIME OF CONCENTRATION = 0.75 HOURS

HYDROGRAPH TIME-HRS

TRAV TIME HRS	11.0	11.5	11.6	11.7	11.8	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9	13.0	13.1	13.2	13.4	13.6	13.8	14.0	14.2	14.4	14.6	14.8	15.0	15.2	15.4	15.6
0.0	15	29	36	56	98	163	249	329	377	389	369	325	275	231	194	165	142	123	107	84	69	58	51	45	41	38	35	33	31	30	28
.25	12	21	24	28	35	52	87	142	214	287	343	369	364	336	295	253	215	162	156	116	90	73	61	53	47	42	39	36	34	32	30
.50	10	16	18	20	23	26	34	49	78	125	186	252	308	344	353	339	309	272	234	171	127	97	78	64	55	48	43	39	37	34	32
.75	8	12	14	15	17	19	22	25	32	46	71	110	162	222	277	317	337	335	316	251	187	138	105	83	68	58	50	45	40	37	35
1.0	6	10	11	12	13	15	16	18	21	24	31	43	64	97	143	196	248	291	318	317	265	203	151	114	89	72	60	52	46	42	38
1.5	4	6	7	7	8	9	10	11	12	13	15	17	19	22	27	37	52	77	111	198	277	306	283	232	171	135	103	82	67	57	49
2.0	2	4	4	4	5	5	6	7	7	8	9	10	11	12	14	15	17	20	24	43	87	158	235	283	286	253	205	158	121	94	76
2.5	1	2	2	2	3	3	4	4	4	5	6	6	7	7	8	9	10	11	12	16	22	36	70	127	197	254	277	263	226	182	141
3	0	1	1	1	1	2	2	2	2	3	3	4	4	5	5	6	6	7	8	9	11	14	19	31	57	102	163	222	259	264	241
4										0	1	1	1	1	1	2	2	2	3	3	4	5	6	8	9	12	16	23	39	68	111
5																			0	1	1	1	2	3	3	4	5	6	8	10	13
6																								0	1	1	1	2	3	3	4
8																															
10																															
15																															
20																															
25																															
30																															

HYDROGRAPH TIME-HRS

TRAV TIME HRS	15.8	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0	32.0	34.0	36.0	38.0	40.0	42.0	44.0	46.0	48.0	50.0	52.0
0.0	27	26	23	22	20	19	17	17	16	15	14	13	12	11	3	2	0														
.25	29	27	25	22	21	19	18	17	16	15	14	13	12	11	4	3	0														
.50	30	29	26	23	22	20	19	17	17	16	14	13	12	11	6	3	1	0													
.75	33	31	27	25	22	21	19	18	17	16	15	13	12	12	9	3	2	0													
1.0	35	33	29	26	23	22	20	19	17	17	15	14	13	12	10	3	2	0													
1.5	44	40	33	29	26	23	22	20	19	17	16	14	13	12	11	6	3	1	0												
2.0	63	54	40	33	29	26	23	22	20	19	17	15	14	13	12	10	4	2	0												
2.5	110	87	55	41	34	29	26	24	22	20	18	16	14	13	12	11	6	3	1	0											
3	203	162	89	56	41	34	29	26	24	22	19	17	15	14	13	12	10	4	2	0											
4	164	212	241	164	93	58	42	34	29	26	22	19	17	15	14	13	12	9	4	2	0										
5	18	28	95	203	229	164	97	60	43	34	26	22	19	17	15	14	13	12	9	4	0										
6	5	7	12	32	101	195	219	163	100	62	35	26	22	19	17	15	14	13	12	9	2	0									
8		0	1	2	4	7	15	41	107	183	161	66	36	26	22	19	17	15	14	13	9	2	0								
10						0	1	2	4	8	49	172	157	70	37	27	22	19	17	15	13	9	2	0							
15												0	1	3	11	62	154	147	77	40	22	17	14	11	5	1	0				
20																	0	1	3	16	141	81	28	19	15	13	8	2	0		
25																					0	4	72	131	46	23	17	14	11	5	1
30																							0	1	25	124	85	31	19	15	13

Table 7-11. Values of K' in Formula $Q = \frac{K'}{n} b^{8/3} s^{1/2}$ for

Trapezoidal Channels

D = depth of water b = bottom width of channel

$\frac{D}{b}$	Side slopes of channel, ratio of horizontal to vertical									
	Vertical	¼-1	½-1	¾-1	1-1	1½-1	2-1	2½-1	3-1	4-1
.01	.00068	.00068	.00069	.00069	.00069	.00069	.00069	.00069	.00070	.00070
.02	.00213	.00215	.00216	.00217	.00218	.00220	.00221	.00222	.00223	.00225
.03	.00414	.00419	.00423	.00426	.00428	.00433	.00436	.00439	.00443	.00449
.04	.00660	.00670	.00679	.00685	.00691	.00700	.00708	.00716	.00723	.00730
.05	.00946	.00964	.00979	.00991	.01002	.01019	.01033	.01047	.01060	.01080
.06	.0127	.0130	.0132	.0134	.0136	.0138	.0141	.0143	.0146	.0150
.07	.0162	.0166	.0170	.0173	.0175	.0180	.0183	.0187	.0190	.0197
.08	.0200	.0206	.0211	.0215	.0219	.0225	.0231	.0236	.0240	.0250
.09	.0241	.0249	.0255	.0262	.0267	.0275	.0282	.0289	.0296	.0310
.10	.0284	.0294	.0304	.0311	.0318	.0329	.0339	.0348	.0358	.0376
.11	.0329	.0343	.0354	.0364	.0373	.0387	.0400	.0413	.0424	.0448
.12	.0376	.0393	.0408	.0420	.0431	.0450	.0466	.0482	.0497	.0527
.13	.0425	.0446	.0464	.0480	.0493	.0516	.0537	.0556	.0575	.0613
.14	.0476	.0502	.0524	.0542	.0559	.0587	.0612	.0636	.0659	.0706
.15	.0528	.0559	.0585	.0608	.0627	.0662	.0692	.0721	.0749	.0805
.16	.0582	.0619	.0650	.0676	.0700	.0740	.0777	.0811	.0845	.0912
.17	.0638	.0680	.0716	.0748	.0775	.0823	.0866	.0907	.0947	.1026
.18	.0695	.0744	.0786	.0822	.0854	.0910	.0960	.1008	.1055	.1148
.19	.0753	.0809	.0857	.0899	.0936	.1001	.1059	.1115	.1169	.1277
.20	.0812	.0876	.0931	.0979	.1021	.1096	.1163	.1227	.1290	.1414
.21	.0873	.0945	.101	.106	.111	.120	.127	.135	.142	.156
.22	.0934	.1015	.109	.115	.120	.130	.139	.147	.155	.171
.23	.0997	.1087	.117	.124	.130	.141	.150	.160	.169	.187
.24	.1061	.1161	.125	.133	.140	.152	.163	.173	.184	.204
.25	.1125	.1236	.133	.142	.150	.163	.176	.188	.199	.222
.26	.119	.131	.142	.152	.160	.175	.189	.202	.215	.241
.27	.126	.139	.151	.162	.171	.188	.203	.218	.232	.260
.28	.132	.147	.160	.172	.182	.201	.217	.234	.249	.281
.29	.139	.155	.170	.182	.194	.214	.232	.250	.268	.302
.30	.146	.163	.179	.193	.205	.228	.248	.267	.287	.324
.31	.153	.172	.189	.204	.218	.242	.264	.286	.306	.347
.32	.160	.180	.199	.215	.230	.256	.281	.304	.327	.371
.33	.167	.189	.209	.227	.243	.271	.298	.323	.348	.396
.34	.174	.198	.219	.238	.256	.287	.316	.343	.370	.423
.35	.181	.207	.230	.251	.269	.303	.334	.363	.392	.450
.36	.189	.216	.241	.263	.283	.319	.353	.385	.416	.478
.37	.196	.225	.252	.275	.297	.336	.372	.406	.440	.507
.38	.203	.234	.263	.288	.312	.353	.392	.429	.465	.537
.39	.211	.244	.274	.301	.326	.371	.413	.452	.491	.568
.40	.218	.253	.286	.315	.341	.389	.434	.476	.518	.600
.41	.226	.263	.297	.328	.357	.408	.456	.501	.546	.633
.42	.233	.273	.309	.342	.373	.427	.478	.526	.574	.668
.43	.241	.283	.321	.357	.389	.447	.501	.553	.603	.703
.44	.248	.293	.334	.371	.405	.467	.525	.580	.633	.740
.45	.256	.303	.346	.386	.422	.488	.549	.607	.664	.777

Table 7-11. Values of K' in Formula $Q = \frac{K'}{n} b^{8/3} s^{1/2}$ for

Trapezoidal Channels (*Continued*)

D = depth of water b = bottom width of channel

$\frac{D}{b}$	Side slopes of channel, ratio of horizontal to vertical									
	Vertical	¼-1	½-1	¾-1	1-1	1½-1	2-1	2½-1	3-1	4-1
.46	.264	.313	.359	.401	.439	.509	.574	.636	.696	.816
.47	.271	.323	.372	.416	.457	.531	.599	.665	.729	.856
.48	.279	.334	.385	.432	.474	.553	.625	.695	.763	.897
.49	.287	.344	.398	.447	.493	.575	.652	.725	.797	.939
.50	.295	.355	.412	.463	.511	.598	.679	.757	.833	.983
.51	.303	.366	.425	.480	.530	.622	.707	.789	.869	1.03
.52	.311	.377	.439	.496	.549	.646	.736	.822	.907	1.07
.53	.319	.388	.453	.513	.569	.671	.765	.856	.945	1.12
.54	.327	.399	.467	.531	.589	.696	.795	.891	.984	1.17
.55	.335	.410	.482	.548	.609	.722	.826	.926	1.025	1.22
.56	.343	.422	.497	.566	.630	.748	.857	.963	1.07	1.27
.57	.351	.433	.511	.584	.651	.775	.889	1.000	1.11	1.32
.58	.359	.445	.526	.602	.673	.802	.922	1.038	1.15	1.37
.59	.367	.456	.542	.621	.694	.830	.956	1.077	1.20	1.43
.60	.375	.468	.557	.640	.717	.858	.990	1.117	1.24	1.49
.61	.383	.480	.573	.659	.739	.887	1.02	1.16	1.29	1.54
.62	.391	.492	.588	.678	.762	.916	1.06	1.20	1.33	1.60
.63	.399	.504	.604	.698	.785	.946	1.10	1.24	1.38	1.66
.64	.408	.516	.620	.718	.809	.977	1.13	1.28	1.43	1.72
.65	.416	.529	.637	.738	.833	1.008	1.17	1.33	1.48	1.79
.66	.424	.541	.653	.759	.857	1.04	1.21	1.37	1.53	1.85
.67	.433	.553	.670	.780	.882	1.07	1.25	1.42	1.59	1.91
.68	.441	.566	.687	.801	.907	1.10	1.29	1.47	1.64	1.98
.69	.449	.579	.704	.822	.933	1.14	1.33	1.51	1.69	2.05
.70	.457	.592	.722	.844	.959	1.17	1.37	1.56	1.75	2.12
.71	.466	.604	.739	.866	.985	1.21	1.41	1.61	1.81	2.19
.72	.474	.617	.757	.889	1.012	1.24	1.46	1.66	1.86	2.26
.73	.483	.631	.775	.911	1.039	1.28	1.50	1.71	1.92	2.34
.74	.491	.644	.793	.934	1.067	1.31	1.54	1.77	1.98	2.41
.75	.499	.657	.811	.957	1.095	1.35	1.59	1.82	2.05	2.49
.76	.508	.670	.830	.981	1.12	1.39	1.63	1.87	2.11	2.57
.77	.516	.684	.849	1.005	1.15	1.43	1.68	1.93	2.17	2.65
.78	.525	.698	.868	1.029	1.18	1.46	1.73	1.99	2.24	2.73
.79	.533	.711	.887	1.053	1.21	1.50	1.78	2.04	2.30	2.81
.80	.542	.725	.906	1.078	1.24	1.54	1.83	2.10	2.37	2.90
.81	.550	.739	.925	1.10	1.27	1.58	1.88	2.16	2.44	2.98
.82	.559	.753	.945	1.13	1.30	1.62	1.93	2.22	2.51	3.07
.83	.567	.767	.965	1.15	1.33	1.67	1.98	2.28	2.58	3.16
.84	.576	.781	.985	1.18	1.36	1.71	2.03	2.34	2.65	3.25
.85	.585	.796	1.006	1.21	1.40	1.75	2.08	2.41	2.72	3.35
.86	.593	.810	1.03	1.23	1.43	1.79	2.14	2.47	2.80	3.44
.87	.602	.825	1.05	1.26	1.46	1.84	2.19	2.54	2.87	3.54
.88	.610	.839	1.07	1.29	1.49	1.88	2.25	2.60	2.95	3.63
.89	.619	.854	1.09	1.31	1.53	1.93	2.31	2.67	3.03	3.73
.90	.628	.869	1.11	1.34	1.56	1.98	2.36	2.74	3.11	3.83

CALCULATION COVER SHEET

CALCULATION NUMBER 119 -CAL- 001 REV. 0

TITLE: BEATTY RAD CLOSURE FINAL CAP RUN-OFF CALCS PAGE 1 OF 6

PURPOSE: DETERMINE RUNOFF ON THE EASTERN SIDE OF THE BEATTY LLRW FINAL CAP AS SHOWN ON DRAWING NV-119-TRE-003 Rev. 0. DRAINAGE WILL BE ROUTED TO A DRAINAGE SWALE LOCATED EAST OF THE CAP IN THE BUFFER ZONE AND THEN SOUTHWARD OFF SITE.

CONCLUSION: PEAK FLOW IS 3 CFS USING THE 100-YEAR, 24-HOUR STORM.

ORIGINATOR: K. Cuff DATE: 9/28/92

CHECKED BY: Mike Cry DATE: 9/28/92

APPROVED BY: K. Cuff DATE: 9/28/92

SUPERSEDES, CALCULATION NO. ______ SUPERSEDED BY, CALCULATION NO. ______

PRELIMINARY ______ FINAL X

OBJECTIVE: DETERMINE RUNOFF QUANTITIES FOR EASTWARD DRAINAGE OFF OF THE FINAL CLOSURE CAP NEAR THE BUFFER ZONE.

GIVEN: SUBWATERSHED CHARACTERISTICS AS SHOWN, BASED ON FINAL CAP DESIGN.

APPROACH: COMPUTE PEAK DISCHARGE OVER THE CLOSED CELL CAP. USE METHOD DESCRIBED IN SOIL CONSERVATION SERVICE TECHNICAL RELEASE 55, "URBAN HYDROLOGY FOR SMALL WATERSHEDS," JUNE 1986, USING THE 100 YEAR, 24-HOUR STORM.

ASSUMPTIONS

1. THE CAP SLOPE WILL RANGE FROM 1-3%. THE CAP OUTSLOPES WILL BE 4:1. THE DRAINAGE SWALE VELOCITY IS ASSUMED TO BE 2 FT/SEC

2. TYPE II STORM (previous Calcs)

3. 100-YR, 24-HOUR STORM EVENT = 2.6 INCHES. (PREVIOUS CALCULATION)
CURVE NUMBER = 77

$$S = \frac{1000}{77} - 10 \qquad S = 2.99$$

$$Q = \frac{(P - .2S)^2}{P + .8S} = \frac{(2.6 - .6)^2}{2.6 + 2.39} = .8 \text{ INCHES}$$

DETERMINE I_a/P
FOR CN = 77, I_a = .597 P = 2.6

I_a/P = .22, USE CHART FOR I_a/P = .3

USEcology

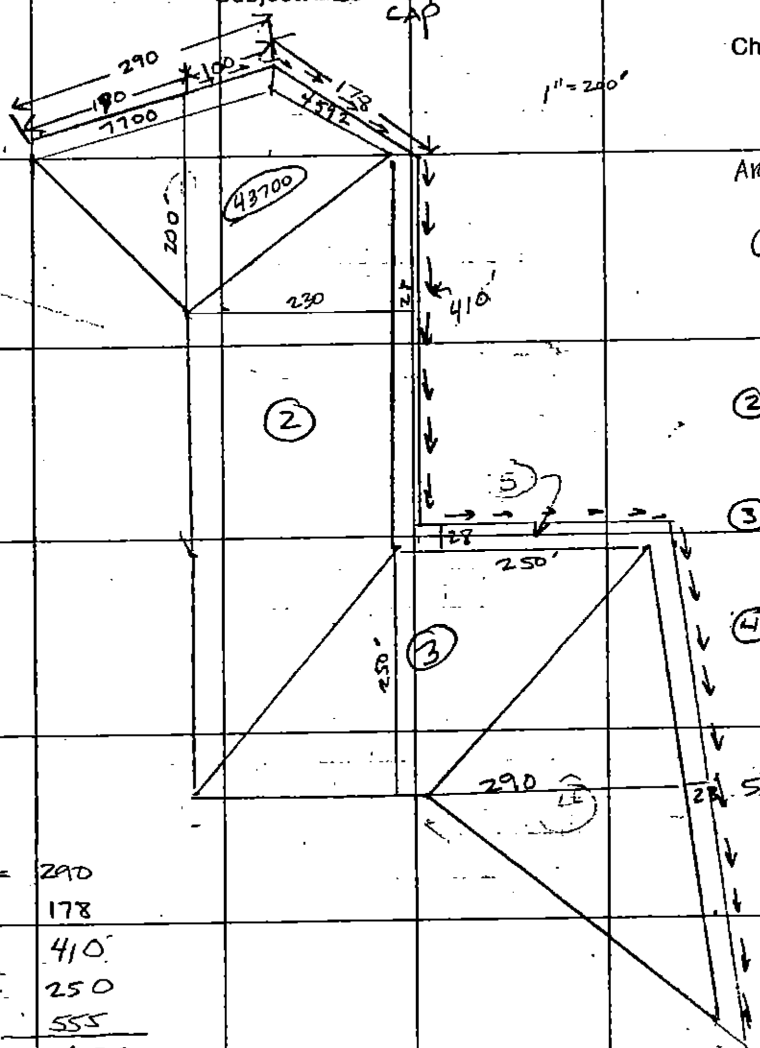
Calculations: RUN-OFF CALCS + DRAINAGE SWALE DESIGN

Subject: BEATTY LLRW FINAL CAP

By: K. C[illegible] Date: 9/28/92

Checked by: ______ Date: ______

1" = 200'



AREA

①	(.5)(380)(70) + (.5)(380)(160) + 7700 + 4592	55992 SF	.0020
②	240 ((413 + 500)/2) + (410)(28)	121,040 FT² SF	.0043
③	247.8 ((255 + 240)/2) + 7000	68,331 SF	.0025
④	(.5)(290)(250) + (.5)(410)(180) + 15540	88,690 SF	.0032
			.0120

$L_T =$ 290
178
410
250
555
1683 FT

COMPUTE SHEET FLOW FOR DRAINAGE DISTANCES 300 FT OR LESS

$$T_t = \frac{.007\,(nL)^{.8}}{P_2^{\,.5}\; s^{.4}}$$

WHERE

n = Mannings Roughness coefficient (from table 3-1) = .13

L = flow length (ft) < 300, otherwise use channel eqn.

P_2 = 2 yr, 24-hr. rainfall ≈ 1" (DEPT. OF COMMERCE, TECH. PAPER NO. 40)

s = slope, ft/ft

T_t = travel time

CHANNEL FLOW

$$T_t = \frac{L}{3600(v)}$$

Assume channel v = 2 FPS

AREA 1

O.L. L=200' s= .0125 T_t = .547
O.L L=28' s= .25 = .034

Ch L= 278 = = .0386
.620 = T_c T_t = 0

DOWNSTREAM SUBAREAS 2,3,4

AREA 2

OL. L= 230' s= 3% T_t = .431
OL L= 28' s= .25 = .034

Ch L= 230 = .032
.497 = T_c

TRAVEL TIME
L= 410
T_t = .057

DOWNSTREAM SUBAREAS 3,4

AREA 3

OL L= 250 s = 1% .715
OL L=28 s = 25% .034

channel L=250 .035
.784 T_c

T_t = .035 hr
L = 250

DOWNSTREAM SUB AREAS - 4

AREA 4

OL 290 s = 1% .806
OL 28 s = 25% .034

channel 290 .040
1.19-

T_t l = 555 = .077

Subject: BEATTY LLRW FINAL CAP

By: K C... Date: 9/28/92

Checked by: Date:

AREA NAME	AREA (MI^2)	T_c (HR)	T_t (HR)	DOWNSTREAM SUBAREA NAMES	ΣT_t	$A_m Q$
1	.0020	.62	0	2, 3, 4	.169	.0016
2	.0043	.497	.057	3, 4	.112	.0034
3	.0025	.784	.035	4	.077	.0020
4	.0032	1.19	.077	—	0	.0026

ROUND $T_c + \Sigma T_t$ to use charts

(1) T_c .62 (.75) .5 .5
ΣT_t .169 (.1) .2 .2
Sum .789 (.85) .7 .7

(2) T_c .497 (.5)
ΣT_t .112 (.1)
Sum .609

(3) T_c .784 1.00 (.75) .75
ΣT_t .077 0 (.1) .1
.861

(4) T_c 1.19 (1)
ΣT_t 0 (0)
Sum 1.19

FIND VALUES, Type 2 STORM $I_a/P = .3$

SUBAREA	T_c	ΣT_t	$A_m Q$	12.4	12.5	12.6	12.7	12.8	13.0	13.2
1	.75	.1	.0016	.10	.22	.36	.47	.53	.48	.36
2	.5	.1	.0034	.84	1.26	1.41	1.33	1.12	.74	.51
3	.75	.1	.0020	.13	.27	.45	.58	.66	.61	.46
4	1.0	0	.0026	.08	.17	.29	.44	.57	.73	.68
				1.15		2.51	2.82	(2.88)	2.56	

PEAK FLOW IS 2.88 CFS AT 12.8 HRS

DESIGN DRAINAGE SWALE

ASSUME MANNINGS ROUGHNESS COEFFICIENT = .018.

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2}$$

MANNING'S FLOW EQUATION FOR OPEN CHANNELS

Q = FLOW, CFS
n = MANNING'S ROUGHNESS COEFF.
A = AREA OF FLOW, FT²
S = slope of energy grade line (FT/LIN. FT OF CHANNEL), ≈ .004
R = HYDRAULIC RADIUS = FLOW AREA / WETTED PERIMETER

$$Q = \frac{1.49}{n} \frac{A^{5/3}}{P^{2/3}} S^{1/2}$$

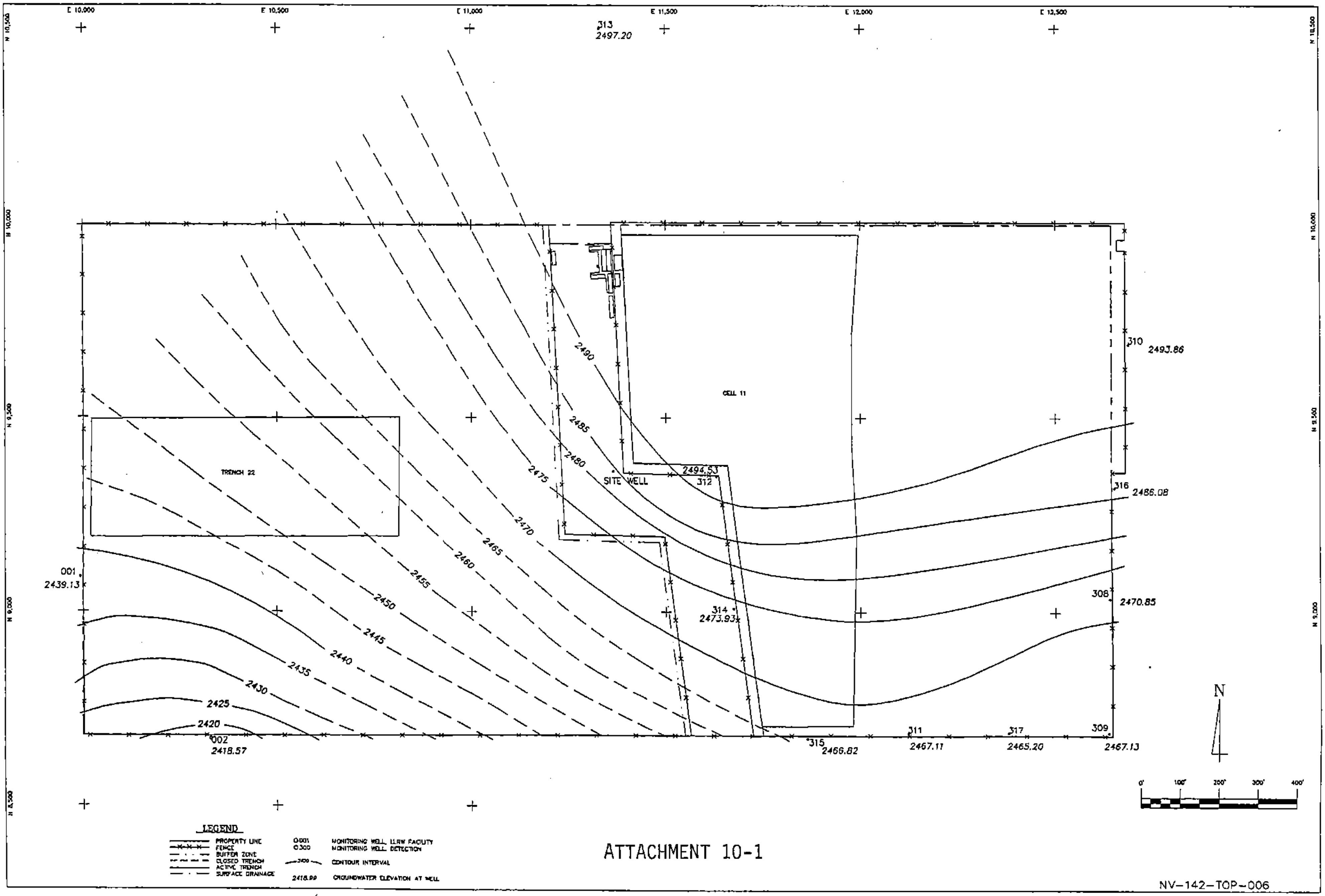
USE TRAPEZOIDAL SWALE

DESIGN Q	S	SWALE SIDE SLOPES	FLOW DEPTH	CALCULATED Q (CFS)	VELOCITY (FPS)
3	.004	10	.5	5.14	2.06
	.004	15	.4	4.26	1.77
	.004	20	.4	5.68	1.77
	.004	25	.3	3.29	1.46

ANY OF THESE CROSS-SECTIONAL AREAS WOULD SATISFY THE DESIGN REQUIREMENTS. THE FINAL SELECTION OF THE DRAINAGE SWALE DESIGN WILL BE BASED UPON SITE CONDITIONS AT THE TIME OF CLOSURE.

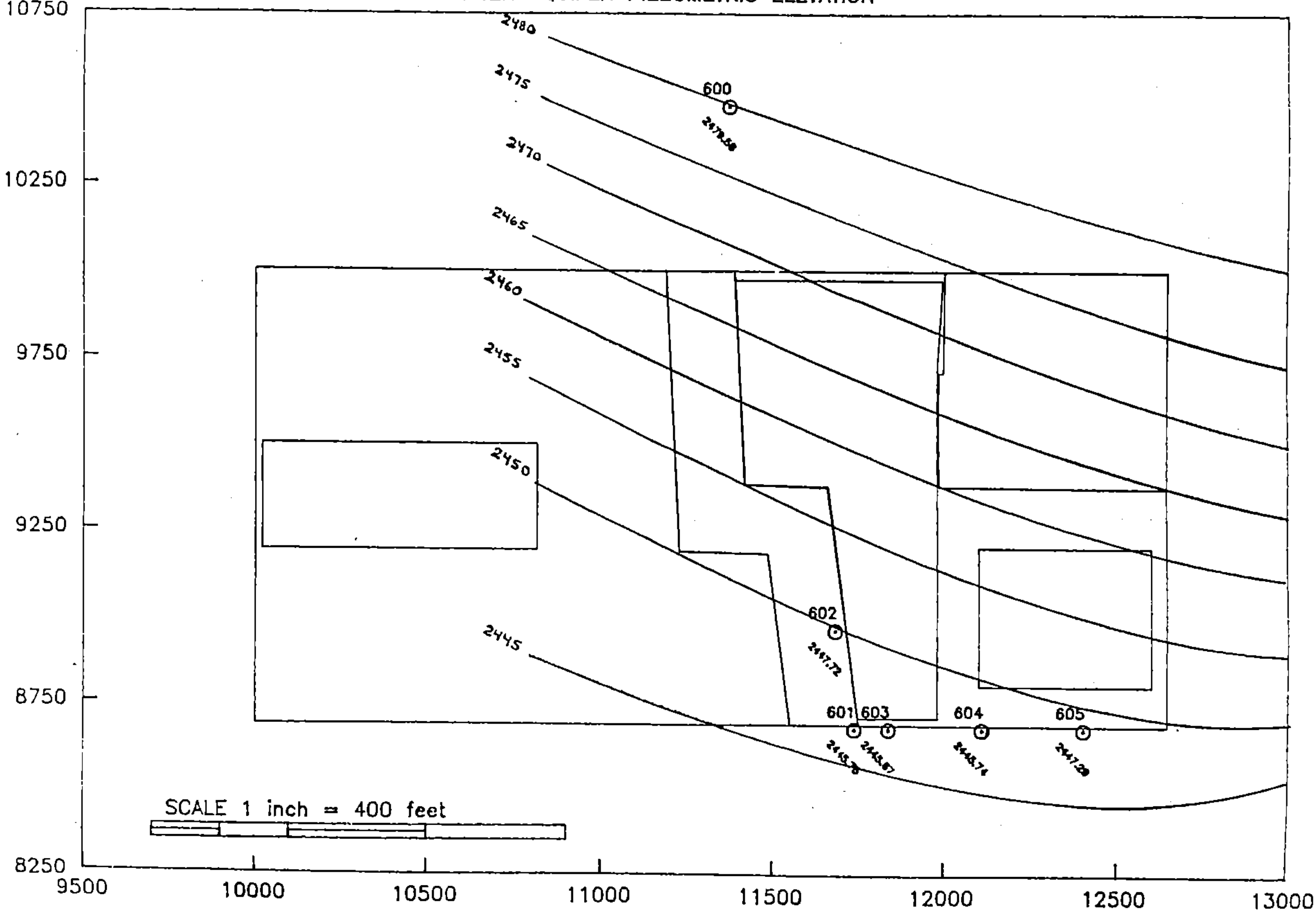
WATER TABLE ELE_ATION MAP
FRIST QUARTER 1992

HAZARDOUS WASTE MANAGEMENT FACILITY
US Ecology, Inc.
BEATTY, NEVADA



BEATTY, NEVADA FACILITY

LOWER AQUIFER PIEZOMETRIC ELEVATION



DECEMBER 1991

ATTACHMENT 10-2

UNSATURATED-ZONE INSTRUMENTATION IN COARSE ALLUVIAL DEPOSITS OF THE AMARGOSA DESERT NEAR BEATTY, NEVADA

David S. Morgan and Jeffrey M. Fischer
U.S. Geological Survey, Carson City, Nev.

ABSTRACT

An unsaturated-zone monitoring shaft near Beatty, Nev., is 1.52 m in diameter and penetrates nearly 14 m of unsaturated fluvial sediments. These sediments comprise silty sand, coarse sandy gravel, and poorly cemented sand, with gravel and scattered cobbles and boulders. Thirty-three lateral ports at 11 levels between 3 and 13 m deep allow access to undisturbed sediments outside the vertical shaft. The prefabricated metal shaft was emplaced in a 2.44-m-diameter hole excavated by using a crane drill with bucket and flight augers.

Laboratory-calibrated thermocouple-psychrometers are being used to measure soil-matrix potential. A method of installing the psychrometers was developed that allows their retrieval, after extended periods in the soil, for cleaning, recalibration, and reinstallation. Primary access holes 2.5 cm in diameter were drilled laterally outward from the monitoring shaft to a distance of approximately 4 m. The psychrometer was then inserted into the primary access hole and sealed into a smaller diameter boring in the undisturbed material at the outer end of the primary access hole.

Data are collected and stored by a programmable measurement control and data-logger system powered by photovoltaic cells. Magnetic-tape data storage is used to back up daily data retrieval via telecommunication with the project headquarters in Carson City, Nev., 520 km north of the study site.

INTRODUCTION

The first commercially operated burial site in the United States for low-level radioactive waste was opened in 1962 near Beatty, Nev. Prior to 1962, waste was either disposed of at sea or buried at federally operated sites. Burial in shallow trenches is widely considered to be the most viable means of isolating low-level radioactive waste from the biosphere because it is a relatively inexpensive and somewhat effective means of keeping radioactivity from becoming a public hazard. The effectiveness of waste isolation by shallow burial depends on a number of factors, including: waste type and form, trench-cap engineering, and local hydrologic and geologic conditions.

The most universal threat to burial-site integrity is posed by water, which may infiltrate the trench cap and transport radionuclides away from the site in the subsurface, or erode the site and transport radionuclides in surface water. Recognizing the importance of water to the long-term stability of radionuclide containment, emphasis has been placed on locating sites in arid areas where maximum reliance may be placed on the natural system to provide containment (1). No complete, fully accepted and tested guidelines or criteria exist for siting disposal facilities in an arid environment.

Evaluation of the Beatty site and other existing or proposed burial sites in arid regions depends on the development of reliable methods of collecting data within the unsaturated zone that will allow determination of the rate and direction of soil-water movement. The geologic and hydrologic conditions at the Beatty site present serious obstacles to the collection of good-quality data. Sediments throughout most of the 85-m-thick unsaturated zone are extremely dry and heterogeneous and contain pebbles and cobbles. Conventional soil sampling and measuring techniques cannot be applied without modification.

OBJECTIVES AND SCOPE

Determination of the suitability of the existing site and the development of criteria for future site selection are the long-term objectives of this study. Successful completion of these goals depends on our ability to estimate the downward rates of soil-water movement in heterogeneous soils. These rates will suggest the maximum rate of radioactive-solute transport in the unsaturated zone and the maximum volume of water available for leaching within the trenches. The prerequisite objective thus becomes the development of suitable instrumentation and sampling methods.

The purpose of this paper is to describe methods of installing instrumentation and measuring soil-matrix potential that are being evaluated at an experimental site adjacent to the Beatty waste-disposal site. At this stage, the research is designed to determine if instrumentation techniques can be developed for the unsaturated zone in coarse desert alluvium and whether the instruments can be used with confidence. Described below are the design, construction, and initial instrumentation of a vertical monitoring shaft that penetrates the upper 13.7 m of variably saturated sediments. A method of installing thermocouple-psychrometers that allows their future removal for inspection, recalibration, and eventual re-installation is presented. The success of the installation-and-retrieval procedure is critical for evaluating the reliability of psychrometer measurements over extended periods of time.

LOCATION AND HYDROGEOLOGIC SETTING

The low-level radioactive waste burial facility is on the Amargosa Desert 17 km southeast of Beatty and 169 km northwest of Las Vegas, Nev. (figure 1). The monitoring shaft is approximately 50 m south of the southwest corner of the burial site.

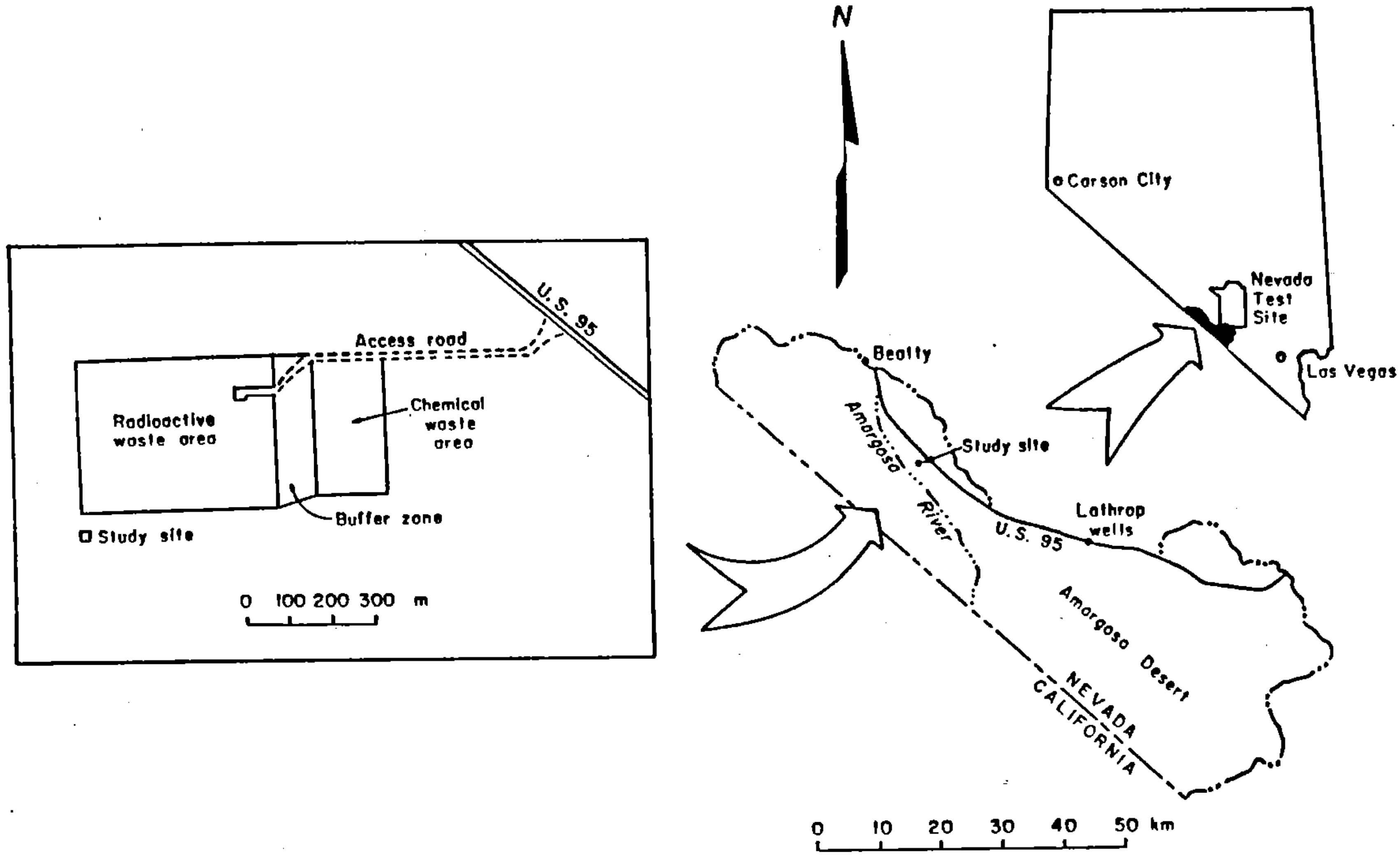


Figure 1. Location of study site.

The Amargosa Desert lies in a northwest-trending valley that is about 13 km wide near the waste-disposal site. The south-flowing Amargosa River is the main drainage in the valley, but it is dry most of the year except along a short reach near Beatty where it is fed by springflow. Sparse vegetation covers the gently undulating valley floor, which is dissected by a number of shallow, dry washes. Most of these washes are tributary to the Amargosa River.

The Amargosa Desert is one of the more arid areas of the United States. Mean annual precipitation ranges from 11.4 cm/yr at Beatty, to 7.4 cm/yr at Lathrop Wells. Seasonal, annual, and spatial variation can be considerable.

Carbonate and clastic sedimentary and metasedimentary rocks form the mountain ranges bounding the Amargosa Desert. The valley floor is underlain by at least 170 m of unconsolidated to weakly indurated alluvial-fan, fluvial, and playa deposits (2). Approximately 85 m of mostly unsaturated sediments underlie the burial site. Mineralogic and stratigraphic evidence strongly suggests that the poorly sorted mixture of boulders, gravel, sand, silt, and clay within the upper 30 m at the waste-burial site is primarily of fluvial origin (3). Below a depth of 30 m, lake- and debris-flow deposits predominate and gravel is less pervasive.

The material within the upper 15 m is horizontally stratified with extreme variation in texture. Some strata consist of medium sand or loamy sand within which 95 percent of the clasts are estimated to be less than 2 mm in diameter. Other strata consist of approximately 90 percent gravel in a loamy-sand matrix. Much of the gravel is 1 to 10 cm in diameter (4). The materials below 2 m are compact, firm to moderately hard when dry, and non-calcareous, suggesting silica cementation. Above a depth of 2 m, the materials are completely unconsolidated due to a composition of approximately 90 percent gravel (1-5 cm) in a matrix of fine silt and clay.

The saturated ground-water flow system is poorly understood in the northern Amargosa Desert due to the scarcity of deep wells. A carbonate-rock aquifer (5) underlies most of the Nevada Test Site and the southern Amargosa Desert, and it is presumed to underlie much of the northern Amargosa Desert, including the valley fill at the monitoring shaft. The regional hydraulic gradient in the area is to the southeast (references 3 and 5, and data from two deep Geological Survey exploratory wells within 3 km of the monitoring shaft).

Very dry conditions prevail throughout most of the unsaturated zone. Volumetric moisture contents of soil within the upper 4 m ranging from 4 to 10 percent were determined by Nichols (3) by using standard oven-drying techniques. At depths as great as 42 m, volumetric moisture contents ranging from 4 to 17 percent have been measured (6). The effects of existing organic matter on these measurements is unknown but probably minimal. Additional data from Nichols show that soil-matrix potentials between 3 and 10 m below land surface range from -10 bars to -70 bars. Water budgets developed by Nichols demonstrate that a potential exists for deep percolation (despite high evaporative demands) if the soil-moisture deficit is partly satisfied by proper antecedent conditions.

DESIGN AND INSTALLATION OF THE MONITORING SHAFT

The 13.7-m monitoring shaft was designed to allow access to an undisturbed vertical profile within the unsaturated zone. A vertical drill hole above a buried instrument could greatly alter the natural moisture conditions even if carefully backfilled. By installing the instrumentation through holes drilled laterally from the monitoring shaft, disturbance of the vertical soil column above the measuring point was avoided.

The metal shaft, which is 1.52 m in diameter and 14.3 m long, was prefabricated by a contractor and shipped by truck to the study site. The monitoring shaft is shown in cross-sectional and plan views in figure 2. Three access ports are located at each of 11 levels between 3 and 13 m below land surface. The three ports, of 30-cm diameter, radiate outward within a 90-degree quadrant of the monitoring shaft at each level (figure 2).

A crane drill equipped with both bucket augers and flight augers was used by the contractor to excavate the hole for the metal shaft. A pilot hole was first augered to full depth and subsequently enlarged by alternately using the flight augers and bucket augers to ream and clean the hole out. Surface casing 2.44 m in diameter had to be used to prevent the upper 2.4 m of loose, gravelly material from caving. The final diameter of the hole below the surface casing was approximately 2.1 m, which left an annular space of about 0.3 m between the hole wall and the outside of the metal shaft. After the metal shaft was lowered into the hole, the annular space at each access port was bridged by a horizontal 30-cm length of casing which was driven through a 30-cm diameter hole in the shaft wall until it abutted the hole wall, and was then welded in place (see figure 3). Finally, the remaining annular space was filled with clean, dry sand. Where the sand backfill was exposed at land surface (between the edge of the surface casing and the outside of the shaft) it was sealed with a layer of concrete 8-10 cm thick to retard infiltration.

Five detachable, hinged work platforms are located at approximately 2.7-m intervals within the shaft. Movement between the platforms and the access ports is facilitated by two aluminum ladders on opposite sides of the shaft. The two ladders may also be used to support a small scaffolding at levels between platforms. The casing ranges in thickness from 0.635 cm in the upper 11.3 m to 0.794 cm in the lower 3.0 m. When workers are in the shaft, ventilation is supplied via a duct of 25.4-cm diameter, which is open at the bottom of the shaft and connected at the top to a 50-m^3/min blower. The shaft is covered at the top by a domed roof of 2.44 m in diameter. The edges of the roof are turned up to intercept precipitation that might otherwise result in greater-than-normal infiltration near the shaft. The intercepted precipitation is allowed to evaporate or it may be manually drained from the roof. The diameter of the roof is approximately the same as that of the area disturbed by installation of the shaft; thus, only the precipitation which would otherwise fall on this area is intercepted. A hatch in the domed roof provides access to the shaft. The entire dome may be removed if neccessary, however, to lower large pieces of equipment into the shaft. Heavy equipment, such as the drill used to construct the lateral holes, was lowered into the shaft using an electric winch and a tripod over the shaft.

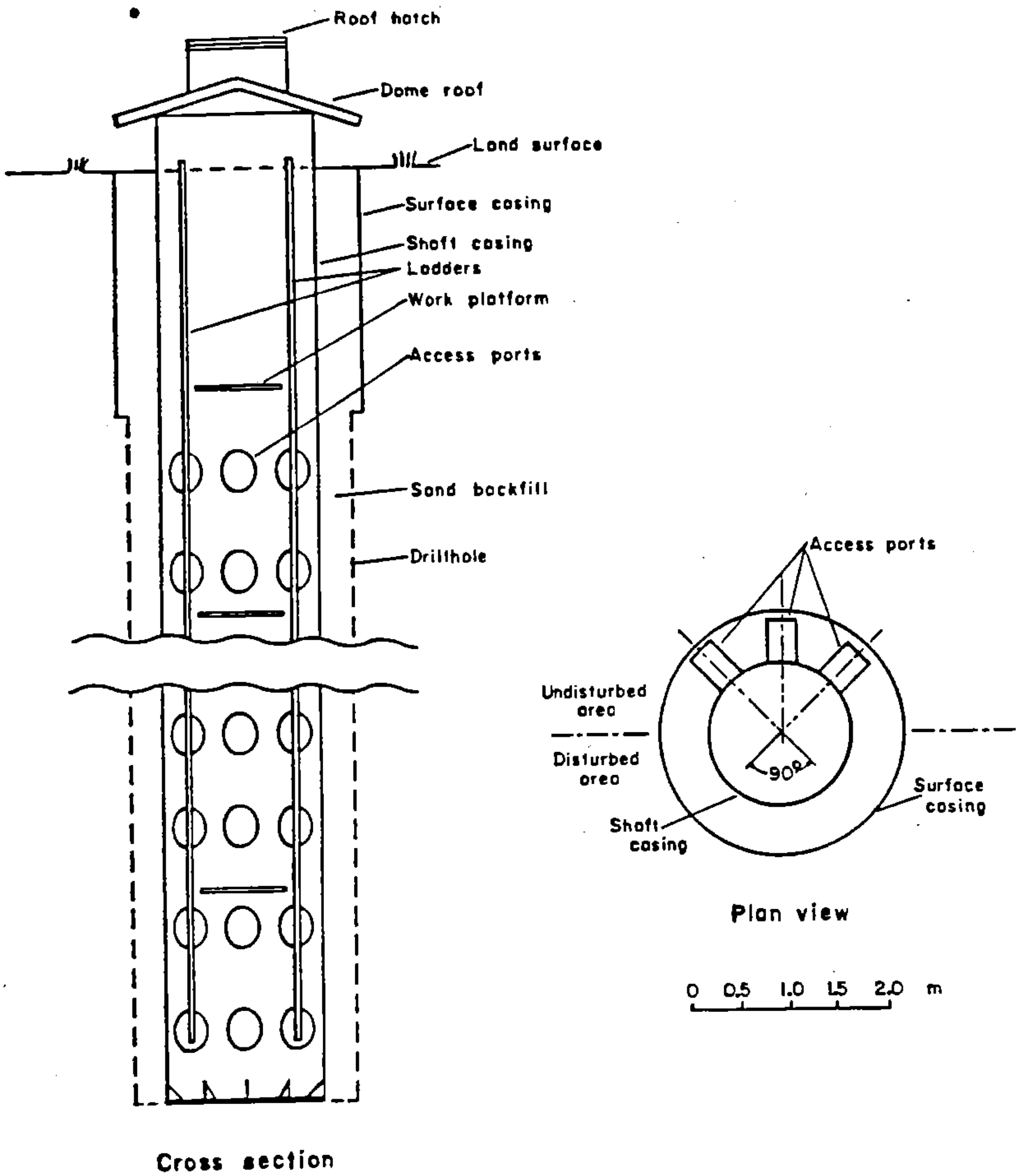


Figure 2. Cross-sectional and plan views of the vertical monitoring shaft.

An undisturbed area was maintained on one side of the shaft site where no foot or vehicle traffic was allowed. When installed, the monitoring shaft was oriented with the access ports facing this area so that moisture movement under conditions of natural vegetative cover and soil compaction could be studied. A 23-m by 38-m rectangular area surrounding the shaft was enclosed by a cyclone fence to discourage vandalism and preserve the natural vegetation and soil-surface conditions.

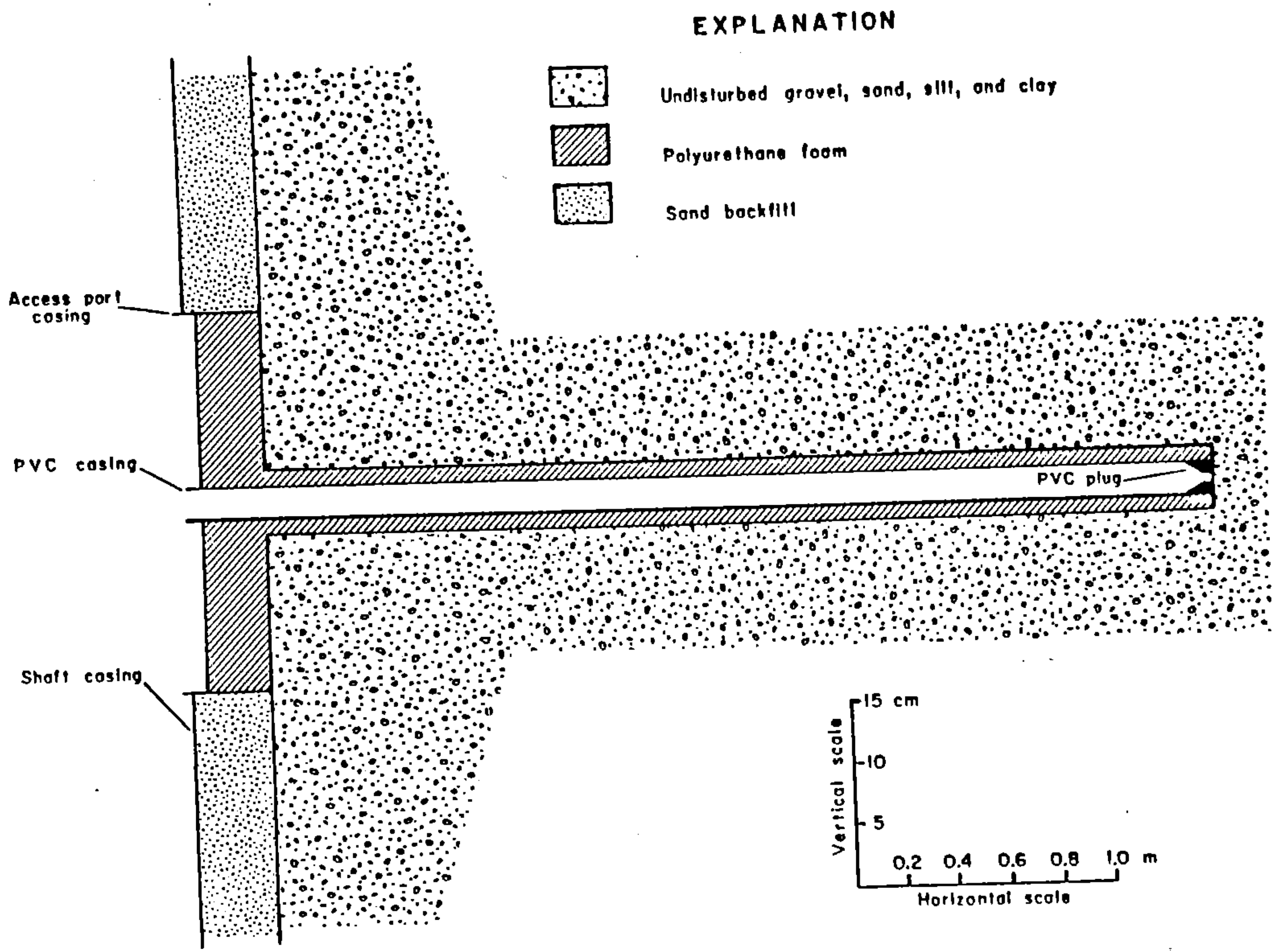


Figure 3. Vertical cross-sectional view of a completed primary access hole.

Access ports are utilized independently to monitor lateral and vertical soil-water movement within the undisturbed profile, under experimental and natural conditions. The installation of thermocouple-psychrometers described in this paper is restricted to one of the three columns of ports. The drilling procedure and technique for completing and instrumenting the lateral holes is described in the following section.

INSTRUMENTATION

Instrument recoverability was an important objective in designing a method of installation. Previous studies have shown that the reliability of thermocouple-psychrometers can be poor in the field (7). Perhaps more importantly, the calibration curve of psychrometers can shift after lengthy exposure to soil moisture and corrosive salts; this makes recoverablility essential so that calibration curves may be checked in the laboratory and field data verified.

Perturbations of the natural soil-temperature conditions can be significant near the monitoring shaft. Lateral temperature gradients and seasonal variations induced by a similar monitoring shaft have been measured at distances as much as 1.8 m from the shaft wall (E. P. Weeks, U.S. Geological Survey, oral commun., 1983). Geohydrologic conditions at the site studied by Weeks are closely similar to those found at Beatty. These temperature effects can cause alteration of the soil-matrix potential (8). The effects of temperature variation have been minimized at the Beatty site (1) by drilling the lateral access holes well beyond the probable range (1.8 m) of significant temperature variation induced by the shaft, (2) by backfilling the annular space around the shaft with sand, which acts as a thermal barrier, and (3) by filling the access ports with an insulating foam seal.

Access to undisturbed soils adjacent to the monitoring shaft was gained by first drilling a 5-cm-diameter primary access hole to a distance of approximately 4 m from the inner wall of the shaft. The holes were drilled using an air-powered blast-hole drill with flush-joint drill pipe and a diamond-impregnated casing shoe. Air was used as a circulation fluid so that no liquid was introduced during the drilling process; the circulation air, as well as the air needed to power the drill, was supplied by a compressor of 17-m^3/min capacity. This drilling method produced good results because the high torque of the drill allowed continuous rotation even when loose gravel and cobbles lodged between the hole wall and the drill pipe. Also, a large volume of air was available to force the rock fragments out of the drill hole.

At each access port, the 30-cm-diameter pipe that bridges the annular space was filled with a 20- to 25-cm-thick "plug" of polyurethane foam sealant. This seal serves two purposes: It prevents surface caving when the primary access hole is drilled, and it helps to thermally isolate the shaft interior from the adjacent soil.

If left uncased, the lateral holes would collapse, making it impossible to remove instruments without damaging them. To insure that the instruments could be recovered from the loose, unconsolidated soils, the primary access holes were completed with flush-coupled PVC (polyvinyl-chloride) casing of

2.54-cm inside diameter (ID). With the drill pipe still in place after drilling outward to a distance of 4 m from the shaft wall, the PVC casing was inserted through the drill pipe and the drill pipe was then withdrawn. The annular space between the PVC casing and the hole wall was then sealed with polyurethane foam. The foam was forced through a small-diameter tube inserted into the annulus. The tube was slowly withdrawn as the injected foam expanded to fill the annular space and provide a hard, airtight, thermally insulating seal. A completed primary access hole is shown in figure 3.

Once a primary access hole was completed, an approximately 9.5-mm-diameter hole was drilled 10 to 15 cm beyond the end of the PVC casing to house the psychrometer in the previously undisturbed soil. A 2.54-cm-diameter PVC plug was glued into the end of the PVC casing (see figures 3 and 4) prior to installation. An inverted cone-shaped depression in the outer end of the plug (figure 4), which reduces to a diameter of 10 mm, acted as a centering guide for the 9.5-mm-diameter masonary drill bit, and later for the psychrometer assembly. Drill cuttings were removed with a vacuum hose.

To install the psychrometers it was neccessary to mount them in semirigid, 9.5-mm-diameter plastic tubing. The psychrometer base was sealed tightly into the end of the tubing, leaving only the tip exposed. The wire leads are protected within the tubing, which extends back to the shaft interior (figure 4). Tubing and psychrometer fit snugly into the 9.5-mm-diameter psychrometer hole at the end of the PVC casing. In addition to protecting the psychrometer and wires, the rigid tubing allows the psychrometer to be pushed into place during installation or pulled out for maintenance. Another PVC plug was placed on the tubing approximately 16-20 cm from the psychrometer tip. The inside end of this plug fits precisely into the inverted cone-shaped depression in the centering plug at the end of the PVC casing. Together they form a tight seal between the psychrometer hole and the primary access hole. A rubber O-ring between the two plugs helps to insure the integrity of this seal. The seal was tested by pressurizing the PVC casing.

Psychrometric measurements were made in the field and in the laboratory during calibration using a programmable measurement-control and data logger system. In the field, the system is powered by photovoltaic cells and a rechargeable battery. The telecommunications capability of the system allows remote data retrieval, reprogramming, and function checking from the project headquarters 520 km north in Carson City, Nev.

All psychrometers were calibrated in the laboratory before installation in the field. Many factors influence the electromotive force output of a psychrometer. Due to the minute size of the manufactured components, no two psychrometers have exactly the same chamber and thermocouple geometry. More importantly, the psychrometer output and the soil-matrix potential both vary with temperature in a highly nonlinear manner (9). For accurate results, each psychrometer must be calibrated for the range of temperatures and matrix potentials likely to be experienced in the field. All psychrometers used in this study are of the screen-caged, Spanner type. They were calibrated by using the procedure described in (9). Test tubes were lined with filter paper saturated with potassium-chloride solutions representing matrix potentials from -8 to -75 bars (10). Each psychrometer lead was

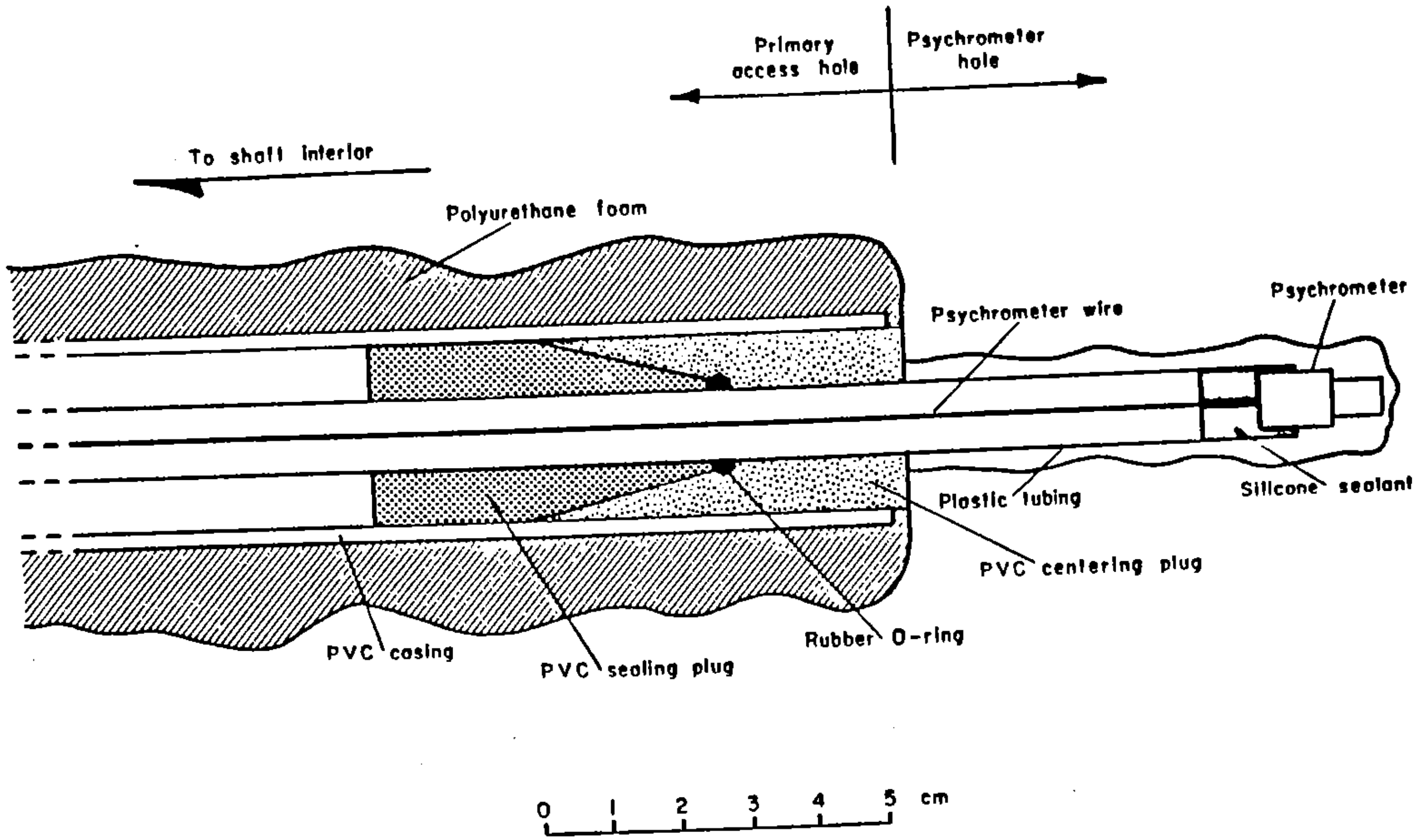


Figure 4. Schematic cross-sectional view of psychrometer installation.

fitted through one hole of a two-hole rubber stopper, which was then firmly inserted into the test tube. The second hole was left open to prevent the development of pressures greater than atmospheric within the calibration chamber. The entire test tube was waterproofed with a silicon sealant, as shown in figure 5, then placed in a constant-temperature water bath and allowed to equilibrate for at least 10 hours.

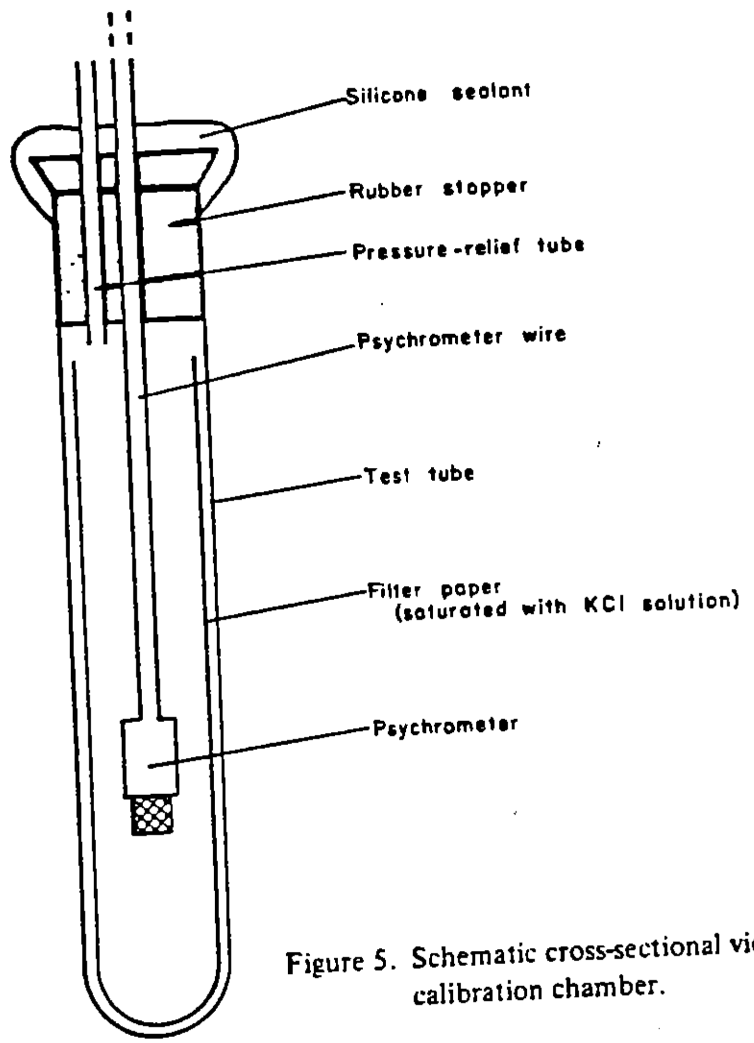


Figure 5. Schematic cross-sectional view of psychrometer calibration chamber.

When equilibrium was achieved, water-potential measurements were made using the Peltier effect (10). A 5-milliamp cooling current was applied for 30 seconds to condense water on the thermocouple junction. Five seconds after the cessation of the cooling current, readings were taken. Each psychrometer was measured at five temperatures (between 5° and 25°C) and five matrix potentials (between -8 and -75 bars), for a total of 25 measurements. Measurements were repeated hourly for 14 hours at each temperature and potential. A typical calibration curve is shown in figure 6. The largest variance from the mean was ± 0.06 microvolt. As shown in figure 6, the variation in microvolt readings is small for a single psychrometer. Three standard deviations, representing 99 percent of the population, would not change readings by more than a microvolt, which is equivalent to an accuracy of ± 2 bars.

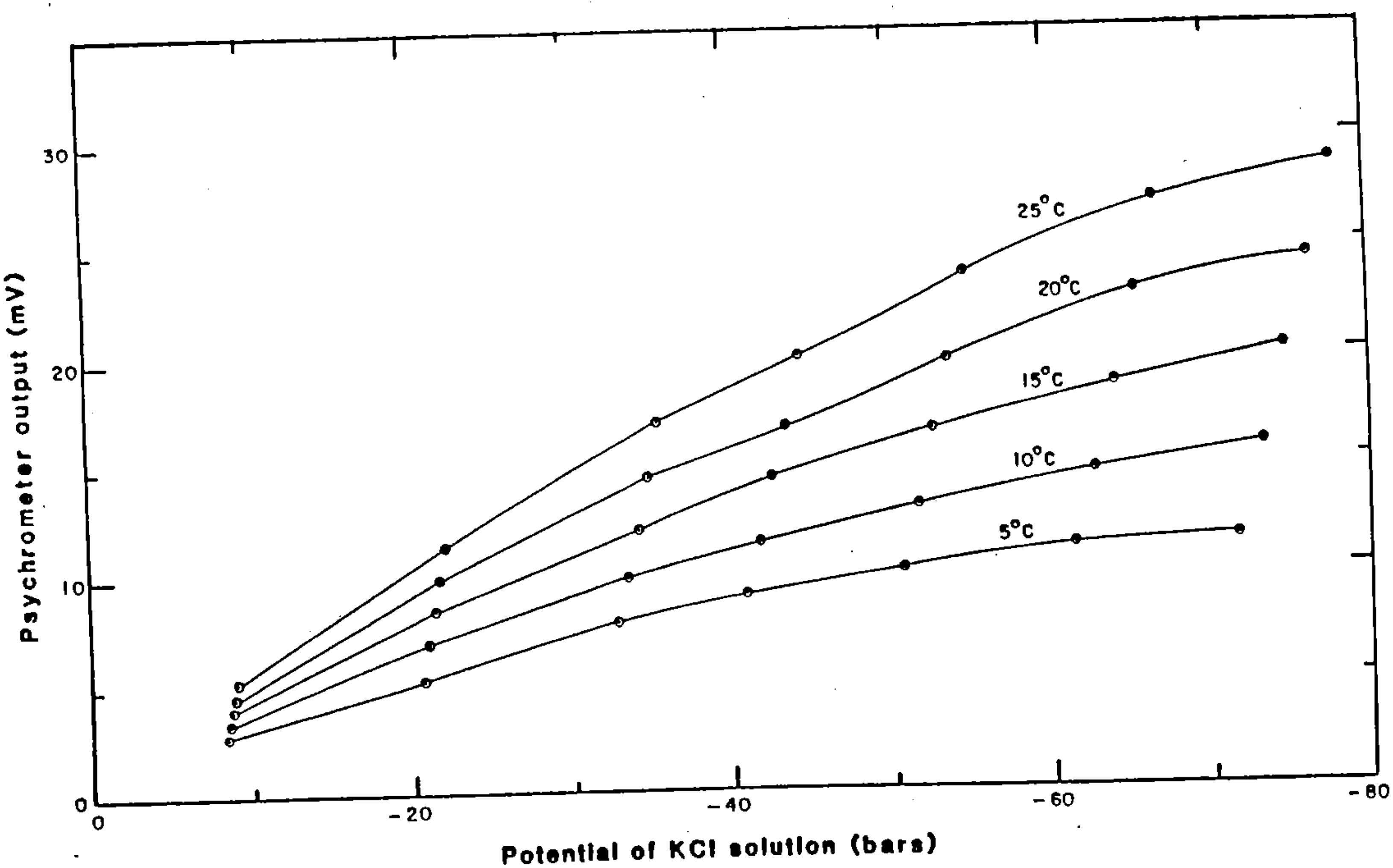


Figure 6. Typical psychrometer calibration curves for 5° intervals between 5° and 25°C.

SUMMARY AND CONCLUSIONS

Specialized methods are required to sample from, and make *in situ* hydrologic measurements within, coarse alluvial deposits in arid regions. One hydrologic property which must be measured accurately in the field in order to estimate the rate and direction of soil-water movement within the unsaturated zone is the soil-matrix potential. Where dry conditions prevail and potentials are less than -2 bars, thermocouple-psychrometers must be used. The reliability and accuracy of psychrometric measurements of soil-matrix potential depends to a great extent on proper preinstallation calibration, installation, and calibration checking after extended periods in the soil.

A method of psychrometer installation that allows later retrieval is being evaluated at a study site near the low-level radioactive-waste disposal facility near Beatty, Nev. If the method is successful, psychrometers installed laterally from a vertical monitoring shaft will be used to determine the vertical soil-matrix potential gradient. These data, together with data on unsaturated hydraulic conductivity and moisture content, will be used to estimate the rate and direction of soil-water movement under natural conditions. The psychrometers will be removed at regular time intervals and the accuracy of their calibration checked to determine the maximum residence time during which accurate measurements are possible. If this residence time proves to be sufficiently long, perhaps less extraordinary methods of installation (which do not allow retrieval) can be used for future work.

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6. Law Engineering and Testing Company, Geohydrologic studies--Beatty, Nevada, Disposal Facility: Project Number 610020.02, 1981, 26 p.

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9. Meyen, R. L., and White, R. S., Calibration of thermocouple psychrometers: A suggested procedure for development of a reliable predictive model, *in* Brown, R. W., and Van Havern, B. P., eds., Psychrometry in water relations research: Proceedings of the Symposium on Thermocouple Psychrometers, March 17-19, 1971, Utah State University, 1972, p. 56-64.

10. Brown, R. W., and Van Havern, B. P., eds., Psychrometry in water relations research: Proceedings of the Symposium on Thermocouple Psychrometers, March 17-19, 1971, Utah State University, 1972, 342 p.

LEASE

This agreement made and entered into this 1st day of May, 1977, by and between the State of Nevada, Department of Human Resources, hereinafter called "LESSOR," and Nuclear Engineering Company, Inc., hereinafter called "LESSEE," a corporation duly organized and existing under the laws of the State of California, authorized to do business in the State of Nevada, having its registered office in Beatty, Nevada, and authorized to engage in the business of receiving, possessing, processing, repackaging, using, storing and disposing of radioactive wastes and materials by License No. 04-3766-01 issued by the Nevada State Health Division, and being further authorized by appropriate permit issued in accordance with applicable provisions of law to engage in the disposal of chemical and toxic wastes and materials.

WITNESSETH:

WHEREAS, LESSOR has determined that a facility for the disposal of low-level radioactive waste materials may be maintained in the State of Nevada; and

WHEREAS, LESSOR has determined that a facility for the disposal of chemical and toxic waste and materials may be maintained in the State of Nevada; and

WHEREAS LESSOR has procured certain real estate hereinafter referred to as the "Site";

NOW, THEREFORE, in consideration of the payments reserved herein and the mutual covenants made by the parties, it is agreed as follows:

I. RENTAL-LICENSE FEE. For and in consideration of the terms, covenants, payments, conditions and restrictions hereinafter set forth, the LESSOR, pursuant to Chapter 374 of the 1961 Statutes of Nevada, does hereby lease, let and demise unto LESSEE, the following described premises situate in the County of Nye, State of Nevada, more particularly described as follows, to wit:

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All that certain piece, parcel or tract of land located in the NW1/4 NE1/4; NE1/4 NW1/4 of Section 35, Twp. 13 South, Range 47 East, M.D.B.&M. containing 80 acres, more or less.

To have and to hold unto the LESSEE for the term of twenty (20) years from the effective date hereof, with the option to extend for an additional term as hereinafter set forth, unless sooner terminated in accordance with the terms of this lease, at a yearly rental of ten thousand ($10,000.00) per year, the first annual payment acknowledged, and succeeding payments to be payable annually within twenty (20) days after the anniversary date of this lease. The rental payments shall be payable to the LESSOR; provided, however, that in the event regulations are promulgated establishing a license fee for the issuance of a license to dispose of low-level radioactive waste it is acknowledged and agreed that LESSEE shall have as a full credit against the payment of the aforestated license fee any and all rental fees previously paid under this lease. Further, LESSOR and LESSEE agree that upon the establishment of a license fee that LESSEE'S responsibility for payment of any and all rental fees, as set forth in this lease, shall immediately cease and the rental fee terms contained herein shall be null and void at that time.

II. <u>RENEWAL OF LEASE</u>. The term of this lease shall be extended for an additional ten (10) year term if, prior to six (6) months before the end of the term but not before nineteen (19) years from the effective date of this lease, the LESSEE makes written request to the LESSOR that it wishes to exercise its option to extend under this paragraph. The LESSOR may, notwithstanding LESSEE'S option herein, declare the lease terminated at the end of the initial term if, after consultation with the State Health Officer, it makes a reasonable determination that, considering the volume of waste materials buried at the Site and the available space remaining, that an extension for an additional term would not be feasible. The LESSOR may, however, extend the lease for a term less than ten (10) years if, after consultation with the State Health Officer, it determines that such an extension is feasible, considering the factors hereinbefore set forth. The LESSOR'S determination of feasibility under this paragraph is subject to review by the State Board of Health.

III. OPPORTUNITY FOR HEARING. Prior to the issuing of any order or the making of any determination including but not limited to the denial, modification or revocation of this lease the LESSOR and the State Board of Health shall give reasonable notice in writing by certified mail to the LESSEE and shall afford the LESSEE an opportunity for a hearing within twenty (20) calendar days after giving the aforesaid notice.

IV. ASSIGNMENT. The LESSEE may not assign the lease, nor any right inuring to its benefit by virtue of any term or covenant herein set forth, without prior written approval of the LESSOR. For purposes of this paragraph a sale or change of Corporate ownership directly affecting this lease shall be deemed an assignment requiring prior written approval by LESSOR as to the technical competence of the assignee to assume burial operations, it being understood and agreed that technical competence shall, as a minimum, be deemed legal and factual capability for successfully obtaining and carrying out lawful activity under either a license issued in accordance with law for the receipt, storage and disposal of low level radioactive waste, or a permit for the disposal of chemical and toxic waste materials. The parties acknowledge and agree that the LESSOR shall not unreasonably withhold its approval of any proposed assignment by LESSEE.

The LESSEE agrees that it will not, without the written consent of the LESSOR, sublet the premises or any part thereof or permit the use of the premises by any party other than the LESSEE.

V. TERMINATION. The LESSOR and LESSEE agree that the primary purpose for which this lease is entered into is the proper burial and disposal of radioactive and chemical and toxic wastes and materials and any other activity which may lawfully be carried out under the terms of License No. 04-3766-01 or any other provision of Nevada Revised Statutes. The parties, therefore, expressly agree that the portion of the lease providing for the disposal or burial of radioactive waste may, at the option of the LESSOR, terminate after hearing and opportunity for judicial review is afforded LESSEE in the event License No. 04-3766-01 and all amendments thereto or any renewal thereof expires without timely application for renewal thereof having been made or for any reason ceases to be effective.

VI. RENEWAL OF LICENSE. The LESSEE shall diligently and expeditiously provide the State Health Officer with information as required by law for processing any application LESSEE may submit for any renewal of its license issued under NRS Chapter 459. Failure on the part of the LESSEE to timely file an application for renewal in accordance with applicable State regulations, after notice to the LESSEE and reasonable opportunity to file following such notice, not to exceed thirty (30) days, may be deemed an expression of intent on the part of the LESSEE to voluntarily surrender the portion of the premises utilized for the disposal of low-level radioactive waste unto the LESSOR who may then declare that part of the lease terminated by serving written notice of its intent to terminate under this paragraph upon LESSEE. In no event, however, shall such an aforesaid voluntary surrender or termination of the LESSEE'S rights to dispose or bury low-level radioactive waste affect the portion of the lease that provides for the disposal of chemical and toxic wastes and materials and in that respect this lease shall continue in full force and effect.

VII. LIMITED TERMINATION--ADJUSTMENT OF BURIAL FEE. The LESSOR and LESSEE further agree that a termination or voluntary surrender of one of LESSEE'S rights to dispose of or store either low-level radioactive wastes or chemical and toxic wastes and materials shall not affect LESSEE'S right under this lease to continue to dispose of or store any of the other aforestated materials not so terminated or surrendered. LESSEE agrees that in the event it continues operations at either Site not so terminated or surrendured LESSEE will renegotiate a reasonable adjustment, if any, in the burial fee applicable to the Site retained by LESSEE.

VIII. COMPLIANCE WITH APPLICABLE LAWS. The LESSEE covenants and agrees that it will use the leased premises only for the purposes for which this lease is entered into and in all respects in accordance with the laws of the State of Nevada, and with the requirements specified in License No. 04-3766-01 and all amendments thereto or renewal thereof. It is expressly understood that the LESSEE shall comply with all applicable laws, rules and regulations of the United States, and all applicable regulations of the State of Nevada as the same are properly promulgated and amended from time to time by the Nevada State Board of Health and the Nevada State Environmental Commission. However, if the LESSEE is required to comply with any Federal or State laws, rules or regulations that render it prohibitive economically or otherwise, for LESSEE to continue its rights and obligations under this lease, the parties agree to immediately renegotiate those provisions of this lease affected by such laws, rules or regulations.

If, within ninety (90) days after LESSEE'S written request to renegotiate the lease, the parties fail to reach agreement, either party shall thereafter have the right to cancel this lease, within thirty (30) days.

IX. INSURANCE. The LESSEE shall provide adequate hazard and fire insurance at its own proper expense on all outbuildings, fixtures and other personal property situate on the leased premises, with loss payable provisions in favor of the LESSEE. The proceeds from any hazard or fire insurance shall be used by the LESSEE to replace all or so much of said outbuildings, fixtures or other personal property as may be economically reasonable and feasible.

X. REPAIRS. The LESSEE shall make all necessary repairs or improvements as may be economically reasonable or feasible to all outbuildings, fixtures and other personal property situate on the leased premises at its own proper expense.

XI. FEES FOR PERPETUAL CARE AND MAINTENANCE. The LESSEE agrees to pay LESSOR the sum of thirteen cents (13¢) for each and every cubic foot of low-level radioactive waste materials and seven cents (7¢) for each and every cubic foot of chemical and toxic waste materials which is disposed of or buried upon the described premises to provide funds for a perpetual care and maintenance trust fund as provided by law.

The amounts payable to LESSOR for the disposal or burial of low-level radioactive waste or chemical and toxic waste under this lease are for a term of ten (10) years from the effective date of this lease. At the expiration of each ten (10) year period the LESSOR and the LESSEE hereby agree to conduct a joint technical study to reevaluate the then existing conditions. Subsequent to the completion of the aforestated joint study should additional funds be determined necessary then the parties agree to renegotiate the cubic foot amounts payable to LESSOR; provided, however, LESSOR agrees that any increase in the amounts to be paid for each and every cubic foot of low-level radioactive waste or chemical and toxic waste disposed of or buried upon the premises shall not exceed one hundred percent (100%) of the then current rates.

XII. PREPAYMENT. LESSEE shall pay to LESSOR the sum of

FIFTY THOUSAND AND NO/100 DOLLARS ($50,000.00) which shall constitute a prepayment for the disposal and/or burial of radioactive, chemical and toxic wastes and materials on the heretofore described premises. All prepayments shall be deposited by LESSOR in the radioactive materials disposal fund as provided by law. The aforesaid prepayment shall be debited by LESSOR in accordance with the existing perpetual care and maintenance contribution rates and the monthly burial or disposal quantities for radioactive, chemical and toxic waste and materials. LESSEE shall provide additional prepayments when the balance of the deposit is equal to five percent (5%) of the original prepayment, notwithstanding that such prepayments may occur at intervals more frequent than on a yearly basis. Furthermore, LESSOR and LESSEE agree that LESSEE shall receive full credit and appropriate adjustments for any and all prepayments made prior to the execution of this lease document. In the event this lease is terminated for whatsoever reason, LESSOR agrees that LESSEE shall receive a full refund for any and all prepayment amounts not previously debited by LESSOR in accordance with all applicable provisions of this lease.

The LESSOR and LESSEE acknowledge and agree that the primary purpose of LESSEE's payment to LESSOR of the cubic foot charge on low-level radioactive, chemical and toxic wastes disposed of or buried at the Site is to provide funds for satisfactory surveillance in conjunction with the implementation of proper safeguards for the public health and safety upon expiration of the lease term or extension thereof and final closure.

XIII. MINIMUM BURIAL DEDUCTION. It is understood that the primary purpose for the assessment of the aforestated burial rate is to ensure the adequate growth of a perpetual care and maintenance fund.

In order to stimulate the growth of the perpetual care and maintenance fund, LESSOR shall deduct for any six(6) month operating period the minimum amount of TWELVE THOUSAND AND NO/100 DOLLARS ($12,000.00) from the burial prepayment as set forth in Section XII herein. The Minimum Burial Deduction amount will be adjusted at the end of each five (5) year calendar period during the term of this lease or any extension thereof. The adjusted minimum deduction amount will be computed by multiplying the annual average of the latest five (5) years' deposits by the then current contribution rates and said adjustment will be effective for the next succeeding five (5) year period.

The LESSOR agrees to make adjustments on a consecutive twelve month basis in the event actual revenue earned by the LESSOR falls below the minimum burial deduction; LESSEE shall receive a credit to the prepayment in the amount of the difference between the minimum burial deduction and the actual revenue earned. However, if the actual revenue earned by the LESSOR from collection of the burial rates set forth in Section XI exceeds the applicable minimum deduction set forth in the preceding paragraph, the actual revenue earned will be deducted from the prepayment set forth in Section XII.

LESSOR and LESSEE agree that LESSEE'S performance as set forth in this provision shall be excused for any month in the event of an act of God, war, riot; fire, lack of adequate fuel; power, labor, transportation; compliance with governmental requests, actions, laws, regulations, orders or action, or in the event of labor trouble, (provided that LESSEE shall not be required to settle a labor dispute against its own best judgment); or any other event beyond the reasonable control of LESSEE; which event prevents the delivery, transportation, acceptance or disposal of waste products.

<u>XIV. VIOLATIONS</u>. The LESSEE will not, without the LESSOR'S consent violate any of the terms and conditions of this lease, or the terms of authorizing licenses issued by the State of

Nevada. If such violations, misuse, or noncompliance occur, which result in lawful revocation of License No. 04-3766-01 or any amendment thereto or renewal thereof, the LESSOR shall have the right, upon written notice of its intention and after providing an opportunity to LESSEE for hearing as provided herein and judicial review, to terminate this lease solely as to that portion thereof providing for radioactive waste disposal.

XV. COMPENSATION TO LESSEE UPON TERMINATION. In the event of such termination of this lease as to that portion providing for radioactive waste disposal should LESSOR relet that portion of the Site to any other party for the same, similar, or allied use, LESSEE shall be entitled to reasonable compensation, including, but not limited to, any and all buildings and other Site improvements left thereon. In the event LESSOR and LESSEE cannot reach an agreement as to the amount of such compensation, the same shall be submitted to arbitration before an arbitrator appointed by the American Arbitration Association. The costs of said arbitration shall be borne equally by the parties.

XVI. WAIVER. The LESSEE agrees that the LESSOR's failure to insist upon the strict performance of any provision of this lease, failure to exercise any right based upon a breach thereof, or the acceptance by the LESSOR of any fees during such breach shall not waive any of the LESSOR'S rights under this lease except when the LESSOR has agreed in writing to waive such rights.

XVII. INDEMNITY. LESSEE agrees to indemnify and save LESSOR harmless from and against any and all claims, demands, suits, damages, expenses and liabilities brought by a third party to the extent that any injury to or death of any person or any damage to or loss of property arises out of the sole negligence of the LESSEE.

XVIII. CLOSURE REQUIREMENTS. Upon final legal termination, legal termination prior to expiration of the term of this

this lease, or formal voluntary surrender of LESSEE'S rights to store or dispose of low-level radioactive waste material, LESSOR and LESSEE acknowledge and agree that LESSEE shall perform the following activities as its sole closure obligation under this lease agreement:

(1) burial of all radioactive waste;

(2) removal of all surface structures and equipment except lighting equipment, fences and gates;

(3) all equipment and facilities which cannot be released by radiation survey after decontamination will be disposed of, or transported from the Site, as radioactive material;

(4) backfilling and mounding of all open trenches, without exception, in accordance with radioactive material license requirements;

(5) reduction of radiation levels to 2mR/hr at ground level within radioactive burial area;

(6) plugging and capping water wells and dry wells;

(7) the East access gate to the radiological burial facility will be sealed shut;

(8) installing alarms on all remaining gates which will activate in Deputy Sheriff's Office in Beatty when gate is opened;

(9) replacement of faulty or damaged fencing;

(10) replacement of any illegible or damaged warning signs; and

(11) final radiation survey and written report to LESSOR which is confirmed by LESSOR.

LESSOR shall reserve the right to waive any or all of the above Site closure conditions.

XIX. RESPONSIBILITY FOLLOWING TERMINATION. The parties hereby expressly agree that, subject to the closure requirements of the preceding paragraph, upon expiration or earlier termination of this lease, all materials buried at the Site prior to and subsequent to such expiration or termination shall be the sole and exclusive responsibility of LESSOR.

XX. ACCESS TO PREMISES. The LESSOR or any person authorized by it shall have access to the leased premises during LESSEE'S regular business hours, or any other time upon giving reasonable notice, for any lawful purpose.

XXI. SOVEREIGN AUTHORITY. It is understood that none of the terms of this lease, nor any of the covenants herein contained, shall operate to restrain the LESSOR from fulfilling its responsibilities in its capacity as sovereign of the State of Nevada, including, but not limited to, a determination on the part of the sovereign that a public emergency exists and that immediate State action be formally determined as necessary. Should the aforestated State action be formally determined as necessary, LESSOR shall, as provided in NRS 459.130 or any amendment thereto, upon LESSEE'S application, promptly afford LESSEE an opportunity to be heard and to present proof that such a condition or activity does not warrant the original determination.

XXII. HEARINGS. All hearings for all alleged violations under this lease other than those specifically stated otherwise or provided for by law shall be submitted to formal hearing before a qualified hearing officer appointed by the Department of Human Resources of the State of Nevada. Within twenty (20) days following the final conclusion of the hearing, the hearing officer shall make a report and ruling which shall contain findings of fact and conclusions of law. The hearing officer shall serve a copy of his report and ruling upon all parties of record to the proceeding.

Any party to the hearing may be represented by counsel, may make oral or written argument, offer testimony, cross-examine witnesses, or take any combination of such actions. The record of such hearing shall be open to public inspection.

<u>XXIII. NOTICES</u>. All notices, demands, requests, consents, approvals, cancellations and/or other communications which may be or are required to be given by either party to the other under this lease shall be in writing and shall be deemed to have been sufficiently given for all purposes when delivered or mailed by certified or registered mail, postage prepaid. Notices to the LESSOR shall be given by mailing to the State of Nevada, Department of Human Resources, Capitol Complex, Carson City, Nevada, 89710. Notice to the LESSEE shall be given by mailing to Nuclear Engineering Company, Inc., 9200 Shelbyville Road, Louisville, Kentucky, 40222.

<u>XXIV. HEADINGS</u>. The provision headings appearing in this lease have been inserted for the purpose of convenience and ready reference. They do not purport to, and shall not be deemed to define, limit or extend the scope or intent of the provisions to which they pertain.

<u>XXV. APPEALS</u>. It is understood that none of the provisions contained in this lease shall affect the LESSEE'S right to appeal any of the rulings or regulations of the LESSOR or the Nevada State Board of Health in the manner prescribed by law.

<u>XXVI. EFFECT OF LEASE</u>. Execution of this lease by LESSOR and LESSEE shall terminate and replace any presently existing lease between the LESSEE and any other party related to the premises described herein.

<u>XXVII. ENTIRE AGREEMENT</u>. This lease embodies the entire agreement between the parties. It may not be modified or

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terminated except as provided herein or by other written agreement between the parties.

IN WITNESS WHEREOF, the parties have hereunto set their hands the day and year in this lease first above written.

APPROVED THIS 12 day of May, 1977.

GOVERNOR OF THE STATE OF NEVADA

STATE OF NEVADA
DEPARTMENT OF HUMAN RESOURCES

ROGER S. TROUNDAY, DIRECTOR
LESSOR

APPROVED AS TO FORM THIS 6 day of May, 1977.
ROBERT LIST
ATTORNEY GENERAL

BY
D. MICHAEL CLASEN
DEPUTY ATTORNEY GENERAL

NUCLEAR ENGINEERING COMPANY, INC.

JAMES N. NEEL, PRESIDENT
LESSEE

(Corporate Seal)

Attest:

ASSISTANT SECRETARY

ADDENDUM AGREEMENT

This Addendum Agreement made and entered into this the seventh day of December, 1979, by and between the State of Nevada, Department of Human Resources, hereinafter called "LESSOR," and Nuclear Engineering Company, Inc., hereinafter called "LESSEE," a corporation duly organized and existing under the laws of the State of California, authorized to do business in the State of Nevada, having its registered office in Beatty, Nevada, and authorized to engage in the business of receiving, possessing, processing, repackaging, using, storing and disposing of radioactive wastes and materials by License No. 13-11-0043-02 issued by the Nevada State Health Division, and being further authorized by appropriate permit issued in accordance with applicable provisions of law to engage in the disposal of chemical and toxic wastes and materials.

W I T N E S S E T H:

WHEREAS, LESSOR and LESSEE entered into a Lease dated May 1, 1977, whereby LESSOR leased to LESSEE certain real property in Nye County, Nevada, hereinafter known as the "Site";

WHEREAS, LESSOR and LESSEE have determined that additional monetary consideration in the form of increased yearly rental payments need to be provided in order that LESSOR may further ensure that it has sufficient personnel to continue and administer its on-site surveillance of that portion of the Site pertaining solely to low-level radioactive waste; and

WHEREAS, LESSOR and LESSEE have mutually agreed to raise the per cubic foot Perpetual Care and Maintenance payments for low-level radioactive waste paid by LESSEE in order to further accelerate the growth of the Perpetual Care and Maintenance Trust Fund maintained by the LESSOR;

NOW, THEREFORE, in consideration of the payments reserved herein and the mutual covenants made by the parties, it is agreed as follows:

I. That Section I, entitled RENTAL - LICENSE FEE, of the May 1, 1977 Lease be amended in part in that the yearly rental of Ten Thousand Dollars ($10,000) per year shall now read Twenty Thousand Dollars ($20,000) per year effective the date of this Addendum Agreement. In all other respects, Section I, entitled RENTAL - LICENSE FEE, of the May 1, 1977 Lease shall remain unchanged. LESSOR acknowledges the receipt of LESSEE's check number 21861, dated December 7, 1979, in the amount of Ten Thousand Dollars ($10,000) and agrees to prorate this amount over the present remaining annual rental period with the remaining balance to be applied towards the next annual rental period.

II. That Section XI, entitled FEES FOR PERPETUAL CARE AND MAINTENANCE, of the May 1, 1977 Lease be amended in part, in that the sum of thirteen cents (13¢) for each and every cubic foot of low-level radioactive waste materials shall now read twenty-five cents (25¢) for each and every cubic foot of low-level radioactive waste materials. However, the LESSOR and LESSEE agree that in recognition of LESSEE's current contractual commitments, that the per cubic foot increase from thirteen cents (13¢) to twenty-five cents (25¢) shall not be immediately effective, but rather shall take effect on the twenty-fifth day of February, 1980. In all other respects, Section XI, entitled FEES FOR PERPETUAL CARE AND MAINTENANCE, of the May 1, 1977 Lease shall remain unchanged.

III. This Addendum Agreement is annexed to and is a part of the May 1, 1977 Lease and is governed by and hereby becomes subject to all of its provisions and promises, except to the extent that those provisions and/or promises are expressly qualified, modified or altered by this Addendum Agreement. The May 1, 1977 Lease, as amended by this Addendum Agreement, remains in full force and effect.

IV. This Addendum Agreement embodies the entire agreement between the parties. It may not be modified or terminated except as provided herein or by other written agreements between the parties.

IN WITNESS WHEREOF, the parties have hereunto set their hands the day and year in this Lease first above written.

APPROVED:

STATE OF NEVADA
DEPARTMENT OF HUMAN RESOURCES

GOVERNOR OF THE STATE OF NEVADA

RALPH R. DISIBIO, DIRECTOR
LESSOR

APPROVED AS TO FORM:

NUCLEAR ENGINEERING CO., INC.

RICHARD BRYAN
ATTORNEY GENERAL

JAMES N. NEEL, PRESIDENT
LESSEE

By:
BRYAN NELSON
DEPUTY ATTORNEY GENERAL

Attest:

DAVID R. HAFENDORFER
ASSISTANT SECRETARY

(affix Corporate Seal)

2912-1
January 1976

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

RECREATION OR PUBLIC PURPOSES LEASE
Act of June 14, 1926, as amended (43 U.S.C. 869 et. seq.)

Serial Number

Nev-057750 (Renewal)

This lease entered into on this 20th day of June, 19 82, by the United States of America, the lessor, through the authorized officer of the Bureau of Land Management, and

State of Nevada
Department of Conservation and Natural Resources
c/o Division of State Lands, 201 South Fall Street
Carson City, NV 89710

, hereinafter called the lessee, pursuant and subject to the terms and provisions of the Recreation and Public Purposes Act and to all reasonable regulations of the Secretary of the Interior now or hereafter in force when not inconsistant with any express and specific provisions herein, which are made a part hereof,

WITNESSETH

Sec 1 The lessor, in consideration of the rents to be paid and the conditions to be observed as hereinafter set forth, does hereby grant and lease to the lessee the right and privilege of using for the purposes hereinafter set forth in the following-described lands together with an option to purchase during the term of the lease:

Mount Diablo Meridian

T. 13 S., R. 47 E.
sec. 26, S½S½;
sec. 35, S½N½, NE¼NE¼, NW¼NW¼;

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Bureau of Land Management
MAY 19 1982
RENO, NEVADA

containing 400 acres together with the right to construct and maintain thereon all buildings or other improvements necessary for such use for a period of 25 years, the rental to be $ 300.00 per 5 year period. If, at the expiration date of the lease the authorized officer shall determine that the lease may be renewed, the lessee herein will be accorded the privilege of renewal upon such terms as may be fixed by the lessor. The lessee may use the premises for a buffer zone (see Addendum attached hereto).

Sec 2 There are reserved to the United States all mineral deposits in said lands, together with the right to mine and remove the same under applicable laws and regulations to be established by the Secretary of the Interior

Sec 3 The lessor reserves the right of entry, or use, by

(a) any authorized person, upon the leased area and into the buildings constructed thereon for the purpose of inspection;

(b) Federal agents and game wardens upon the leased area on official business.

(c) the United States, its permittees and licensees, to mine and remove the mineral deposits referred to in Sec 2, above

Sec 4. In consideration of the foregoing, the lessee hereby agrees

(a) To improve and manage the leased area in accordance with the ~~plan of development and management dated~~ application filed June 26, 1961 and supplemental information filed September 13, 1961, and approved by an authorized officer on February 15, 1962 or any modification thereof hereinafter approved by an authorized officer, and to maintain all improvements, during the term of this lease, in a reasonably good state of repair

(b) To pay the lessor the annual rental above set forth in advance during the continuance of this lease.

(c) Not to allow the use of the lands for unlawful purposes or for any purpose not specified in this lease unless consented to under its terms, not to prohibit or restrict directly or indirectly, or permit its agents, employees, contractors (including, without limitation, lessees, sublessees, and permittees), to prohibit or restrict the use of any part of the leased premises or any of the facilities thereon by any person because of such person's race, creed, color, sex, or national origin.

(d) Not to assign this lease or to change the use of the land, without first receiving the consent of the authorized officer of the Bureau of Land Management.

(e) That this lease may be terminated after due notice to the lessee upon a finding by the authorized officer that the lessee had failed to comply with the terms of the lease; or has failed to use the leased lands for the purposes specified in this lease for a period of 5 consecutive years; or that all or part of the lands is being devoted to some other use not consented to by the authorized officer, or that the lessee has not complied with his development and management plans referred to in subsection 4(a).

(f) That upon the termination of this lease by expiration, surrender, or cancellation thereof, the lessee, shall surrender possession of the premises to the United States in good condition and shall comply with such provisions and conditions respecting the removal of the improvements of and equipment on the property as may be made by an authorized officer.

(g) To take such reasonable steps as may be needed to protect the surface of the leased area and the natural resources and improvements thereon.

(h) Not to cut timber on the leased area without prior permission of, or in violation of the provisions and conditions made by an authorized officer.

(i) That nothing contained in this lease shall restrict the acquisition, granting, or use of permits or rights-of-way under existing laws by an authorized Federal officer.

Sec. 5. *Equal Opportunity Clause.* During the performance of this contract, the lessee agrees as follows:

(a) The lessee will not discriminate against any employee or applicant for employment because of race, color, religion, sex, or national origin. The lessee will take affirmative action to ensure that applicants are employed, and that employees are treated during employment, without regard to their race, color, religion, sex, or national origin. Such action shall include, but not be limited to the following: employment, upgrading, demotion, or transfer; recruitment or recruitment advertising; layoff or termination; rates of pay or other forms of compensation; and selection for training, including apprenticeship. The lessee agrees to post in conspicuous places, available to employees and applicants for employment, notices to be provided by the contracting officer setting forth the provisions of this nondiscrimination clause.

(b) The lessee will, in all solicitations or advertisements for employees placed by or on behalf of the lessee, state that all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, or national origin.

(c) The lessee will send to each labor union or representative of workers with which he has a collective bargaining agreement or other contract or understanding, a notice, to be provided by the agency contracting officer, advising the labor union or workers' representative of the lessee's commitments under Section 202 of Executive Order 11246 of September 24, 1965, as amended, and shall post copies of the notice in conspicuous places available to employees and applicants for employment.

(d) The lessee will comply with all provisions of Executive Order No. 11246 of September 24, 1965, as amended, and of the rules, regulations, and relevant orders of the Secretary of Labor.

(e) The lessee will furnish all information and reports required by Executive Order No. 11246 of September 24, 1965, as amended, and by the rules, regulations, and orders of the Secretary of Labor, or pursuant thereto, and will permit access to his books, records, and accounts by the contracting agency and the Secretary of Labor for purposes of investigation to ascertain compliance with such rules, regulations, and orders.

(f) In the event of the lessee's noncompliance with the nondiscrimination clauses of this contract or with any of such rules, regulations, or orders, this permit may be cancelled, terminated or suspended in whole or in part and the lessee may be declared ineligible for further Government contracts in accordance with procedures authorized in Executive Order No. 11246 of September 24, 1965, as amended, and such other sanctions may be imposed and remedies invoked as provided in Executive Order No. 11246 of Sept. 24, 1965, as amended, or by rule, regulation, or order of the Secretary of Labor, or as otherwise provided by law.

(g) The lessee will include the provisions of Paragraphs (a) through (g) in every subcontract or purchase order unless exempted by rules, regulations, or orders of the Secretary of Labor issued pursuant to Section 204 of Executive Order No. 11246 of September 24, 1965, as amended, so that such provisions will be binding upon each subcontractor or vendor. The lessee will take such action with respect to any subcontract or purchase order as the contracting agency may direct as a means of enforcing such provisions including sanctions for noncompliance. *Provided however.* That in the event the lessee becomes involved in, or is threatened with litigation with a subcontractor or vendor as a result of such direction by the contracting agency, the lessee may request the United States to enter into such litigation to protect the interests of the United States.

Sec. 6. The lessee may surrender this lease or any part thereof by filing a written relinquishment in the appropriate BLM office. The relinquishment shall be subject to the payment of all accrued rentals and to the continued obligation of the lessee to place the lands in condition for relinquishment in accordance with the applicable lease terms in subsections 4(f) and 4(g) and the appropriate regulations.

Sec. 7. The lessee further agrees to comply with and be bound by those additional terms and conditions identified as

Appendix A and Addendum which are attached hereto

and which are made a part hereof.

Sec. 8. No Member of, or Delegate to, the Congress, or Resident Commissioner, after his election or appointment, and either before or after he has qualified, and during his continuance in office, and no officer, agent or employee of the Department of the Interior, except as otherwise provided in 43 CFR, Part 7, shall be admitted to any share or part of this lease, or derive any benefit that may arise therefrom, and the provisions of Title 18 U.S.C. Sections 431–433, relating to contracts, enter into and form a part of this lease, so far as the same may be applicable.

For Execution by Lessee

In Witness Whereof:

[signature]

(Signature of Lessee's Authorized Officer)

[signature]

(Signature of Witness)

(Date)

For Execution by The United States

The United States of America

By [signature]

(Authorized Officer)

Chief, Lands and Minerals Operations

(Title)

SEP 14 1982

(Date)

ADDENDUM TO RECREATION AND PUBLIC PURPOSES LEASE Nev-057750

1. If antiquities including, but not limited to, archaeological items, paleontological objects or other objects of historic or scientific interest are discovered on the leased area, the lessee shall leave the items or conditions intact and inform the District Manager;

2. Lessee shall comply with the applicable Federal and State laws and regulations concerning the use of pesticides (i.e., insecticides, herbicides, fungicides, rodenticides, and other similar substances) in all activities/operations authorized under this lease. The lessee shall obtain approval of a written plan prior to the use of such substances from the Authorized Officer. The plan must provide the type and quantity of material to be used; the pest, insect and fungus to be controlled; the method of application; the location for storage and disposal of containers; and other information that the Authorized Officer may require. The plan should be submitted no later than December 1 of any calendar year that covers the proposed activities for the next fiscal year (i.e., December 1, 1979, deadline for a fiscal year 1981 action). Emergency use of pesticides may occur. The use of substances on or near the leasehold shall be in accordance with the approved plan. A pesticide shall not be used if the Secretary of the Interior has prohibited its use. A pesticide shall be used only in accordance with its registered uses and within other limitations if the Secretary has imposed limitations. Pesticides shall not be permanently stored on public lands authorized for use under this lease.

3. Regulations pertaining to the Recreation and Public Purposes Act prohibit use of public lands for disposal of permanent or long term hazardous waste. Accordingly, the leased lands shall be used as a buffer area only.

Appendix A

The lease of the herein described land is also subject to the following conditions and limitations:

(a) The lessee or its successor in interest shall comply with and shall not violate any of the terms or provisions of Title VI of the Civil Rights Act of 1964 (78 Stat. 241) and requirements of the regulations, as modified or amended, of the Secretary of the Interior issued pursuant thereto (43 CFR 17) for the period that the land leased herein is used for the purpose for which the lease was issued pursuant to the act cited or for another purpose involving the provision of similar services or benefits;

(b) If the lessee or its successor in interest does not comply with the terms or provisions of Title VI of the Civil Rights Act of 1964 and the requirements imposed by the Secretary of the Interior issued pursuant to that title during the period which the land described herein is used for the purpose for which the lease was issued pursuant to the act cited or for another purpose involving the provision of similar services or benefits, said Secretary or his delegate may declare the terms of this grant terminated in whole or in part;

(c) The lessee, by acceptance of this lease, agrees for itself and its successors in interest that a declaration of termination in whole or in part of this grant shall, at the option of the Secretary of the Interior or his delegate, operate to revest in the United States full title to the land involved in the declaration;

(d) The United States shall have the right to seek judicial enforcement of the requirements of Title VI of the Civil Rights Act of 1964, and the terms and conditions of the regulations, as modified or amended, of the Secretary of the Interior issued pursuant to said Title VI, in the event of their violation by the lessee or its successor in interest;

(e) The lessee or its successor in interest will, upon request of the Secretary of the Interior or his delegate, post and maintain on the property conveyed by this document signs or posters bearing a legend concerning the applicability of Title VI of the Civil Rights Act of 1964 to the property conveyed;

(f) The conditions and limitations contained in paragraphs (a) through (e) shall constitute a covenant running with the land, binding on the lessee and its successors in interest for the period for which the land leased herein is used for the purpose for which this lease was issued or for another purpose involving the provision of similar services or benefits.

Form 2912-1
(January 1976)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

2 1 1982

RECREATION OR PUBLIC PURPOSES LEASE
Act of June 14, 1926, as amended (43 U.S.C. 869 et. seq.)

Serial Number

Nev-057750 (Renewal)

This lease entered into on this 20th day of June, 19 82, by the United States of America, the lessor, through the authorized officer of the Bureau of Land Management, and

State of Nevada
Department of Conservation and Natural Resources
c/o Division of State Lands, 201 South Fall Street
Carson City, NV 89710

, hereinafter called the lessee, pursuant and subject to the terms and provisions of the Recreation and Public Purposes Act and to all reasonable regulations of the Secretary of the Interior now or hereafter in force when not inconsistent with any express and specific provisions herein, which are made a part hereof,

WITNESSETH:

Sec 1. The lessor, in consideration of the rents to be paid and the conditions to be observed as hereinafter set forth, does hereby grant and lease to the lessee the right and privilege of using for the purposes hereinafter set forth in the following-described lands together with an option to purchase during the term of the lease:

Mount Diablo Meridian

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NEVADA STATE OFFICE
RENO, NEVADA

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Sec. 2 There are reserved to the United States all mineral deposits in said lands, together with the right to mine and remove the same under applicable laws and regulations to be established by the Secretary of the Interior

Sec 3. The lessor reserves the right of entry, or use, by

(a) any authorized person, upon the leased area and into the buildings constructed thereon for the purpose of inspection;

(b) Federal agents and game wardens upon the leased area on official business;

(c) the United States, its permittees and licensees, to mine and remove the mineral deposits referred to in Sec 2, above

Sec 4. In consideration of the foregoing, the lessee hereby agrees

(a) To improve and manage the leased area in accordance with the ~~plan of development and management~~ application filed June 26, 1961 and supplemental information filed September 13, 1961, and approved by an authorized officer on February 15, 1962 or any modification thereof hereinafter approved by an authorized officer, and to maintain all improvements, during the term of this lease, in a reasonably good state of repair.

(b) To pay the lessor the annual rental above set forth in advance during the continuance of this lease.

(c) Not to allow the use of the lands for unlawful purposes or for any purpose not specified in this lease unless consented to under its terms, not to prohibit or restrict, directly or indirectly, or permit its agents, employees, contractors (including, without limitation, lessees, sublessees, and permittees), to prohibit or restrict the use of any part of the leased premises or any of the facilities thereon by any person because of such person's race, creed, color, sex, or national origin.

(d) Not to assign this lease or to change the use of the land, without first receiving the consent of the authorized officer of the Bureau of Land Management.

(e) That this lease may be terminated after due notice to the lessee upon a finding by the authorized officer that the lessee had failed to comply with the terms of the lease; or has failed to use the leased lands for the purposes specified in this lease for a period of 5 consecutive years; or that all or part of the lands is being devoted to some other use not consented to by the authorized officer; or that the lessee has not complied with his development and management plans referred to in subsection 4(a).

(f) That upon the termination of this lease by expiration, surrender, or cancellation thereof, the lessee, shall surrender possession of the premises to the United States in good condition and shall comply with such provisions and conditions respecting the removal of the improvements of and equipment on the property as may be made by an authorized officer.

(g) To take such reasonable steps as may be needed to protect the surface of the leased area and the natural resources and improvements thereon.

(h) Not to cut timber on the leased area without prior permission of, or in violation of the provisions and conditions made by an authorized officer.

(i) That nothing contained in this lease shall restrict the acquisition, granting, or use of permits or rights-of-way under existing laws by an authorized Federal officer.

N E V A D A R A D C L O S U R E C O S T S
CLOSURE FUND BALANCE

NET PRESENT VALUE @ 2% $2,392,765

CLOSURE YEAR	ANNUAL CLOSURE COST '92 DOLLAR	CLOSURE FUND BALANCE @ 2% GROWTH
6/30/92		$5,292,590
1993	$696,283	$4,649,232
1994	$141,943	$4,600,274
1995	$29,115	$4,663,165
1996	$29,115	$4,727,313
1997	$29,115	$4,792,744
1998	$29,115	$4,859,484
1999	$29,115	$4,927,559
2000	$29,115	$4,996,996
2001	$29,115	$5,067,821
2002	$179,115	$4,990,062
2003	$29,115	$5,060,748
2004	$29,115	$5,132,849
2005	$29,115	$5,206,391
2006	$29,115	$5,281,404
2007	$29,115	$5,357,917
2008	$29,115	$5,435,960
2009	$29,115	$5,515,565
2010	$29,115	$5,596,761
2011	$29,115	$5,679,581
2012	$29,115	$5,764,058
2013	$29,115	$5,850,224
2014	$29,115	$5,938,114
2015	$29,115	$6,027,761
2016	$29,115	$6,119,202
2017	$137,343	$6,104,243
2018	$29,115	$6,197,213
2019	$29,115	$6,292,042
2020	$29,115	$6,388,768
2021	$29,115	$6,487,429
2022	$29,115	$6,588,062
2023	$29,115	$6,690,709
2024	$29,115	$6,795,408
2025	$29,115	$6,902,201
2026	$29,115	$7,011,130
2027	$29,115	$7,122,238
2028	$29,115	$7,235,568
2029	$29,115	$7,351,164
2030	$29,115	$7,469,073
2031	$29,115	$7,589,339
2032	$29,115	$7,712,011
2033	$29,115	$7,837,137
2034	$29,115	$7,964,764
2035	$29,115	$8,094,945
2036	$29,115	$8,227,729

2037	$29,115	$8,363,169
2038	$29,115	$8,501,317
2039	$29,115	$8,642,229
2040	$29,115	$8.785,958
2041	$29,115	$8,932,563
2042	$279,115	$8,832,099
2043	$29,115	$8,979,626
2044	$29,115	$9,130,104
2045	$29,115	$9,283,591
2046	$29,115	$9,440,148
2047	$29,115	$9,599,836
2048	$29,115	$9,762,718
2049	$29,115	$9,928,857
2050	$29,115	$10,098,319
2051	$29,115	$10,271,171
2052	$29,115	$10,447,479
2053	$29,115	$10,627,314
2054	$29,115	$10,810,746
2055	$29,115	$10,997,846
2056	$29,115	$11,188,688
2057	$29,115	$11,383,346
2058	$29,115	$11,581,899
2059	$29,115	$11,784,422
2060	$29,115	$11,990,995
2061	$29,115	$12,201,700
2062	$29,115	$12,416,619
2063	$29,115	$12,635,837
2064	$29,115	$12,859,439
2065	$29,115	$13,087,513
2066	$29,115	$13,320,148
2067	$137,343	$13,449,208
2068	$29,115	$13,689,077
2069	$29,115	$13,933,744
2070	$29,115	$14,183,304
2071	$29,115	$14,437,855
2072	$29,115	$14,697,497
2073	$29,115	$14,962,332
2074	$29,115	$15,232,464
2075	$29,115	$15,507,999
2076	$29,115	$15,789,044
2077	$29,115	$16,075,710
2078	$29,115	$16,368,109
2079	$29,115	$16,666,356
2080	$29,115	$16,970,568
2081	$29,115	$17,280,865
2082	$29,115	$17,597,367
2083	$29,115	$17,920,200
2084	$29,115	$18,249,489
2085	$29,115	$18,585,364
2086	$29,115	$18,927,956
2087	$29,115	$19,277,400
2088	$29,115	$19,633,834
2089	$29,115	$19,997,395
2090	$29,115	$20,368,228
2091	$29,115	$20,746,478
2092	$529,115	$20,632,293

GRAVEL CAP DESIGN ANALYSIS
USING THE WIND EROSION EQUATION
BEATTY LOW-LEVEL RADIOACTIVE WASTE DISPOSAL SITE
BEATTY, NEVADA

The effects of wind erosion on the cell caps at the Beatty, Nevada Low-Level Radioactive Waste Disposal site were evaluated using the Wind Erosion Equation (WEE).[1] The WEE expresses the amount of erosion, in tons per acre per year, from a given soil surface as a function of several parameters. Soil loss is a function of cloddiness, surface roughness, surface soil moisture, vegetation, wind velocity and windward distance across the cap surface and is expressed by:

$$A' = f\ (K', C', L', T', V')$$

where

A' = soil loss

K' = a soil erodibility index

T' = a soil ridge roughness factor

C' = a climate factor

L' = field length along the prevailing wind erosion direction

V' = an equivalent quantity of vegetative cover

Climatic Factor C'

The climatic factor C' combines two aspects of the erosion process - wind velocity and near-surface water content. C' has been calculated for most regions of the United States on an average monthly basis; however there has been no evaluation done in Nevada. However, as noted below, a C' value was selected for an area with similar climatic features.

At the present time, the USGS is reviewing hourly weather data recorded at the Beatty facility since 1986. The compiled data should be available by January, 1990. For this study, for the purpose of estimating the wind erosion at the site, wind velocity data obtained from the National Weather Service for Las Vegas was used in the calculation. The values are:

1 "Design and Construction of Covers for Solid Waste Landfills", U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, NTIS No. PB80-100381, Aug. 1979.

Case	Wind Speed
Average Wind	9.1 mi/hr
Average Gusts	30 mi/hr*
Maximum Recorded Gusts	75 mi/hr

The C' values shown for the surrounding areas were reviewed (See attached Figure 68[1]). Wind speeds below 13 mph are indicated by experimentation to be nonerosive (C'=0). By reviewing the map showing C' values for areas with similar climatic features and the wind data from Las Vegas, a C' value of 70% will be used in the calculation.

Soil Erodibility K'

Soil erodibility K' incorporates the nature of the soil and an adjustment for knoll or hill configuration. K' is equal to the product of the soil erodibility factor from attached Figure 69[1] and the knoll adjustment obtained from attached Figure 70[1]. To obtain the value for percent coarse fraction required to determine the erodibility factor, three samples were obtained from site stockpiles. A grain size analysis was performed on each. The results are attached. The worst case (i.e. the sample with the largest percentage of fines) was used to obtain the erodibility index. A coarse percentage of 46% corresponded to an erodibility index from Figure 69 of 40 tons/acre. The knoll adjustment factor from Figure 70 is 1.5 for an average assumed cap slope of approximately 3%.

Soil Ridge Roughness Factor T'

Soil ridge roughness is a measure of the surface roughness other than caused by clods or vegetation. It is determined from direct observations and given in terms of the actual amplitude measurement from crest to trough in the ground microtopography. Since final capping activities have not begun, it was assumed that the cap will be graded to a ridge roughness of approximately 2".

From the attached Figure 71[1], a soil ridge roughness of 2" corresponds to a value of .52 for T'.

* Estimated

Field Length Factor L'

The equivalent field length L' is defined as the unsheltered distance along the direction of prevailing wind erosion. From a site topographic map, it was estimated that this distance is approximately 1000'.

Vegetative Cover V'

The vegetative cover quantity V' combines type and orientation effects with the actual tons per acre of vegetative cover at site closure. An average value of 1000 lbs/acre was used in the calculation. This value is estimated to be representative of the density of vegetation to be present on the site caps at closure.

WEE Calculation

There are several steps involved to obtain the soil loss for a particular soil type. The parameters K', T', and C' are multiplied as shown below to obtain the variables A'_1, A'_2, and A'_3. The values for A'_2 and A'_3, along with the parameter L' are used in a nomograph (Figure 72) to determine another variable A'_4. To get the actual amount of soil loss due to wind erosion, the chart, attached Figure 74[1], is used. The chart uses the variable A'_4, which has already been determined and V' to determine the value for soil loss, which the chart refers to as A'_5.

A'_1 = K' x 1.5 (Knoll Adjustment Factor)
= 40 tons/acre x 1.5
= 60 tons/acre

A'_2 = A'_1 x T'
= 60 tons/acre x .52
= 31.2 tons/acre

A'_3 = A'_2 x C'
= 31.2 tons/acre x .70
= 21.8 tons/acre

As stated above, a graphical solution is used to determine A'_4. Refer to attached Figure 72[1]. Using L' = 1000, a value of 14 tons/acre/year is obtained.

The chart on attached Figure 74[1] is used to determine soil loss. For V' = 1000 lbs/acre and A'_4 = 14 tons/acre/year, A'_5 = 9 tons/acre/year.

A cap thickness above grade of 7 feet will be used to estimate the amount of material that may be lost due to wind erosion over a design life of 500 years. Using a thickness of 7 feet will result in the most conservative value, since the actual design thickness of the closure cap ranges from 7 to 13 feet above grade. The unit weight of the cap material is assumed to be approximately 108 lb/ft^3.

$$\text{Soil loss rate} = \frac{9\ \text{tons}}{\text{Acre}} \times \frac{2000\ \text{lb}}{1\ \text{ton}} \times \frac{1\ \text{acre}}{43560\ \text{ft}^2} \times \frac{\text{ft}^3}{108\ \text{lb}} = .004\ \text{ft/year}$$

After 50 years, .20 feet of fine grained material may be eroded.

The percentage of fine graded material will decrease due to the erosion process. The following ratios were used to obtain a new percentage of coarse and fine material.

New cap thickness = 7.00 - .20 = 6.80 ft

	Original Cap	After 50 Years
$\frac{\%\ \text{Passing \#200}}{\text{Cap thickness}}$	$\frac{3.8}{7.0} = 54\%$	$\frac{3.8 - .20}{7.0 - .20} = 53\%$
% Retained	46%	47%

The 47% at year 50 is now used to determine a new K'.

New K' (from Figure 69) = 38 ton/acre

A'_2 = 38 x 1.5 x .52 = 29.6 tons/acre

A'_3 = 29.6 x .70 = 20.7 tons/acre

A'_4 = (from Figure 72) = 12 tons/acre

A'_5 = (from Figure 74) = 7 tons/acre/yr = .003 ft/yr

After the next 100 years, .30 ft of fine grained material may be eroded. The change in the percentage of fine and coarse grained material is shown as:

	After 50 Years	After 150 Years
% Passing #200 / Cap Thickness	$53\% = \frac{3.60}{6.80}$	$\frac{3.60 - .30}{6.80 - .30} = \frac{3.3}{6.5} = 51\%$
% Retained	47%	49%

Again, the 49% at year 150 is now used to determine a new K'.

New K' (from Figure 69) = 36 ton/acre

A'_2 = 28 tons/acre
A'_3 = 19.7 tons/acre
A'_4 = 11 tons/acre/yr
A'_5 = 6.5 tons/acre/yr = .003 ft/yr

After an additional 150 years .45 feet of fine grained material may be eroded. The change in the percentage of fine and coarse grained material is shown as:

	After 150 Years	After 300 Years
% Passing #200 / Cap Thickness	$\frac{3.3}{6.5} = 51\%$	$\frac{3.3 - .45}{6.5 - .45} = \frac{2.85}{6.05} = 47\%$
% Retained	49%	53%

The 53% at year 300 is now used to determine a new K'.

New K' (from Figure 69) = 32 tons/acre

A'_2 = 25.0 tons/acre
A'_3 = 17.5 tons/acre
A'_4 = 9.0 tons/acre/yr
A'_5 = 5.5 tons/acre/yr = .002 ft/yr

After an additional 200 years, .4 feet of fine grained material may be eroded.

Conclusion

At the end of the design life of 500 years approximately 1.35 feet of fine grained material may have been eroded, which equates to a final thickness of 5.65 feet in the areas where the original above grade cap thickness was a minimum of 7.00 feet. This analysis assumes that the fine grained material is eroded uniformly throughout the thickness of the cap, which is a very conservative assumption. Generally only the upper 6 inches to a foot is affected by wind erosion after which the coarse graded fraction prevents any further cap loss. The analysis also conservatively assumes there will be no soil dispositon or maintenance performed on the cap, such as placing additional material in areas that are affected by wind erosion.

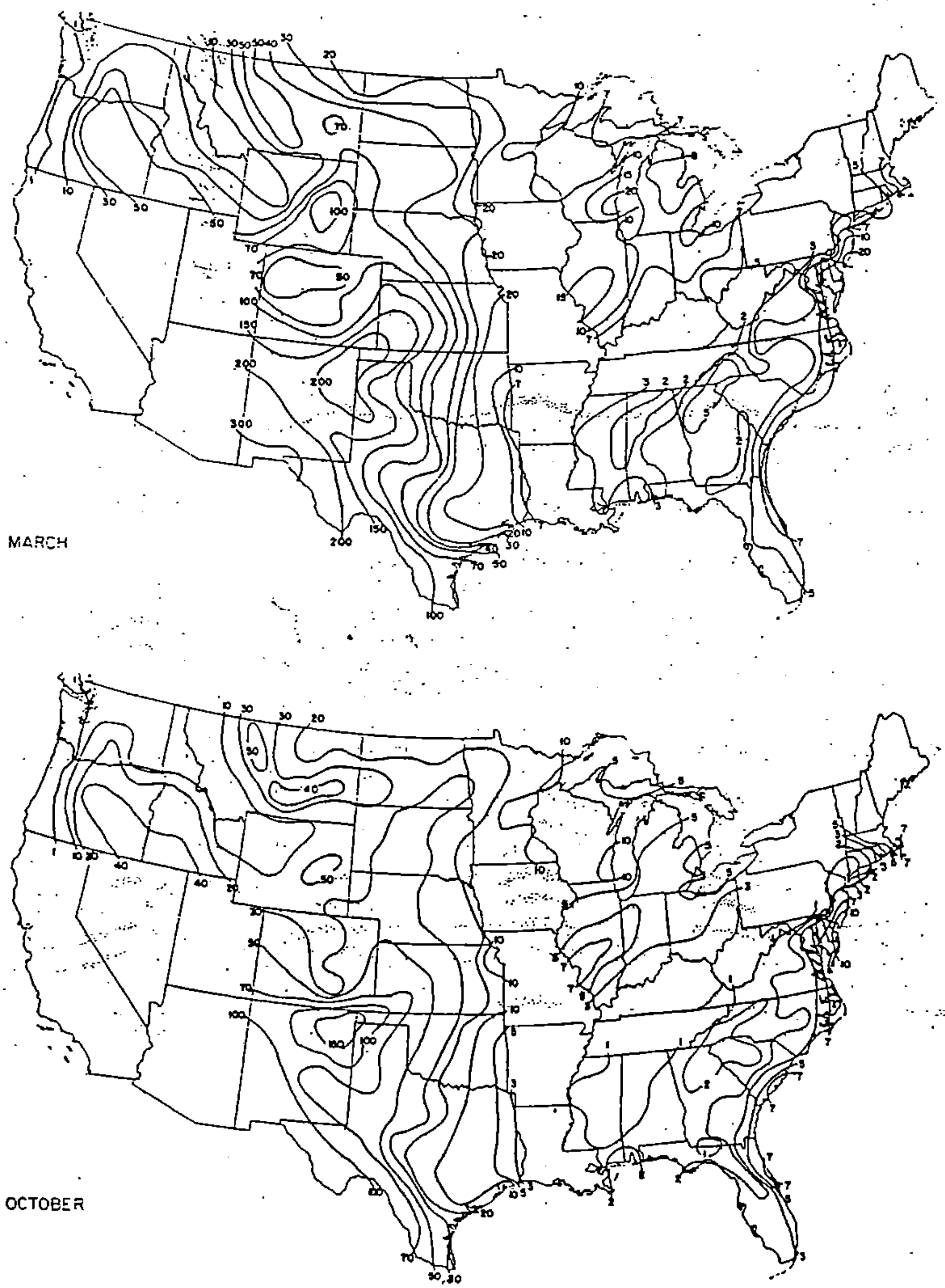


Figure 68. Wind erosion climatic factor C' in percent for March and October.[93]

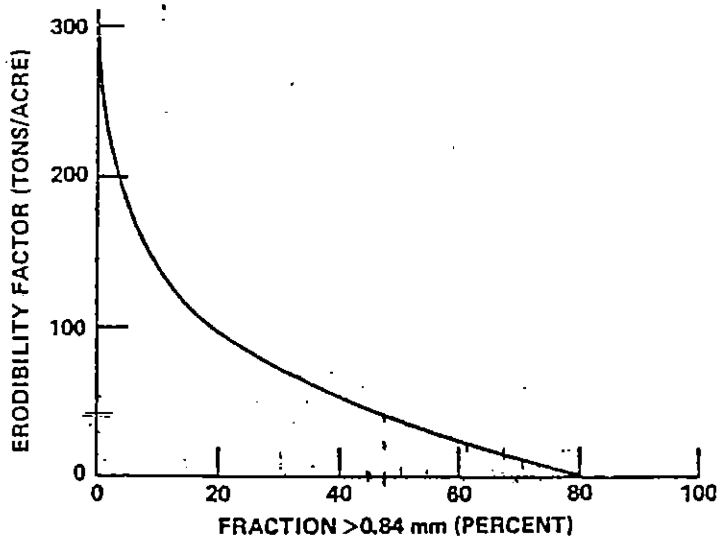


Figure 69. Wind erosion versus percent coarse fraction.[93]

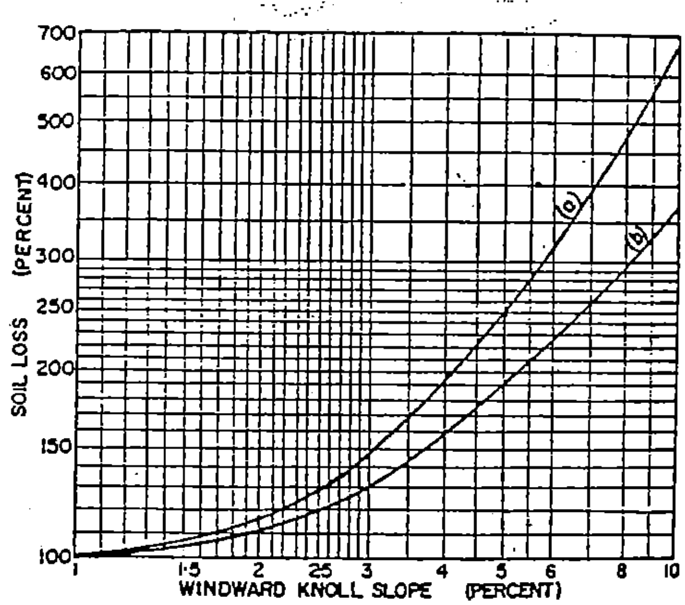
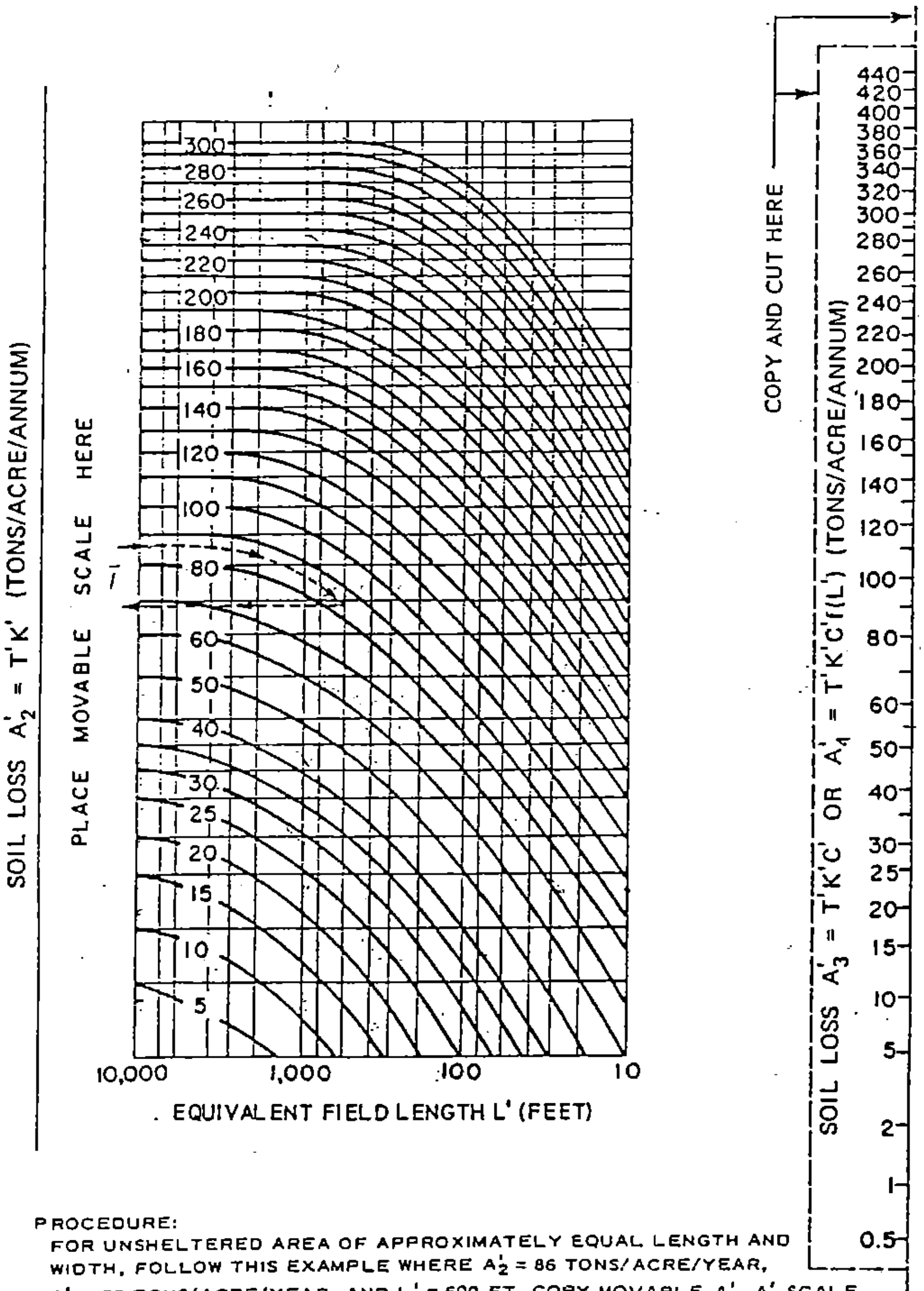


Figure 70. Knoll adjustment (a) from top of knoll and (b) from upper third of slope.[95] (Reproduced by permission of Soil Science Society of America.)



PROCEDURE:

FOR UNSHELTERED AREA OF APPROXIMATELY EQUAL LENGTH AND WIDTH, FOLLOW THIS EXAMPLE WHERE A_2' = 86 TONS/ACRE/YEAR, A_3' = 55 TONS/ACRE/YEAR, AND L' = 600 FT. COPY MOVABLE A_3', A_4' SCALE AND PLACE THE COPY ALONG LEFT SIDE OF CHART. MOVE UP TO MATCH 55 (A_3') ON MOVABLE SCALE TO 86 (A_2') ON CHART. FOLLOW CURVE FOR 86 TO RIGHT TO INTERSECTION WITH 600 (L'). RETURN HORIZONTALLY LEFT TO MOVABLE SCALE AND READ A_4' = 42 TONS/ACRE/YEAR. FOR SOLVING THE MORE COMPLICATED CASE WHERE AREA LENGTH GREATLY EXCEEDS WIDTH, CONSULT THE ORIGINAL REFERENCE.[93]

Figure 72. Chart for determining soil loss A_4' from A_2', A_3', and L'.[93]

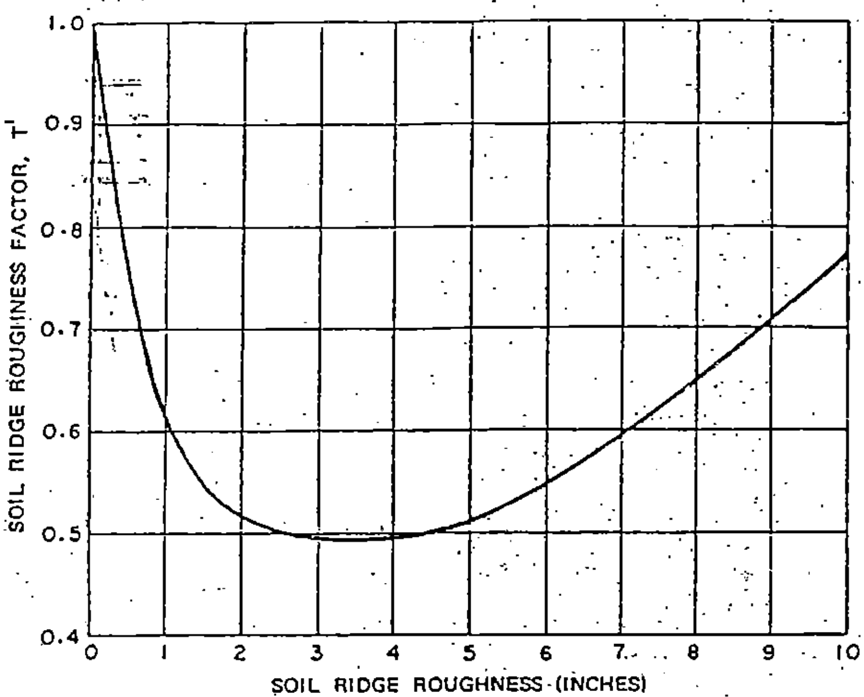


Figure 71. Soil ridge roughness factor T' from actual soil ridge roughness.93

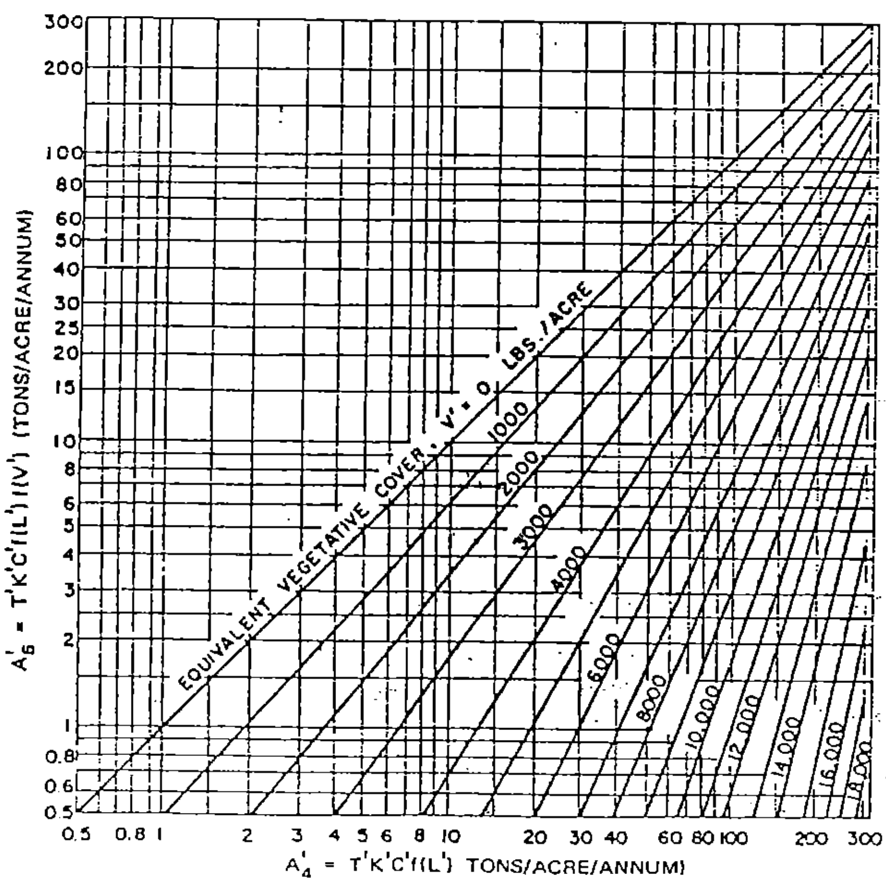


Figure 74. Chart for determining soil loss A'4 93