The Influence of Small Mammal Burrowing Activity on Water Storage at the Hanford Site

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EXECUTIVE SUMMARY

The *Permanent Isolation Surface Barrier Development Plan* identifies tasks that need to be completed to design a final protective barrier to implement in-place disposal of radioactive waste. The Biointrusion task focused on the need to evaluate the impacts that burrowing animals could have on the integrity of a protective barrier system. This report summarizes the animal intrusion work activities and literature surveys that were conducted by Westinghouse Hanford Company (WHC) in fiscal years 1988-1990 with respect to small mammals and water storage. The objective of this task was to determine the degree to which small mammal burrow systems affect the loss or retention of water.

An animal intrusion lysimeter facility was constructed and installed in fiscal year 1988. The facility consists of two outer boxes buried at grade that serve as receptacles for six animal intrusion lysimeters. At the beginning of each test the lysimeters were lined with a 28-mil plastic liner and filled with a fine soil from the McGee Ranch, a soil site near the intersections of State Highways 24 and 240. Small burrowing animals common to the Hanford Site environs (pocket mice, pocket gophers, Townsend ground squirrels) were introduced during a 3- to 4-month period, and they were allowed to burrow. During the course of each test, supplemental precipitation was added monthly to three of the lysimeters with a rainfall simulator, at a rate equivalent to a Hanford 100-yr storm. Soil moisture samples were taken before and after each test, while soil moisture measurements were taken with a hydroprobe during the test period.

Five tests (three summer, two winter) were completed during the study period. Information collected from the tests indicated that (1) during summer months, water was lost in all the lysimeters, including the supplemental precipitation added with the rainfall simulator; (2) during winter months, lysimeters containing animals and controls (no animals) gained water; and (3) the data did not indicate that any long-term water storage had occurred as a result of burrowing activity.

The soil moisture profile graphs generated were indistinguishable from any of the five tests that lysimeters contained animals or the lysimeters that served as controls (i.e., contained no animals). This results of the study do not indicate that animal burrows at Hanford Site facilitate the retention of water at depth.

The lack of any significant water storage at depth and the overall water loss in the lysimeters occurred despite the following conditions that were imposed on the lysimeters: (1) no vegetative cover (therefore, no plant transpiration), (2) no water runoff (all water contained); (3) higher than normal animal and burrow densities, (4) supplemental precipitation added at rates not normally expected to occur, and (5) animals usually burrow to the bottom of the lysimeters.

The data indicate that little difference exists between control and animal lysimeters in the amount of water stored. Initially, during high-precipitation events when some burrows are open at the surface, water was able to infiltrate through the burrows faster and deeper than normal; however, within a relatively short period of time this excess water was removed. This was also observed in concurrent studies conducted at the

Hanford Site regarding the effect of badger burrows on water distribution (Cadwell, 1991). If this is the case, then the overall water loss must be attributed to processes that occur equally in control and treatment lysimeters (surface evaporation). Other variables such as soil turnover and subsequent drying from burrowing activities and burrow ventilation affects assist in the removal of soil moisture, but the overriding factor is soil evaporation as a result of high ambient temperatures during the spring and summer.

This study did not address all potential climate changes, runoff events and potential effects of other burrowing animals. However, increased water storage at the Hanford Site under the present climatic conditions appear to be negligible, considering that a protective barrier will allow for runoff, have a vegetative cover, experience normal animal densities and normal precipitation events. Studies conducted elsewhere in environments that receive more natural precipitation and have lower ambient temperatures may not observe results as pronounced as those observed at the Hanford Site.

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THE EFFECT OF BURROWING ACTIVITIES OF SMALL MAMMALS ON WATER STORAGE AT THE HANFORD SITE

1.0 INTRODUCTION

The amount and rate at which water may penetrate a protective barrier and come into contact with buried radioactive waste is a major concern. Because burrowing animals eventually will reside on the surface of any protective barrier, the effect these burrow systems may have on the loss or retention of water needs to be determined. Studies at the Hanford Site (Landeem and Mitchell, 1981 and 1982; Gano, 1979) and other U.S. Department of Energy (DOE) sites (Arthur et al., 1986; Hakonson et al., 1979; Winsor and Wicker, 1980; Garten, 1980) have documented the impact burrowing animals can have on the uptake and redistribution of radionuclides, but little quantitative information exists about the role borrowing activities of small burrows may have on the loss or retention of water.

The first section of this document summarizes the known literature relative to small mammals and the effects that burrowing activities have on water distribution, infiltration, and the overall impact of burrows on the ecosystem. Topics that are summarized include burrow air pressures, airflow, burrow humidity, microtopography, mounding, infiltration, climate, soil evaporation, and discussions of large pores relative to water distribution.

The second section of this document provides the results of the study that was conducted at the Hanford Site to determine what effect small mammal burrows have on water storage. This Biointrusion task is identified in the *Permanent Isolation Surface Barrier Development Plan* (Wing, 1993) in support of protective barriers. This particular animal intrusion task is one part of the overall animal intrusion task identified in *Animal Intrusion Test Plan* (Landeem et al., 1990) (Figure 1).

2.0 LITERATURE SURVEY

A survey of the scientific literature regarding the effects of animal burrow systems on water dynamics does not yield much conclusive or quantitative information. As noted by Ursic and Esher (1988), "the effect of burrows on hydrology has been largely overlooked." Studies on the effects of burrowing on water distribution are confounded by such factors as climate, soil texture, soil structure, soil temperature, soil layering, soil water content, pore size distribution, soil porosity, soil depth, surface slope, burrow configurations, species differences, and timing and intensity of natural precipitation events (Dixon and Peterson, 1971). The sections below summarize published data about the influence of animal burrows and large pore spaces related to the distribution, infiltration, and storage of water.

Figure 1. Animal Intrusion Tasks Associated with Design of a Protective Barrier.

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2.1 Small Mammals and Invertebrates

Studies by Day (1931) and Gabrielson (1938) suggested that pocket-gopher tunnels accumulate and channel runoff, thereby initiating gullies. However, other researchers (Grinnel, 1933; Taylor, 1935) thought that this would happen only rarely. Ellison (1946), in a study of the effects of erosion by pocket gophers in Utah, concluded that in instances of melting snow and rainstorms, gopher tunnels are insignificant in initiating gullies. Turner et al. (1973) concluded that pocket gophers cause patchy soil moisture conditions; increased infiltration existed where the gophers loosened the soil; and created depressions. However, when fine-soil particles from soil casts seal the surface (which results in rapid run-off from mounds), decreased infiltration occurs (Turner et al., 1973).

Popova (1962) observed that soil was wetter at a greater depth below bank vole burrows, but surface soils dryness increased along the route of some burrows, especially in pine forests. Olszewski and Skoczen (1965) observed that, in dry months, mole tunnels running under the surface of a pasture were marked with tracks of dried grass. Mole tunnels also were observed, in a freshly sown and harrowed field, to have caused the formation of dry streaks on the soil surface. Abaturon (1972) observed that the bulk density of the soil was decreased and infiltration increased in an area occupied by ground squirrels.

Dixon and Peterson (1971) concluded that large pores can have a profound effect on the infiltration of water into the soil, but they determined that water movement into large pores was related to subsurface microroughness and microporosity. Their air-earth model predicted that these two properties interact to funnel rainwater into the soil and displace air from the soil. Edwards et al. (1979) demonstrated that surface-connected holes can effectively transmit water when more water is applied to the soil surface than can infiltrate it. The effectiveness of the holes as water channels was governed by depth, diameter, and density.

Gardner (1962) demonstrated that pores not connected with the surface do not transmit water rapidly, but holes and cracks that are open at the surface can move significant volumes of free surface water much deeper and faster than can be calculated by Darcy-type solutions alone. Chichester and Smith (1978) looked at the movement of labeled fertilizer in some lysimeter experiments and concluded that large pore flow occurs only during or soon after heavy rainfall, and the fertilizer effectively bypassed water held in the small-pore soil matrix.

A study conducted in a forest ecosystem in Mississippi (Ursic and Esher, 1988) determined that the opportunity for detention and retention of rainfall was enhanced by the burrowing activities of shrews. The shrew burrows in that study were large and concentrated in the upper 15 cm of soil. The burrows were also frequently opened at the soil surface. Reductions in storm flow volumes 12 to 15 yr after replacing poor quality, upland hardwoods with loblolly pine were only partially explained by increased interception of rainfall and transpiration. Much of the residual reductions were postulated to be caused by small mammal burrows. In simulated rain trials with short-tailed shrews,

surface runoff decreased more than 25% (Figure 2). Overland flow for the design storm (Figure 14) was minimal during the first half of the application, during which 2.5 cm of water was applied in 15 minutes. The burrow then collapsed, and the hydrograph thereafter closely approximated the earlier runoff rates from the control plot. Mean runoff volumes in all simulated rainfall trials decreased by more than 25% despite the fragile burrows and more than 50% for 4 of the 12 runs.

Ehlers (1975) found that earthworm burrows reaching the surface improve water drainage, but those burrows not reaching the surface contribute little to infiltration. Because the majority of the earthworm burrows are blocked by soil particles, the channels do not share in water infiltration. Ehlers (1975) also noted that water infiltration through earthworm channels only occurred at high rain intensities, because at low intensities no tension-free water existed at the soil surface, and all the water infiltrated through the soil matrix according to hydraulic potential gradients. Hopp and Slater (1948) found that earthworms increased infiltration rates by a factor of four on tight, fine-textured soils.

Figure 2. Hydrograph Showing the Effect of Shrew Burrows on Surface Runoff.

2.2 Large Pores and Channel Systems

The need for large pores to be open and exposed to free surface water before they can contribute to infiltration is inferred by Darcy's equation, which indicates that water moves only in the direction of decreasing hydraulic head. Hydraulic head always increases in the direction of a large pore isolated from free water by a surface seal. Dixon and Peterson (1971) conducted field experiments to test their channel system concept, which contends that a network of large soil pores, when functional, provide a subterranean arterial system for rapidly distributing free surface water to locations within the soil matrix and for exhausting soil air displaced from this matrix (Figure 3). The soil matrix referred to serves as a water storage sink called the capillary system.

The channel system includes the soil surface and a subsurface network of large pores that fill and drain mostly by gravity before and after the surface is exposed to free or ponded water. The channel system includes large pores produced by clay shrinkage, tillage, earthworms, ants, animal burrows, internal erosion, pebble dissolution, and entrapped air. In contrast, the capillary system comprises small pores within and between soil aggregates.

The rate and route of water infiltration in each system are controlled primarily by microtopography roughness and channel openness. Six different combinations of roughness and openness (called channel-system states) were studied (Figure 4). States A, B, and C represented rough surfaces with open, constricted (i.e., unstable), and closed channel ports, respectively. States D, E, and F represented plane or smooth surfaces with open, constricted, and closed channel ports (Figure 4), respectively. For state A, water penetration rates were rapid and flow routes relatively direct, whereas for state F, rates were slow and routes were extremely tortuous. The results supported the hypothesis that water penetration rates and routes are a function of the combination of soil surface openness and roughness.

2.3 Large-Mammal Burrow Systems (badgers and coyotes)

Cadwell et al. (1989) and Cadwell (1991) measured simulated rainfall events in large burrows dug by coyotes and badgers on the Hanford Site. Burrows excavated by coyotes and badgers are characterized by having large openings that are always open and exposed to the surface (Channel system A, Figure 4) (Photo 1). In simulated rainfall experiments, Cadwell et al. (1989) observed the diversion of surface water deep into the soils below and around the burrow systems; however, the water was subsequently withdrawn. Vegetation measurements showed that plant densities were significantly greater in the vicinity of badger burrows. This vigorous growth of invading plant species near burrows undoubtedly resulted in the extraction of water through plant transpiration. Enhanced evaporation from the soil surfaces exposed by burrowing also removed soil water near burrows. The data also showed that the soil beneath badger burrows in midsummer was drier than in adjacent soils away from the burrow sites.

2.4 Prairie Dog Burrow Systems

If burrows do act as conduits for water to more easily infiltrate at depth, animals that excavate elaborate burrow systems with large openings might be more vulnerable to precipitation events. Prairie dogs, which are a lot larger than the species evaluated in this study, dig burrow systems that average 13 m long and 13 cm in diameter (Sheets et al., 1971). A large domelike mound is constructed from the excavated soil with a hole in the middle. These burrows are relatively permanent structures, and many probably have endured for centuries (King, 1984).

The large mounds are known to function as dikes to prevent the torrential rains of the prairie summers from flooding the burrows. Carlson and White (1987) investigated the effects of prairie dogs on mound soils and concluded that the soil genesis processes are slower beneath prairie dog mounds than beside the mound because precipitation moistens the mound materials more frequently than the underlying buried soil.

Figure 3. The Channel System. It consists of a (A) soil surface cover, (B) free water surface, (C) microdepressions, (D) a water intake orifice, (E) microelevation, (F) air exhaust orifice, (G) subsurface channel, and (H) channel wall. The capillary system consists of (I) textural and structural pores within the soil mass (Dixon and Peterson, 1971).

Figure 4. Idealized Channel System States Representing Six Combinations of Soil Surface Roughness and Openness.

- State A:** A highly functional channel system that rapidly transfers and distributes free surface water to subsurface borders of the capillary system and readily exhausts displaced soil air. A soil with this type of channel system would have numerous stable open channel ports exposed to free water and some nearby open to the atmosphere. The soil surface is rough, open and covered with vegetation. *This system would be similar to badger burrows and larger burrowing rodents such as prairie dogs and Townsend ground squirrels.*
- State B:** Similar to state A except that the channel ports are unstable and constrict when exposed to free water. These constrictions impede water entry and air exit, consequently channel system B contributes less to infiltration than system A. The extent of channel port constriction depends on the intensity of the water source. For instance, an intense rainstorm may completely close channel ports.
- State C:** State C differs from State B in that channel ports are completely closed. Infiltrating water cannot enter such channels until the bordering regions of the capillary system become saturated and not then if channel air pressure is above atmospheric. These closed channels function primarily as reservoirs for entrapped air, and thus as barriers to water movement within the capillary system. *This system would be typical of pocket mice and pocket gophers. Both species plug burrow entrances which isolates burrow opening from any atmospheric contact.*
- State D:** This state differs from State A only by surface roughness, but this profoundly affects water flow since the flat surface of state D favors lateral hydraulic balance. Under intense rainfall on sloping land, a thin, relatively uniform layer of water would accumulate on the D surface. Ports would receive too little water for rapid water intake and too much for low-pressure exhausting of displaced air. Because of this inefficient port action, system D would contribute less to infiltration than system A.
- State E:** Similar to state D except that the soil surface lacks cover and is unstable. As in state B, channel ports constrict on exposure to free water. These constrictions reduce the infiltration contribution of system E well below system D.
- State F:** Sealing an E surface converts it to state F. The smooth, closed F surface is hydraulically and pneumatically disconnected from subsurface channels, i.e., it is hydraulically isotropic. Under this state, infiltration is the lowest of all the states. Water must move along the small pathways of this system against increasing displaced soil air pressure.

Photo 1. Typical Badger Excavation at the Hanford Site.

2.5 Burrow Air Pressures

Dixon and Peterson (1971) also indicated that soil air pressure studies support the channel system concept by showing that small air pressures greatly reduce infiltration. During natural rainfall conditions, water generally cannot enter the soil unless an equal volume of air escapes the soil surface. When channel openings are closed, they function primarily as reservoirs for entrapped air, and thus as barriers to water movement within the capillary system. Buildup in soil air pressure further limits infiltration under this state by blocking water flow in the larger structural pores of the capillary system. Wilson and Luthin (1963) observed soil air pressures up to 14 cm of water in homogeneous soil columns vented to the atmosphere and up to 110 cm in unvented columns. They indicated that soil air pressure reduces the number of large pores active in transmitting water. In a column experiment Horton (1940) showed that an entrapped air pressure of only 2.5 cm nearly reduced the infiltration rate by half.

Soil air pressures in burrow systems of the Great Basin pocket mouse and pocket gopher, which are common at the Hanford Site, are probably effective in limiting the movement of water into tunnels, because burrow entrances are plugged and isolated from any surface contact.

2.6 Airflow Effects

2.6.1 Prairie Dogs

Studies of prairie dog burrow systems have shown (Krebs and Davies, 1981; Vogel et al., 1973) how airflow ventilates the subterranean tunnels. Prairie dog tunnels are usually simple U-shaped passages with at least two openings to the surface. Vogel et al. (1973) indicated that the mounds around the burrow entrances were different. A high steep sided 'crater' mound exists at one end, and at the other end a low rounded 'dome' exists (Figure 5). When a breeze crosses the mounds, air enters the burrow through the lower mound and leaves through the higher. This keeps the burrow systems dry and reduces soil moisture at depth.

2.6.2 Moles

Two distinct openings may not be an absolute requirement for airflow in a burrow system. Olszewski and Skozen (1965) put anemometers in mole burrows that lacked obvious openings and entrances. Mole burrow systems are similar to those of pocket gophers. Olszewski and Skozen found that air speeds in the burrows correlated with wind speeds above. However, in the case of an atmospheric calm, the airflow in the burrows was lower but constant, probably as a result of differences in air density, which is caused by temperature differences. They were also able to demonstrate that air enters the tunnel systems through freshly excavated mole hills, which drips out the tunnels (thermoregulation) and provides oxygen for the burrow inhabitants.

Figure 5. Airflow in a Prairie Dog Burrow (Vogel et al., 1973).

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Olszewski and Skozen (1965) also observed that, after heavy precipitation events, numerous ventilating openings turn up in the tunnel systems. This has the result of intensifying airflow in the burrows which probably warms and dries the burrows as quickly as possible. Winter temperature measurements of these burrow systems found that the walls of nest chambers were covered with hoarfrost in many cases, whereas the tunnels were warm and dry.

2.7 Burrow Humidity

Burrow systems must be constructed in such a way that desert rodents optimize the expenditure of water through excretion and evaporation from the lungs. Schmidt-Nielsen and Schmidt-Nielsen (1950) investigated the burrow microclimate in burrow systems of two species of kangaroo rats in Arizona at the driest and hottest time of the year. Their data showed that definite ventilation effects existed that kept tunnels dry and that the amount of water vapor in the burrows was two to five times higher than the outside air (Figure 6). Their investigations showed that even during the driest season the soil contains enough water to keep a closed air space in the ground at 30 cm saturated with water vapor. They also noted that, after one rainfall of 4 mm during the study, a marked influence on burrow air humidity existed.

Figure 6. Humidity Measurements Inside and Outside a Kangaroo Rat Burrow.

2.8 Soil Microtopography

2.8.1 Mounding

Several species of burrowing animals are known to significantly alter the surface soil topography and soil structure (Johnson et al., 1987), which can cause patchy soil moisture distributions. Studies of burrowing behavior by pocket gophers have suggested that these animals are instrumental in forming many of the Mima mounds that are widespread west of the Mississippi River, from southern British Columbia to northern Mexico (Arkley and Brown, 1954; Cox and Hunt, 1990). Much of the Columbia Plateau of eastern Washington, northeastern Oregon, and southwestern Idaho is covered by Mima-mounded grassland. Over time the formation of these mounds can create a swale and hummock effect, which creates patchy soil moisture conditions away from the mounds where burrow entrances are located.

Arkley and Brown (1954) excavated pocket gopher burrows as part of Mima mound investigations and noted that the nests were located just below the crest of the dome (Figure 19). The method by which the gopher accumulates soil into a mound is explained by (1) the tendency to place the nest in a well-drained spot where the soil is the deepest, thus, generation after generation of gophers may keep building nests near the crest of any high spot in the land surface, or over a window in a hardpan; and

(2) gophers when tunneling move soil beneath the body and force the soil backward to a surface opening. Thus, over a long period of time, the gopher, by digging outward to form a nest, tends to move the soil toward the opening, which allows the mound to rise gradually. Arkley and Brown (1954) also documented areas in Oregon where mound areas grew 12 in. (30.48 cm) in 22 yr.

In some areas of California, ground squirrels are so abundant that they have an enormous effect on soil morphology and also create Mima moundlike surface microtopography (Borst, 1968). Earth material excavated by the squirrels form mounds up to several meters in diameter and 0.75 m high. The mounds range in particle size from clay to cobbles up to 15 cm in diameter. These animals are the dominant pedogenic agents in the soils of this area. Water distribution is affected when patchy soil moisture conditions are created from the uneven microtopography.

Studies of moles in pasture areas of Poland (Skoczen et al., 1976) indicated that the number of mole hills per hectare ranged from 4,107 to 21,063. The percent of the occupied surface by the molehills fluctuated between 4.3 and 11.2%. Their study on the influence of mole tunnels on soil moisture distribution after natural precipitation events showed that the presence of mole tunnels had a drying influence on the adherent soil layers both in the post-dry period and after rainfalls. The study also observed that a moisture increase existed at tunnel ends immediately after a rainfall, suggesting that soil layers may be humidified by water running along and seeping from tunnels. They concluded that there is a general tendency towards drying.

2.8.2 Surface Sealing (Mounds)

Mounds formed by the Great Basin pocket mouse and northern pocket gopher evolve gradually from mounds that are characterized as moist loose excavated puffs of soil to older mounds that become sealed and harder as a result of fine soil particles that fill in the micropores. In the initial stages these mounds serve as a sponge during rainfall events. In the latter stages, as these mounds undergo settling, they become relatively impervious to water penetration and facilitate runoff away from burrow entrances (Photos 2 and 3).

In an evaluation of surface factors affecting the rate of intake of water by soils, Duley (1939) observed that the rapid reduction in the rate of intake by cultivated soils (as rain falls on the surface) was accompanied by the formation of a thin, compact layer at the soil surface, and the water was able to pass through this layer only slowly. Duley (1939) postulated that this thin, compact surface layer was caused by a structural disturbance, caused in part by the beating of rain and the sorting action of wind and water, which allows fine soil particles to be fitted around the larger ones to form a relatively nonpervious seal. Duley's data showed that the thin, compact layer that forms at the soil surface of cultivated soils during rains had a greater effect on intake of water than did the soil type, slope, moisture content, or profile characteristics.

Photo 2. Example of a Fresh Pocket Gopher Mound (1 day old) Excavated by Same Animal as Shown in Photo 3.

Photo 3. Example of an Older Mound (1 month old) Excavated by Same Animal.
(The old mound has settled and so sheds water more easily.)

2.8.3 Hummock/Swale Effects

Many studies have indicated that the availability of soil moisture, which is mostly determined by topography, is a major factor in controlling species distributions (Barnes and Harrison, 1982). As mentioned previously, burrowing animals have been documented to cause hummock/swale effects. Patchy soil moisture conditions, which are caused by hummock/swale topography, were investigated at the Hanford Site (Cadwell, 1991; Link et al., 1994). The objective of the study was to determine if relationships exist between hummock/swale topography and soil water dynamics under normal and enhanced precipitation regimes. Three conditions were tested in the study: (1) hummocks dominated by spiny hopsage, (2) bare swales, and (3) swales dominated by sagebrush. The data indicated that coppice dune topography and related vegetational patterns caused patterns in soil water storage and soil water content with depth. Bare swales were wetter than either hopsage hummocks or sagebrush swales, while hopsage hummocks and sagebrush swales were not significantly different (Figure 7). The effect of adding supplemental precipitation on end-of-season soil water storage and profile patterns in the study was negligible. The Hanford Site semi-arid ecosystem can recycle to the atmosphere at least twice the normal precipitation, given that additional water comes in the spring. This study indicated that all supplemental precipitation that was added had been recycled to the atmosphere within 215 days.

Figure 7. Soil Water Storage Dynamics in Bare Swales, Irrigated Bare Swales, Spiny Hopsage Hummocks, and Irrigated Spiny Hopsage Hummocks (Cadwell, 1991).

Other studies at the Hanford Site have shown a seasonal effect regarding the addition of supplemental precipitation (Wildung and Garland, 1988). They found no effect of supplemental precipitation on soil water contents in coppice dunes and swales when irrigated in the spring. However, they observed increased soil water levels in irrigated hummocks in the fall and winter, which was maintained after subsequent irrigation in the spring.

2.9 Climate

Climatic conditions can have profound effects on soil water dynamics. The Hanford Site study discussed below was conducted in an area of Washington State that is hot from the end of March to October. The average annual precipitation received at the Hanford Site does not exceed 6 in. (15 cm). The summers are warm with low humidity and a high percentage of clear days. The high daily temperatures, the considerable sunshine, and the long days favor rapid plant growth when supplemental precipitation is added.

Data from the Irrigated Research and Extension Center (IREC) near Prosser, Washington indicate that the total evaporation from April to October, inclusive, is 49.9 in. (127 cm) (Kleingartner, 1977). On the basis of the data from IREC, the average evaporation is 5.78 in. (15 cm) in April, increases to 10.09 in. (26 cm) in July, and decreases in August 8.5 in. (21.5 cm). Further decreases in September and October are sharp. The evaporation correlates with the average maximum and minimum temperatures (Figure 8). In many water-deficient areas, such as the Great Plains, 60% of the precipitation is estimated to be evaporated back to the atmosphere (Hanks et al., 1967).

Campbell and Harris (1977) studied water losses from a sagebrush community in eastern Washington during a drought year (1973) and a higher-than-normal-precipitation year (1974). During 1973 the total precipitation was 14.6 cm. Evaporation was estimated to be 6.5 cm (45% of precipitation). In 1974 precipitation was 35.7 cm and 8.2 cm or 23% was estimated to be lost to evaporation. These observations can be used to infer the effect on desert ecosystem production of increasing or decreasing annual precipitation. At the beginning of the 1974 growing season the soil was filled to 100% field capacity so additional early spring precipitation would not have changed transpiration or production significantly. The excess moisture could only have gone to deep drainage or evaporation.

Campbell and Harris (1977) concluded that reduced precipitation would decrease water available for transpiration in two ways: the input would be less, and smaller rains would result in a larger fraction of the moisture being lost to evaporation. The result would be a greater decrease in production than proportionate to the decrease in precipitation.

Figure 8. Monthly Average Maximum and Minimum temperatures, 1924-1976, Inclusive; and Evaporation from a Free Water Surface, 1967-1976, Inclusive, at IREC (Kleingartner 1977).

2.10 Small-Mammal Burrow Systems and Configurations

The configuration of small-mammal burrows is such that the six-channel system states described by Dixon and Peterson (1971) are probably represented at one time or another in many burrow systems by many different burrowing animals. Depending on the species, burrows can be relatively simple with few entrances or complex with many entrances and exits (Reynolds and Laundre, 1988). The particular kind of burrow system can affect water distribution as illustrated in the channel system states previously discussed (Figure 4).

2.10.1 Great Basin Pocket Mice

Scheffer (1938) excavated burrow systems of Great Basin pocket mice in eastern Washington and found complex and extensive burrow systems, reaching depths of 1.0 to 1.5 m, including nest chambers, seed caches, and several branches from 3.0 to 4.5 m long.

Complex burrow systems for the Great Basin pocket mouse also were verified at the Hanford Site by Kritzman (1974) and Landeen and Mitchell (1981). Landeen and Mitchell (1981) also indicated how pocket mice construct distinctive mounds, which often are part of a larger mound system that may be elevated above the normal

landscape. These mounds form slopes that can facilitate runoff away from burrow entrances, located on these mounds.

Burrow systems excavated by the Great Basin pocket mouse, which is the most common small burrowing mammal found on the Hanford Site (Fitzner and Gray, 1991), probably most closely correspond to channel system states C, B, and A (in that order). Channel system C is one where channel ports are completely closed. Like many desert rodents, the Great Basin pocket mouse plugs the entrances and exits to the burrow system, effectively isolating the burrow from any surface contact (Scheffer, 1938). An example of a Great Basin pocket mouse burrow system excavated and mapped at the Hanford Site is presented in Figure 9. Appendix E shows other Great Basin pocket mouse burrow systems excavated at the Hanford Site.

2.10.2 Pocket Gophers

Pocket gopher burrow systems also closely resemble channel system C described above (Figure 4). Pocket gophers are prolific burrowers and, like the Great Basin pocket mouse, plug burrow entrances and also backfill tunnels that are no longer wanted (Cameron et al., 1988). Thorne and Anderson (1990) followed a single adult pocket gopher for 158 days and recorded 112 m of tunnel length. Soil excavated during the tunnel construction was deposited in 134 mounds, 68 plugs, and 77 m of backfilled tunnels.

Ross et al. (1968) suggested that pocket gopher mounds are, in effect, "puffs" of soil formed by animals disturbing and mixing the soil in a particular spot. Mounds created by pocket gophers in Minnesota were compared to the surrounding undisturbed soil (Ross et al., 1968). The mounds were characterized as having lower bulk densities and lacking a definite soil structure, which resulted in increased water permeability. During precipitation events, mounds act as water buffers because initially more water infiltrates into the mound than the surrounding soil. However, within a short time the water is removed through evaporation and mounds actually become drier than the underlying soil. The increased water permeability observed in mounds is more pronounced when the mounds are relatively young. After the soil has been exposed to the environment, mounds sometimes become somewhat hardened as pore spaces are filled by fine soil particles and, in many cases, facilitate runoff from the mound.

Grant et al. (1980) measured water infiltration rates and volumetric water contents in pocket gopher mounds in Colorado and verified the conclusions stated previously by Ross et al. (1968). Rates of infiltration of rainfall and evaporation of soil water were measured on five mounds and on five undisturbed areas with a rainfall simulator for 15 minutes after a simulated rainfall event. Soil cores were taken at 6-hour intervals up to 72 hours, and they were analyzed for percent of moisture.

Figure 9. Example of a Great Basin Pocket Mouse Burrow System Excavated at the Hanford Site.

The data of Grant et al. (1980) (Figure 10) indicated that infiltration rates were significantly higher on mounds than on undisturbed areas ($p < 0.05$). Figure 11, which shows the average volumetric soil water content versus time for mounds and undisturbed areas indicates that essentially all evaporation (and percolation) occurred within 24 hours after the simulated rainfall events. The marked drop in soil water that occurred during the first 6 hours (Figure 11) was caused primarily by evaporation. The slight rise in soil water content between 54 and 66 hours was from natural rainfall. Overall, they found the average volumetric soil water content for mounds and undisturbed areas was not significantly different.

Grant et al. (1980) also reported that the density of vegetation immediately adjacent to the pocket gopher mounds was significantly higher than vegetation density 50 cm from the edge of mounds. This increase did not appear to be caused by the increased soil water content. While infiltration rates are significantly higher on mounds than on undisturbed prairie, the resulting differences in soil water content are neither large nor persistent (Figure 11). Grant et al. (1980) surmised that the increased plant density was a response to increased nutrient availability. This difference in soil chemistry also has been observed in harvester ant mounds (Rogers and Lavigne, 1974) and in prairie dog mounds (Carlson and White, 1987).

Ellison and Aldous (1952) observed that vegetation production was greater when pocket gophers were present, which reduced water infiltration in the soil from transpiration. McDonough (1974) also noted that mound building and soil turnover activities by pocket gophers favored the maintenance of aggressive perennials at high densities.

2.10.3 Townsend Ground Squirrel Burrow Systems

Townsend ground squirrel burrow systems are more similar to prairie dog burrow systems than the other two rodent species evaluated in this study. Townsend ground squirrels are larger than pocket mice and pocket gophers and often create large mounds of excavated soil around areas with entrance and exit holes similar to prairie dogs. There are no studies that have documented burrow ventilation effects in Townsend ground squirrel burrows, but there probably is airflow in Townsend ground squirrel burrow systems. These entrances and exits are seldom plugged and maintain continuous contact with the surface.

Water entry into these burrow systems does not appear to cause stress or harm to these species. Two things these species do that mitigate the effects of intense precipitation events are found in the burrow configuration: (1) burrow systems are complex and branch in many different upward and sideward directions (Manville, 1959; Shaw, 1925), so during extreme precipitation events, waterflow is probably diverted into many side channels before it can reach storage sites and nesting areas; and (2) mounds can act as dikes to divert water from the burrow.

Figure 10. Average Rate of Infiltration for Pocket Gopher Mounds and Undisturbed Prairie Plots (time zero represents the beginning of the experiment).

Figure 11. Average Volumetric Soil Water Contents for Pocket Gopher Mounds and Undisturbed Prairie Plots (time zero represents the termination of the experiment).

3.0 HANFORD STUDY

As previously mentioned, burrowing mammals will reside on any kind of protective barrier constructed. To address questions concerning the potential effects of burrowing mammals relative to water storage at the Hanford Site, an animal intrusion facility was constructed at the Hanford Meteorological Station (Figure 12). The objective of the study was to determine the degree that small mammal burrow systems affect the loss or retention of water at the Hanford Site.

3.1 Construction

Six animal lysimeters [5 ft by 5 ft by 6 ft (1.5 m by 1.5 m by 1.8 m) deep] and two outer boxes big enough to hold three lysimeters each were constructed in 1987 (Figure 12). The six individual animal lysimeters were designed so they could be disassembled and reused at the end of each test period (Photo 4). The outer boxes were installed in the ground at grade and buried approximately 100 ft (92 m) apart. At the beginning of each test the lysimeters were lined with a 28-mil plastic liner and filled with McGee Ranch soil. The McGee Ranch is a fine-soil site that has been identified for protective barrier use (Last et al., 1987), near the intersection of State Highways 24 and 240 (Figure 13).

In tests 1 and 2, each lysimeter was filled with 6 to 8 in. (15 to 20 cm) of pea gravel, with a geotextile material on top of the gravel. Four feet (1.2 m) of McGee Ranch soil was then added. In tests 3 through 5, the pea gravel and geotextile materials were not used. The soil was wet down and mixed before being placed in the lysimeters, allowing the soil to be compacted to facilitate animal burrowing. After the lysimeters were filled with soil, conductance probes (test 1 only) and two hydroprobe ports were installed in each lysimeter (tests 2 through 5). Soil core samples were collected at 6-in. (15-cm) intervals at the beginning and end of each test, and they were analyzed for soil moisture content. Soil-moisture measurements also were collected at this time and during the test period with a neutron probe at 6-in. (15-cm) intervals in all lysimeters.

3.2 Animals

Small burrowing mammals common to the Hanford Site environs were selected for the study. The species selected are prolific burrowers and are common at the Hanford Site and throughout the Great Basin region of the western United States. These species will probably always reside at the Site. Even if the climate were to change drastically, there would always be small burrowing mammals at the Hanford Site similar to the species used in this study.

Animal Intrusion Lysimeter Facility

Experimental Design

Three Species of Animals Used

- Animals Introduced into and Allowed To Burrow in the Lysimeters
- Supplemental Precipitation Added to Three of the Lysimeters
- Water Movement through the Lysimeters Is Monitored
- After 4-Month Period, the Animals Are Released and the Burrow Systems Are Mapped
- The Lysimeters Are Refilled and New Treatment Combinations Initiated

Figure 12. Location of the Animal Intrusion Lysimeter Facility.

WHC-EP-0730

Photo 4. Installation of an Animal Lysimeter.

Photo 5. Townsend Ground Squirrel in Native Habitat at the Hanford Site.

Figure 13. Experimental Design of the Small-Mammal Water Infiltration Study.

H9007012.1a

Animals were live trapped with Sherman traps and placed in the lysimeters within 3 to 5 days of when the hydroprobe ports were installed. Test periods lasted 3 to 4 months. The three small mammals used in this study were the Great Basin pocket mouse (*Perognathus parvus*), the Northern pocket gopher (*Thomomys talpoides*), and the Townsend ground squirrel (*Spermophilus townsendii*).

Two species of animals were used per test, with one animal in each lysimeter. Two of the lysimeters served as controls during each test period (containing no animals). Small depressions were excavated with a trowel before the animals were placed into the lysimeter to encourage them to begin burrowing. Food and water were added liberally to each animal lysimeter throughout the course of the study. All lysimeters were covered with a hardware cloth screen to prevent the animals from escaping and to provide protection from predators. At the end of each test period, the animals were removed, and the lysimeters were removed and disassembled. When possible, burrow systems were excavated and mapped.

3.2.1 Townsend Ground Squirrel

Townsend ground squirrels are 180 to 240 mm long, weigh 160 to 252 g, and reside in the sagebrush and grassland areas of southeastern Washington. They have short tails, and their bodies are smoke-gray washed with pinkish buff. Townsend ground squirrels are considered pests by the agricultural community because the squirrels feed on green vegetation. These squirrels are colonial and the burrow usually has a rim of dirt 4 to 6 in. (10 to 15 cm) high around the burrow entrance (Photo 5). They become dormant in May/June, and they emerge January to March (Burt and Grossenheider, 1980).

3.2.2 Great Basin Pocket Mouse

Great Basin pocket mice are 140 to 176 mm long, including the tail. Adults weigh from 18 to 30 g and are olive-gray, usually washed with fulvous on the belly. Great Basin pocket mice can be found in the sagebrush, chaparral, pinon, and yellow pine habitats of Washington, Oregon, Idaho, Nevada, and California. They are the most common small burrowing mammal in sagebrush habitats of southeastern Washington (Photo 6). Generally this species is inactive in winter, when it survives on seed caches stored in the burrow and elsewhere (Burt and Grossenheider, 1980).

3.2.3 Northern Pocket Gopher

The northern pocket gopher is 127 to 165 mm long and weighs 75 to 130 gm. This gopher is grayish, sometimes washed with brown; the nose is brown or blackish (Photo 7). Northern pocket gophers are widespread in all the western states and many parts of Canada. Pocket gophers are active day and night throughout the year. In winter, they tunnel through snow and push loose dirt into tunnels. When snow melts, long ropelike cores of dirt settle to the surface (Photo 8). They are considered harmful wherever they appear in cultivated areas, especially alfalfa fields (Burt and Grossenheider, 1980).

Photo 6. Great Basin Pocket Mouse in Native Habitat at the Hanford Site.

Photo 7. Northern Pocket Gopher Excavating a Burrow in a Lysimeter.

3.3 Rainfall Simulator

A rotating-boom rainfall simulator (i.e., rainulator), modified after Swanson (1965), was used to apply supplemental precipitation to boxes 1A, 1B, and 1C on a monthly basis during each test period (Photo 9). Water was applied at an intensity of 2.5 in./hour (6 cm/hour) for 13 minutes, which is the equivalent of the Hanford Site 100-yr storm (Stone et al., 1983). This adds 0.55 in. (1.3 cm) of water in 13 minutes. Applying supplemental precipitation at this rate several times during each test probably has not happened previously at the Hanford Site. To simulate overland flow and ponding effects, as much water as possible was applied during one precipitation event. Ponding and runoff effects were accomplished at the application rates mentioned previously.

3.4 Soil Moisture Measurements

In test 1, a method for soil moisture measurements was used that consisted of a conductivity probe (Gardner, 1986) fashioned with many electrodes evenly spaced along a wooden dowel, which was inserted into the soil. An alternating-current bridge was used to detect changes in electrical resistance of the soil beneath paired electrodes. Based on the results of test 1, and concurrent studies by Cadwell et al. (1989), too many inconsistencies were noted in the conductance probe data and so, in all subsequent tests, neutron probes were used instead.

A neutron probe consists of a fast-neutron source, a slow-neutron detector, and a scaler (Campbell et al., 1990). The scaler counts the slow neutrons that have been slowed down and reflected back to the detector by the water in the soil. The number of slow neutrons measured is related to the amount of water present in the soil. Some inherent problems exist in interpreting the hydroprobe results and correlating those results to animal burrowing. The animals can create void spaces around the hydroprobe ports during burrowing activity, which can affect the integrity of the hydroprobe readings. Because of this potential problem, the hydroprobe data was only reviewed to indicate overall trends in soil moisture conditions (i.e., wetter or drier).

Photo 8. Soil Cast From Pocket Gopher Burrowing Activity in the Winter.

Photo 9. Rainfall Simulator Applying Precipitation to Three Lysimeters.

4.0 RESULTS

Appendices A and B contain the results of the soil moisture profile changes calculated from the gravimetric soil samples for all tests and the complete set of soil conductance and neutron probe readings. Graphs of soil moisture changes throughout each test were generated from the gravimetric soil sampling and are presented in Appendix C. Appendix D presents graphs that were generated using the neutron probe data.

4.1 Test 1 (Summer Treatment)

Test 1 was conducted from April 1988 to October 1988 with Great Basin pocket mice and Townsend ground squirrels (Table 1). Table 2 shows the soil moisture profile changes that were measured in test 1 and all other tests. Supplemental precipitation was applied three times during test 1.

All of the lysimeters, including the two controls (which contain no animals), lost water in this test. Information from test 1 indicated that the 1.65 in. (4.2 cm) of supplemental precipitation applied with the rainulator to the lysimeters with animals was removed. The water in the soils of the lysimeters (even those lysimeters receiving supplemental precipitation) was not being stored, but was evaporating. The data did not indicate a significant difference in the water contents of the soils at depth in the lysimeters with animal burrows, compared with the water content of soils at depth in the control lysimeters, which did not have animal burrows.

Figure 14 compares a pocket mouse and a control lysimeter that had both received supplemental precipitation. The pocket mouse plot started with 19.84% moisture and ended up with 9.64% moisture (a net loss of 11.27%). The control plot started with 17.36% moisture and ended up with 10.92% (a net loss of 6.44%). The pocket mouse plot lost 4.8% more moisture than the control. No difference existed between the control (no animal) lysimeter and a Townsend ground squirrel lysimeter that had both received supplemental precipitation. Both of these lysimeters had a net moisture loss of 6.44%. The three lysimeters, including the control (containing no animal) that did not receive supplemental precipitation, had ending soil moisture values between 8 and 8.5%. This indicates that the data did not show any obvious effects on water storage as a result of animal burrowing.

The pocket mouse in lysimeter 1A penetrated the geotextile layer without any problem and some of the pea gravel had been removed to some of the upper tunnels. Soil moisture measurements were not taken in the pea gravel. There was no visible evidence of water in the pea gravel in any of the lysimeters.

Table 1. Individual Lysimeters and Species
Assignments Presented for all Five Tests.

Test Number	Description	Lysimeter	Species
One	Summer April 88 - Oct. 88	1A* 1B* 1C* 2A 2B 2C	Pocket Mouse Control Townsend Ground Squirrel Control Townsend Ground Squirrel Pocket Mouse
Two	Winter Nov 88 - April 89	1A 1C 2A 2B 2C	Pocket Gopher Control Pocket Mouse Pocket Gopher Control Pocket Gopher
Three	Summer May 89 - Aug 89	1A* 1B* 1C* 2A 2B 2C	Townsend Ground Squirrel Pocket Gopher Control Townsend Ground Squirrel Pocket Gopher Control
Four	Winter Oct 89 - Feb 90	1A* 1B* 1C* 2A 2B 2C	Pocket Gopher Pocket Mouse Control Pocket Mouse Pocket Gopher Control
Five	Summer April 90 - Aug 90	1A* 1B* 1C* 2A 2B 2C	Townsend Ground Squirrel Pocket Mouse Control Townsend Ground Squirrel Pocket Mouse Control

*Supplemental precipitation added with rainulator

Table 2. Summary of Overall Soil Moisture Changes Calculated from Soil Sample Collected at the Beginning and End of Each Test Period.

Test Number	Box ID Number	Species	Rainulator (Yes or No)	Initial Moisture %	Ending Moisture % ^a	Change %
Summer, April 88 - October 88						
1	1A	P. mouse	Yes	16.55	8.85	-7.70
1	1B	Control	Yes	14.78	-4.94	-4.94
1	1C	Townsend	Yes	14.77	9.83	-4.94
1	2A	Control	No	13.90	-5.55	-5.55
1	2B	Townsend	No	13.51	8.33	-5.18
1	2C	P. mouse	No	11.97	-3.53	-3.53
Winter, November 88 - April 89						
2	1A	P. gopher	No	8.99	10.44	+1.55
2	1B	Control	No	8.68	10.04	+1.39
2	1C	P. mouse	No	8.82	11.02	+2.20
2	2A	P. gopher	No	7.85	10.93	+3.08
2	2B	Control	No	9.04	10.48	+1.44
2	2C	P. gopher	No	8.11	10.71	+2.60
Summer, May 89 - August 89						
3	1A	Townsend	Yes	14.25	10.59	-3.67
3	1B	P. gopher	Yes	13.85	10.65	-3.19
3	1C	Control	Yes	14.73	10.92	-3.81
3	2A	Townsend	No	13.86	8.60	-5.26
3	2B	P. gopher	No	14.42	8.40	-6.03
3	2C	Control	No	14.37	9.52	-4.85
Winter, October 89 - February 90						
4	1A	P. gopher	Yes	9.14	10.25	+1.11
4	1B	P. mouse	Yes	8.59	10.17	+1.58
4	1C	Control	Yes	10.92	12.58	+1.66
4	2A	P. gopher	No	11.05	10.64	+0.41
4	2B	P. gopher	No	9.99	10.95	+0.96
4	2C	Control	No	9.52	11.41	+1.89
Summer, April 90 - August 90						
5	1A	Townsend	Yes	13.17	9.02	-2.89
5	1B	P. mouse	Yes	12.83	9.03	-3.80
5	1C	Control	Yes	13.68	9.26	-4.42
5	2A	Townsend	No	11.88	6.76	-5.12
5	2B	P. mouse	No	12.01	8.42	-3.59
5	2C	Control	No	12.13	8.18	-3.59

^aAverage soil moisture from core samples in soil only, initial water contents are averages of 2 samples' depth; ending moisture contents are single samples

Figure 14. Soil Moisture Profile Changes Measured in Test 1 (a lysimeter containing a pocket mouse and a control lysimeter with added supplemental precipitation).

Soil Moisture Profile Changes (Test 1) With Supplemental Precipitation

H9402043.3

4.2 Test 2 (Winter Treatment)

Test 2 was conducted from November 1988 to April 1989 using Great Basin pocket mice and pocket gophers (Table 1). Table 2 shows the soil moisture profile changes measured in test 2.

Frozen soil conditions and frozen water lines during test 2 prevented the addition of supplemental precipitation. However, 4.14 in. (10.5 cm) of supplemental precipitation was added in the form of natural precipitation (rain and snow) that, according to the Hanford Meteorological Station, was 178% of normal by the end of March.

Test 2 provided a good comparison of soil moisture conditions under natural precipitation conditions during the winter season. All six lysimeters had a net increase in soil moisture (Table 1). The largest increases in soil moisture in all the lysimeters occurred from 18 to 30 in. (46 to 76 cm) with the 18 in. (46 cm) depth showing the most change. The least amount of change in soil moisture occurred from the 42- to 48-in. (107- to 122-cm) depth. This is illustrated in Figure 15, which shows initial soil moisture conditions at the beginning and at the end of test 2 in a pocket mouse lysimeter and a control lysimeter.

Figure 15. Soil Moisture Profile Changes Measured in Test 2 (a lysimeter containing a pocket mouse and a control lysimeter with ambient precipitation).

Soil Moisture Profile Changes (Test 2) Ambient Precipitation (Winter)

H9402043.18

Hydroprobe readings from test 2 also confirm increasing soil moisture conditions in all six lysimeters during the test period. Figures 16 and 17 show this trend for a pocket gopher and a control lysimeter. The hydroprobe readings also indicate little change in soil moisture conditions below 30 in. (76 cm).

The pocket mouse in lysimeter 1A and the pocket gophers in lysimeters 2A and 2C penetrated the geotextile layer without any problem and some of the pea gravel had been removed to some of the upper tunnels. Soil moisture measurements were not taken in the pea gravel. There was no visible evidence of water in the pea gravel. Pea gravel and the geotextile material were placed in the lysimeters to see if these materials would act as a barrier to burrowing. The results from the first two tests showed that the geotextile material was not a deterrent to burrowing, so the pea gravel and geotextile material were not used in subsequent tests.

4.3 Test 3 (Summer Treatment)

Test 3 was conducted from May 1989 to August 1989 using Townsend ground squirrels and pocket gophers (Table 1). Table 2 presents the soil moisture profile changes that occurred during test 3. Supplemental precipitation was added with the rainulator three times during test 3.

Figure 16. Hydroprobe Measurements Observed in Test 2
(a lysimeter containing a pocket gopher and no supplemental precipitation).

Figure 17. Hydroprobe Measurements Observed in Test 2
(a control lysimeter and no supplemental precipitation).

Data collected from test 3 indicated that all of the lysimeters lost water. As in test 1, the 1.65 in. (4.2 cm) of supplemental precipitation, which was applied with the rainulator to three of the lysimeters, was removed. An example of this is shown in Figure 18 with the three lysimeters that received supplemental precipitation. The soil moisture graphs (Appendix C) do not indicate which lysimeters contained animals and which lysimeters served as the controls (containing no animals). As in test 1, any obvious effects of water storage in regards to animal burrowing was not observed.

The hydroprobe readings that were observed during test 3 also show the same overall trend of moisture loss. Figure 19 illustrates this point with a lysimeter that contained a pocket gopher and supplemental precipitation. The overall trend depicted in Figure 6 is less water accounted for at all depths during the test.

4.4 Test 4 (Winter Treatment)

Test 4, using pocket gophers and pocket mice, was started in October 1989 and ended in February 1990 (Table 1). Table 2 presents the soil moisture profile changes recorded during test 4. Supplemental precipitation [1.10 in. (2.8 cm)] was added with the rainulator two times during test 4. This was in addition to the 2.63 in. (6.7 cm) of natural precipitation (rain and snow) that was recorded during the test period.

According to the gravimetric soil moisture data calculated from soil cores, all of the lysimeters, except 2A, gained water. Lysimeter 2A, which contained a pocket gopher with no supplemental precipitation added, lost 0.61% overall moisture during test 4. However, the hydroprobe data from lysimeter 2A and all other lysimeters indicated a

Figure 18. Soil Moisture Profile Changes Measured in Test 3
(a lysimeter with added supplemental precipitation).

Figure 19. Hydroprobe Measurements Observed in Test 3
(a lysimeter containing a pocket gopher and added supplemental precipitation).

gain in soil moisture during test 4. For some unexplained reason, the gravimetric soil moisture results from lysimeter 2A are not consistent with the gravimetric results from the other five lysimeters in test 4 nor the gravimetric results from test 2, which also was conducted in the winter.

An example of the overall increase in soil moisture observed during test 4 is shown in Figure 20 (a lysimeter with pocket gopher and supplemental precipitation). The two control plots, 1C (supplemental precipitation added) and 2C (no water added), gained the most water (Figures 5, 21, and 22, respectively).

The hydroprobe readings from all six lysimeters in test 4 also show the trend of increasing soil moisture conditions. An example of this is shown in Figures 21 and 22 [lysimeters containing a pocket mouse and supplemental precipitation (1B) and a pocket mouse and no supplemental precipitation (2B)]. Both graphs show increasing moisture conditions over time and that very little change in soil moisture occurred below 18 in. (46 cm).

Figure 20. Soil Moisture Profile Changes Measured in Test 4
(a lysimeter containing a pocket gopher and added supplemental precipitation).

Figure 21. Hydroprobe Measurements Observed in Test 4
(a lysimeter containing a pocket mouse and added supplemental precipitation).

Figure 22. Hydroprobe Measurements Observed in Test 4
(a lysimeter containing a pocket mouse and no supplemental precipitation).

4.5 Test 5 (Summer Treatment)

Test 5 was conducted from April 1990 to August 1990 using Townsend ground squirrels and pocket mice (Table 1). Table 2 presents the soil moisture profile changes recorded during test 5. Supplemental precipitation was added three times during the test period.

Test 5 followed the same trends as the previous summer treatments in that all the lysimeters lost water. The amount of water lost was similar among those lysimeters that received supplemental precipitation (Table 2). Figures 23 and 24 show the overall water loss for lysimeters containing Great Basin pocket mice, with supplemental precipitation added (1B) and without supplemental precipitation (2B). No effects caused by adding supplemental precipitation could be detected.

The hydroprobe readings from the two lysimeters that contained Great Basin pocket mice (1B, 2B) also show the same trend described above (Figures 25 and 26). These two graphs are similar in appearance; the data depicted in these figures do not indicate a noticeable difference between the lysimeter that received the supplemental precipitation the lysimeter that did not.

Figure 23. Soil Moisture Profile Changes Measured in Test 5
(a lysimeter containing a pocket mouse and added supplemental precipitation).

Soil Moisture Profile Changes (Test 5) Pocket Mouse (With Supplemental Precipitation)

H9402043.50

Figure 24. Soil Moisture Profile Changes Measured in Test 5
(a lysimeter containing a pocket mouse and no supplemental precipitation).

Soil Moisture Profile Changes (Test 5) Pocket Mouse (With No Supplemental Precipitation)

H9402043.53

Figure 25. Hydroprobe Measurements Observed in Test 5
(a lysimeter containing a pocket mouse and added supplemental precipitation).

Figure 26. Hydroprobe Measurements Observed in Test 5
(a lysimeter containing a pocket mouse and no supplemental precipitation).

4.6 Burrow Configurations

Table 3 presents the results of the burrow excavations that were conducted for tests 1 through 4. Burrows were unable to be excavated for test 5 because of soil sloughing and collapse, which occurred when the lysimeters were removed. Pocket gophers were the most prolific burrowers, followed by pocket mice and Townsend ground squirrels (Photo 10). The average depth of burrows was the same for pocket mice and pocket gophers (48 in.). Except to show the amount of burrowing in each lysimeter, this data cannot be extrapolated to pertain to natural conditions. The experimental design imposed on this study had a major effect on the amount of burrowing activity (Figure 12).

There are not enough data points to make meaningful comparisons of burrowing behavior among species or seasons. However, these burrow excavations did verify the plugging of burrow entrances and tunnels by pocket gophers and pocket mice, which is well documented. The constant burrowing and soil turnover exhibited by these small mammals did have the effect of altering the microtopography of the soil surface. Small depressions, holes, and mounds were created as a result of burrowing activities.

4.7 Evaluation of Hanford Data

The present study, which was conducted in an arid environment (the Hanford Site), did not indicate that small mammal burrows were allowing any significant water storage at depth and what water might be gained during the winter or high precipitation events would be removed during the spring and summer months, even when supplemental precipitation was added. This is especially significant because the experimental design imposed conditions on the lysimeters that should have contributed to increased water storage at depth. These conditions were caused by lack of vegetative cover, no water runoff, high animal and burrow densities, supplemental precipitation added at rates that do not occur normally, and burrows that extended to the bottom of the lysimeters.

4.7.1 Transpiration

During the study, vegetation was not allowed to become established. This eliminated any water loss from transpiration, which can be profound. Campbell and Gee (1990) and Gee et al. (1993) (lysimeter studies at the Hanford Site) showed that vegetation was the most important factor in preventing drainage. Vegetated treatments completely masked the three-times-average precipitation treatments on an annual basis by removing all available water from both the ambient and three-times-average treatments to a common water content and potential. The minimum water storage for vegetated treatments was about half that for nonvegetated treatments. Gee et al. (1993) concluded after 6 yr of testing with no drainage occurring in vegetated treatments that surface isolation barrier designs with vegetated capillary barriers, will be successful in preventing recharge at the Hanford Site waste sites.

Photo 10. Cross-Section of Pocket Gopher Burrow and Food Cache in One Lysimeter.

Photo 11. Holes and Depressions Created by the Townsend Ground Squirrel Fill Up Rapidly During High-Precipitation Events.

Table 3. Total Length (inches) and Maximum Depth of Burrow Systems for Tests 1-4.

Test Number	Lysimeter number	Species	Total length	Maximum depth
Summer treatment				
One	1A ^a	Pocket mouse	201	48
One	1C ^a	Townsend	54	24
One	2B	Townsend	32	16
One	2C	Pocket mouse	321	40
Winter treatment				
Two	1A	Pocket gopher	384	44
Two	1C	Pocket mouse	192	42
Two	2A	Pocket gopher	444	52
Two	2C	Pocket gopher	570	52
Summer treatment				
Three	1A ^a	Townsend	186	45
Three	1B ^a	Pocket gopher	213	57
Three	2A	Townsend	54	26
Three	2B	Pocket gopher	420	54
Winter treatment				
Four	1A ^b	Pocket gopher	318	58
Four	1B ^b	Pocket mouse	156	55
Four	2A	Pocket gopher	102	12
Four	2B	Pocket mouse	261	55

^a1.65 in. added water^b1.10 in. added water

The animal intrusion data reported here essentially show the same effects (water being removed) even without vegetation present. If vegetation had been allowed to grow in the animal-intrusion lysimeters, the overall water loss would have been greater and occurred at an even faster rate. Plant densities are usually greater in the vicinity of animal burrows.

4.7.2 Water Runoff

The design of the lysimeters ensured that no water runoff occurred during precipitation events, all water was contained. Even though the Hanford Site is considered to be a semi-arid environment, and water inputs are small, runoff can occur even though it is small and localized, occurring with infrequent heavy rains (Campbell and Harris, 1981).

During this study, the water infiltration rate was faster than the other two lysimeters, when supplemental precipitation was added to those lysimeters containing

Townsend ground squirrels. The water had penetrated the soil matrix faster and deeper in the short term compared to lysimeters containing Great Basin pocket mice and pocket gophers. This was because there were usually several open holes and depressions that had been excavated by the ground squirrels, which facilitated the entry of water into the soil matrix (Photo 11). These burrow systems closely resemble channel system A, described previously by Dixon and Peterson (1971), which is characterized by numerous stable open channel ports exposed to free water and open to the atmosphere. Under this system, water is rapidly transferred to subsurface borders of the capillary system and readily exhausts displaced soil air.

4.7.3 Burrow Density

Burrow and animal densities were much higher than normal. Home range sizes were significantly less than would be found in a natural shrub steppe environment. By limiting animals to a small confined area and increasing the burrow densities, any burrow effects on water storage should have been observed.

4.7.4 Supplemental Precipitation

The supplemental precipitation, added by the rainulator in amounts equivalent to a 100-yr storm on a monthly basis, greatly exceeds any amount of water that could be expected to occur naturally, especially when these were applied two or three times during the test periods.

4.7.5 Burrow Depths

Because the animals usually burrowed to the bottom of the lysimeters, channels were created by which water could potentially reach the bottom of the lysimeter. Despite these conditions, the data did not indicate that animal burrows were contributing to water storage at depth.

4.8 Water Loss in Burrows

Water loss in our study probably resulted from a combination of at least three factors: (1) high ambient temperatures, which resulted in soil evaporation, (2) soil turnover and subsequent drying, and (3) burrow ventilation effects. All of the small mammals in this study were constantly turning the soil over (i.e., burrowing). Commonly, soil was excavated by the small mammals and brought to the surface during the night, and the soil was wetter than the surrounding surface soil. Usually within a few hours (or less) this excavated soil had dried out and looked like the surface soil.

Open and closed burrows allow air to enter, which has dries out the soil (King, 1984). This has been documented in many of the studies with moles, prairie dogs, and bank voles, which are discussed in previous sections. This same phenomenon undoubtedly occurs with the species used in this study.

The results from our study support the literature cited previously, especially concerning water infiltration and large pores connected to the surface. This study indicated that during high-precipitation events, open burrows made by Townsend ground squirrels and connected to the surface allowed water to penetrate deeper and faster than normal. However, this excess water was removed relatively quickly and actually made the burrow systems and surrounding soil drier than in nonburrow areas (Figure 27). This suggests that these burrow systems will actually enhance the long-term removal of water from the barrier, concerning especially those systems made by burrowing animals such as ground squirrels, which have open-burrow systems.

Burrow systems formed by Great Basin pocket mice and pocket gophers that are not connected to the surface reduce water infiltration because of burrow air pressures and mounding effects, which inhibit water penetration into a burrow by acting as a buffer or by diverting excess water away from the burrow system (Figure 27). These burrow systems also effectively slow down water infiltration by nature of the general burrow configuration (i.e., branching, mounding, and upturns).

4.8.1 Soil Water Evaporation

The data suggests that the high ambient temperature that results in soil water evaporation is probably the overriding factor contributing to the water losses observed in the present study. The two winter treatments were the only treatments that gained water during that time of the year when ambient temperatures were low.

Figure 27. Overview of All Abiotic and Biotic Factors That Influence Soil Moisture in Open and Closed Burrow Systems.

5.0 SUMMARY

Five animal intrusion tests were completed as part of this study. Information collected from these five tests indicated the following.

- During the summer months, a net water loss exited in all the lysimeters, including the controls and those lysimeters that received supplemental precipitation.
- During the winter months, all lysimeters gained water. This is probably a seasonal effect during a time when precipitation is greater and evaporation is low and may not be related to burrowing impacts on moisture.
- The data did not indicate that any long-term water storage had occurred as a direct result of animal burrowing activity. The soil moisture profile graphs generated from all five tests [lysimeters containing animals and lysimeters serving as controls (no animals)] were similar. This study did not indicate that animal burrows at the Hanford Site facilitate the retention of water at depth.

The lack of any significant water storage at depth and the overall water loss in the lysimeters occurred despite conditions that could be considered worst-case scenarios, which were imposed on the lysimeters. These conditions included no vegetative cover (no plant transpiration); no water runoff (all water contained); higher-than-normal animal and burrow densities; supplemental precipitation added at rates not expected to occur normally; and animals burrowed to the bottom of the lysimeters. The overall water loss appears to be caused primarily by soil evaporation, which is caused by high ambient temperatures in the spring and summer. Other causes of water loss are probably a combination of (1) constant soil turnover and subsequent drying, and (2) burrow ventilation effects.

This study did not address all potential climate changes, runoff events, and potential effects of other burrowing animals. However, increased water storage at the Hanford Site under the present climatic conditions appear to be negligible, considering that a protective barrier will allow for runoff, have a vegetative cover, experience normal animal densities and normal precipitation events. Studies conducted elsewhere in environments that receive more natural precipitation and have lower ambient temperatures may not observe results as pronounced as those observed at the Hanford Site.

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APPENDIX A

**SOIL MOISTURE PROFILE CHANGES CALCULATED FROM THE GRAVIMETRIC SOIL
SAMPLING AT THE BEGINNING AND END OF EACH TEST**

Table A-1. Soil Moisture Profile Changes During First Test Conducted April 88 to October 88. (sheet 1 of 2)

Box number	Depth (in.)	Initial moisture (%)	Ending moisture (%)	Percent change
Species: Pocket Mouse				
1A	6	19.82	6.89	-12.93
1A	12	18.66	8.67	-9.99
1A	18	18.82	9.31	-9.51
1A	24	21.38	9.46	-11.92
1A	30	19.31	10.90	-8.41
1A	36	20.14	10.92	-9.22
1A	42	20.42	10.74	-9.68
1A	48	19.99	10.23	-9.76
1A	54	20.01		-20.01
Average		19.84	9.64	-11.27
Species: Control				
1B	6	16.48	7.87	-8.61
1B	12	14.74	9.45	-5.29
1B	18	17.74	11.10	-6.64
1B	24	18.25	11.78	-6.47
1B	30	20.94	12.38	-8.56
1B	36	17.28	12.46	-4.82
1B	42	16.11	11.42	-4.69
1B	48	17.34		
Average		17.36	10.92	-6.44
Species: Townsend				
1C	6	14.76	8.57	-6.19
1C	12	14.66	9.90	-4.76
1C	18	16.02	10.42	-5.60
1C	24	17.51	11.45	-6.06
1C	30	18.86	12.22	-6.64
1C	36	18.90	12.28	-6.62
1C	42	19.99	11.68	-8.31
1C	48	18.18	10.81	-7.37
Average		17.36	10.92	-6.44

Table A-1. Soil Moisture Profile Changes During First Test Conducted
April 88 to October 88. (sheet 2 of 2)

Box number	Depth (in.)	Initial moisture (%)	Ending moisture (%)	Percent change
Species: Control				
2A	6	18.70	5.68	-13.02
2A	12	15.97	8.30	-7.67
2A	18	18.58	9.44	-9.14
2A	24	16.16	9.93	-6.23
2A	30	16.95	10.68	-6.27
2A	36	12.95	10.30	-2.65
2A	42	13.92	9.59	-4.33
Average		16.18	8.09	-7.04
Species: Townsend				
2B	6	17.34	6.12	-11.22
2B	12	17.34	8.15	-9.19
2B	18	17.03	9.75	-7.28
2B	24	14.90	10.39	-4.51
2B	30	15.41	10.30	-5.11
2B	36	13.34	9.15	-4.19
2B	42	14.16	9.88	-4.28
Average		15.65	8.31	-6.54
Species: Pocket Mouse				
2C	6	13.01	8.49	-4.52
2C	12	11.85	4.87	-6.98
2C	18	14.56	9.18	-5.38
2C	24	13.63	10.12	-3.51
2C	30	13.86	10.61	-3.25
2C	36	13.71	10.84	-2.87
2C	42	14.94	10.66	-4.28
Average		13.65	8.46	-4.40

Table A-2. Soil Moisture Profile Changes During Second Test.
(sheet 1 of 2)

Box number	Depth (in.)	Initial moisture (%)	Ending moisture (%)	Percent change
Species: Pocket Gopher				
1A	6	10.69		
1A	12	11.03	12.37	1.34
1A	18	10.05	12.78	2.73
1A	24	9.53	11.55	2.02
1A	30	8.72	13.53	4.81
1A	36	9.63	11.99	2.36
1A	42	10.11	9.88	-0.23
1A	48	9.28	9.64	0.36
Average		9.88	11.68	1.91
Species: Control				
1B	6	9.39	9.73	0.34
1B	12	9.64	11.23	1.59
1B	18	9.94	13.06	3.13
1B	24	9.72	12.04	2.33
1B	30	8.66	11.91	3.24
1B	36	9.49	9.06	-0.44
1B	42	9.45		
1B	48	9.80		
Average		9.51	11.17	1.70
Species: Pocket Mouse				
1C	6	8.40	10.73	2.33
1C	12	9.34	12.24	2.90
1C	18	9.28	15.08	5.81
1C	24	9.60	13.90	4.31
1C	30	10.15	13.47	3.32
1C	36	10.90	11.74	0.84
1C	42	9.60	11.53	1.93
1C	48	10.22	10.54	0.32
Average		9.68	12.40	2.72

Table A-2. Soil Moisture Profile Changes During Second Test.
(sheet 2 of 2)

Box number	Depth (in.)	Initial moisture (%)	Ending moisture (%)	Percent change
Species: Pocket Gopher				
2A	6	8.22	10.47	2.25
2A	12	7.71	11.57	3.85
2A	18	6.34	13.86	7.52
2A	24	9.49	16.06	6.57
2A	30	9.73	13.86	4.13
2A	36		12.76	4.81
2A	42	9.64	10.52	0.88
2A	48	9.38	9.34	-0.04
Average		8.56	12.30	3.75
Species: Control				
2B	6	9.42	8.07	-1.35
2B	12	7.56	11.98	4.41
2B	18	11.18	14.23	3.05
2B	24	11.85	14.78	2.93
2B	30	10.37	11.38	1.01
2B	36	4.87	12.29	
2B	42	9.49	10.08	0.59
2B	48	9.31		
Average		9.26	11.83	1.77
Species: Pocket Gopher				
2C	6	6.92	9.49	2.57
2C	12	8.01	13.91	5.90
2C	18	9.08	14.83	5.76
2C	24	9.60	14.56	4.96
2C	30	8.23	11.36	3.13
2C	36	9.66		1.77
2C	42	10.01	10.37	0.36
2C	48	9.27	10.30	1.03
Average		8.85	12.03	3.18

Table A-3. Soil Moisture Profile Changes During Third Test.
(sheet 1 of 2)

Box number	Depth (in.)	Initial moisture (%)	Ending moisture (%)	Percent change
Species: Townsend Ground Squirrel				
1A	6	15.38	7.47	-7.91
1A	12	14.25	9.79	-4.46
1A	18	15.78	11.72	-4.05
1A	24	15.64	12.17	-3.47
1A	30	16.62	12.93	-3.70
1A	36	17.52	13.73	-3.79
1A	42	17.20	13.02	-4.18
1A	48	18.39	13.65	-4.74
1A	54	18.95	12.35	-6.60
Average		16.64	11.87	-4.77
Species: Pocket Gopher				
1B	6	17.01	8.74	-8.27
1B	12	14.04	9.57	-4.47
1B	18	14.24	10.57	-3.67
1B	24	15.11	12.13	-2.98
1B	30	15.38	12.43	-2.94
1B	36	16.65	13.82	-2.83
1B	42	16.85	13.70	-3.15
1B	48	17.32	12.26	-5.06
1B	54	17.98	14.36	-3.62
Average		16.07	11.96	-4.11
Species: Control				
1C	6	17.99	7.28	-10.71
1C	12	15.97	10.53	-5.44
1C	18	15.66	11.50	-4.15
1C	24	16.46	12.40	-4.06
1C	30	17.33	12.67	-4.66
1C	36	17.80	12.66	-5.14
1C	42	17.82	14.64	-3.17
1C	48	18.69	13.67	-5.02
1C	54	17.87	15.27	-2.60
Average		17.29	12.29	-5.00

Table A-3. Soil Moisture Profile Changes During Third Test.
(sheet 2 of 2)

Box number	Depth (in.)	Initial moisture (%)	Ending moisture (%)	Percent change
Species: Townsend Ground Squirrel				
2A	6	16.20	6.90	-9.30
2A	12	16.49	9.08	-7.40
2A	18	16.35	10.09	-6.26
2A	24	16.72	10.10	-6.62
2A	30	16.09	8.36	-7.72
2A	36	15.67	10.80	-4.87
2A	42	17.41	10.80	-6.61
2A	48	15.09	9.33	-5.76
2A	54	14.83	9.28	-5.55
Average		16.09	9.42	-6.68
Species: Pocket Gopher				
2B	6	15.56	6.19	-9.37
2B	12	15.83	7.64	-8.19
2B	18	16.91	9.99	-6.91
2B	24	19.73	12.19	-7.54
2B	30	18.32	4.87	-13.45
2B	36	16.55	9.07	-7.48
2B	42	15.05	10.83	-4.22
2B	48	16.46	10.12	-6.34
2B	54	17.36	12.05	-5.31
Average		16.86	9.22	-7.65
Species: Control				
2C	6	15.28	5.69	-9.58
2C	12	15.22	7.40	-7.82
2C	18	15.26	10.41	-4.85
2C	24	16.48	11.55	-4.94
2C	30	17.88	11.67	-6.21
2C	36	17.53	11.07	-6.46
2C	42	17.58	11.53	-6.05
2C	48	17.02	12.35	-4.66
2C	54	18.90	13.50	-5.40
Average		16.79	10.57	-6.22

Table A-4. Soil Moisture Profile Changes During Fourth Test.
(sheet 1 of 2)

Box number	Depth (in.)	Initial moisture (%)	Ending moisture (%)	Percent change
Species: Gopher				
1A	6	8.64	11.89	3.24
1A	12	9.38	11.92	2.54
1A	18	9.86	12.93	3.07
1A	24	9.69	10.45	0.76
1A	30	9.86	10.64	0.78
1A	36	10.31	11.08	0.77
1A	42	10.93	11.23	0.30
1A	48	11.34	11.67	0.33
1A	54	10.62	10.99	0.37
Average		10.07	11.42	1.35
Species: Pocket Mouse				
1B	6	7.52	14.12	6.59
1B	12	9.37	12.38	3.01
1B	18	9.11	11.79	2.68
1B	24	8.33	11.61	3.28
1B	30	9.63	11.63	2.00
1B	36	10.37	12.10	1.73
1B	42	10.65	7.46	-3.19
1B	48	9.57	10.34	0.77
1B	54	10.08	10.66	0.58
Average		9.41	11.34	1.94
Species: Control				
1C	6	7.28	13.15	5.87
1C	12	10.53	13.42	2.88
1C	18	11.50	13.96	2.45
1C	24	12.40	13.95	1.55
1C	30	12.67	15.18	2.51
1C	36	12.66	15.42	2.76
1C	42	14.64	13.63	-1.02
1C	48	13.67	15.06	1.39
1C	54	15.27	15.84	0.57
Average		12.29	14.40	2.11

Table A-4. Soil Moisture Profile Changes During Fourth Test.
(sheet 2 of 2)

Box number	Depth (in.)	Initial moisture (%)	Ending moisture (%)	Percent change
Species: Gopher				
2A	6	7.97	11.62	3.65
2A	12	9.72	11.92	2.20
2A	18	10.06	10.90	0.84
2A	24	14.68	12.78	-1.91
2A	30	13.99	10.75	-3.24
2A	36	15.46	12.86	-2.60
2A	42	14.53	12.31	-2.23
2A	48	13.75	12.14	-1.61
2A	54	12.25		
Average		12.49	11.91	-0.61
Species: Pocket Mouse				
2B	6	8.99	12.09	3.09
2B	12	10.21	12.90	2.70
2B	18	9.32	12.10	2.78
2B	24	10.35	12.42	2.07
2B	30	11.24	12.33	1.09
2B	36	12.37	12.11	-0.25
2B	42	12.82	12.55	-0.27
2B	48	12.69	11.87	-0.82
2B	54	12.06		
Average		11.12	12.30	1.30
Species: Control				
2C	6	5.69	10.94	5.24
2C	12	7.40	10.78	3.38
2C	18	10.41	12.87	2.47
2C	24	11.55	13.09	1.54
2C	30	11.67	13.27	1.60
2C	36	11.07	14.98	3.91
2C	42	11.53	11.27	-0.25
2C	48	12.35	14.37	2.02
2C	54	13.50	14.47	0.98
Average		10.57	12.89	2.32

Table A-5. Soil Moisture Profile Changes During Fifth Test.
(sheet 1 of 2)

Box number	Depth (in.)	Initial moisture (%)	Ending moisture (%)	Percent change
Species: Townsend				
1A	6	15.08	5.62	-9.45
1A	12	14.70	7.40	-7.31
1A	18	16.90	9.37	-7.54
1A	24	14.56	10.37	-4.20
1A	30	14.68	12.16	-2.52
1A	36	15.98	12.37	-3.61
1A	42	15.28	11.83	-3.44
1A	48	14.24	10.60	-3.64
Average		14.69	9.98	-5.21
Species: Pocket Mouse				
1B	6	13.22	5.78	-7.44
1B	12	15.32	7.22	-8.10
1B	18	17.71	10.15	-7.56
1B	24	14.63	10.45	-4.18
1B	30	14.00	9.23	-4.77
1B	36	16.37	12.22	-4.15
1B	42	12.31	12.67	0.36
1B	48	14.34	12.06	-2.28
Average		14.78	9.97	-4.77
Species: Control				
1C	6	16.04	6.96	-9.08
1C	12	16.69	8.61	-8.09
1C	18	15.24	10.59	-4.65
1C	24	17.08	10.63	-6.45
1C	30	16.89	11.69	-5.20
1C	36		10.42	
1C	42	15.64	11.08	-4.56
1C	48	13.44	12.05	-1.39
Average		12.29	14.40	2.11

Table A-5. Soil Moisture Profile Changes During Fifth Test.
(sheet 2 of 2)

Box number	Depth (in.)	Initial moisture (%)	Ending moisture (%)	Percent change
Species: Townsend				
2A	6	12.62	4.66	-7.96
2A	12	13.32	4.43	-8.89
2A	18	13.86	7.27	-6.59
2A	24	13.42	8.31	-5.11
2A	30	13.80	9.62	-4.18
2A	36	14.51	9.31	-5.20
2A	42	13.84	6.94	-6.90
2A	48	12.52	7.72	-4.80
Average		12.49	11.91	-0.61
Species: Pocket Mouse				
2B	6	12.83	6.09	-6.74
2B	12	12.72	7.19	-5.54
2B	18	15.25	10.33	-4.92
2B	24	16.67	10.04	-6.63
2B	30	13.18	10.18	-3.00
2B	36	14.05	9.65	-4.40
2B	42	12.52	10.57	-1.95
2B	48	12.15	9.69	-2.46
Average		13.59	9.22	-4.45
Species: Control				
2C	6	15.74	5.46	-10.28
2C	12	15.99	8.08	-7.91
2C	18	15.37	8.48	-6.89
2C	24	13.91	10.32	-3.59
2C	30	13.07	9.69	-3.38
2C	36	12.17	9.42	-2.75
2C	42	12.79	10.02	-2.77
2C	48	11.60	10.12	-1.49
Average		13.73	8.95	-4.88

APPENDIX B

**CONDUCTANCE AND HYDROPROBE DATA
(COLLECTED FOR TESTS 1 THROUGH 5)**

Table B-2. Hydroprobe Readings Observed During Test Two. (sheet 1 of 6)

Nov 88-Apr 89			NOV18	DEC8	JAN5	JAN31	MAR10	MAR20	MAR28	APR7	APR12
BOX 1A PG		DEPTH									
PROBE 11		5	3591	3243	3195	2158	3531	2969	2943	2003	2467
		11	4782	4091	4896	4283	8223	7529	6668	5394	5127
		17	4589	4194	4467	4447	7692	7428	7110	5750	5358
		23	4556	4537	4942	4519	6101	7363	7070	6406	6181
		29	4622	4371	4647	4465	4598	5940	6193	6097	6338
		35	4704	4421	4719	4594	4689	4878	5207	5365	5625
BOX 1A PG		DEPTH									
PROBE 12		5	3750	2185	3730	1764	5172	2857	3746	2740	2780
		11	4550	4365	4766	4326	9032	8034	7010	5942	5490
		17	4486	4314	4291	4348	8826	8379	7542	6896	6462
		23	4208	4254	4456	4331	7379	7669	7505	7001	6601
		29	4050	4155	4327	4318	5672	6236	6213	6246	6234
		35	4229	4412	4285	4179	4468	4731	4996	5209	5403
BOX 1A PG		DEPTH									
AVERAGE		5	3671	2714	3463	1961	4352	2913	3345	2372	2624
		11	4666	4228	4831	4305	8628	7782	6839	5668	5309
		17	4538	4254	4379	4398	8259	7904	7326	6323	5910
		23	4382	4396	4699	4425	6740	7516	7288	6704	6391
		29	4336	4263	4487	4392	5135	6088	6203	6172	6286
		35	4467	4417	4502	4387	4579	4805	5102	5287	5514

Table B-2. Hydroprobe Readings Observed During Test Two. (sheet 2 of 6)

Nov 88-Apr 89			NOV18	DEC8	JAN5	JAN31	MAR10	MAR20	MAR28	APR7	APR12
BOX 1B CO		DEPTH									
PROBE 13		5	3922	2610	3364	3007	4793	2793	3864	2647	2575
		11	4759	4673	5123	4659	9772	8513	7517	6333	5806
		17	4695	4645	4964	4674	9689	8853	8144	7105	6806
		23	4679	4795	4996	4739	9890	9051	8583	7831	7476
		29	4762	4747	5035	4822	9961	8710	8198	7546	7340
		35	4934	4890	5169	4873	6060	7146	7297	7150	6899
BOX 1B CO		DEPTH									
PROBE 14		5	3319	1868	2991	1754	5850	4302	3887	3232	2632
		11	4194	3899	4382	4148	6586	6713	6135	5276	5020
		17	4660	4435	4792	4643	5133	5663	5957	5983	5933
		23	4620	4701	4862	4501	4736	4766	5291	5681	5595
		29	4386	4379	4374	4280	4388	4384	4568	4593	4838
		35	4626	4803	4839	4870	4973	4793	4781	4776	4925
BOX 1B CO		DEPTH									
AVERAGE		5	3621	2239	3178	2381	5322	3548	3876	2940	2604
		11	4477	4286	4753	4404	8179	7613	6826	5805	5413
		17	4678	4540	4878	4659	7411	7258	7051	6544	6370
		23	4650	4748	4929	4620	7313	6909	6937	6756	6536
		29	4574	4563	4705	4551	7175	6547	6383	6070	6089
		35	4780	4847	5004	4872	5517	5970	6039	5963	5912

Table B-2. Hydroprobe Readings Observed During Test Two. (sheet 3 of 6)

Nov 88-Apr 89			NOV18	DEC8	JAN5	JAN31	MAR10	MAR20	MAR28	APR7	APR12
BOX 1C PM		DEPTH									
PROBE 15		5	2858	3513	3348	2641	5987	3874	4718	3321	1678
		11	4424	4537	4670	4581	9148	8141	7477	6077	5208
		17	4271	4298	4510	4492	8339	8239	7468	6616	6258
		23	4652	4362	4404	4383	5369	7059	7060	6561	6444
		29	4442	4562	4604	4503	4696	6142	6563	6220	6196
		35	4772	4920	4987	4680	5009	5091	5595	5683	5716
BOX 1C PM		DEPTH									
PROBE 16		5	3019	3163	3194	2674	6740	3601	3288	2593	2862
		11	4257	4204	4190	4041	8184	7442	6622	5920	5690
		17	4685	4648	4610	4448	7895	8130	7558	7257	7036
		23	4657	4597	4702	4698	5446	7030	7113	6775	6600
		29	4569	4555	4722	4557	4586	5352	5711	5939	6080
		35	4753	4808	4589	4642	4739	4567	4836	5188	5313
BOX 1C PM		DEPTH									
AVERAGE		5	2939	3338	3271	2658	6364	3738	4003	2957	2270
		11	4341	4371	4430	4311	8666	7792	7050	5999	5449
		17	4478	4473	4560	4470	8117	8185	7513	6937	6647
		23	4655	4480	4553	4541	5408	7045	7087	6668	6522
		29	4506	4559	4663	4530	4641	5747	6137	6080	6138
		35	4763	4864	4788	4661	4874	4829	5216	5436	5515
			NOV18	DEC8	JAN5	JAN31	MAR10	MAR20	MAR28	APR7	APR12

Table B-2. Hydroprobe Readings Observed During Test Two. (sheet 4 of 6)

Nov 88-Apr 89			NOV18	DEC8	JAN5	JAN31	MAR10	MAR20	MAR 28	APR7	APR12
BOX 2A PG		DEPTH									
PROBE 21		5	2363	3208	4357	2141	4798	3349	3397	3176	1742
		11	4178	4058	4183	4150	8238	7379	6586	5744	4845
		17	4351	4454	4394	4326	7526	7562	7122	6458	6316
		23	4690	4575	4375	4561	5271	6874	6758	6547	6643
		29	4614	4491	4101	4401	4778	5462	5976	6114	6187
		35	4337	4412	4234	4496	4730	4690	4990	5362	5413
BOX 2A PG		DEPTH									
PROBE 22		5	2952	1879	2769	2524	8133	5963	5366	3683	3763
		11	3250	2803	2945	2975	8225	7315	6291	5435	4935
		17	3213	2984	2896	3022	6120	6215	5724	5354	5190
		23	4076	3963	3973	4000	4392	4773	5049	5437	5499
		29	4631	4212	4465	4409	4520	4525	5047	5298	5454
		35	4386	3961	4094	4112	4231	4425	4382	4529	4686
BOX 2A PG		DEPTH									
AVERAGE		5	2658	2544	3563	2333	6466	4656	4382	3430	2753
		11	3714	3431	3564	3563	8232	7347	6439	5590	4890
		17	3782	3719	3645	3674	6823	6889	6423	5906	5753
		23	4383	4269	4174	4281	4832	5824	5904	5992	6071
		29	4623	4352	4283	4405	4649	4994	5512	5706	5821
		35	4362	4187	4164	4304	4481	4558	4686	4946	5050

Table B-2. Hydroprobe Readings Observed During Test Two. (sheet 5 of 6)

Nov 88-Apr 89			NOV 18	DEC8	JAN5	JAN31	MAR10	MAR20	MAR 28	APR7	APR12
BOX 2B CO		DEPTH									
PROBE 23		5	4085	4195	4360	4040	5440	4452	5612	4096	3696
		11	4862	5065	5595	5388	9590	8484	7733	6825	6526
		17	5220	5133	5549	5291	8767	8442	8002	7366	7002
		23	5109	5028	5169	5046	6288	7744	7408	7126	6858
		29	4747	4999	5002	4947	5322	6813	7038	6912	6793
		35	5140	5275	5121	5047	5199	5976	6697	6708	6820
BOX 2B CO		DEPTH									
PROBE 24		5	3691	3652	3301	2679	7177	3520	5206	3329	3218
		11	4007	4148	4479	4349	10351	8843	7633	6811	6556
		17	4847	4750	4831	4704	11419	9418	8466	7950	7596
		23	5014	5140	5430	5010	8301	8502	8054	7707	7620
		29	4612	4694	4669	4752	6336	6600	6739	6673	6615
		35	4932	4897	4696	4748	5394	5101	5369	5913	5886
BOX 2B CO		DEPTH									
AVERAGE		5	3888	3924	3831	3360	6309	3986	5409	3713	3457
		11	4435	4607	5037	4869	9971	8664	7683	6818	6541
		17	5034	4942	5190	4998	10093	8930	8234	7658	7299
		23	5062	5084	5300	5028	7295	8123	7731	7417	7239
		29	4680	4847	4836	4850	5829	6707	6889	6793	6704
		35	5036	5086	4909	4898	5297	5539	6033	6311	6353

Table B-2. Hydroprobe Readings Observed During Test Two. (sheet 6 of 6)

Nov 88-Apr 89			NOV18	DEC8	JAN5	JAN31	MAR10	MAR20	MAR28	APR7	APR12
BOX 2C PG		DEPTH									
PROBE 25		5	2695	2646	3611	3091	5727	4472	3558	3414	2183
		11	3977	4099	4130	4051	7232	7285	6687	5995	5603
		17	4172	4123	4272	3988	5428	7076	6976	6719	6712
		23	4598	4361	4542	4385	4407	5680	6302	6375	6335
		29	4435	4366	4657	4418	4550	4657	5252	5577	5785
		35	4598	4705	4813	4775	4824	4835	4914	5284	5407
BOX 2C PG		DEPTH									
PROBE 26		5	2636	2539	2841	1315	5064	3134	3884	2401	2594
		11	3370	3293	3384	3037	7419	6801	6350	5504	5517
		17	4084	3984	3713	3708	5702	6969	6897	6775	6581
		23	4204	4319	4167	4218	4490	5501	6214	6610	6585
		29	3614	3770	3610	3667	3702	3792	4384	4979	5354
		35	3810	3904	3988	3993	4082	4095	4106	4217	4456
BOX 2C PG		DEPTH									
AVERAGE		5	2666	2593	3226	2203	5396	3803	3721	2908	2389
		11	3674	3696	3757	3544	7326	7043	6519	5750	5560
		17	4128	4054	3993	3848	5565	7023	6937	6747	6647
		23	4401	4340	4355	4302	4449	5591	6258	6493	6460
		29	4025	4068	4134	4043	4126	4225	4818	5278	5570
		35	4204	4305	4401	4384	4453	4465	4510	4751	4932

Table B-3. Hydroprobe Readings Observed During Test Three. (sheet 1 of 9)

May-Aug 89			MAY23	JUN12	JUN18	JUN20	JUN28	JULY5	JUL19	JUL26	AUG16	AUG18	AUG24	
BOX 1A TGS		DEPTH												
PROBE 11		6	6881	5100	5322	5684	5246	5235	5320	5071	4629	5591	5048	
		12	7545	6619	6682	6699	6522	6506	6776	6612	6045	6052	6368	
		18	7464	6968	7078	6886	6963	6728	7195	6551	6321	6272	6509	
		24	7751	7575	7637	7451	7397	7483	7836	7318	6912	7031	7055	
		30	8596	8297	8459	8234	8191	8326	8720	8150	7666	7730	7944	
		36	8613	8417	8160	8283	8119	8106	8515	7846	7639	7523	7582	
		42	9049	8850	8833	8634	8806	8849	9449	8421	7994	7841	7987	
		48	10321	9798	9814	9686	9780	9939	10305	9445	9160	9266	9207	
		54	11305	11063	10804	10961	10886	10809	11301	11509	9842	10113	9828	
BOX 1A TGS		DEPTH												
PROBE 12		6	6411	4490	4946	4588	4030	3406	3142	3221	2706	3642	3171	
		12	6822	6104	5958	5879	5283	5014	5114	4947	4499	5115	4989	
		18	6803	6391	6377	6213	6198	6020	6351	5982	5604	5881	5719	
		24	6630	6528	6478	6341	6396	6402	6483	6085	5942	5970	6027	
		30	7712	7428	7344	7341	7319	7290	7501	7167	6654	6747	6796	
		36	7618	7717	7677	7622	7469	7425	7076	6683	6294	6363	6149	
		42	7912	7631	7699	7744	7711	7423	7618	7226	6752	6817	6762	
		48	8893	8680	8746	8743	8618	8644	8732	8300	7952	7959	7972	
		54	9504	9494	9222	9235	9041	9083	9349	8923	8341	8467	8421	

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Table B-3. Hydroprobe Readings Observed During Test Three. (sheet 2 of 9)

May-Aug 89		MAY23	JUN12	JUN18	JUN20	JUN28	JULY5	JUL19	JUL26	AUG16	AUG18	AUG24
BOX 1A TGS	DEPTH											
AVERAGE	6	6646	4795	5134	5136	4638	4321	4231	4146	3668	4617	4110
	12	7184	6362	6320	6289	5903	5760	5945	5780	5272	5584	5679
	18	7134	6680	6728	6550	6581	6374	6773	6267	5963	6077	6114
	24	7191	7052	7058	6896	6897	6943	7160	6702	6427	6501	6541
	30	8154	7863	7902	7788	7755	7808	8111	7659	7160	7239	7370
	36	8116	8067	7919	7953	7794	7766	7796	7265	6967	6943	6866
	42	8481	8241	8266	8189	8259	8136	8534	7824	7373	7329	7375
	48	9607	9239	9280	9215	9199	9292	9519	8873	8556	8613	8590
	54	10405	10279	10013	10098	9964	9946	10325	10216	9092	9290	9125
BOX 1B PG	DEPTH											
PROBE 13	6	7041	5676	5458	5811	5343	5278	5922	5630	4937	5493	5283
	12	7477	6646	6195	6494	6656	6565	6602	6392	6058	6111	6267
	18	7355	6966	6476	6687	6881	6881	6877	6804	6471	6544	6610
	24	7485	7132	6830	7093	6995	6903	6989	6954	6455	6646	6702
	30	8152	7869	7092	7588	7433	7451	7718	7560	7358	7260	7473
	36	8024	7836	7712	7760	7812	7732	7883	7554	7412	7345	7365
	42	8096	7836	7960	7829	7921	7597	7622	7203	7571	7226	7338
	48	9070	9131	8759	9015	8984	8337	8341	8077	8200	8172	8157
	54	10092	9613	9570	9575	9449	9078	9137	8691	8486	8624	8675

Table B-3. Hydroprobe Readings Observed During Test Three. (sheet 3 of 9)

May-Aug 89			MAY23	JUN12	JUN18	JUN20	JUN28	JULY5	JUL19	JUL26	AUG16	AUG18	AUG24	
BOX 1B PG		DEPTH												
PROBE 14		6	7019	5357	5294	5385	5303	5163	5077	5006	4376	4874	4737	
		12	6919	6248	6195	6029	5987	6035	6052	5866	5360	5430	5273	
		18	7074	6522	6476	6480	6542	6433	6423	6026	5739	5767	5633	
		24	7058	6981	6830	7056	6906	6821	6751	6187	6334	6414	6225	
		30	7331	6910	7092	7134	6929	6899	6985	6853	6784	6702	6827	
		36	7831	7917	7712	7746	7829	7645	7931	7706	7578	7508	7474	
		42	7962	8042	7960	7881	8037	8007	7967	7871	7426	7516	7429	
		48	8851	8720	8759	8570	8776	8647	8840	8525	8250	8407	8167	
		54	9758	9572	9570	9460	9375	9375	9468	9148	8854	8886	8904	
BOX 1B PG		DEPTH												
AVERAGE		6	7030	5517	5376	5598	5323	5221	5500	5318	4657	5184	5010	0
		12	7198	6447	6195	6262	6322	6300	6327	6129	5709	5771	5770	0
		18	7215	6744	6476	6584	6712	6657	6650	6415	6105	6156	6122	0
		24	7272	7057	6830	7075	6951	6862	6870	6571	6395	6530	6464	0
		30	7742	7390	7092	7361	7181	7175	7352	7207	7071	6981	7150	0
		36	7928	7877	7712	7753	7821	7689	7907	7630	7495	7427	7420	0
		42	8029	7939	7960	7855	7979	7802	7795	7537	7499	7371	7384	0
		48	8961	8926	8759	8793	8880	8492	8591	8301	8225	8290	8162	0
		54	9925	9593	4785	9518	9412	9227	9303	8920	8670	8755	8790	0

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Table B-3. Hydroprobe Readings Observed During Test Three. (sheet 4 of 9)

May-Aug 89			MAY23	JUN12	JUN18	JUN20	JUN28	JULY5	JUL19	JUL26	AUG16	AUG18	AUG24	
BOX 1C CO	DEPTH													
PROBE 15	6		7261	5379	5361	5578	5305	5257	4981	5124	4549	6341	5177	
	12		7760	6914	6729	6934	6817	6541	6733	6480	5952	6330	6262	
	18		7777	7411	7335	7259	7295	7137	7293	7025	6658	6736	6600	
	24		8437	8159	8135	8004	8058	7718	7851	7901	7494	7505	7396	
	30		8954	8527	8621	8167	8602	8241	8346	8194	7730	7930	7733	
	36		9064	8704	8783	8803	8847	8509	8712	8258	8138	7932	8138	
	42		9720	9717	9429	9408	9294	9288	9282	9023	8730	8719	8559	
	48		9715	9879	9701	9711	9503	9427	9464	9120	8609	8943	8687	
	54		10169	9957	9902	9959	9801	9759	9835	9489	8999	8978	8875	
BOX 1C CO	DEPTH													
PROBE 16	6		7918	5483	5447	5651	5402	5305	5140	5200	4809	5491	5013	
	12		7437	6414	6426	6256	6341	6177	6138	6079	5909	5846	5863	
	18		7105	6560	6550	6472	6442	6491	6459	6406	6101	5990	6065	
	24		8093	7615	7554	7752	7650	7473	7561	7377	7061	7113	7086	
	30		8264	8135	7747	7991	8135	7968	7851	7120	7286	7479	7396	
	36		8568	8592	8485	8204	8322	8178	8101	7890	7631	7779	7739	
	42		8941	8964	8879	8785	8937	8736	8564	8473	8133	8118	7948	
	48		9720	9708	9591	9336	9345	9436	9264	9059	8822	8558	8770	
	54		10502	10372	10210	10234	9863	9805	9640	9585	9088	9121	9419	

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Table B-3. Hydroprobe Readings Observed During Test Three. (sheet 5 of 9)

May-Aug 89			MAY23	JUN12	JUN18	JUN20	JUN28	JULY5	JUL19	JUL26	AUG16	AUG18	AUG24	
BOX 1C CO		DEPTH												
AVERAGE		6	7590	5431	5404	5615	5354	5281	5061	5162	4679	5916	5095	0
		12	7599	6664	6578	6595	6579	6359	6436	6280	5931	6088	6063	0
		18	7441	6986	6943	6866	6869	6814	6876	6716	6380	6363	6333	0
		24	8265	7887	7845	7878	7854	7596	7706	7639	7278	7309	7241	0
		30	8609	8331	8184	8079	8369	8105	8099	7657	7508	7705	7565	0
		36	8816	8648	8634	8504	8585	8344	8407	8074	7885	7856	7939	0
		42	9331	9341	9154	9097	9116	9012	8923	8748	8432	8419	8254	0
		48	9718	9794	9646	9524	9424	9432	9364	9090	8716	8751	8729	0
		54	10336	10165	10056	10097	9832	9782	9738	9537	9044	9050	9147	0
BOX 2A TGS		DEPTH												
PROBE 21		6	8130	6479	6359	6215	6138	6126	6523	5375	4978	4974	4958	
		12	7940	7133	7102	7021	6668	6839	6516	6432	5858	5901	5925	
		18	7528	7016	6764	6652	6619	6633	6504	6361	6000	6117	6104	
		24	8001	7805	7714	7435	7392	7568	7217	7055	6594	6767	6637	
		30	8053	7741	7583	7382	7438	7655	7199	7042	6976	6661	6798	
		36	8432	8246	8056	8017	7887	8034	7723	7565	7172	7203	7156	
		42	8158	8077	7955	7998	7734	7903	7692	7239	6875	7065	7071	
		48	8275	8309	8230	8057	8119	8061	7659	7513	7350	7100	7410	
		54	8509	8687	8478	8462	8310	8450	8025	7902	7559	7604	7783	

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Table B-3. Hydroprobe Readings Observed During Test Three. (sheet 6 of 9)

May-Aug 89		MAY23	JUN12	JUN18	JUN20	JUN28	JULY5	JUL19	JUL26	AUG16	AUG18	AUG24	
BOX 2A TGS	DEPTH												
PROBE 22	6	7686	5677	5999	5487	5420	5069	5009	4786	4652	4537	4468	
	12	7792	6962	6674	6665	6479	6391	6192	6069	5677	5811	5766	
	18	7661	7005	6945	6965	6705	6796	6441	6372	6108	6045	6007	
	24	8582	8121	7871	7726	7706	7650	7392	7365	6942	6972	6982	
	30	7280	7277	6953	6850	6800	6866	6519	6530	6387	6191	6215	
	36	8484	8200	8058	7927	7894	7896	7889	7766	7265	7331	7312	
	42	8579	8487	8462	8467	8233	8229	8084	7891	7575	7573	7590	
	48	8181	7957	7893	7793	7835	7760	7576	7285	7085	7003	7084	
	54	8444	8583	8344	8055	8199	8233	8002	7806	7418	7286	7305	
BOX 2A TGS	DEPTH												
AVERAGE	6	7908	6078	6179	5851	5779	5598	5766	5081	4815	4756	4713	0
	12	7866	7048	6888	6843	6574	6615	6354	6251	5768	5856	5846	0
	18	7595	7011	6855	6809	6662	6715	6473	6367	6054	6081	6056	0
	24	8292	7963	7793	7581	7549	7609	7305	7210	6768	6870	6810	0
	30	7667	7509	7268	7116	7119	7261	6859	6786	6682	6426	6507	0
	36	8458	8223	8057	7972	7891	7965	7806	7666	7219	7267	7234	0
	42	8369	8282	8209	8233	7984	8066	7888	7565	7225	7319	7331	0
	48	8228	8133	8062	7925	7977	7911	7618	7399	7218	7052	7247	0
	54	8477	8635	8411	8259	8255	8342	8014	7854	7489	7445	7544	0

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Table B-3. Hydroprobe Readings Observed During Test Three. (sheet 7 of 9)

May-Aug 89			MAY23	JUN12	JUN18	JUN20	JUN28	JULY5	JUL19	JUL26	AUG16	AUG18	AUG24	
BOX 2B PG		DEPTH												
PROBE 23		6	7010	5775	5678	5604	5541	5479	5543	5279	4710	4839	4800	
		12	8149	6983	7342	7001	7224	7160	7130	6978	6637	6694	6614	
		18	8825	7436	8093	8010	7885	7955	7789	7717	7454	7287	7365	
		24	8851	8064	8095	8046	8011	7778	7822	7650	7358	7032	7143	
		30	8672	8190	7526	7757	7343	7507	7231	7249	6719	6947	6863	
		36	8394	7730	7740	7640	7683	7619	7502	7393	6963	7042	6972	
		42	8437	8175	8071	7853	7897	8042	7737	7504	7370	7412	7345	
		48	9300	9000	8781	8645	8394	8278	7950	7813	7859	7814	7758	
		54	9814	9713	9673	9758	9039	8703	8375	8596	8350	8619	8437	
BOX 2B PG		DEPTH												
PROBE 24		6	7055	5202	5210	5035	4826	4740	4400	4221	4094	4175	4296	
		12	7571	6786	6619	6515	6510	6399	6385	6264	5794	6077	6241	
		18	8617	8111	8065	7902	7651	7895	7646	7551	7124	7253	7303	
		24	8880	8383	8277	8100	8150	8053	7945	7720	7552	7476	7184	
		30	8684	8259	8077	8083	8050	7888	7738	7753	7542	7384	7307	
		36	8314	8031	7808	7762	7834	7792	7371	7538	7238	7010	7184	
		42	8277	8174	8197	7962	7626	7908	7479	7292	6953	7160	7104	
		48	9537	9375	9173	9171	8675	9124	8557	8622	8224	8211	8183	
		54	10063	9938	10051	9866	9451	9628	9543	9331	9202	8931	8850	

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Table B-3. Hydroprobe Readings Observed During Test Three. (sheet 8 of 9)

May-Aug 89		MAY23	JUN12	JUN18	JUN20	JUN28	JULY5	JUL19	JUL26	AUG16	AUG18	AUG24
BOX 2B PG	DEPTH											
AVERAGE	6	7033	5489	5444	5320	5184	5110	4972	4750	4402	4507	4548 0
	12	7860	6885	6981	6758	6867	6780	6758	6621	6216	6386	6428 0
	18	8721	7774	8079	7956	7768	7925	7718	7634	7289	7270	7334 0
	24	8866	8224	8186	8073	8081	7916	7884	7685	7455	7254	7164 0
	30	8678	8225	7802	7920	7697	7698	7485	7501	7131	7166	7085 0
	36	8354	7881	7774	7701	7759	7706	7437	7466	7101	7026	7078 0
	42	8357	8175	8134	7908	7762	7975	7608	7398	7162	7286	7225 0
	48	9419	9188	8977	8908	8535	8701	8254	8218	8042	8013	7971 0
	54	9939	9826	9862	9812	9245	9166	8959	8964	8776	8775	8644 0
BOX 2C CO	DEPTH											
PROBE 25	6	7384	5679	5628	5559	5356	5203	5100	4974	4627	4741	4799
	12	7789	6897	6876	6885	6879	6812	6692	6610	6259	6345	6370
	18	8523	8026	7837	7635	7775	7775	7579	7479	7214	7055	7020
	24	8620	8317	8165	7961	7871	7876	7794	7748	7331	7303	7422
	30	9289	9034	9061	8858	8909	8748	8643	8523	8038	8027	7875
	36	9257	8917	8972	8792	8608	8574	8241	8325	7884	8156	7883
	42	8562	8509	8535	8220	8226	8279	8078	7711	7453	7292	7420
	48	8966	8941	8918	8638	8672	8650	8268	8309	7878	8079	7904
	54	9972	9846	9795	9598	9641	9565	9254	9091	8724	8793	8750

Table B-3. Hydroprobe Readings Observed During Test Three. (sheet 9 of 9)

May-Aug 89		MAY23	JUN12	JUN18	JUN20	JUN28	JULY5	JUL19	JUL26	AUG16	AUG18	AUG24
BOX 2C CO	DEPTH											
PROBE 26	6	7247	6303	5157	5205	5138	5112	4882	4531	4494	4521	4616
	12	7204	7620	6457	6391	6010	6216	5822	5984	5770	5767	6033
	18	8293	8168	7556	7466	7372	7223	7106	7052	6818	6847	6622
	24	8565	9012	8138	7972	7900	7928	7618	7558	7197	7328	7339
	30	9446	8402	9059	8659	8742	8787	8574	8334	7996	7826	7881
	36	8869	8067	8484	8566	8170	8127	8088	7919	7474	7620	7416
	42	8487	9337	8234	8086	8088	7978	7606	7692	7207	7141	7306
	48	9419	10014	8954	8890	8976	8938	8748	8880	8182	8260	8111
	54	10009	12019	10037	9692	9751	9620	9346	9389	8894	8791	8698
BOX 2C CO	DEPTH											
AVERAGE	6	7316	5991	5393	5382	5247	5158	4991	4753	4561	4631	4708
	12	7497	7259	6667	6638	6445	6514	6257	6297	6015	6056	6202
	18	8408	8097	7697	7551	7574	7499	7343	7266	7016	6951	6821
	24	8593	8665	8152	7967	7886	7902	7706	7653	7264	7316	7381
	30	9368	8718	9060	8759	8826	8768	8609	8429	8017	7927	7878
	36	9063	8492	8728	8679	8389	8351	8165	8122	7679	7888	7650
	42	8525	8923	8385	8153	8157	8129	7842	7702	7330	7217	7363
	48	9193	9478	8936	8764	8824	8794	8508	8595	8030	8170	8008
	54	9991	10933	9916	9645	9696	9593	9300	9240	8809	8792	8724

Table B-4. Hydroprobe Readings Observed During Test 4. (sheet 1 of 9)

OCT 89-FEB 90			OCT3	OC19	OC25	NOV2	NO13	NO21	DEC4	DE19	JAN3	JA12	JA24	JA31
BOX 1A PG		DEPTH												
PROBE 11		6	4221	3687	5275	5042	5050	7124	7066	6145	6741	7841	7150	5846
		12	4651	4682	4904	4984	5080	5944	6280	6419	5867	6860	6868	5835
		18	4817	4947	8966	4890	5072	4977	5359	5481	5480	5778	5921	5848
		24	5921	5503	5966	5653	5449	5477	5633	5921	5671	5842	5950	5814
		30	5610	5606	5537	5536	5690	5514	5519	5428	5696	5620	5569	5847
		36	5927	5795	5723	5774	5745	5746	5649	5843	5887	5877	5972	6063
		42	6219	5982	6003	6055	6106	6098	6042	5999	6104	6124	5969	5709
		48	6212	6118	6194	6215	6164	6295	6255	6160	6184	5975	6053	
		54	6516	6418										
BOX 1A PG		DEPTH												
PROBE 12		6	4271	3635	5529	4950	5231	6223	6480	5791	6652	6979	6419	5880
		12	5339	4741	4962	5027	5201	5718	5950	6086	6244	6781	6660	6423
		18	5334	5095	5068	5020	5329	5312	5647	5887	6514	6307	6614	6557
		24	4860	5004	5024	5012	5175	5057	5181	5227	5674	5547	5773	5766
		30	5759	5730	5611	5722	5711	5691	5691	5707	5703	5970	5837	5830
		36	6087	6088	5906	5866	5871	5934	5887	6083	5969	6012	5903	5932
		42	6411	6035	5837	5824	5960	5801	5797	5963	5887	5940	5931	5862
		48	6592	5909	6104	5982	6124	6089	6056	6054	6108	6024	5953	5832
		54		6189										

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Table B-4. Hydroprobe Readings Observed During Test 4. (sheet 2 of 9)

OCT 89-FEB 90		OCT3	OC19	OC25	NOV2	NO13	NO21	DEC4	DE19	JAN3	JA12	JA24	JA31
BOX 1A PG	DEPTH												
AVERAGE	6	4246	3661	5402	4996	5141	6674	6773	5968	6697	7410	6785	5863
	12	4995	4712	4933	5006	5141	5831	6115	6253	6056	6821	6764	6129
	18	5076	5021	7017	4955	5201	5145	5503	5684	5997	6043	6268	6203
	24	5391	5254	5495	5333	5312	5267	5407	5574	5673	5695	5862	5790
	30	5685	5668	5574	5629	5701	5603	5605	5568	5700	5795	5703	5839
	36	6007	5942	5815	5820	5808	5840	5768	5963	5928	5945	5938	5998
	42	6315	6009	5920	5940	6033	5950	5920	5981	5996	6032	5950	5786
	48	6402	6014	6149	6099	6144	6192	6156	6107	6146	6000	6003	5771
	54		6304			0	0	0	0	0			
BOX 1B PM	DEPTH												
PROBE 13	6	4184	4067	5831	5800	5906	7813	7955	6747	7229	8541	7872	7415
	12	5060	4967	5377	5549	5408	7680	7409	6672	6229	8146	7586	7378
	18	5041	4944	5307	5104	5150	6082	6258	6215	5613	6325	6510	6363
	24	5211	5324	5326	5483	5385	5531	5849	6120	6068	6085	6354	6408
	30	5549	5622	5651	5694	5689	5698	5816	6156	6075	5856	6277	6329
	36	5805	5741	5890	5961	5841	5801	5827	5920	5920	6110	6089	6099
	42	6488	6295	6441	6331	6468	6342	6499	6347	6501	6668	6671	6678
	48	6361	6381	6351	6372	6479	6518	6322	6371	6376	6433	6286	6363
	54	6454	6354										

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Table B-4. Hydroprobe Readings Observed During Test 4. (sheet 3 of 9)

OCT 89-FEB 90			OCT3	OC19	OC25	NOV2	NO13	NO21	DEC4	DE19	JAN3	JA12	JA24	JA31
BOX 1B PM		DEPTH												
PROBE 14		6	4373	3943	5369	5414	5216	6977	7020	6997	7469	8028	7475	7119
		12	5306	5192	5275	5371	5397	6371	6689	6390	6287	7564	7553	7076
		18	5479	5144	5182	5285	5249	5482	5875	6000	5719	6419	6752	6659
		24	4725	4691	4981	4994	5324	5137	5379	5416	5359	5456	5823	5794
		30	5443	5163	5510	5556	5550	5566	5518	5571	5528	5611	5825	6008
		36	5535	5517	5475	5505	5561	5553	5547	5546	5524	5600	5721	5612
		42	5004	5003	4981	4952	4985	5011	5077	5024	5053	4959	5201	5088
		48	4955	5130	5206	5233	5192	5281	5298	5328	5475	5545	5335	5317
		54	5119	5437										
BOX 1B PM		DEPTH												
AVERAGE		6	4279	4005	5600	5607	5561	7395	7488	6872	7349	8285	7674	7267
		12	5183	5080	5326	5460	5403	7026	7049	6531	6258	7855	7570	7227
		18	5260	5044	5245	5195	5200	5782	6067	6108	5666	6372	6631	6511
		24	4968	5008	5154	5239	5355	5334	5614	5768	5714	5771	6089	6101
		30	5496	5393	5581	5625	5620	5632	5667	5864	5802	5734	6051	6169
		36	5670	5629	5683	5733	5701	5677	5687	5733	5722	5855	5905	5856
		42	5746	5649	5711	5642	5727	5677	5788	5686	5777	5814	5936	5883
		48	5658	5756	5779	5803	5836	5900	5810	5850	5926	5989	5811	5840
		54	5787	5896			0	0	0	0	0			

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Table B-4. Hydroprobe Readings Observed During Test 4. (sheet 4 of 9)

OCT 89-FEB 90			OCT3	OC19	OC25	NOV2	NO13	NO21	DEC4	DE19	JAN3	JA12	JA24	JA31
BOX 1C CO		DEPTH												
PROBE 15		6	4593	4750	6726	6213	6591	7877	7866	6786	7245	8529	7925	7432
		12	5994	5906	6532	6583	6260	7601	7481	7014	6646	8135	7820	7755
		18	6401	6479	6463	6609	6636	7137	7157	7099	6840	7539	7466	7681
		24	6959	6873	7134	6917	7001	7152	7361	7466	7104	7411	7659	7698
		30	7376	7268	7279	7340	7453	7429	7455	7781	7524	7618	7891	7697
		36	7704	7537	7497	7652	7475	7391	7574	7601	7674	7674	7864	7887
		42	8141	8052	8172	8135	8052	8112	7939	8029	8153	8013	8365	8242
		48	8282	8133	8074	8180	7960	8208	8171	8219	8162	8197	8137	8315
		54	8497	8392										
BOX 1C CO		DEPTH												
PROBE 16		6	4793	4827	5967	5929	6214	7446	7541	6987	7334	8299	7637	7292
		12	5669	5552	6020	6083	5894	6855	7052	6471	6351	7515	7575	7218
		18	5890	5900	6038	6127	5959	6197	6645	6582	6086	6899	6935	7095
		24	6917	6755	6829	6728	6742	6796	7002	6908	6943	7155	7284	7389
		30	7111	6960	7056	6794	6946	7100	7110	7132	7102	7151	7349	7358
		36	7252	7216	7182	7282	7225	7137	7283	7304	7352	7453	7477	7524
		42	7551	7689	7701	7602	7363	7539	7583	7677	7618	7566	7877	7811
		48	8231	8140	8075	8032	8235	7930	8025	8080	8640	8262	8161	8353
		54	8669	8616										

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Table B-4. Hydroprobe Readings Observed During Test 4. (sheet 5 of 9)

OCT 89-FEB 90	OCT3	OCT19	OCT25	NOV2	NO13	NO21	DEC4	DE19	JAN3	JA12	JA24	JA31
BOX 1C CO	DEPTH											
AVERAGE	6	4693	4789	6347	6071	6403	7662	7704	6887	8414	7781	7362
	12	5832	5729	6276	6333	6077	7228	7267	6743	7825	7698	7487
	18	6146	6190	6251	6368	6298	6667	6901	6841	7219	7201	7388
	24	6938	6814	6982	6823	6872	6974	7182	7187	7283	7472	7544
	30	7244	7114	7168	7067	7200	7265	7283	7457	7385	7620	7528
	36	7478	7377	7340	7467	7350	7264	7429	7453	7564	7671	7706
	42	7846	7871	7937	7869	7708	7826	7761	7853	7790	8121	8027
	48	8257	8137	8075	8106	8098	8069	8098	8150	8230	8149	8334
	54	8583	8504			0	0	0	0			
BOX 2A PG	DEPTH											
PROBE 21	6	4867	4431	4462	4411	4814	5083	5713	5364	6906	6444	6038
	12	5298	5422	5136	5072	5238	5264	5703	5404	6447	6564	6319
	18	6790	6693	6537	6540	6554	6576	6669	6579	7012	7272	7065
	24	8172	7968	7854	7874	7771	7592	7664	7622	7908	7734	7861
	30	7670	7531	7278	7249	7136	7345	7072	7293	7246	7285	7318
	36	8604	8189	8096	8220	8155	8258	8041	8020	7954	8030	8103
	42	8674		8456	8324	8376	8414	8327	8341	8390	8246	8431
	48											
	54											

Table B-4. Hydroprobe Readings Observed During Test 4. (sheet 6 of 9)

OCT 89-FEB 90		OCT3	OCT19	OCT25	NOV2	NO13	NO21	DEC4	DE19	JAN3	JAN12	JAN24	JAN31
BOX 2A PG	DEPTH												
PROBE 22	6	3779	3680	3570	3586	4124	4585	5457	5257	6249	6803	6385	6023
	12	5166	5449	5167	5362	5484	5402	5551	5666	5743	6403	6561	6306
	18	6456	6592	6482	6507	6611	6471	6516	6594	6253	6514	6743	6746
	24	8198	8230	7829	7907	7831	7905	7815	7805	7828	7733	8041	8021
	30	8407	8021	7882	7896	7812	7842	7842	7816	7833	7754	7934	7897
	36	7573	7440	7391	7298	7305	7317	7173	7289	7193	7258	7342	7360
	42	6815	6786	6791	6764	6740	6647	6870	6755	6749	6790	6748	6875
	48	6626	6551	6826	6802	6693	6628	6720	6725	6565	6607	6754	6599
	54	6482	6703										
BOX 2A PG	DEPTH												
AVERAGE	6	4323	4056	4016	3999	4469	4834	5585	5311	5849	6855	6415	6031
	12	5232	5436	5152	5217	5361	5333	5627	5535	5550	6425	6563	6313
	18	6623	6643	6510	6524	6583	6524	6593	6587	6406	6763	7008	6906
	24	8185	8099	7842	7891	7801	7749	7740	7714	7753	7821	7888	7941
	30	8039	7776	7580	7573	7474	7594	7457	7555	7542	7500	7610	7608
	36	8089	7815	7744	7759	7730	7788	7607	7655	7659	7606	7686	7732
	42	7745	3393	7624	7544	7558	7531	7599	7548	7511	7590	7497	7653
	48		3276	3413		3347	3314	3360	3363	3283	3304	3377	3300
	54		3352			0	0	0	0	0			

Table B-4. Hydroprobe Readings Observed During Test 4. (sheet 7 of 9)

OCT 89-FEB 90			OCT3	OC19	OC25	NOV2	NO13	NO21	DEC4	DE19	JAN3	JA12	JA24	JA31
BOX 2B PM		DEPTH												
PROBE 23		6	4616	4214	4615	4740	5402	6153	6925	6446	6746	8298	7463	7420
		12	5404	5455	5434	5549	5483	5852	6465	6450	6052	7836	7561	7538
		18	5430	5597	5694	5656	5643	5589	5988	6065	5836	6678	7050	6974
		24	5431	5726	5646	5630	5674	5632	5672	5786	5839	6046	6310	6282
		30	6163	6032	6178	6122	6172	6068	6079	5999	5991	6092	6335	6171
		36	7046	7021	6987	6904	6841	6887	6914	6799	6760	6762	6929	6931
		42	7749	7721	7579	7424	7500	7269	7534	7457	7521	7515	7562	7453
		48	7394	7157	7105	7046	7105	7024	6999	6954	7094	7022	7018	7071
		54	7422	7331										
BOX 2B PM		DEPTH												
PROBE 24		6	5136	4751	4730	4663	5190	5554	6033	6081	6410	7638	6813	6399
		12	4968	5053	5074	5118	4995	5086	5642	5637	5534	6440	6744	6573
		18	5264	5278	5428	5296	5380	5465	5530	5763	5643	5903	6477	6428
		24	5412	5403	5413	5490	5521	5491	5442	5598	5479	5638	5823	5867
		30	5990	5800	5921	5867	5889	5879	5925	5870	5873	6049	5998	6124
		36	6516	6478	6491	6348	6323	6384	6280	6401	6355	6462	6619	6427
		42	6679	6626	6614	6607	6491	6416	6519	6359	6482	6542	6579	6651
		48												
		54												

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Table B-4. Hydroprobe Readings Observed During Test 4. (sheet 8 of 9)

OCT 89-FEB 90			OCT3	OC19	OC25	NOV2	NO13	NO21	DEC4	DE19	JAN3	JA12	JA24	JA31
BOX 2B PM		DEPTH												
AVERAGE		6	4876	4483	4673	4702	5296	5854	6479	6264	6578	7968	7138	6910
		12	5186	5254	5254	5334	5239	5469	6054	6044	5793	7138	7153	7056
		18	5347	5438	5561	5476	5512	5527	5759	5914	5740	6291	6764	6701
		24	5422	5565	5530	5560	5598	5562	5557	5692	5659	5842	6067	6075
		30	6077	5916	6050	5995	6031	5974	6002	5935	5932	6071	6167	6148
		36	6781	6750	6739	6626	6582	6636	6597	6600	6558	6612	6774	6679
		42	7214	7174	7097	7016	6996	6843	7027	6908	7002	7029	7071	7052
		48					3553	3512	3500	3477	3547	3511	3509	3536
		54					0	0	0	0	0			
BOX 2C CO		DEPTH												
PROBE 25		6	4655	4708	5068	5004	5761	6182	6757	6514	7006	8177	7223	7216
		12	5941	6043	6131	6037	6054	6401	6629	6468	6464	7503	7415	7251
		18	6896	6683	6726	6645	6693	6746	6735	6933	6825	7194	7389	7184
		24	6949	7040	6906	6953	6963	6902	6824	6855	6874	7135	7190	7145
		30	7400	7460	7410	7341	7296	7203	7315	7398	7298	7455	7373	7421
		36	7535	7348	7261	7233	7190	7296	7261	7385	7058	7420	7254	7589
		42	7151	6937	6992	6836	6821	6774	6846	6927	6838	6805	6949	6969
		48	7426	7260	7357	7267	7186	7269	7187	7152	7132	7245	7424	7171
		54	8343	8119										

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Table B-4. Hydroprobe Readings Observed During Test 4. (sheet 9 of 9)

OCT 89-FEB 90			OCT3	OC19	OC25	NOV2	NO13	NO21	DEC4	DE19	JAN3	JA12	JA24	JA31
		12	5618	5521	6131	5636	5761	5867	6094	5949	5975	6605	6564	6397
		18	6541	6380	6726	6407	6353	6384	6607	6450	6482	6931	7036	6870
		24	6976	6847	6906	6912	6764	6876	6843	6845	6859	6771	7130	6984
		30	7387	7386	7410	7403	7357	7466	7352	7275	7442	7468	7349	7421
		36	7289	6973	7261	6969	7064	6905	6851	6846	7016	7042	6974	7022
		42	6867	6883	6992	6601	6547	6786	6694	6797	6736	6717	6811	7004
		48	7845	7720	7357	7630	7533	7506	7401	7414	7378	7466	7588	7512
		54	8353	8229										
BOX 2C CO		DEPTH												
AVERAGE		6	4613	4672	5068	4978	5578	6045	6550	6245	6780	7732	6974	6861
		12	5780	5782	6131	5837	5908	6134	6362	6209	6220	7054	6990	6824
		18	6719	6532	6726	6526	6523	6565	6671	6692	6654	7063	7213	7027
		24	6963	6944	6906	6933	6864	6889	6834	6850	6867	6953	7160	7065
		30	7394	7423	7410	7372	7327	7335	7334	7337	7370	7462	7361	7421
		36	7412	7161	7261	7101	7127	7101	7056	7116	7037	7231	7114	7306
		42	7009	6910	6992	6719	6684	6780	6770	6862	6787	6761	6880	6987
		48	7636	7490	7357	7449	7360	7388	7294	7283	7255	7356	7506	7342
		54	8348	8174			0	0	0	0	0			

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Table B-5. Hydroprobe Readings Observed During Test 5. (sheet 1 of 9)

April-August 1990			APR 26	MAY 10	MAY 30	AUG 8					
BOX 1A TGS		DEPTH									
PROBE 11		6	3448	4271	4296	2724					
		12	5745	6101	5854	4972					
		18	6413	6303	6401	5885					
		24	6974	6659	6715	6222					
		30	6966	6818	6497	6249					
		36	7310	6893	6855	6613					
		42	7346	7326	7225	6907					
		48	7376	7249	7155	7029					
		54									
BOX 1A TGS		DEPTH									
PROBE 12		6	4815	5031	5003	3952					
		12	6008	5896	5847	5054					
		18	6074	5959	5822	5350					
		24	6181	6058	5878	5644					
		30	7289	7143	6893	6814					
		36	7214	7328	7407	6815					
		42	6955	6856	6773	6434					
		48	6871	6652	6806	6613					
		54									

Table B-5. Hydroprobe Readings Observed During Test 5. (sheet 2 of 9)

April-August 1990			APR 26	MAY 10	MAY 30	AUG 8					
BOX 1A TGS		DEPTH									
AVERAGE		6	4132	4651	4650	3338	0	0	0	0	0
		12	5877	5999	5851	5013	0	0	0	0	0
		18	6244	6131	6112	5618	0	0	0	0	0
		24	6578	6359	6297	5933	0	0	0	0	0
		30	7128	6981	6695	6532	0	0	0	0	0
		36	7262	7111	7131	6714	0	0	0	0	0
		42	7151	7091	6999	6671	0	0	0	0	0
		48	7124	6951	6981	6821	0	0	0	0	0
		54	0	0	0	0	0	0	0	0	0
BOX 1B PM		DEPTH									
PROBE 13		6	4348	4759	4777	3587					
		12	6150	6406	6220	5442					
		18	7018	6682	6769	6110					
		24	6498	6477	6509	6139					
		30	7022	6844	6842	6439					
		36	7420	7396	7056	6729					
		42	7398	7218	7182	6608					
		48	7250	7074	7102	6748					
		54									

Table B-5. Hydroprobe Readings Observed During Test 5. (sheet 3 of 9)

April-August 1990		APR 26	MAY 10	MAY 30	AUG 8					
BOX 1B PM	DEPTH									
PROBE 14	6	4085	4442	4189	3073					
	12	5315	5334	5307	4574					
	18	6537	6448	6095	5615					
	24	6588	6482	6323	5904					
	30	7003	7039	6882	6473					
	36	6910	6882	6859	6533					
	42	6777	6656	6537	6229					
	48	7088	7102	7021	6784					
	54									
BOX 1B PM	DEPTH									
AVERAGE	6	4217	4601	4483	3330	0	0	0	0	0
	12	5733	5870	5764	5008	0	0	0	0	0
	18	6778	6565	6432	5863	0	0	0	0	0
	24	6543	6480	6416	6022	0	0	0	0	0
	30	7013	6942	6862	6456	0	0	0	0	0
	36	7165	7139	6958	6631	0	0	0	0	0
	42	7088	6937	6860	6419	0	0	0	0	0
	48	7169	7088	7062	6766	0	0	0	0	0
	54	0	0	0	0	0	0	0	0	0

Table B-5. Hydroprobe Readings Observed During Test 5. (sheet 4 of 9)

April-August 1990			APR 26	MAY 10	MAY 30	AUG 8					
BOX 1C CO		DEPTH									
PROBE 15		6	3538	3982	3935	3009					
		12	6022	6295	5984	5145					
		18	6875	6837	6867	6127					
		24	7585	7356	7393	6695					
		30	7645	7536	7413	6738					
		36	7314	7229	7262	6464					
		42	8490	8305	7979	7425					
		48	8466	8399	8125	7617					
		54									
BOX 1C CO		DEPTH									
PROBE 16		6	3820	4254	4287	3536					
		12	6113	6201	6028	5243					
		18	6637	6619	6610	6070					
		24	7676	7656	7638	7020					
		30	8242	8287	8164	7327					
		36	7840	7825	7465	7056					
		42	6976	6729	6787	6241					
		48	7087	6953	7025	6538					
		54									

Table B-5. Hydroprobe Readings Observed During Test 5. (sheet 5 of 9)

April-August 1990			APR 26	MAY 10	MAY 30	AUG 8					
BOX 1C CO		DEPTH									
AVERAGE		6	3679	4118	4111	3273	0	0	0	0	0
		12	6068	6248	6006	5194	0	0	0	0	0
		18	6756	6728	6739	6099	0	0	0	0	0
		24	7631	7506	7516	6858	0	0	0	0	0
		30	7944	7912	7789	7033	0	0	0	0	0
		36	7577	7527	7364	6760	0	0	0	0	0
		42	7733	7517	7383	6833	0	0	0	0	0
		48	7777	7676	7575	7078	0	0	0	0	0
		54	0	0	0	0	0	0	0	0	0
BOX 2A TGS		DEPTH									
PROBE 21		6	2398	2269	2856	1523					
		12	4714	4536	4645	3489					
		18	5412	5163	4949	4204					
		24	5607	5279	5141	4484					
		30	5976	5755	5604	5400					
		36	6702	6805	6757	6361					
		42	7475	7599	7430	6975					
		48	7647	7518	7454	7049					
		54									

Table B-5. Hydroprobe Readings Observed During Test 5. (sheet 6 of 9)

April-August 1990			APR 26	MAY 10	MAY 30	AUG 8					
BOX 2A TGS		DEPTH									
PROBE 22		6	3409	3813	3967	2866					
		12	5208	5193	5123	4336					
		18	5896	5776	5523	4997					
		24	5602	5589	5494	5037					
		30	5813	5843	5652	5421					
		36	6702	6575	6408	6098					
		42	7607	7479	7594	7081					
		48	7693	7447	7412	7161					
		54									
BOX 2A TGS		DEPTH									
AVERAGE		6	2904	3041	3412	2195	0	0	0	0	0
		12	4961	4865	4884	3913	0	0	0	0	0
		18	5654	5470	5236	4601	0	0	0	0	0
		24	5605	5434	5318	4761	0	0	0	0	0
		30	5895	5799	5628	5411	0	0	0	0	0
		36	6702	6690	6583	6230	0	0	0	0	0
		42	7541	7539	7512	7028	0	0	0	0	0
		48	7670	7483	7433	7105	0	0	0	0	0
		54	0	0	0	0	0	0	0	0	0

Table B-5. Hydroprobe Readings Observed During Test 5. (sheet 7 of 9)

April-August 1990			APR 26	MAY 10	MAY 30	AUG 8					
BOX 2B PM		DEPTH									
PROBE 23		6	3556	3779	4174	3007					
		12	5555	5474	5457	4826					
		18	6275	6407	6215	5727					
		24	6585	6491	6394	5935					
		30	6384	6172	6191	5831					
		36	5994	6102	5877	5637					
		42	5962	6239	6172	5863					
		48	6897	6868	6875	6595					
		54									
BOX 2B PM		DEPTH									
PROBE 24		6	4292	4028	4364	3565					
		12	5647	5681	5704	4835					
		18	6317	6412	6253	5661					
		24	6547	6376	6309	5862					
		30	6503	6355	6254	5931					
		36	6738	6764	6664	6241					
		42	6538	6602	6438	6017					
		48	6643	6611	6457	6402					
		54									

Table B-5. Hydroprobe Readings Observed During Test 5. (sheet 8 of 9)

April-August 1990			APR 26	MAY 10	MAY 30	AUG 8					
BOX 2B PM		DEPTH									
AVERAGE		6	3924	3904	4269	3286	0	0	0	0	0
		12	5601	5578	5581	4831	0	0	0	0	0
		18	6296	6410	6234	5694	0	0	0	0	0
		24	6566	6434	6352	5899	0	0	0	0	0
		30	6444	6264	6223	5881	0	0	0	0	0
		36	6366	6433	6271	5939	0	0	0	0	0
		42	6250	6421	6305	5940	0	0	0	0	0
		48	6770	6740	6666	6499	0	0	0	0	0
		54	0	0	0	0	0	0	0	0	0
BOX 2C CO		DEPTH									
PROBE 25		6	3766	3606	4066	3084					
		12	5226	5290	5403	4505					
		18	5790	5707	5711	5248					
		24	6363	6252	6067	5846					
		30	6866	6916	6781	6235					
		36	7551	7465	7419	6902					
		42	7206	7268	7236	6951					
		48	7635	7650	7486	7326					
		54									

Table B-5. Hydroprobe Readings Observed During Test 5. (sheet 9 of 9)

April-August 1990			APR 26	MAY 10	MAY 30	AUG 8					
BOX 2C CO		DEPTH									
PROBE 26		6	3039	2782	3354	2560					
		12	5233	5299	5328	4425					
		18	5502	5433	5564	5176					
		24	5784	5757	5696	5328					
		30	5978	6042	5866	5673					
		36	6743	6719	6689	6317					
		42	7582	7603	7376	6956					
		48	7297	7295	7114	6782					
		54									
BOX 2C CO		DEPTH									
AVERAGE		6	3403	3194	3710	2822	0	0	0	0	0
		12	5230	5295	5366	4465	0	0	0	0	0
		18	5646	5570	5638	5212	0	0	0	0	0
		24	6074	6005	5882	5587	0	0	0	0	0
		30	6422	6479	6324	5954	0	0	0	0	0
		36	7147	7092	7054	6610	0	0	0	0	0
		42	7394	7436	7306	6954	0	0	0	0	0
		48	7466	7473	7300	7054	0	0	0	0	0
		54	0	0	0	0	0	0	0	0	0

APPENDIX C

SOIL MOISTURE GRAPHS GENERATED FROM GRAVIMETRIC

SOIL SAMPLING FOR TESTS

Figure C-1. Soil Moisture Profile Changes (Test 1)
(Pocket Mouse with No Supplemental Precipitation).

Figure C-2. Soil Moisture Profile Changes (Test 1)
[Control (No Animal) with No Supplemental Precipitation].

Figure C-3. Soil Moisture Profile Changes (Test 1)
[Control (No Animal) with No Supplemental Precipitation].

Soil Moisture Profile Changes (Test 1)

H9402043.5

Figure C-4. Soil Moisture Profile Changes (Test 1)
(Townsend with Supplemental Precipitation).

Soil Moisture Profile Changes (Test 1)

H9402043.4

Figure C-5. Soil Moisture Profile Changes (Test 1)
[Control (No Animal) with Supplemental Precipitation].

Soil Moisture Profile Changes (Test 1)

H9402043.2

Figure C-6. Soil Moisture Profile Changes (Test 1)
(Pocket Mouse with Supplemental Precipitation).

Soil Moisture Profile Changes (Test 1)

H9402043.1

Figure C-7. Soil Moisture Profile Changes (Test 2)
[Pocket Gopher with Ambient Precipitation (Winter)].

Soil Moisture Profile Changes (Test 2)

H9402043.14

Figure C-8. Soil Moisture Profile Changes (Test 2)
[Pocket Gopher with Ambient Precipitation (Winter)].

Soil Moisture Profile Changes (Test 2) Ambient Precipitation (Winter)

H9402043.15

Figure C-9. Soil Moisture Profile Changes (Test 2)
[Control (No Animal) with Ambient Precipitation (Winter)].

Soil Moisture Profile Changes (Test 2) Ambient Precipitation (Winter)

Figure C-10. Soil Moisture Profile Changes (Test 2)
[Pocket Mouse with Ambient Precipitation (Winter)].

Soil Moisture Profile Changes (Test 2) Ambient Precipitation (Winter)

Figure C-11. Soil Moisture Profile Changes (Test 2)
[Control (No Animal) with No Supplemental Precipitation].

Soil Moisture Profile Changes (Test 3) Control (No Animal) No Supplemental Precipitation

H9402043.31

Figure C-12. Soil Moisture Profile Changes (Test 3)
(Pocket Gopher with No Supplemental Precipitation).

Soil Moisture Profile Changes (Test 3) Pocket Gopher (No Supplemental Precipitation)

H9402043.32

Figure C-13. Soil Moisture Profile Changes (Test 3)
(Townsend with No Supplemental Precipitation).

Soil Moisture Profile Changes (Test 3) Townsend (No Supplemental Precipitation)

H9402043.33

Figure C-14. Soil Moisture Profile Changes (Test 3)
(Townsend with Supplemental Precipitation).

Soil Moisture Profile Changes (Test 3) Townsend (Supplemental Precipitation)

H9402043.34

Figure C-15. Soil Moisture Profile Changes (Test 3)
[Control (No Animal) with Supplemental Precipitation].

Figure C-16. Soil Moisture Profile Changes (Test 3)
(Pocket Gopher with Supplemental Precipitation).

Figure C-17. Soil Moisture Profile Changes (Test 4)
(Pocket Mouse with Supplemental Precipitation).

Figure C-18. Soil Moisture Profile Changes (Test 4)
[Control (No Animal) with Supplemental Precipitation].

Figure C-19. Soil Moisture Profile Changes (Test 4)
(Pocket Gopher with No Supplemental Precipitation).

Soil Moisture Profile Changes (Test 4) Pocket Gopher (No Supplemental Precipitation)

H9402043.39

Figure C-20. Soil Moisture Profile Changes (Test 4)
(Pocket Mouse with No Supplemental Precipitation).

Soil Moisture Profile Changes (Test 4) Pocket Mouse (No Supplemental Precipitation)

H9402043.38

Figure C-21. Soil Moisture Profile Changes (Test 4)
[Control (No Animal) with Supplemental Precipitation].

Soil Moisture Profile Changes (Test 4) Control (No Animal) Supplemental Precipitation

Figure C-22. Soil Moisture Profile Changes (Test 5)
[Control (No Animal) with No Supplemental Precipitation].

Soil Moisture Profile Changes (Test 5) Control (No Animal) With No Supplemental Precipitation

Figure C-23. Soil Moisture Profile Changes (Test 5)
(Townsend with No Supplemental Precipitation).

Soil Moisture Profile Changes (Test 5) Townsend (With No Supplemental Precipitation)

H9402043.52

Figure C-24. Soil Moisture Profile Changes (Test 5)
[Control (No Animal) with Supplemental Precipitation].

Soil Moisture Profile Changes (Test 5) Control (No Animal) With Supplemental Precipitation

H9402043.51

Figure C-25. Soil Moisture Profile Changes (Test 5)
(Townsend with Supplemental Precipitation).

APPENDIX D

**SOIL MOISTURE GRAPHS GENERATED FROM CONDUCTANCE AND
HYDROPROBE DATA FOR TESTS 1 THROUGH 5**

Figure D-1. Conductivity Resistance (Test 1)–Summer
(Pocket Mouse with No Supplemental Precipitation).

Figure D-2. Conductivity Resistance (Test 1)–Summer
(Townsend with No Supplemental Precipitation).

Figure D-3. Conductivity Resistance (Test 1)–Summer
[Control (No Animal) with No Supplemental Precipitation].

Figure D-4. Conductivity Resistance (Test 1)–Summer
(Townsend with Supplemental Precipitation).

Figure D-5. Conductivity Resistance (Test 1)–Summer
(Pocket Mouse with Supplemental Precipitation).

Figure D-6. Conductivity Resistance (Test 1)–Summer
[Control (No Animal) with Supplemental Precipitation].

Figure D-7. Hydroprobe Readings (Test 2)–Winter
(Pocket Gopher with No Supplemental Precipitation).

Figure D-8. Hydroprobe Readings (Test 2)–Winter
(Pocket Gopher with No Supplemental Precipitation).

Figure D-9. Hydroprobe Readings (Test 2)–Winter
(Pocket Mouse with No Supplemental Precipitation).

Figure D-10. Hydroprobe Readings (Test 2)–Winter
[Control (No Animal) with No Supplemental Precipitation].

Figure D-11. Hydroprobe Readings (Test 3)–Summer
[Control (No Animal) with No Supplemental Precipitation].

Hydroprobe Readings (Test 3) Control (No Animal) With No Supplemental Precipitation

Figure D-12. Hydroprobe Readings (Test 3)–Summer
(Pocket Gopher with No Supplemental Precipitation).

Hydroprobe Readings (Test 3) Pocket Gopher (No Supplemental Precipitation)

Figure D-13. Hydroprobe Readings (Test 3)–Summer
(Townsend with No Supplemental Precipitation).

Figure D-14. Hydroprobe Readings (Test 3)–Summer
[Control (No Animal) with Supplemental Precipitation].

Figure D-15. Hydroprobe Readings (Test 3)–Summer
(Townsend with Supplemental Precipitation).

Figure D-16. Hydroprobe Readings (Test 4)–Winter
(Pocket Gopher with No Supplemental Precipitation).

Figure D-17. Hydroprobe Readings (Test 4)–Winter
[Control (No Animal) with No Supplemental Precipitation].

Hydroprobe Readings (Test 4) Control (No Animal) With No Supplemental Precipitation

Figure D-18. Hydroprobe Readings (Test 4)–Winter
(Pocket Gopher with Supplemental Precipitation).

Hydroprobe Readings (Test 4) Pocket Gopher (With Supplemental Precipitation)

Figure D-19. Hydroprobe Readings (Test 4)–Winter
[Control (No Animal) with Supplemental Precipitation].

Figure D-20. Hydroprobe Readings (Test 5)–Summer
(Townsend with Supplemental Precipitation).

Figure D-21. Hydroprobe Readings (Test 5)–Summer
(Townsend with No Supplemental Precipitation).

Figure D-22. Hydroprobe Readings (Test 5)–Summer
[Control (No Animal) with Supplemental Precipitation].

Figure D-23. Hydroprobe Readings (Test 5)–Summer
[Control (No Animal) with No Supplemental Precipitation].

WHC-EP-0730

APPENDIX E

**GREAT BASIN POCKET MOUSE BURROW SYSTEMS EXCAVATED
AND MAPPED AT THE HANFORD SITE**

Figure E-1. Example of Great Basin Pocket Gopher Mounds that Become Elevated above Normal Landscape.

Figure E-2. Cross Section of a Great Basin Pocket Mouse Burrow System Excavated at the Hanford Site.

H9311023.9

Figure E-3. Cross Section of a Great Basin Pocket Mouse Burrow System Excavated at the Hanford Site.

H9311023.5

Figure E-4. Cross Section of a Great Basin Pocket Mouse Burrow System Excavated at the Hanford Site.

Figure E-5. Cross Section of a Great Basin Pocket Mouse Burrow System Excavated at the Hanford Site.