CHAPTER 8

RADIOLOGICAL PATHWAYS THROUGH THE BIOSPHERE

8.1 INTRODUCTION

In order to evaluate the performance of a disposal system at Yucca Mountain, the potential radiation dose to members of the public must be estimated. This estimation requires identifying the potential pathways of radionuclides from the repository to the biosphere. These pathways include "the air, water, food and other components of the landscape that are accessible to humans as well as the humans themselves; estimates of the concentrations that will be present in air, water, food, and other materials with which humans might come into contact; and estimates of the probabilities that humans will be exposed to contaminated air, water, food, or other materials leading to a radiation dose" (NAS95).

To estimate dose, assumptions must be made concerning the location and exposure scenarios of an individual or group of individuals who are likely to be at greatest risk from potential releases of radionuclides from the repository after closure and removal of institutional controls. Prior to closure, such assumptions are unnecessary because possible contamination levels can be measured with considerable accuracy both within and outside the repository footprint. This chapter examines the key assumptions necessary to calculate doses associated with potential post-closure release of radioactivity from a repository at Yucca Mountain.

Figure 8-1 illustrates the major radioactivity pathways from a repository at Yucca Mountain to humans. For the Yucca Mountain repository, the doses and risks to the critical groups for the atmospheric pathway (nearby and world population) are not considered to be significant relative to the doses and risks to critical groups from ground water pathways. The existing conditions and potential changes in geologic, hydrologic, and atmospheric (climate) conditions in the Yucca Mountain vicinity which affect radionuclide transport are described in Chapter 7, with climatic changes taken into consideration to develop the range of hydrological parameters included in the radionuclide transport assessments.

During the post-closure period, the ground water will transport radionuclides released from the repository to the surrounding area. As currently envisioned, the repository at Yucca Mountain will be located in the unsaturated zone, approximately 400 meters (m) above the aquifer that is within the tuff strata underlying the site. A deeper aquifer is in the carbonate rocks underlying

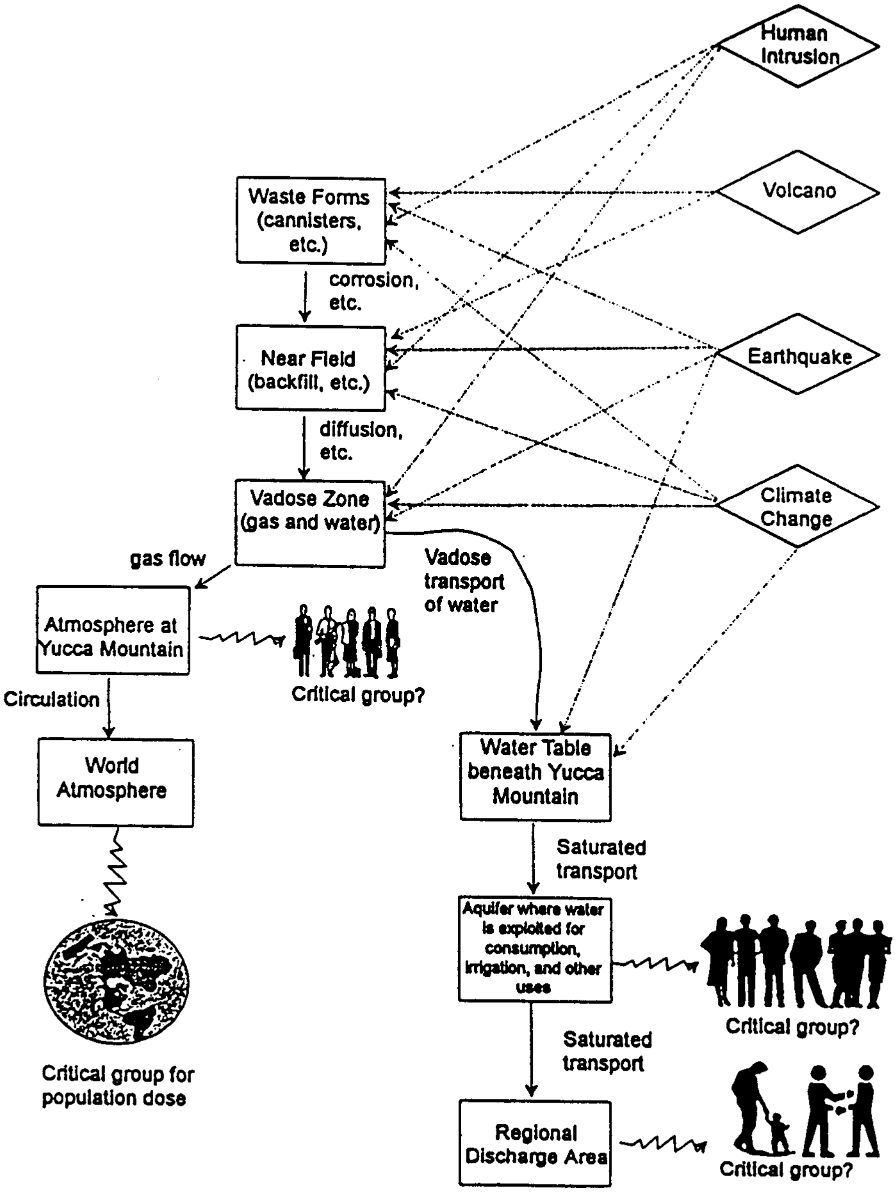

Figure 8-1. Schematic Illustration of the Major Pathways from a Repository at Yucca Mountain to Humans (Ref. NAS95)

the tuff. Ground water flow in both aquifers appears to be to the south-southeast from the site, with the tuff aquifer discharging to the alluvial aquifer which is under much of the Amargosa Valley. The deeper carbonate rock aquifer initially discharges in surface springs in the area known as Ash Meadows in the southeast portion of the Amargosa Valley and may also discharge in Death Valley. Based on the current understanding of the ground water flow in the vicinity of the proposed repository, the areas of highest potential exposures are presumed to be to the east and south of Yucca Mountain. Figure 8-2 shows the current land use in the area surrounding Yucca Mountain.

This chapter presents information regarding the characteristics of the Yucca Mountain area, including past, current, and potential use of the region. Information concerning the demographics and ecosystems of Nye County and the Amargosa Valley are included in appendices to this report. Based on this information, four scenarios involving human use of potentially contaminated ground water in the area surrounding Yucca Mountain are discussed. These scenarios can be used to define the critical groups from which EPA will determine the reasonably, maximally exposed individual (RMEI). One particular scenario, that of the subsistence farmer, is described in detail. This chapter concludes with a consideration and discussion of a special exposure scenario in which future generations intrude unknowingly into the repository in their efforts to locate resources, such as minerals or water.

8.2 PAST, CURRENT, AND POTENTIAL USE OF THE YUCCA MOUNTAIN REGION

8.2.1 Past Use of the Yucca Mountain Region

This historical review of land use in the vicinity of Yucca Mountain is intended to provide background to the definition of reasonable possible exposure scenarios for post-closure dose assessments. These exposure scenarios are based on current land use and a reasonable extrapolation of these trends into the future. Such extrapolations must be consistent with historical land uses to assure that a possible exposure scenario is not overlooked simply because an historic land use is not currently practiced.

In defining the post-closure exposure scenarios, biosphere conditions are assumed to remain as they are today, with the exception of the predictable effects of climatic conditions. Within these defined variations in biosphere conditions, possible land uses are extrapolated from current use considering historic factors and other constraints that limit such uses. In establishing the exposure scenarios, institutional impediments to use (e.g., the denial of access to the NTS) may be disregarded, but technological impediments (e.g., the costs of well drilling or farming on steep

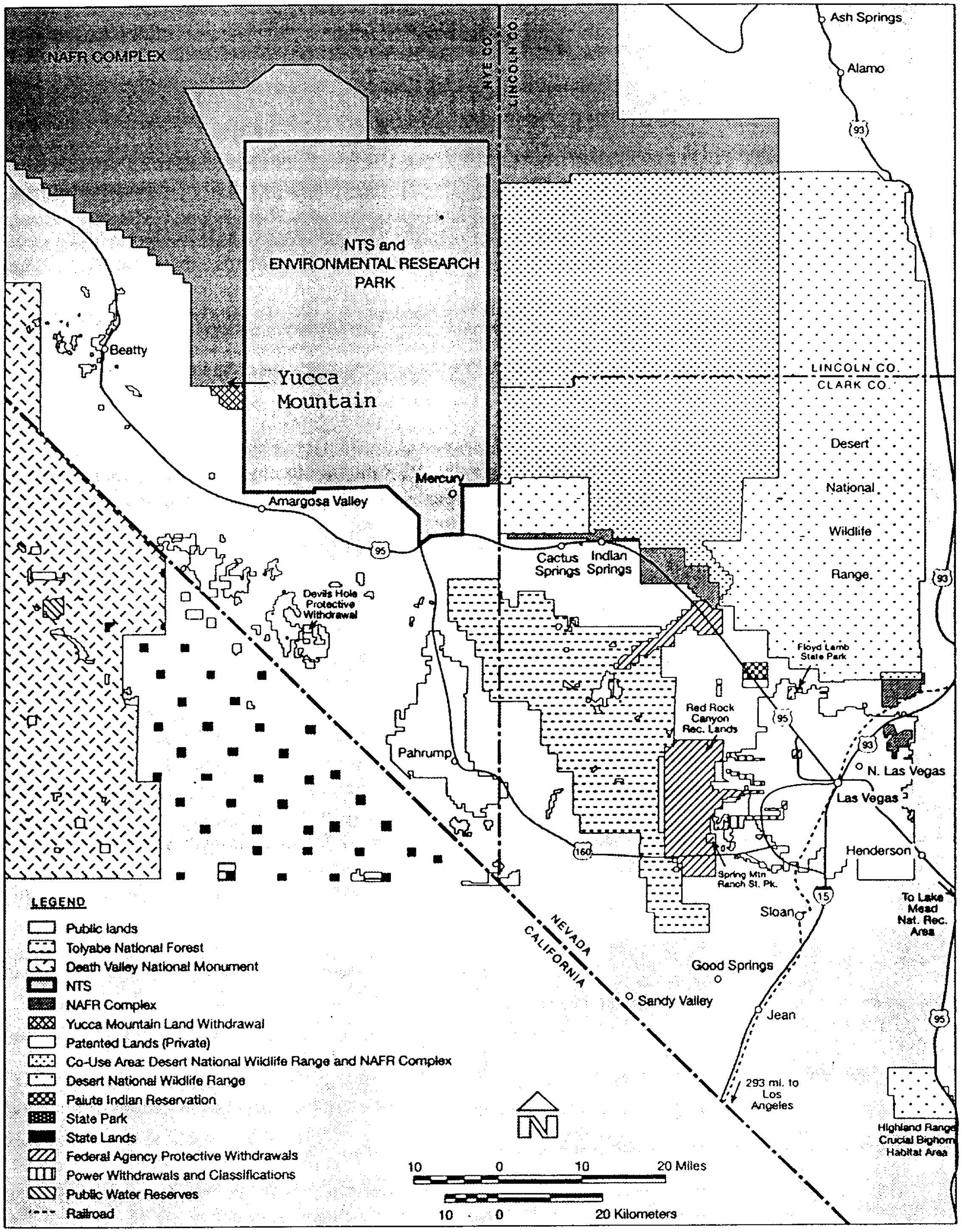

Figure 8-2. Yucca Mountain and Surrounding Land Use (Source: DOE96)

slopes) must be factored into the definition. Without this assumption of a constant level of technology and its associated cost constraints, the range of possible land use scenarios for any location would be unlimited.

8.2.1.1 Historic Native American Settlement and Use

In its attempts to understand the socioeconomic impacts of siting a high-level nuclear waste repository at Yucca Mountain, the State of Nevada's Agency for Nuclear Projects/Nuclear Waste Project Office (NWPO) has conducted a number of studies relative to Native American concerns. These studies are listed in the references at the end of this chapter.

The proposed repository site at Yucca Mountain would be located on a border between what were Western Shoshone and Southern Paiute lands. There were two large Native American cultural entities whose territories once covered what is now central and southern Nevada, southern Utah, and the adjacent areas of California (NWP95). The extensive literature on these people suggests that the groups had lived in the area since prehistoric times and survived by hunting and gathering food from the region. They moved about in extended family groups from base camps established near water, fuel, and food. During the winter, the base camps were in and near Oasis Valley, Death Valley, Kawich Valley, Ash Meadows, Pahrump and Lower Amargosa Valleys, Indian Springs, Las Vegas, and Moapa. From these base camps, the groups went to Yucca Mountain to hunt game and gather a variety of plant foods. Archaeological studies in this area have located over 400 sites in the Yucca Mountain area and its immediate vicinity. Based upon these studies, it appears that Native Americans inhabited the land from 12,000 years ago to the immediate past, including the drainage areas at the base of Yucca Mountain (e.g., Forty Mile Wash). Around 6,000 years ago, camp sites appeared at the higher elevations on Yucca Mountain, including the saddles and low passes, used mainly for hunting. 2,000 years ago the settlement pattern again shifted upward to small rock shelters at the top of steep slopes on Yucca Mountain and outlying ridges. These sites were used mainly for seed gathering rather than hunting (NWP90a).

Prior to the American push westward, both the Shoshone and Paiutes were divided into smaller subgroups, ranging in size from a few families to 100 or more persons. Each of these subgroups occupied a region with permanent water and food which generally consisted of a valley and its adjacent mountains. Historical data suggest that several Western Shoshone and Southern Paiute subgroups lived in the immediate vicinity of Yucca Mountain. Included were six camps in Oasis Valley, the present site of Beatty, Nevada, as well as several camps in the Belted Range, Ash Meadows, and the Pahrump and Lower Amargosa Valleys. Several camp groups have also been identified in the Indian Springs/Cane Springs area to the southeast. These are shown in Figures

8-3, 8-4, and 8-5 (indicated by triangles). The winter village sites were homes to which people returned while they were engaged in hunting and gathering activities. They were also sites of permanent residence from approximately November to May (NWP90a).

The area used by the Oasis Valley population for subsistence extended from the Grapevine Mountains in the west to the Sarcobatus Flat in the north, and from the Belted Range in the east to the middle of the Amargosa Desert in the south. Yucca Mountain is included in this area, its apparent attraction being Bighorn Sheep and seed resources (NWP90a).

Religious Significance

The Western Shoshone and Southern Paiute people are deeply religious; their beliefs are based upon their relationships with the land and its resources. Like other Native Americans, they believed that the earth is a living being, along with all other natural forces.

> *In addition to animating the universe, power could be focused everywhere--in beings, such as humans, plants and animals, and in springs, rocks, mountains, caves, and other features of the natural landscape. Animal progenitors, in the myth-time 'when animals were people,' were, along with the Earth and others, among the most powerful beings. They were considered to be 'bosses,' 'owners,' 'masters,' 'beautiful progenitors' of present-day species. Each set the course for its species, and at the same time, set human customs through a series of adventures and misadventures. Particularly active in this period were Coyote and Wolf, often portrayed as dueling brothers, but also Mountain Lion, Badger, water beings such as Frog, raptorial birds, and a host of others. Their activities, myth-specific, were mapped onto the landscape in a myriad of place names, often associated with individual features of the geography such as rock formations, specific caves or springs, petroglyph and pictograph panels, trails, washes or arroyos, and much more. People, even today if they have been properly instructed, cannot move about the landscape without thinking of and feeling these links to the past. They also feel the power emanating from these specific features as well as more generally.* (NWP90a, p. 15, 16).

The most apparent sources of power are associated with caves, springs and other water sources, and especially mountains. Although the winter habitation area shown in the previous figures refer to lowlands in the vicinity of springs, each is also defined with reference to mountain peaks in the area. The mountains around Yucca Mountain are a very sacred place, along with other peaks in Death Valley and those around Beatty.

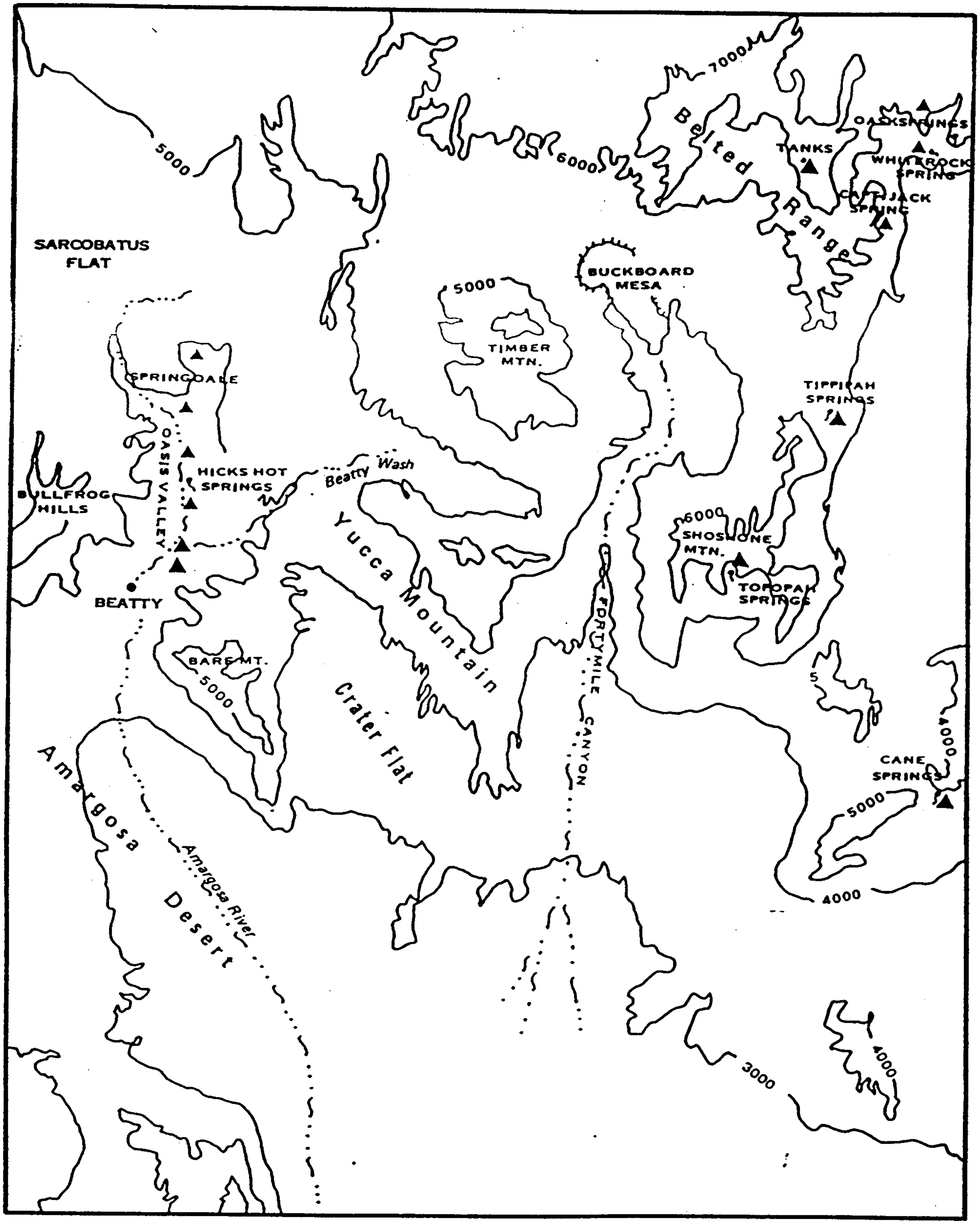

Figure 8-3. Winter Sites Near Beatty and Belted Range (*Contour Intervals 1000 ft.*)

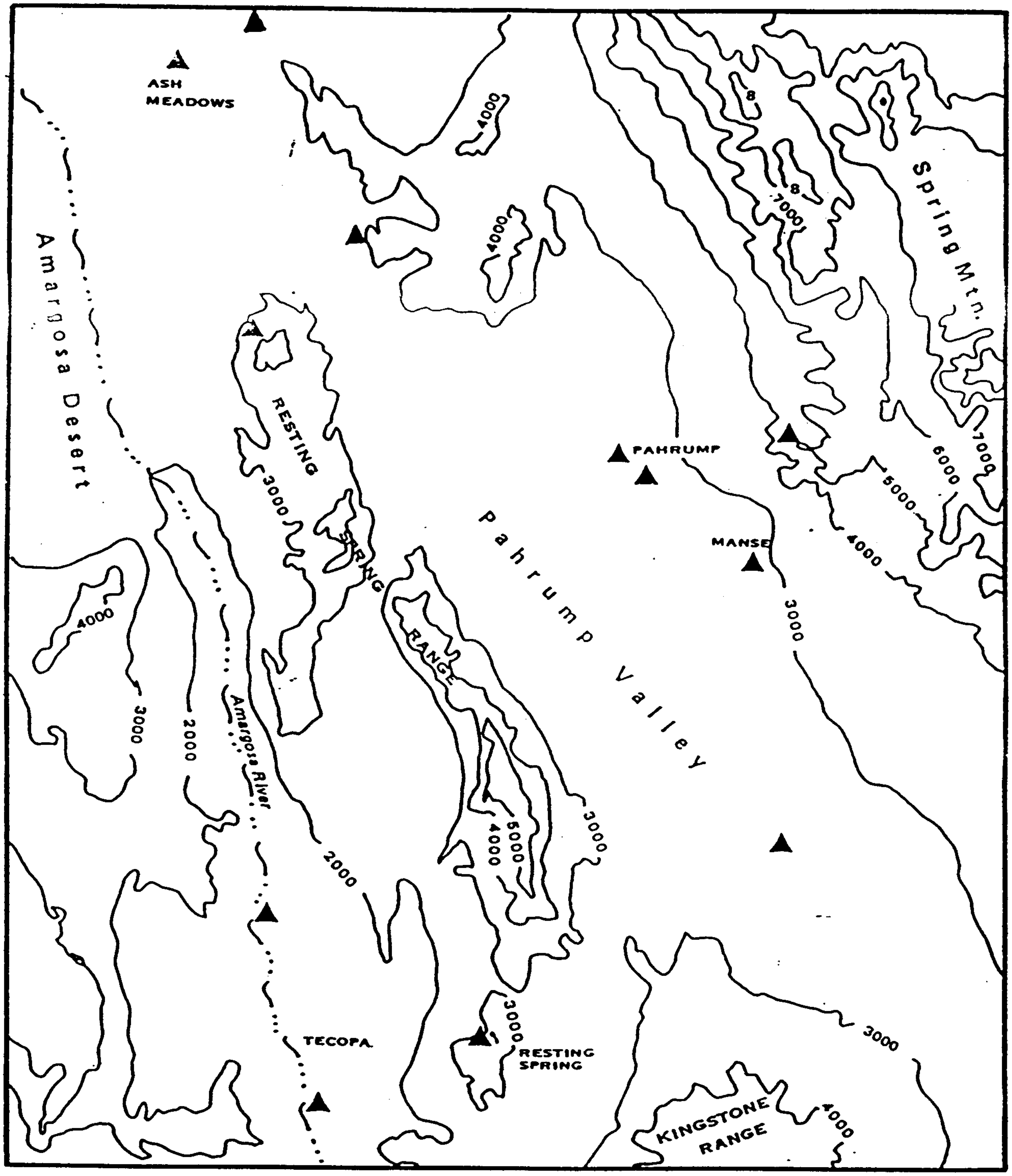

Figure 8-4. Major Winter Sites in Ash Meadows and Pahrump Valley (*Contour Intervals 1000 ft.*)

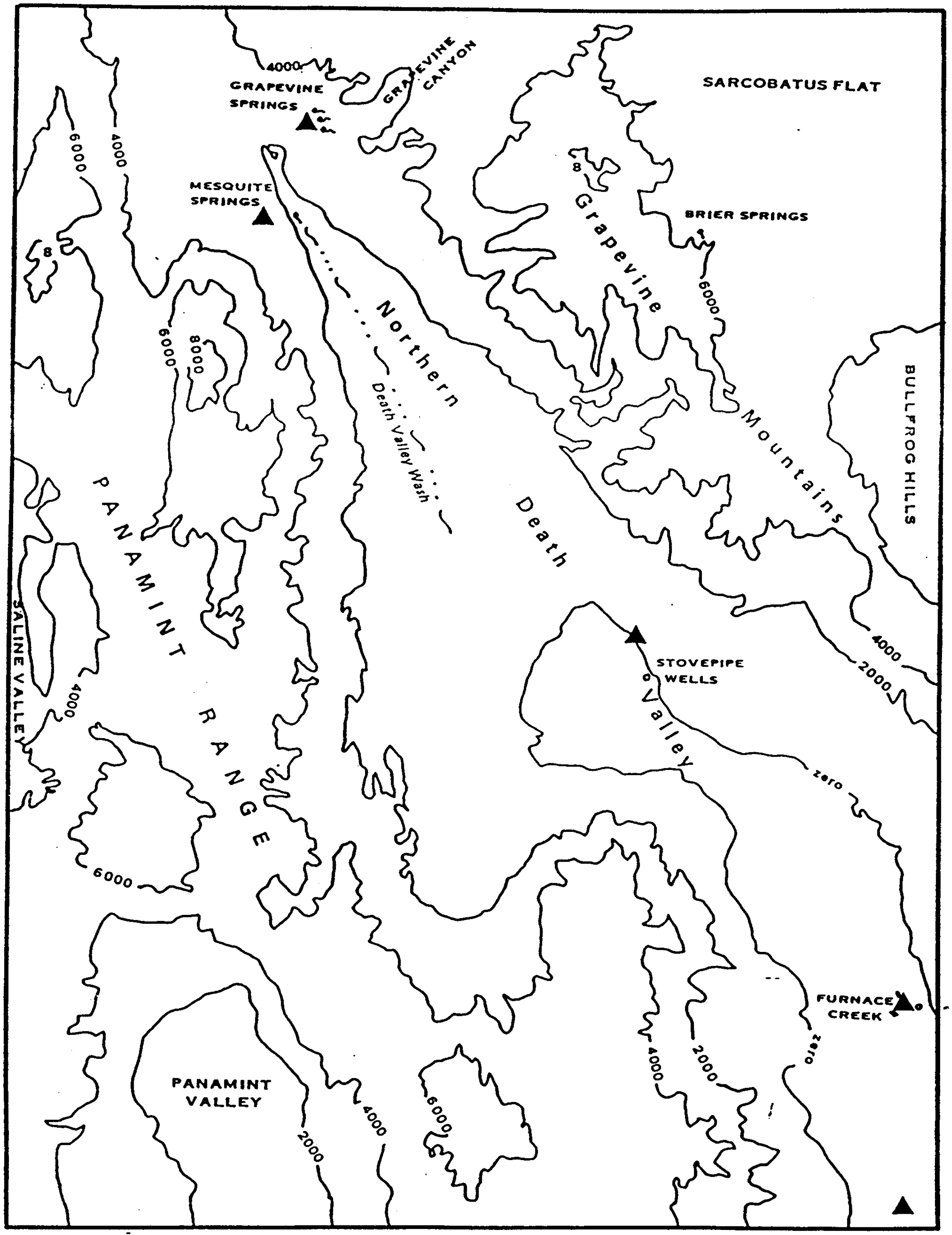

Figure 8-5. Major Winter Sites in Northern and Central Death Valley (*Contour Intervals 2000 ft.*)

In summary,

> *According to Native Americans, the whole earth is sacred because it is the source of life, and there are many places on the landscape where communication with the spirits and processes of renewal can take place. Of specific importance is the belief that landmarks cannot be moved or altered. Consequently, land-altering activities threaten not only sacred places but concepts of the entire natural order. This more generalized view is well expressed in Western Shoshone and Southern Paiute concepts of a living, breathing Earth with waters flowing uninterrupted and interconnected through it (or her, in Western Shoshone, Sogobia, 'Mother Earth'), as well as their concepts of 'power' free in nature and unpredictably localized. Native American tribal religions also have rituals and ceremonies that are involved with continuing, or constantly renewing the creation process, and keeping proper forces (such as again, Western Shoshone and Southern Paiute 'power') in balance (Federal Agencies Task Force, 1979). The sacred is conceptually totally enmeshed with the natural, with the earth and other natural phenomena seen as one with humans, plants and animals. The sacred is a force in itself, and it calls for the harmonious integration of land and people (Deloria, Jr., 1973; Curtis, 1988:3).* (NWP90a, pp. 35, 36).

An excellent description of these people and their religion is contained in NWP90a, which is the result of extensive research over a number of years. The remainder of this section is taken from this report.

8.2.1.2 Early Non-Native Settlement of the Amargosa Valley

In the 1870s, the mining boom in the Death Valley area attracted the first non-native settlers to Amargosa Valley. In 1873, Charles King established a ranch in the Ash Meadows area (near the Devil's Hole Protected Withdrawal area shown in Figure 8-2) where he had 1,300 cattle grazing on the extensive grasslands watered by the surface springs in the area. In 1874, the Lee brothers staked a claim near King's ranch and also established a herd of cattle. By the end of the 1870s, homesteaders had claimed most of the land from Beatty to the Pahrump Valley that was watered by springs and seeps. The mining camps in the area provided the market for the vegetables and beef raised on these farms and ranches. When mining declined in the early 1880s, most of the homesteaders were forced to abandon their lands (McC92).

The next period of growth in the area occurred in the early 1900s. The discovery of gold and silver in the Tonopah-Goldfield district to the Northwest of the Amargosa Valley, the founding of Las Vegas, and the continued exploitation of the borax resources in Death Valley to the south brought railroads through the Amargosa Valley. The Las Vegas and Tonopah railroad (LV&T) entered the Valley west of the present day town of Mercury and ran across the Valley along the route now followed by Nevada Rt. 95. The LV&T operated from 1906 to about 1918. The Tonopah and Tidewater railroad (T&T) was begun in 1904, with a route planned to connect Tonopah, NV with Tecopa, CA. While the planned line was never completed, it did operate between California and Rhyolite, west of Beatty. The route followed the gorge of the Amargosa River along the southwest boundary of the Valley. During the 1920s and 1930s, the T&T provided the major transportation corridor for products moving into and out of the Amargosa Valley. While agriculture continued in the Ash Meadows area, the broad flat expanse of the Valley to the northwest was unoccupied until officials of the T&T railroad decided to "prove" the land in 1915, perhaps envisioning the revenues that would be generated once homesteaders claimed the tens of thousands of available acres and began shipping their products on the T&T (McC92).

The T&T ranch, established in the southern end of the valley east of the T&T right of way, proved that the land was arable with irrigation, but it failed to attract homesteaders; the conditions imposed by the Homestead Act were too difficult to meet in the desolate area (McC92). Recognizing this problem, officials of the T&T railroad persuaded Senator Pittman of Nevada to sponsor legislation in 1919 to make it possible for individuals to acquire 640 acres (one section) of Nevada desert land. Under the terms of the 1919 legislation, a claim could be made on four adjacent sections of public land in Nevada that was "unreserved, unappropriated, nonmineral, and non-timbered" and that was "not known to be susceptible to successful irrigation at a reasonable cost from any known source of water supply” (McC92). If within two years the claimant could show that sufficient underground water had been developed to produce a profitable agricultural crop on at least 20 acres of the land, rights to one-fourth of the claim (640 acres or one section) could be obtained (McC92).

Far from attracting an influx of homesteaders, only five claims were filed under the 1919 legislation, all by employees of the Pacific Coast Borax Company which owned the T&T railroad. These claims were patented in 1927 and the homesteaders transferred their claims to the company, creating a contiguous holding, centered on the T&T ranch, of the best agricultural land in the Amargosa Valley. A number of wells were dug on the property, at depths of 72 to 88 feet, and crops including alfalfa, vegetables, grapes, fruits, and nuts were raised. A small dairy herd was also established. Despite the success of the T&T ranch in showing that the soil could be productive, the prospect of the Amargosa Valley becoming a productive agricultural center faded with the decline of the T&T railroad in the 1930s. The railroad ceased operations in 1940 (McC92).

The creation of the Nevada Test Site and the passage of the Desert Land Act (sometimes referred to as the Desert Entry Act) in the early 1950s marked the next stage in the settlement of the Amargosa Valley. The Nevada Test Site did not bring the influx of population to the Valley that might have been expected. While Lathrop Wells (now part of the town of Amargosa Valley) was considered as a possible location to house the workers at the Test Site, the Atomic Energy Commission opted for a location closer to Las Vegas and established the town of Mercury approximately 20 miles to the east of Lathrop Wells (NYE93a).

The Desert Land Act did lure more homesteaders to the Amargosa Valley. Under the terms of the Act, a person could claim 320 acres of unreserved land (a half-section); if within three years they developed sufficient ground water resources to cultivate the land and "proved the land" by bringing 40 acres into production, they could purchase the "patented" land for $1.25 per acre. Patents granted under the Desert Land Act almost tripled private ownership of the acreage in the Valley (NYE93a).

It should be noted that all of the agricultural development that took place in the Amargosa Valley up through the 1960s was on a modest scale; no large-scale commercial farms were created. This changed in the late 1960s when the Spring Meadows Ranch was established in the Ash Meadows area on 5,645 acres obtained through a land swap with the Bureau of Land Management. Through additional purchases of private lands, the owners of Spring Meadows Ranch were able to expand their holding to 12,000 acres. They also attained the rights to a majority of the water allocated to the area. Wells were drilled, pumping began, and a cattle and alfalfa operation employing about 100 persons was created. With their increased use, water levels fell in the wells and springs in the Ash Meadows area, causing a heated controversy over the impact on endangered species (McC92).

In 1978, following a 1976 Supreme Court decision in its favor, the government established a minimum water level for Devil's Hole to protect the endangered Devil's Hole pupfish. With the restriction placed on pumping, the owners of Spring Meadows Ranch sold out to Preferred Equities, a land development company based in Pahrump, NV. Preferred Equities planned to develop a residential community of 50,000 persons. Towards that end, the company purchased additional property bringing its total holdings to about 17,000 acres. The plan was highly controversial; in the early 1980s, the Nature Conservancy purchased more than 12,600 acres of land and the associated water rights to prevent development of the area. Subsequently, in 1984, the U.S. Fish and Wildlife Service purchased the Nature Conservancy's interest and permanently withdrew the land from development (McC92).

8.2.2 Current Demographics and Land Use

The boundaries of the unincorporated town of Amargosa Valley encompass almost 500 square miles of the Amargosa Desert. The boundaries of the town include all of the area where the highest potential doses from a repository at Yucca Mountain are anticipated, with the exception of the lands to the east and southeast that are part of the Nevada Test Site. Located 90 miles north of Las Vegas and 330 miles from Los Angeles, the remoteness and arid climate of the area are reflected by its population of fewer than 1,000 residents (NYE93a). Only about 11 percent of the land (about 35,000 acres) is held privately; the remainder is under Federal control.

In 1993, only slightly more than 1,000 acres of land were cultivated in the Amargosa Valley (NYE93a). The assessed value of these lands for tax purposes in 1993 was slightly less than $120,000, or about $120/acre (NYE93a). This is consistent with the average value of about $230/acre for agricultural real estate (land and buildings) in Nevada (NEV95). Although two commercial alfalfa farms and one commercial sod farm are operating full-time in the Valley, most farms in the Amargosa Valley are operated on a part-time basis with other employment serving as the primary source of income. Fewer than 30 persons are employed in the "Farming and Agricultural Services" sector of the economy (NYE93a). The lack of large-scale commercial agricultural development in the Amargosa Valley is not surprising given the following factors listed by the U.S. Department of the Interior: "primary soil deficiencies such as coarse textures, low water-holding capacity, high infiltration rates, and poor inherent fertility combined with extremely hot summers, high winds, and distances from markets and services” (NYE93a).

The difficulties in making a living off agriculture in the Amargosa Valley are also illustrated by the experience under the Desert Land Act. Prior to 1954, there were only eight wells and 8,000 acres under patent in the Valley. Between 1954 and 1960, 167 new wells were drilled and 17,700 acres were patented under the Act. However, the amount of land in actual agricultural production remained small with fewer than 1,000 acres in production, and by 1973, only 17 wells were still used for irrigation (NYE93a). While the Act attracted many potential settlers, most arrived and departed in a very short period (NYE93a).

Despite the difficulties, a wide range of crops and livestock can be raised. Alfalfa, hay and grass, wheat, fruits and melons, vegetables, cotton, nuts, poultry, beef cattle, dairy cattle, and fish are being or have been grown on farms and ranches in the Valley.

Both historically and currently, agricultural activities have been restricted to the Ash Meadows area and the portion of the Amargosa Valley known as Amargosa Farms (the private lands southwest of Amargosa Valley shown on Figure 8-2). Currently, no farming occurs closer than about 23 kilometers (km) south of the site. Readily accessible water from springs and seeps are sufficient to explain why the land in the Ash Meadows area was the first to be used for agriculture; cattle could be grazed on existing grasslands and crops could be raised without having to develop wells for irrigation. Similarly, proximity to the T&T railroad and relatively shallow depths to the ground water are sufficient to explain why agriculture developed in the Amargosa Farms area during the 1920s and 1930s. Yet, after examining Figure 8-2, it is reasonable to ask whether or not the lack of agricultural activities along the current route 95 and north towards Yucca Mountain simply reflects historical facts (e.g., the loss of rail transport with the early demise of the LV&T railroad and the withdrawal of lands for the Nevada Test Site) or fundamental differences in the quality of the lands and soils and/or the availability of water. This issue is explored in the following section which addresses the economics of ground water development and use; the topography and soil conditions in the areas south and southeast of Yucca Mountain; and other factors which may affect the future use of the region.

Farming and agriculture in the vicinity of Yucca Mountain are a primary concern for this BID because these activities would be principal users of water that might become contaminated by radionuclides released from a repository at Yucca Mountain. In perspective, these activities are only a small fraction of the economic base of the region and Nye County, providing only about 3 percent of the employment of the County. Principal employment sectors in past years have included services (35 percent), mining (18 percent), construction (11 percent), retail trade (9 percent), and government employment (8 percent) (NYE98). As shown in the 1998 baseline projection of Nye County population growth (NYE98a) the total population of Nye County is expected to increase from 33,750 in 1998 to 51,160 in 2008, with the population of Amargosa Valley increasing by about 50 percent.

Although farming constitutes only a small fraction of the employment in the region, it is by far the major user of water. As shown in Table 8.4, in recent years irrigation has consumed about 10,000 acre-feet of water annually, corresponding to about 75 percent of all water use. The largest user of the irrigation water is alfalfa farming in the Amargosa Farms region. These farms consume on the order of 90 percent of the water used for irrigation. As discussed in Section 8.2.3.2, each alfalfa farm consumes on average 1,275 acre-feet of water per year for irrigation.

During approximately the past decade, Nye County has put intensive effort into trying to broaden the economic base of the region, because of declining employment in areas such as mining and government employment, and growing opportunities in areas such as recreation and tourism, home-based telecommunications, and expansion of the military-retiree community. Part of the effort at economic diversification has led to the concept of the Nevada Science and Technology Corridor, which would extend along U.S. Highway 95 from Indian Springs and Pahrump in the south to Tonapah in the north. It would pass through Amargosa Valley, Beatty, and Goldfield. The region is seen to have high economic development potential and would benefit from expanded and diversified activities at the Nevada Test Site, such as the potential Lockheed/Martin Venture Star space shuttle program.

One of the principal elements of the Corridor's economic activities would be the Amargosa Valley Science and Technology Park, described in detail in the March 1998 Master Plan for the Park (NYE98). The Park would be located in a nine-mile-square area at the intersection of U.S. Highway 95 and State Route 373, i.e., at the part of the unincorporated Town of Amargosa Valley known as Lathrop Wells, about 20 km south of the proposed Yucca Mountain repository. (Lathrop Wells is the current location of human habitation closest to Yucca Mountain; there are at present about 15 residents at this location.) The Park would include, as initial facilities, a science and technology museum, located on a 220-acre site just north of Highway 95 and to the west of the Lathrop Wells highway junction, and a commercial office/manufacturing /storage facility on 22 acres adjacent to the museum site. Future facilities that would be part of the Park would include a heavy industry area, a facility for research on renewable energy sources, a facility for operations/administration research, a desert research area, and an aeropark. Most of these facilities would be located to the north of Highway 95, i.e., in the area between the southern boundary of the NTS and Lathrop Wells.

The Nevada Science and Technology Museum concept has recently evolved into the Desert Space Station Science Museum (NYE00). This 95,000-square-foot museum would be designed to resemble a space station. The topics of its indoor and outdoor exhibits would relate to the Nevada Test Site, Nellis Air Force Range, and the Mohave Desert. Equipment would include a 3-D IMAX theater and a Digistar II planetarium. It has been estimated that the museum would attract about 374,000 visitors annually (NYE00). Conveyance of land for the facility from the U.S. Bureau of Land Management is expected to occur during 2000 (NYE00a).

These plans and the forthcoming initiation of their implementation indicate that future human activities in the Lathrop Wells area, 18-20 km south of the proposed repository location, will be extensive and non-agricultural. Existing wells in the area have been typically completed into sands and gravels with water levels on the order of 100 to 150 m below grade. Use of water at this depth for agriculture and irrigation would be economically marginal at best, especially in comparison with the shallow depth to water in the area currently used for agriculture, i.e., the region southwest of Lathrop Wells (see Figure 8-8).

Nye County will have to file for and obtain water rights for the anticipated Technology Park facilities. At present, water in Amargosa Valley has been over-appropriated, which means that all further applications for water for irrigation will be denied, i.e., new, additional farms in the Lathrop Wells area requiring irrigation water would not be permitted. Applications for water for other uses, such as the Technology Park, are considered on a case-by-case basis, taking into consideration whether they are in the "public good". If the State Engineer denies appropriation of water rights for the Technology Park, options are to purchase rights from others, to file elsewhere, or to build a pipeline.

Nye County recently filed ten water-rights applications for a total of 34,250 acre-feet of ground water from the basins north of Highway 95 (i.e., the Crater Flat, Jackass Flats, Rock Valley, Mercury Valley, and Frenchman Flat basins) (NYE00a). The filings were made in order to provide future water supplies to areas where they will be needed and to protect the resource from speculators. Most of the basins are within the NTS boundaries; the applications are expected to be protested by federal government agencies, and final action could be many years away.

8.2.3 Factors Affecting Future Use of the Region

8.2.3.1 Hydrologic Characteristics and Use

Data indicate that the overall ground water flow direction in the alluvial aquifer is to the south and southwest, with local variations (DOE96). Hydraulic gradients in the alluvial basins vary widely, both between different basins and within any given basin. In the central section of the Amargosa Desert, the hydraulic gradient is approximately 0.002 (refer to Figure 7-26 for a map of the potentiometric surface in the Amargosa Desert). These aquifers are recharged directly by precipitation, by runoff from the surrounding mountains, by infiltration from the underlying bedrock formations, and possibly by returns of irrigation water and percolation of wastewaters. Water leaves the alluvial aquifers by flowing to other basins, percolation to the volcanic or carbonate aquifers, evapotranspiration, and pumping for domestic and irrigation uses. (See Section 7.1.2 for more information.)

Ground water flow in the volcanic aquifer is generally to the south, with a strong tendency to the east in some areas. In one area about three km upgradient from the proposed repository site, water levels drop over 275 meters in slightly less than two km. The precise cause of this large gradient is not known. Outside of this large-gradient zone, hydraulic gradients measured in the volcanic units are quite low, around 0.0003.

The volcanic aquifer is recharged primarily by melting snow on uplands north of Yucca Mountain (e.g., Timber Mountain), with occasional intense rainstorms adding to the infiltration. There may also be some unquantified recharge from the underlying carbonate aquifer. The location and amount of the volcanic aquifer discharges are not currently known, but water very likely moves to the south to enter the alluvium as the volcanic layer pinches out south of the test site boundary; the location of this pinchout is thought to be approximately at the latitude of Lathrop Wells (DOE95) (see Figure 7-21). A few wells account for some discharge, supplying water for the Nevada Test Site and Yucca Mountain characterization activities (FRI94).

Flow direction and gradients in the Paleozoic carbonate aquifer are not well-defined because very few wells have penetrated this layer. However, regional flows are generally thought to be southward. The velocities in an area of similar rock outside the study area have been estimated at 0.006 to 60 m per day. The carbonate aquifer can be recharged directly where highly fractured rocks are exposed at the surface at higher elevations, where precipitation is greatest. Recharge also occurs by infiltration from the overlying volcanic and alluvial deposits. The carbonate aquifer is known to discharge at Ash Meadows, southeast of Yucca Mountain, and probably in Death Valley, about 100 km south-southwest of Yucca Mountain. Other discharge points may include small, low-flowing springs, though most of these are not in the study area (USG75).

The chemical quality of ground water in the area varies considerably. Generally, ground water in wells closest to the discharge area of the system (mainly Death Valley and the Amargosa Desert) contains high concentrations of dissolved minerals and is unsuitable for most uses, though it is generally useable for irrigation. Water quality as measured by total dissolved solids (TDS) is highly variable, with values typically ranging from greater than 200 mg/L to less than 1,000 mg/L. Occurrences of TDS greater than 1,000 mg/L are not uncommon; in discharge areas, TDS values can range from 10,000 to as high as 80,000 mg/L (see Table 8-1). Individual dissolved constituents also occur over a wide range, as shown in the following tabulation of data obtained from analyses of water in the Amargosa Desert.

Table 8-1. Range in Concentration of Dissolved Constituents in Ground Water in the Amargosa Desert (Source: after NDC63, p. 36)

	Range (in parts per million)	
Constituent	**Low**	**High**
Calcium (Ca)	1.9	85
Magnesium (Mg)	1.0	26
Sodium (Na)	41	1060
Potassium (K)	3.2	88
Bicarbonate plus Carbonate	102	778
(HCO_3 + CO_3)	Bicarbonate plus Carbonate	102
Sulfate (SO_4)	24	484
Chloride (Cl)	6.0	1050
Fluoride (F)	0.6	7.9
Nitrate (NO_3)	0.0	17
Total Dissolved Solids (TDS)*	217	79,700

* Note: TDS data taken from USG90.

The alluvial aquifers tend to have high concentrations of fluoride; water from the tuff aquifer is dominated by bicarbonates of sodium and also contains small amounts of silica, calcium, magnesium, and sulfate. The wells that supply water for the Nevada Test Site and for characterization activities at Yucca Mountain draw from the tuff aquifer (including human consumption) and have shown no deterioration in water quality despite decades of pumping. Water from the carbonate aquifer shows elevated levels of calcium and magnesium carbonates. This water also has increased levels of sodium and potassium if it has percolated through the tuff formation.

In terms of water rights, Nevada is an appropriative state and limits the amount of water that may be withdrawn from any hydrographic basin to the perennial yield for that basin, i.e., the yield that reflects sustainable withdrawals given the natural recharge and discharge of the hydrographic basin. Ground water "mining" is not allowed. Water for almost all human activities (consumption, irrigation, ranching) is currently drawn from the alluvial and the lower carbonate aquifers; water is only taken from the tuff aquifer for use at the Nevada Test Site and for characterization activities at Yucca Mountain. Access to the volcanic aquifer is currently limited for two reasons. First, the volcanic aquifer is not believed to extend much farther south than the southern boundary of the NTS, and access to the NTS is currently restricted. Second, productive water bearing zones within the volcanic aquifer are sufficiently deep as to make drilling too costly except for large organizations such as government agencies or large corporations.

The major users of ground water in the area are the town of Amargosa Valley and small rural communities in the northeast Amargosa Desert (Figure 8-6). In Amargosa Valley, water is supplied by wells into the alluvial aquifer. Primary uses are domestic, agricultural, mining (specialty clays), recreation (e.g., golf courses), and industrial. Most residences are supplied by individual wells, though some trailer parks, public facilities, and commercial establishments are served by small, private water companies. A number of springs also supply water, primarily to the resort area in Death Valley.

The hydrographic basin in which Amargosa Valley is located (Basin 230) currently is rated at a perennial yield of 34,000 acre-feet per year. The 1993 population of Basin 230 was about 1,100. While currently allocated usage rights for Basin 230 stand at a little more than 41,000 acre-feet per year, the actual usage has not yet exceeded the estimated perennial yield.

8.2.3.2 Ground Water Use

Water rights in Nevada are strictly controlled by the state and appropriated to users on a case-by-case basis. Ground water use in Nevada is regulated by the Department of Conservation and Natural Resources through the State Engineer’s Office. For purposes of water resources administration, Nevada is divided into 253 hydrographic basins (see USG88a for details). The state limits the amount of water that may be withdrawn from any hydrographic basin to the perennial yield for that basin.

The five hydrographic basins listed in Table 8-2 are of principal interest to the consideration of a repository at Yucca Mountain. Figure 8-7 shows the location of these basins.

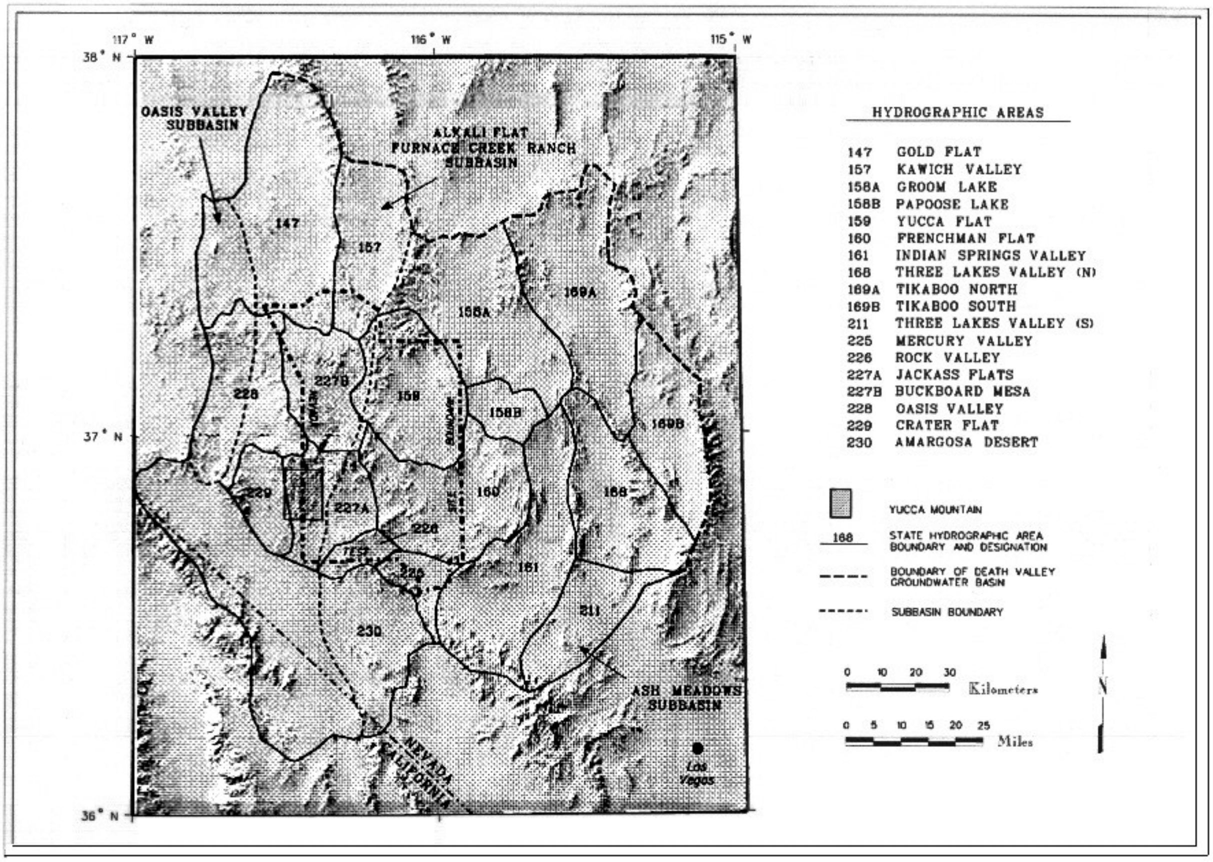

Figure 8-6.Map Showing Boundaries of Ground Water Subbasins in the Study Area (DOE95a)

Table 8-2. Hydrographic Basins in the Vicinity of Yucca Mountain

Hydrographic Basin Name	Number
Mercury Valley	225
Rock Valley	226
Forty Mile Canyon - Jackass Flats	227-A
Crater Flats	229
Amargosa Desert	230

The regional aquifers in the five hydrographic basins that are used for human activity include the volcanic aquifer, the valley fill aquifer and the lower carbonate aquifer. The welded tuff aquifer is locally important; it is developed only in the southwestern areas of the Nevada Test Site. This

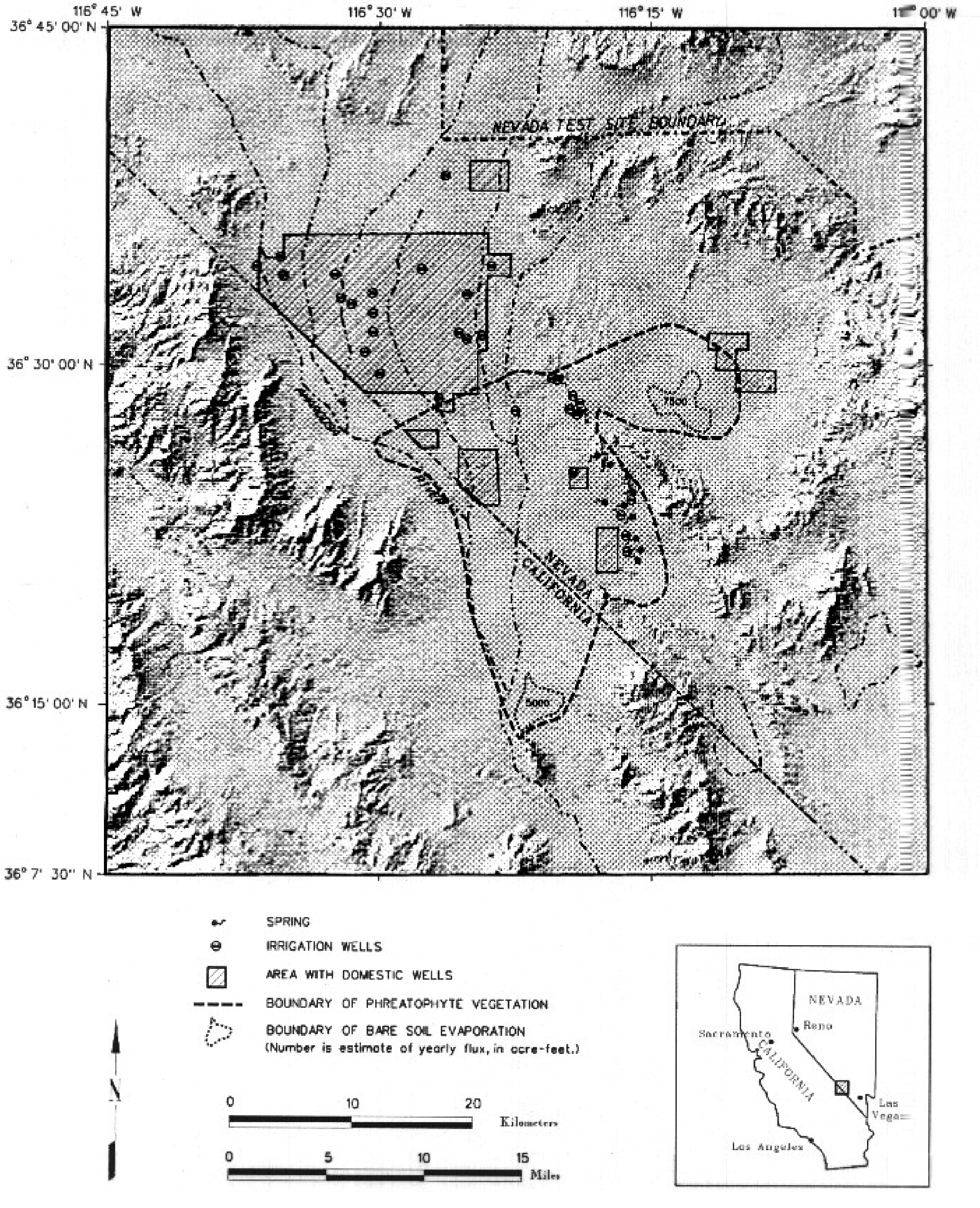

Figure 8-7. Ground Water Usage in the Amargosa Desert (USG91a)

water is withdrawn from two water wells (J-12 and J-13) located in Basin 227-A and is used for all site characterization activities at Yucca Mountain, including human consumption. A significant percentage of this water is used to wet local unpaved roads for dust suppression (STE95). Well J-13 currently is being pumped at a rate of 550 gallons per minute and Well J-12 is being pumped at a rate of 800 gallons per minute, depending on demand (DOE95f).

Most of the water pumped from the Ash Meadows ground water subbasin is pumped from the lower carbonate aquifer (USG76). In 1971, ground water withdrawals associated with the planned development of a large agricultural enterprise caused a decline in the water level of the pool at Devil's Hole. This natural pool, formed from the collapse of the limestone bedrock, is the only habitat of the Devil's Hole pupfish, an endangered species. As a consequence of court action, ground water withdrawals in this area are now restricted to a degree that is sufficient to maintain the water level in Devil's Hole (USG76a).

The Nevada Test Site (NTS) receives its water from wells drilled on the NTS. The NTS accommodates a worker population of approximately 5,000 individuals, most of whom reside in Las Vegas and other nearby communities; a very small percentage of this workforce resides in Mercury on an intermittent basis. There are 12 NTS wells that currently withdraw water from the Ash Meadows ground water subbasin for construction, drilling, fire protection, and consumption uses. Some of the water requires treatment before distribution (DOE95a).

Table 8-3 indicates that ground water usage rights are over-allocated in Basin No. 230 by approximately 17,000 acre-feet per year. However, actual usage in Basin No. 230 has thus far not exceeded the estimated perennial yield. Available usage figures demonstrate that annual basin-wide withdrawals have not been in excess of approximately 12,000 acre-feet per year. A 1993 pumpage inventory (State of Nevada, Division of Water Resources, Las Vegas Office) for the Amargosa Desert Basin shows that the actual ground water usage for 1993 was 11,300 acre-feet. In 1993, water actually pumped and used for irrigation was 8,559 acre-feet, or about 30 percent of the amount allocated for that purpose; water for mining operations stood at 44 percent of the allocated amount; and water for community and municipal uses was little more than four percent of the allocation (NYE93a). Table 8-4 provides a breakdown of 1993 ground water usage in Basin 230 by category.

In 1997, the total ground water use in Basin 230 was 13,902 acre feet (AV197). Water pumped and used for irrigation was 9,349 acre-feet, or about one-third of the allocation for this purpose. Other uses in 1997 can be compared with those of 1993 in Table 8-4. The increase in use between 1993 and 1997 does not necessarily represent a net growth over time; water usage in Basin 230 fluctuates significantly, depending primarily on the level of irrigation and mining activities in a given year.

Table 8-3. Water Appropriations by Hydrographic Basin in the Study Area

Hydrographic Basin	Perennial Yield	Total Appropriated	Approved Use				
			Irrigation	Community	Municipal	Stock/ Other	Mining
225	8,000	0	0	0	0	0	0
226	8,000	0	0	0	0	0	0
227-A	4,000	56	0	39	0	17	0
229	900	2,995	0	0	0	61	2,934
230	34,000*	41,093	28,600	85	2,486	4,255	5,667

* The perennial yield is a combined total for all of the above basins and Basin #228. (Source: Hydrographic area summaries, State Engineer's Office Nevada Department of Conservation and Natural Resources.)

Table 8-4. 1993 Ground Water Pumpage Inventory for Basin No. 230

Ground Water User/Use	Pumpage (acre-feet)	
	1993	1997
Irrigation	8,559	9,349
Irrigation (no permits or certificates)	150	1,105
American Borate (314 acre-feet pumped from CA side)	512	666
Industrial-Mineral Ventures	495	251
St. Joe Bull Frog	1,474	1,589
Commercial, Quasi-Municipal, Domestic	110	942

The 1993 ground water withdrawals for the Jackass Flats Basin (No 227-A) and Mercury Valley Basin (No. 225) were 205 and 338 acre-feet, respectively (USG95b). The pumpage from Basin 227-A reflects withdrawals from the J-12 and J-13 wells described earlier. Data for 1997 for these basins are not available.

Two mineral production operations are located in the Amargosa Desert. One operation, owned by the American Borate Corporation and located between Amargosa Valley, Nevada and Death Valley Junction, California, was decommissioned in July 1986. The facility consisted of a large mineral processing plant and a housing development for its employees. Water for the community was pumped from a shallow well and was treated by a reverse osmosis process to reduce total dissolved solids before distribution. The other operation is owned by the IMV Division of Floridin, Inc. and is also located between Amargosa Valley, Nevada and Death Valley Junction, California. As of 1995, the operation employed approximately 53 people to mine specialty clays (DOE95a).

In addition to well production, a number of springs supply water to the region. The main concentration of springs is in Death Valley in the vicinity of Furnace Creek Ranch, approximately 60 km southwest of Yucca Mountain. The water supply for the National Park Service facilities is derived principally from three groups of springs: Travertine Springs, Texas Springs, and Nevares Springs. The population served by this water supply varies during the year. From October through April, approximately 800 persons live in the area on a semipermanent basis and an additional 2,000 persons live in the area as visitors. From May through September, the number of semipermanent residents decreases and there are few visitors (DOE95a).

Three resorts are located within the boundaries of the Death Valley National Monument: the Stovepipe Wells Hotel, Furnace Creek Inn, and Furnace Creek Ranch. Water for the Stovepipe Wells Hotel is trucked in from Nevares Spring. Water for Furnace Creek Inn and Furnace Creek Ranch is reportedly conveyed from an excavated sump lined with drainage tile in the Furnace Creek Wash (DOE95a).

Crater Flat (Basin No. 228) is currently overdrawn because of an appropriation made to Saga Exploration, Inc. for development of the Panama-Sterling Mine, located on the east side of Bare Mountain. The mine uses its own well for its heap-leach operation and relies on municipal water for its potable water. The mine employs approximately 40 individuals and is expected to be in operation until 1997 or 1998 (DOE95a).

The proposed repository at Yucca Mountain would be about 400 meters above the aquifer that occurs in the tuff members underlying the site. The tuff aquifer appears to discharge to the alluvial aquifer that underlies much of Amargosa Valley (YOU72). At the northern end of the Amargosa Valley, on Jackass Flats, approximately five to seven km south-southeast of the site, the depth to the ground water (tuff aquifer) is approximately 300 m. In the Amargosa Farms area, between 30-40 km south- southwest of Yucca Mountain, the (alluvial) aquifer is at a depth of 10-40 m. A deep aquifer in carbonate rock underlies the tuff aquifer and portions of the alluvial aquifer. This carbonate rock aquifer lies at a depth of more than 1,000 m at the northern end of the valley (Jackass Flats) and discharges at or near the surface in the Ash Meadows area approximately 45 km southeast.

The feasibility of using a ground water resource depends on the economic value of the water to the user, the costs of drilling the well, and the costs of pumping water from the well. While much has been written on the theory and practice of determining the economic value of water to the user, it is sufficient for present purposes to recognize that: (1) the marginal value of water varies greatly depending on its use, and (2) agricultural use for irrigation generally has the lowest marginal value, while domestic use for drinking and hygiene has the highest marginal value. Preliminary estimates of the marginal value of water for irrigation in the Amargosa Valley, based on the economics of raising alfalfa (the major cash crop), suggest a marginal value of about $40.00 per acre-foot (DOE91). Based on long-range plans for providing water to users in Las Vegas, a marginal value of about $800 per acre-foot can be assumed for domestic uses (MIK92). Marginal values for other agricultural uses or industrial and mining uses would be intermediate between these values and would depend upon the specific crop, process or resource being produced. When the costs of drilling and pumping water are less than the marginal value for the intended use, the ground water resource can be economically developed.

Figure 8-8 shows the depths to ground water in the vicinity of Yucca Mountain and the locations of existing wells and boreholes (DRI94). Table 8-5 lists the wells and boreholes that are designated as being privately owned and provides information on their exact locations, depth to water, and well depth. Examination of the well data in Table 8-5 identifies 34 wells for which the use is shown as "irrigation" or "domestic/irrigation" and for which the depth of the well and the depth to ground water is known. The averages for these wells (excluding surface springs and seeps) include an average depth of less than 300 feet and a depth to water of less than 100 feet, which is consistent with the heavy concentration of wells depicted in Figure 8-6 at locations where the depth to ground water is less than 100 feet. The deepest wells used for human consumption other than J-12 and J-13 in the NTS are those near Lathrop Wells. At 23 km from Yucca Mountain, these vary from 90 m to 120 m depth to water. Figure 8-9 shows the depth to water versus the distance from Yucca Mountain in graphical form.

Water Availability/Perennial Yields

In order to estimate the population that may be supported at some time in the future by the water resources available in the Yucca Mountain area, the following analysis was performed.

Perennial yield is defined as the maximum amount of water that can be withdrawn from the ground water system for an indefinite period of time without causing a permanent depletion of the stored water or causing a deterioration in the quality of the water (NDC63). It is ultimately

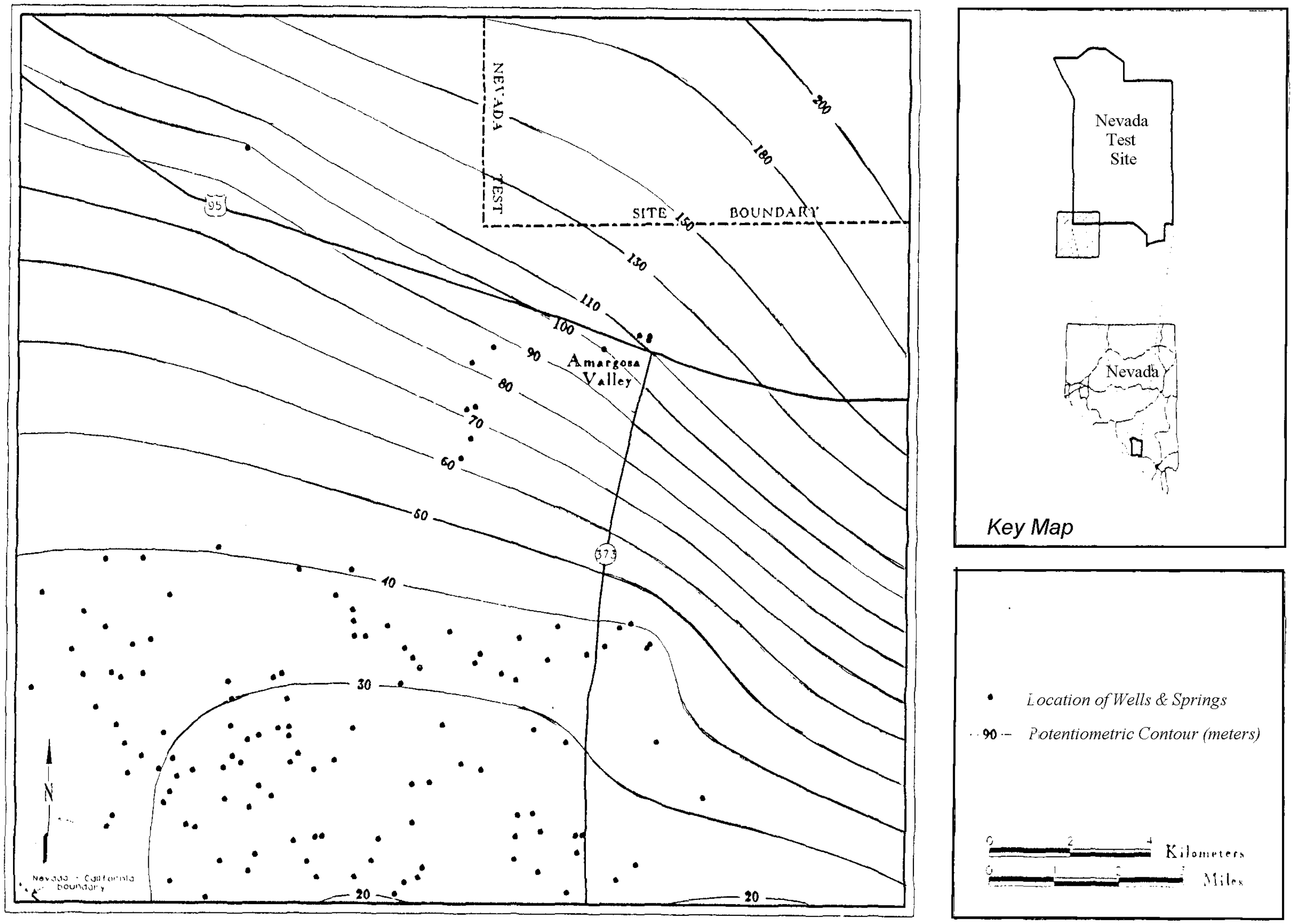

Figure 8-8. Locations of Water Wells in the Amargosa Farms Area (DRI94)

Table 8-5. Wells and Boreholes in the Amargosa Valley

Well Name	Latitude	Longitude	Surface Altitude	Well Depth (meters)	Depth to water (m)	Well Use	Well Owner	Distance from Yucca Mt. (“X”)(Km)
USW Diane	36:51:21	116:27:56				Meteorological	Government	0.5
USW H-5	36:51:22	116:27:55		1219	704.2	Hydrologic Testing	Government	0.7
USW STN2	36:51:19	116:27:56				Meteorological	Government	0.8
USW UZ-N70	36:51:48	116:27:40				Precip. Gauge	Government	0.9
USW UZ-N64	36:51:13	116:27:49				Precip. Gauge	Government	1
USW UZ-N98	36:51:35	116:27:16				Precip. Gauge	Government	1.4
USW STN3	36:51:17	116:27:06				Meteorological	Government	1.8
UE-25 NFCW	36:51:16	116:27:01				Precip. Gauge	Government	1.9
USW H-1	36:51:58	116:27:12		1829	572	Hydrologic Testing	Government	2
USW UZ-N75	36:50:31	116:27:53				Precip. Gauge	Government	2.1
USW UZ-N40	36:51:17	116:26:50				Precip. Gauge	Government	2.2
USW UZ-N88	36:50:24	116:28:24				Precip. Gauge	Government	2.4
UE-25 UZN#18	36:51:20	116:26:37				Precip. Gauge	Government	2.5
USW UZ-N95	36:50:15	116:28:04				Precip. Gauge	Government	2.6
UE-25 UZN#2	36:51:41	116:26:36				Precip. Gauge	Government	2.7
USW UZ-N52	36:50:25	116:27:06				Precip. Gauge	Government	2.8
USW UZ-N15	36:53:15	116:27:47				Precip. Gauge	Government	3.1
USW UZ-N16	36:53:16	116:27:46				Precip. Gauge	Government	3.1
UE25 WT#04	36:51:40	116:26:03		482	439	Water Level Monitoring	Government	3.2
USW UZ-N66	36:50:01	116:27:19				Precip. Gauge	Government	3.3
UE-25 UZN#13	36:51:35	116:26:00				Precip. Gauge	Government	3.4
USW GA-1	36:53:28	116:27:51				Precip. Gauge	Government	3.5
USW H-3	36:49:42	116:28:01		1219	750.8	Hydrologic Testing	Government	3.6
UE-25 UZN#60	36:50:14	116:26:21				Precip. Gauge	Government	3.8
UE-25 WT#16	36:52:39	116:25:34		519	473	Water Level Monitoring	Government	4
UE-25 STN1	36:50:34	116:25:49				Meteorological /AQ	Government	4.1
UE-25 WX Station 1	36:50:06	116:26:04				Meteorological	Government	4.3
UE-25 STN6	36:53:40	116:26:45				Meteorological /AQ	Government	4.4
USW UZ-N57	36:49:28	116:27:28				Precip. Gauge	Government	4.4
USW Carolyn	36:49:06	116:27:56				Meteorological	Government	4.7
USW UZ-N67	36:49:13	116:26:55				Precip. Gauge	Government	4.9
UE-25 1PTH	36:49:38	116:25:21	1115	1806	1298	Water Level Monitoring	DOE	5
USW UZ-13	36:48:57	116:28:01				Precip. Gauge	Government	5

Table 8-5. Wells and Boreholes in the Amargosa Valley (Continued)

Well Name	Latitude	Longitude	Surface Altitude	Well Depth (meters)	Depth to water (m)	Well Use	Well Owner	Distance from Yucca Mt. (“X”)(Km)
UE-25 c#1	36:49:47	116:25:43		914	401	Hydrologic Testing	Government	5.1
UE-25 p#1	36:49:38	116:25:21		1805	384	Water Level Monitoring	Government	5.3
UE-25 STN8	36:49:42	116:25:35				Meteorological	Government	5.4
PLUG HILL	36:48:43	116:29:26				Meteorological	Government	5.7
UE-25 WT#14	36:50:32	116:24:35		399	346	Water Level Monitoring	Government	5.9
UE-25 STN4	36:51:51	116:24:15				Meteorological	Government	6
UE-25 UZ#4	36:51:42	116:26:26				Infiltration Monitoring	Government	6
UE-25 WT#15	36:51:16	116:23:38	1084	415	354	Water Level Monitoring	DOE	6.3
Fran Ridge	36:49:17	116:24:55				Meteorological	Government	6.6
UE-25 WT#17	36:48:22	116:26:26		443	394	Water Level Monitoring	Government	6.6
UE-25 UZ#5	36:51:41	116:26:26				Infiltration Monitoring	Government	7
UE-25 WT#13	36:49:43	116:23:51	1033	352	303	Water Level Monitoring	DOE	7.1
UE-25 JF#1	36:51:16	116:23:38	1084		354	GW Monitoring	DOE	7.5
UE-25 JF#2	36:49:43	116:23:51	1033		303	GWM	DOE	7.6
40-mile No. 2	36:54:15	116:23:57				Meteorological	Government	8
J-13	36:48:28	116:23:40	1011	1063	283.2	“	DOE	8
UE-25 UZN#85	36:48:44	116:24:06				Precip. Gauge	Government	8.2
UE-25 WT#03	36:47:58	116:24:58		348	300	Water Level Monitoring	Government	8.4
UE-25 Robin	36:48:55	116:23:42				Meteorological	Government	8.5
UE-25 WT#12	36:46:56	116:26:16		399	346	Water Level Monitoring	Government	9.3
CF2, USW VH-1	36:47:32	116:33:07	964	763	278	Water Level Monitoring	DOE	10.5
USW VH-1	36:47:32	116:33:07		762	184.2	Water Level Monitoring	Government	10.5
J-12	36:45:54	116:23:24	954	347	226.2	“	DOE	14
UE-25 JF#3	36:45:27	116:23:23	945		217	GWM	DOE	14
USW CF1, Gexa 4	36:55:20	116:37:03	1199	488	244	IND	NV Gold	15
CF3, Cind-r-lite Well	36:41:05	116:30:26	832	140	98	IND	Cind-r-Lite	16.5
CF1a, Gexa 3	36:54:45	116:38:39	1245	214	63	IND	NV Gold	19
#22 NECO	36:46:00	116:41:30	850	175	86	Industrial	Private	21
J-11	36:47:06	116:17:06	1050	405	317.4	GW Monitor/Dom	DOE	21
#34 Lathrop Well	36:38:27	116:26:23	796	NA	90	Dom/Irrigation	Private	23
#37 Lathrop	36:38:36	116:23:57	812	120	105	Public Supply	Water Co.	23
#38 Lathrop	36:38:32	116:23:48	812	::	120	Unused	Water Co.	23
#35 Lathrop 15s/49e	36:37:40	116:26:40	784	148	78	IND	DOM	24
#39 Amargosa	36:37:14	116:26:45	777	467	73	Observation	Private	25

Table 8-5. Wells and Boreholes in the Amargosa Valley (Continued)

Well Name	Latitude	Longitude	Surface Altitude	Well Depth (meters)	Depth to water (m)	Well Use	Well Owner	Distance from Yucca Mt. (“X”)(Km)
USW AD17	36:38:35	116:23:47				Water Level Monitoring	Government	25
#57 A. Sasse Well	36:35:28	116:28:42	746	87	21	**	Private	27
USW AD1	36:41:30	116:41:12	802	293	82	Water Level Monitoring	NA-6 USGS	27
USW AD2	36:38:25	116:24:33	805	229	99		NV DOT	27.2
#59 Well 16s/49E 08acc	36:34:35	116:28:40	738	62	45	DOM	Private	28
#60 K. Garey Well	36:34:18	116:27:42	741	94	46	Irrigation	Private	28
#63 School house 15aaa	36:34:00	116:26:00	744	120	51	DOM	Private	28
RV-1 (TW-5)	36:38:15	116:17:59	932		207	GW Monitoring	DOE	28
#39 Private Well	36:34:55	116:36:40	725	38	0	DOM	Private	29
#41 Private Well	36:34:50	116:35:30	727	80	34	Irrigation	Private	29
#43 Kirker Well	36:34:25	116:33:20	725	46	32	DOM	Private	29
#44 Bob Nichols Well	36:34:03	116:32:31	725	56	29	Dom/irrigation	Private	29
#45 Well 16s/48e Amargo	35:33:58	116:33:18	724	50	30	**	Private	29
#46 Amargosa Well 15dda	36:33:25	116:32:35	719	**	**	**	Private	29
#53 Amargosa Well 24aaa	36:33:13	116:30:25	722	146	29	Irrigation/DOM	Private	29
#58 K. Finical Well	36:34:56	116:28:41	739	60	45	Domestic	Private	29
#61 School Well 09dcc	36:34:10	116:27:35	739	58	49	Public Supply	Muni	29
#62 Amargosa Well 12ddd	36:34:20	116:24:50	750	**	**	**	**	29
USW RV1	36:38:15	116:17:59				Water Level Monitoring	Government	29.6
#42 Sullivan Well	36:34:15	116:35:20	722	**	40	DOM	Private	30
#64 Amargosa Well 16ccc	35:33:11	116:28:09	726	**	**	**	**	30
#65 Amargosa Well 18dc	36:33:23	116:29:44	723	105	33	Unused	**	30
#67 Amargosa Well 23add	36:33:10	116:25:10	732	116	32	Irrigation	Private	30
#71 Well 07bcd Cook	36:34:25	116:23.50	756	60	42	Dom/Irrigation	Private	30
#52 Amargosa Well 23da	36:32:44	116:31:35	713	140	24	Irrigation	Private	31
#66 Jacob’s #2	36:32:49	116:29:19	720	94	30	**	Private	31
#40 Private Well	36:34:25	116:36:50	722	46	23	Dom/Irrigation	Private	32
#47 Amargosa Well 17abb	36:34:00	116:35.10	722	85	31	Irrigation	Private	32
#48 Amargosa Well 17ccc	36:33:09	116:35:47	718	**	**	**	Private	32
#49 Amargosa Well 18bcc	36:34:00	116:35:20	720	110	27	Irrigation	Private	32
#50 Amargosa Well 18dad	36:33:32	116:35:49	722	**	**	**	Private	32
#51 Lathrop Well 23bcdb	36:33:00	116:32:10	716	100	29	Irrigation	Private	32
#69 Well 35baa Amargosa	36:31:27	116:25:37	714	100	26	Dom/Irrigation	Private	32
USW AD5	36:33:10	116:23:40	725	106	37	Water Level Monitoring	BLM	32.8
USW AD6	36:23:13	116:13:38	732	207	13	Water Level Monitoring	USGS	32.8
#21 Matthew’s Well	36:31:32	116:24:00	707	**	**	**	Private	33

Table 8-5. Wells and Boreholes in the Amargosa Valley (Continued)

Well Name	Latitude	Longitude	Surface Altitude	Well Depth (meters)	Depth to water (m)	Well Use	Well Owner	Distance from Yucca Mt. (“X”)(Km)
#55 Smith’s Well 36aaa	36:31:28	116:30:24	709	91	21	Irrigation	Private	33
USW AD3	36:35:26	116:35:29	730	73	40		Davidson, Robt.	33
#56 John Mills Well	36:30:35	116:30:50	701	124	13	DOM/Irrigation	Private	34
#68 Well 35aaa Amargosa	36:31:10	116:25:10	708	52	30	Irrigation	Private	34
#70 Well 36aba Amargosa	36:31:20	116:24:20	712	**	0	Irrigation	Private	34
#73 Well 17s/48e lab	36:30:28	116:30:25	702	41	16	Unused	Private	34
USW AD4	36:34:28	116:23:47	756	82	36		Cook, L.C.	34.4
#74 Lyle Recs. #2	36:29:38	116:30:01	698	152	12	Irrigation	Private	35
#76 Well 09aa Copeland	36:29:40	116:26:58	695	6	5	Unused	Private	35
#72 Lyle Recs. #2	36:29:20	116:31:10	697	**	**	**	Private	36
#75 Well 08ddb	36:29:04	116:28:08	693	99	15	Unused	Private	36
#77 Well Mecca Club	36:29:36	116:25:15	694	56	20	DOM	Private	37
#78 Well 15bbd Amargosa	36:28:39	116:26:37	690	110	17	Unused	Private	37
#11 Fairbanks Spring	36:29:26	116:20:30	695	NA	0	Irrigation	Private	38
#27 Soda Spring	36:29:22	116:20:10	695	NA	**	Irrigation	Private	38
#79 Well 15 bc Amargosa	36:28:32	116:26:43	690	157	15	Irrigation	Private	38
#02 Amargosa Tracer #1	36:32:13	116:13:37	733	202	13	Observation	NV State	39
#03 Amargosa Tracer #2	36:32:11	116:13:39	732	252	12	Observation	NV State	39
#04 Amargosa Tracer #3	36:32:13	116:13:80	732	246	12	Observation	NV State	39
#26 Rogers Sp.	36:28:40	116:19:20	695	NA	**	Irrigation	Private	39
#84 Well 19aab Amargosa	36:28:00	116:22:30	698	30	5	Irrigation	Private	39
#20 Longstreet Sp.	36:28:04	116:19:30	701	NA	0	Irrigation	Private	40
#80 Well 28bcd Amargosa	36:26:50	116:27:40	689	**	**	**	Private	40
#81 Well 29acc Amargosa	36:26:50	116:28:17	683	**	**	**	Private	40
#96 Well 27bbb	36:27:00	116:32:15	685	91	14	Irrigation	Private	40
USW AD9	36:28:48	116:26:46	691	121	22		Gilgan’s No.	40
#05 Army1	36:35:30	116:02:14	961	593	239	Observation	Army	41
#23 Pt. Rocks Hwy. Well	36:33:33	116:06:42	859	244	138	Destroyed	Private	41
#28 Spring 17s/50e	36:27:36	116:19:04	715	NA	**	Unused	**	41
#83 Well 14cac Flowing	36:28:20	116:18:55	713	28	0	Irrigation	Private	41
#06 Ash Tree Spring	36:25:35	116:24:42	664	NA	0	Domestic	Private	42
#29 Spring 18s/49e Clay C	36:25:30	116:23:50	664	NA	0	Unused	**	42
#85 Well 23bb2 Flowing	36:27:50	116:19:05	713	46	0	Irrigation	Private	42
#89 Tenneco #3	36:24:51	116:25:41	658	224	22	Industrial	Private	42

Table 8-5. Wells and Boreholes in the Amargosa Valley (Continued)

Well Name	Latitude	Longitude	Surface Altitude	Well Depth (meters)	Depth to water (m)	Well Use	Well Owner	Distance from Yucca Mt. ("X")(Km)
USW AM1a, Fairbanks Sp.	36:29:26	116:20:28	691		0		FWS	42
USW AD7	36:30:09	116:30:27	703	34	20		Blackman	42.5
#82 Well 36ccd	36:25:30	116:24:25	671	213	**	Industrial	Private	43
#88 Well 02caa Tenneco #2	36:24:59	116:25:10	664	114	20	Industrial/Public Supply	Private	43
#90 Well 11bbb Amargosa	36:24:35	116:25:15	658	**	**	**	Private	43
#91 Well 06dac	36:24:54	116:22:37	658	**	**	**	Private	43
USW AD10	36:25:25	116:27:43	668	332	3	Water Level Monitoring	NA-9 USGS	43
USW SP1	36:29:26	116:20:28				Spring-Discharge Monitoring	Government	43.2
#87 Well 08c1	36:29:00	116:09:10	729	122	10	DOM/Irrigation	Private	44
#92 07bbb	36:24:33	116:16:57	707	152	7	IND	Private	44
#94 Ash Meadows	36:24:03	116:16:08	707	86	0	Irrigation	Private	44
USW AM1, Rogers Sp.	36:28:56	116:19:53	691	62	31		FWS	44
#09 Crystal Spring	36:25:16	116:19:19	671	Spring	0	Irrigation	Private	45
#10 Devils Hole	36:25:32	116:17:27	720	***	0	Public Supply	Water Co.	45
#86 Well 23b Flowing	36:27:40	116:12:10	710	7	0	Domestic	Private	45
#93 Spring Meadows	36:24:00	116:16:05	704	91	5	Irrigation	Private	46
USW AM2, Five Springs	36:27:55	116:19:04	722	38	0		FWS	46.5
#24 Pt. Rocks Sp.	36:24:02	116:16:25	701	NA	0	Irrigation	Private	47
#25 Pr. Rocks Sp. Rock	36:24:05	116:16:15	707	NA	0	Irrigation	Private	47
#19 J. Rabbit Sp.	36:23:24	116:16:41	692	NA	0	Irrigation	Private	48
#07 Big Spring	36:22:29	116:16:26	683	NA	0	Irrigation	Private	49
#08 Bore Spring	36:21:47	116:16:21	683	NA	0	Irrigation	Private	49
USW AD11	36:19:57	116:17:52	717	610	69	Water Level Monitoring	GS-3 USGS	49
USW AM3, Garner's Well	36:25:55	116:20:53	658	62	43		Garner, G.	50
AM5a, Crystal Pool	36:25:13	116:19:27	669		Surface		FWS	51
USW AD8	36:29:29	116:08:57	730	66	10		Cherry Patch	51
USW SP2	36:25:13	116:19:27				Spring-Discharge Monitoring	Government	51
USW AM4, Devils Hole (A.M.)	36:25:32	116:17:27	720				NPS	51.5
USW AM5, Devils Hole Well	36:25:30	116:17:15	733	61	15		FWS	52
#33 Well 15 F.L. DVJ	36:18:33	116:22:00	622	5	0	Test	Water Co.	53
#95 Well 14c1 DVJ	36:18:15	116:24:46	662	45	1	**	Private	53
USW AM6, Pt. Rocks. No.	36:24:32	116:16:57	707	152	42		FWS	53.6
#54 Jacob's Well #1	36:32:19	116:30:24	714	50	26	Irrigation	Private	54

Table 8-5. Wells and Boreholes in the Amargosa Valley (Continued)

Well Name	Latitude	Longitude	Surface Altitude	Well Depth (meters)	Depth to water (m)	Well Use	Well Owner	Distance from Yucca Mt. ("X")(Km)
USW AM7, t. Rocks So.	36:24:20	116:16:37	712	179	40		FWS	54.5
#18 GS-8 F.L. DVJ	36:17:00	116:22:02	611	10	0	Testing	Water Co.	55
DV-1, Texas Spring	36:27:28	116:50:11				DOM	NPS	56
USW SP5	36:27:28	116:50:11				Spring-Discharge Monitoring	Government	56
USW SP3	36:22:29	116:17:15				Spring-Discharge Monitoring	Government	56.8
#14 GS-12 F.L. DVJ	36:16:27	116:22:12	613	9	1	Testing	Water Co.	57
USW AD12	36:20:21	116:13:30	741	482	24	Water Level Monitoring	GS-1 USGS	57
#17 GS-4 F.L. DVJ	36:15:53	116:21:21	611	7	1	Testing	Water Co.	58
USW SP4	36:22:52	116:42:53				Spring-Discharge Monitoring	Government	58
#12 Franklin Lake	36:15:15	116:22:08	611	41	0	Testing	Water Co.	59
#13 Franklin Lake	36:15:15	116:22:08	611	102	0	Testing	Water Co.	59
#15 GS-15 F.L. DVJ	36:15:16	116:22:01	611	7	2	Testing	Water Co.	59
#16 GS-18 F.L. DVJ	36:14:44	116:21:57	610	8	4	Testing	Water Co.	59
AM-8	36:22:29	116:16:25	683		Surface	Domestic	FWS	59
AM8, Big Spring	36:22:29	116:16:25	683		Surface		FWS	59
DV-2	36:22:52	116:42:53	634		Surface	Industrial	US Borax	60
DV-3	36:22:30	116:39:29	832		198	Industrial	US Borax	60
#30 Well 05 Franklin L. DVJ	36:14:15	116:22:21	610	NA	2	TEST	Water Co.	61
#32 Well 13 F.L.D VJ	36:14:43	116:23:31	611	11	3	TEST	Water Co.	61
#31 Well 10 Franklin L. DVJ	36:14:12	116:22:30	609	10	2	TEST	Water Co.	62
USW AD15	36:19:54	116:18:12				Water Level Monitoring	Government	62
USW AD14, DVJ Well+A297	36:18:17	116:24:47	623	69	1		Ettie, Lee	62.5
USW AD16	36:20:14	116:13:39				Water Level Monitoring	Government	63
USW AD13	36:17:24	116:32:42	824	610	117	Water Level Monitoring	S-1 USGS	64
GS-10	36:17:00	116:22:02	617	7.25	-0.73	Piezometer	"	76.3
GS-12	36:16:27	116:22:12	613	8.84	0.82	Piezometer	"	77.9
GS-02	36:16:05	116:21:27	613	3.57	0.4	Piezometer	"	78
GS-04	36:15:53	116:21:21	612	6.83	1	Piezometer	"	78.4
GS-17	36:15:16	116:22:01	612	10.67	2.42	Piezometer	"	79.1
Well 13	36:14:43	116:23:31	608	5.55	3.02	Water Level Monitoring	Government	79.9
GS-18	36:14:44	116:21:57	611	8.2	3.4	Piezometer	"	80.1

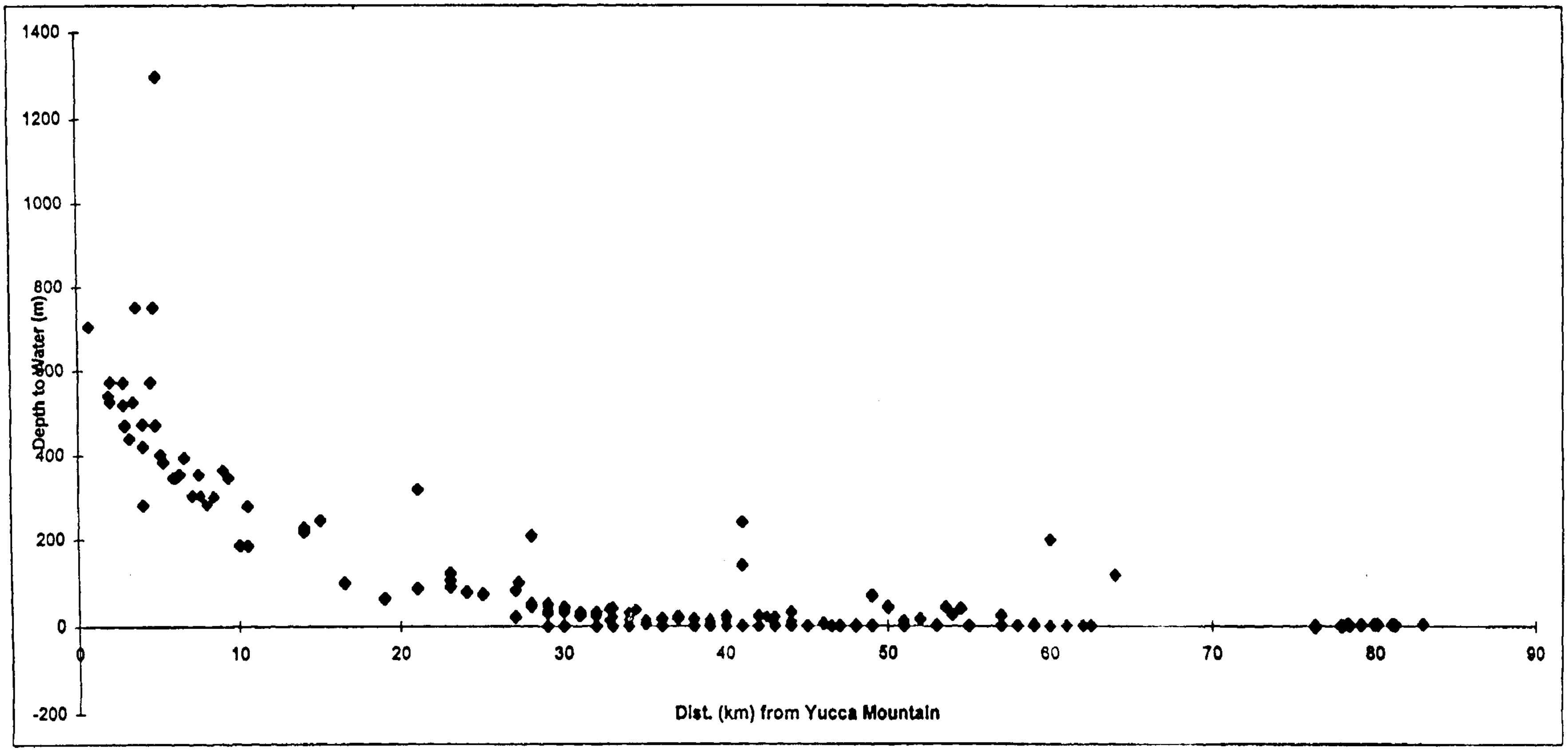

Figure 8-9. Wells and Boreholes in the Amargosa Valley
Only 15 Persons Currently Live at the 20 km Distance,
in the location known as Lathrop Wells.

limited by the amount of water annually recharged to or discharged from the ground water system through natural processes in addition to that which might become available by artificial recharge and water returned to the ground water system by infiltration of irrigation or waste water.

In estimating perennial yields, the effects that ground water development may have on the natural circulation in the ground water system should be considered. The location of the withdrawal centers in the ground water system may permit optimum utilization of available supply. Alternately, the location of withdrawal centers may be ineffective in the utilization of the available water supply. The location of the wells may favor improving the initial quality with time or may result in deterioration of quality under continued withdrawals. Development by wells may or may not induce recharge in addition to that received under natural conditions. Part of the water discharged by wells may re-enter the ground water reservoir by infiltration of excess irrigation or waste water and thus be available for re-use. Ground water discharged by wells eventually reduces the natural discharge. In practice, decreasing natural discharge by pumping is difficult, except when the wells are located where the water table can be lowered to a level that eliminates evapotranspiration in the natural area of discharge or underflow from the basin.

There are a number of means by which the perennial yield can be calculated. The State of Nevada accepts the method proposed by NDC63, which estimates the perennial yield of hydrologic basins by assuming that perennial yield is equal to the volume of water that would naturally discharge through evapotranspiration and lateral outflow (underflow). In other words, perennial yield is considered equal to total natural basin discharge.

An alternative method to that presented by NDC63 for the determination of perennial or safe aquifer yields is presented by Linsley et al. (LIN82), in which the perennial yield is expressed as a function of the quantity of water available. This hydraulic limitation is often expressed by the equation:

$$G = P - Q_s - ET + Q_g - S_g - S_s \tag{1}$$

where G is safe yield (i.e., perennial yield); P is precipitation on the area tributary to the aquifer; Q_s is surface streamflow from the same area; ET is evapotranspiration; Q_g is net ground water inflow to the area; S_g is the change in ground water storage; and S_s is the change in surface storage. If the equation is evaluated on a mean annual basis, S_s will usually be zero. All terms in Eq. (1) are subject to artificial change. G can be computed only by assuming the specific conditions for each item. For example, artificial recharge operations can reduce Q_s. Irrigation diversion from influent streams may increase evapotranspiration. Lowering the water table by pumping may increase ground water inflow (or reduce ground water outflow) and may make gaining streams into losing streams.

The factors that control the assumptions on which Eq. (1) is evaluated are primarily economic. The feasibility of artificial recharge or surface diversion is usually determined by economics. If water levels in the aquifer are lowered, pumping costs are increased. Theoretically, there is a water-table elevation at which pumping costs equal the value of the water pumped and below which water levels should not be lowered. Practically, the increased cost is often passed on to the ultimate consumer. The minimum water level is determined after excessive lowering of the water table results in contamination of the ground water by upcoming and inflow of undesirable waters.

The permanent withdrawal of ground water is called mining. If the storage in the aquifer is small, excessive mining may be disastrous to any economy dependent on the aquifer for water. On the other hand, many ground water basins contain vast reserves of water and planned withdrawal of the water at a rate that can be sustained over a long period may be a practical use of this resource. The annual increment of mined water, S_g in Eq. (1), increases the yield. Thus, Eq. (1) cannot properly be considered an equilibrium equation or evaluated in terms of mean annual values. It can be evaluated correctly only on the basis of specified assumptions for a stated period of years. The following discussion presents a methodology by which the various parameters in Eq. (1) were determined for the Yucca Mountain area.

The hydrographic areas (HA) that are most relevant to the determination of perennial yields downgradient of Yucca Mountain are basin numbers 225, 226, 227-A, 229 and 230. Table 8-6 presents the water budget information for these hydrographic areas, obtained from the State of Nevada’s water planning report (NDC71). Each of the column entries are discussed below.

Column 1 - Hydrographic Basin Number

The State of Nevada has been subdivided into 253 hydrographic basins. The boundaries for each basin are generally coincident with surface-water divides defined by topography.

Column 2 - Hydrographic Basin Name

Almost all of the current ground water use downgradient of Yucca Mountain is derived from the Amargosa Desert Hydrographic Basin (ADHB). Those basins within the study area that are hydraulically connected to the ADHB via ground water include Mercury Valley (HB 225), Rock Valley (HB 226), Jackass Flats (HB 227-A), and Crater Flat (HB 229).

Table 8-6. Ground Water Budget for Hydrographic Basins in Study Area (Source: NDC71)

Hydrographic Basin Number	Hydrographic Basin	Ground Water Recharge From Precipitation (ac.-ft/yr.)	Ground Water Inflow		Ground Water Discharge to the surface (ac.-ft./yr.)	Ground Water Outflow	
			Acre Feet/ Year	**From Hydrographic Area**		**Acre Feet/ Year**	**To Hydrographic Area**
225	Mercury V.	250	16,000	160	0	17,000	230
226	Rock V.	30	17,000	160, 227-A	0	17,000	230
227-A	Jackass Flats	900	7,200	227B	0	8,100	230
229	Crater Flat	220	1,500	228	0	1,700	230
230	Amargosa Desert	600	44,000[*]	225, 226, 227-A, 229	24,000	19,000	Death Valley

[*] This value of 44,000 is inconsistent with respect to the other data presented in the table; it should total the ground water inflow from all of the contributing basins (i.e., 43,800 acre-feet/year), as well as total basin discharge (i.e., 43,000 acre-feet/year).

Column 3 - Ground Water Recharge from Precipitation

Ground water recharge from precipitation represents the volume of precipitation that moves vertically through the unsaturated zone (region above the water table) and becomes available for pumping. Other sources of recharge (e.g., irrigation return flow) are thought to be insignificant and are not included in this column.

Column 4 - Ground Water Inflow

The ground water inflow is the volume of ground water that enters the hydrologic area from other hydrologic basins. In the case of the ADHB, ground water enters from Hydrologic Basins 225, 226, 227-A and 229. The volumes derived from each of these basins are presented in acre-feet/year and total 43,800 acre-feet/year. As noted in the table, these values should total ground water inflow into ADHB (44,000 acre-feet/year). Apparently either an error was made in the data entries or the value was rounded to 44,000.

Column 5 - Ground Water Surface Discharge

The ground water surface discharge volumes represent the volume of water that is discharged to the surface via streams and seeps, in addition to water that is removed from the aquifer by evaporation and the transpiration of plants. In the perennial yield calculations performed below, this discharge is actually treated as ground water outflow and is assumed to be available for consumption. The rationale for this assumption, presented in DOI63, is that once the water table has sufficiently dropped below some point, significant transpiration and surface discharges will no longer occur.

All of the 24,000 acre-feet/yr that is discharged to the surface in the ADHB is removed from the system by evapotranspiration. Furthermore, almost all of this water is attributed to spring discharges at Ash Meadows.

Column 6 - Ground Water Outflow

The ground water outflow is the volume of ground water that flows out of the hydrologic basin into adjacent basins. The table indicates that the outflow from the ADHB of 19,000 acre-feet/yr flows into the Death Valley Hydrographic Basin. Note that ground water outflow (19,000 acre-feet/yr) added to evapotranspiration (24,000 acre-feet/yr) should be equal to ground water inflow (43,000 acre-feet/yr) for Basin # 230. However, it is unclear why a discrepancy of 800 acre-feet/yr exists. This discrepancy will not significantly affect perennial yield estimates.

The site for the proposed Yucca Mountain repository lies primarily within hydrographic basin 227A (Figure 8-6). For this basin, as shown in Table 8-3, the perennial yield cited in Nevada's water planning report (NDC71) is 4,000 acre-feet per year. The water planning report also indicates that the storage volume for this basin is 7,400 acre-feet per foot (Table 8-7). In contrast, the perennial yield for Basin 230, Amargosa Desert, is 34,000 acre-feet per year, and the storage volume is stated in NDC71 to be 35,000 acre-feet per foot. The perennial yield for Basin 230 is therefore seen to be nearly the full amount of the storage volume per foot of depth, while the perennial yield for Basin 227A is only about 50 percent of the storage volume per foot.

Because of data limitations, the perennial yield estimate of 4,000 acre-feet per year for Basin 227A is not derived from water budget relationships such as Equation 1. It is, instead, an estimate of the water that can be removed annually without significantly altering the ground water regime. Habitation of Basin 227A and direct use of its water resources in domestic or irrigation wells is not expected because of the large well depth that would be required across most of the basin (Figure 8-9). The Basin 227A water may, however, be extracted in the future and exported to locations such as Pahrump, where water supplies are already oversubscribed, as part of the county-wide water utilization strategy.

Size of Potential Populations

The following paragraphs examine the size of the potentially-affected population that could be sustained by the ground water available in the Yucca Mountain region. The available ground water has been defined as that ground water which is contained within Hydrographic Basins 225, 226, 227-A, 229 and 230. These hydrologic basins are considered to be the most relevant to the analysis because they are located downgradient of Yucca Mountain to a distance of approximately 50 miles. Since Basins 225, 226, 227-A, and 229 discharge into Hydrographic Basin 230, this basin (HB 230) is used in the calculations.

In Eq. (1), precipitation (P) minus evapotranspiration (ET) is assumed to equal ground water recharge. Table 8-6 indicates that Basin #230 receives 600 acre-feet/yr of recharge from precipitation. There is no significant surface streamflow (Q_s) or change in surface storage (S_s). As mentioned previously, S_g represents the annual increment of mined water and should be set to zero for perennial yield determinations. This suggests that Eq. (1) may be written as:

$$G = 600 + Q_g \tag{2}$$

Table 8-6 indicates that 44,000[26] acre-feet/yr enters Basin #230 as lateral ground water inflow (Q_g) from other hydrographic areas (225, 226, 227-A, 229). Therefore, based on Eq. (2), the total volume of yearly sustainable water under current conditions would be 44,600 acre-feet/yr. A ground water modeling study performed in USG95c, and an alternative analysis (NDC63), indicate sustainable yields may be closer to 24,000 acre-feet/yr. Furthermore, the State of

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[26] Although there may be a slight error in the reported value, it is used, rather than the corrected value, because its use will provide higher population estimates.

Nevada assumes a perennial yield of 24,000 acre-feet/yr for Basin #230. The State's estimates are based on work reported in NDC63 in which the authors estimated that discharge via evapotranspiration is 23,500 acre-feet/yr and ground water outflow is 500 acre-feet/yr for a total perennial yield of 24,000 acre-feet/yr. However, USG88a indicates that ground water outflow could be as high as 19,000 acre-feet/yr. In this case, NDC63's method of determining perennial yields (i.e., evapotranspiration plus lateral ground water discharge) would result in a perennial yield of 42,500 acre-feet/yr. Therefore, the estimate of 44,600 acre-feet/yr appears to represent a reasonable upper bound maximum for the water available. This value would also tend to maximize the estimates of the potentially-affected population size.

In 1993, there were approximately 1,100 people residing within Basin #230. The water withdrawal for the same year from the underlying aquifer was 11,300 acre-feet (Table 8-4). This translates to a yearly per capita withdrawal rate of 10.27 acre-feet (this value is relatively large and reflects water use primarily for irrigation). If it is assumed that future water consumption in the area is proportional to current per capita water consumption rates, the total population that could be sustained by a perennial yield of 44,600 acre-feet/yr is 4,342 people.

A scenario that provides a reasonable upper bound on the number of people that could be supported by the ground water in this area can be made by assuming that all water use in the basin would be consumed entirely by domestic use, possibly exported to Las Vegas. Van der Leeden et al. (VAN90) indicate that the average person in the United States utilizes 86.5 gallons per day (gal/day) of water for domestic use (0.097 acre-feet/yr). Van der Leeden et al. (VAN90) also indicate that the average individual in the State of Nevada utilizes 141 gal/day (0.16 acre-feet/yr), which is somewhat higher than the national average. In order to maximize the size of the potentially-affected population, the lower value for domestic water use (0.097 acre-feet/yr) is used in conjunction with an assumed sustainable yield of 44,600 acre-feet/yr. This results in a potentially-affected population size of 459,794; this value is expected to be a reasonable maximum.

The water use data of 1997 provide a basis for estimating the per capita water use for a community large enough to have water uses beyond strictly domestic consumption. As shown in Table 8-4, water use for Basin 230 in 1997 for domestic, quasi-municipal, and commercial uses totaled 942 acre-feet. This usage encompasses all demands except irrigation, mining, and other commercial uses, and can be considered representative for the ranges of activities of a typical small rural residential community in the region. As shown in the details of the 1997 report, AV197, these uses and activities include typical household uses such as drinking water; watering of lawns and windbreaks; and small commercial operations such as gas stations and fast-food stores. Because of local conditions, the population in the region does not grow significant quantities of leafy vegetables, root vegetables, and fruit and grain crops for its own use.

The non-commercial use of 942 acre-feet was consumed by a total of 1,143 (estimated) residents of the region. The average per-person use for the range of activities engaged in by this population was therefore about 0.8 acre-feet per year. Dramatic changes in the demographic characteristics of the population in the region is not expected in the future, so this value might be taken as representative for non-commercial uses by future communities in the region.

The largest water use in the area down gradient from the repository is for irrigation, particularily for the cultivation of feedstock (primarily alfalfa cultivation). Feedstock cultivation in the recent past has varied in response to change in demand from local users, particularily the local dairy industry, but has shown a general increase over the last ten years. The extent of cultivation is expected to peak in the near future due to water limits on the water available for allocation. Estimates of the number of acres under cultivation for feedstock production (largely alfalfa) are given in Table 8-7. Water consumption for alfalfa cultivation varies as a function of soil and weather conditions, and the number of harvests through the year. Records of historical water use for alfalfa cultivation indicate a range of 2.7 to 5.0 acre-feet/acre, with 5 acre-feet/acre as the current allocation limit for this type of farming. Currently there are nine farms cultivating feedstock, with acreage sizes ranging from approximately 65 to 800 acres. It is estimated that a total of 2,500 acres was cultivated in 1999 and that water usage of alfalfa irrigation is, as limited by current allocations, five acre-feet per acre. The nine alfalfa-growing operations have an average size estimated to be 255 acres. This results in an average annual water use for irrigation of 1,275 acre-feet per year. The domestic use of water by a small farming community of 25 people is estimated to be 10 acre-feet per year, so the average volume of water that would supply the annual water needs of a hypothetical future agricultural small community would be 1,285 acre-feet.

Table 8-7. Estimates of Acreage Under Cultivation for Feedstock (DeL99, TRW96, TRW98)

Year	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000***
Acres Under Cultivation	1,120	1,400	1,750	1,650	2,290	2,720	3,100

* Estimated Limit Based on Water Allocation

The estimates above assume that no “mining” of the water occurs. To evaluate the additional size of the population that could be affected if the hydrographic areas were mined of their resources, the following calculation is made.

USG88a presents the volume of water that can be derived from each of the hydrographic areas for each foot of aquifer dewatered (Table 8-8). The total volume available for all five hydrographic basins per foot of drawdown is 43,900 acre-feet. For the purpose of these calculations, it was assumed that the maximum drawdown that could be achieved without significant water-quality deterioration is 1,000 feet. NDC63 indicates that in many instances the ground water is already of relatively poor quality. The assumption that the water would remain potable after the water table is drawn down 1,000 feet may be overly optimistic. The assumed drawdown of 1,000 feet would yield 43,900,000 acre-feet from storage. Since this mined water represents a one-time occurrence, its use must be integrated over some time period to determine how many additional people could be supported. If this time frame is set to 10,000 years, the additional volume that would be available is 4,390 acre-feet/yr; if the time frame is one million years, the additional volume derived from mining the aquifer would be 44 acre-feet/yr. Therefore, under an assumed time frame of 10,000 years, an additional 427 (4390/10.27) people per year could be served at current usage rates, and 45,257 (4390/.097) people at lower usage rates. Similarly, for a one million-year time frame, the increase in population that could be sustained from additional water due to mining would range from 4 to 454 people per year.

Table 8-8. Ground Water Storage Values for Relevant Hydrographic Basins (USG88a)

Hydrographic Basin Number	Hydrographic Basin	Ground Water Storage in Upper 1 ft Saturation (AF)
225	Mercury V.	minor
226	Rock V.	1,500
227-A	Jackass Flats	7,400
229	Crater Flat	-
230	Amargosa Desert	35,000

In summary, the preceding calculations indicate that the reasonable upper bounds for the number of people that could be supported by ground water in the ADHB is roughly about half a million (459,794 from sustainable yield and 45,257 from mining for a total of 505,051). These calculations do not provide any indication of the potential geographic distribution of future populations in the ADHB. Thus, it is not possible to reliably predict the extent to which any or all of such future populations might be exposed to possible radionuclides in ground water coming from the Yucca Mountain repository.

8.2.3.3 Soil and Topographic Constraints

The economics of well development and pumping costs are consistent with both the current demographics and the historical development seen in Amargosa Valley. However, given the fact that permanent settlement in the Valley has only occurred over the past century, it is important to ascertain whether or not the inherent nature of the soils and/or the topography are conducive to or constrain further development of the area. To obtain insights into this question, soil and topographic characteristics in the immediate vicinity of the proposed repository site have been obtained from the U.S. Geological Service (USGS) and the Natural Resource Conservation Service (NRCS).

From the topographic maps, slopes in the immediate vicinity of the proposed repository typically exceed 15 percent, which would preclude large scale agricultural activities as they are currently practiced in the Valley. Not only are slopes of this magnitude not amenable to heavily-mechanized farming methods, the soil on these slopes is very rocky. Small scale plots might be feasible in the fan skirts and insets in the immediate vicinity, but such lands are not extensive.

The soils encountered farther downgradient of Yucca Mountain, southwest of the Nevada Test Site (NTS) and in the vicinity of the junction of U.S. Route 95 and Nevada Route 373 (historically known as Lathrop Wells), have slopes well within the limits that are suitable for agriculture. Soils near the junction of U.S. Route 95 and Nevada Route 373 and farther south in the Amargosa Farms area were evaluated for agricultural production using data from the NRCS and site-specific data collected from soil pits that were excavated in the area (M&O99). The dominant soil map units in the area between Yucca Mountain and the Amargosa Farms area include: Corbilt Gravelly Fine Sandy Loam, Warm, 2-4 percernt slopes (2030); Yermo, hot-Arizo association (2054); Shamrock Gravelly Fine Sandy Loam, 2-4 percent slopes (2070); and Sanwell-Sanwell, warm Yermo Association (2451) (see map, Appendix III).

Based on the Map Unit Intepretation data base (RCS98), all of these soils have characteristics that are potentially unsuitable for residential/sustainable farming (USD93). Descriptions of individual soil series documenting these characteristics may be found in Appendices B and C of

M&O99. Potentially unsuitable characteristics include shallow indurated soil horizons or maximum values of pH, electrical conductivity, or sodium adsorption ratio that meet or exceed the limits that inhibit plant growth.

Despite potentially unsuitable characteristics, these same soil map units have supported commercial and residential agriculture in the Amargosa Farms area for several years. Several possible reasons for this apparent contradiction, such as conservative soil quality guidelines, adapted crop species, and management practices that overcome soil deficiencies, were put forth in M&O99. These reasons, and past history, suggest that many of the soils between Amargosa Farms and Yucca Mountain may also be used for agricultural production if sufficient irrigation water is available.

In summary, agricultural activity would be limited around Yucca Mountain as a result of adverse conditions, such as steep slopes, rocky terrain, and shallow soils. Also, as shown in Figure 8-9, the depths to water are great, which would make the cost of irrigation extremely high. Southwest of the NTS, in the vicinity of the junction of U.S. Route 95 and Nevada Route 373, the topography is more conducive to agricultural production. All of the soils in this area have some characteristics that are considered potentially unsuitable for agricultural production, but these same soils have been used for production farther south in the Amargosa Farms region for several years. It therefore appears that agricultural production would be feasible in the Lathrop Wells area if amounts of irrigation water are sufficient.

8.2.3.4 Field Survey Findings

Water Resources and Current Agricultural Activities

As previously discussed, water resources of Amargosa Valley are currently over-allocated. However, State officials have acknowledged that only a fraction of the allocated water rights is being used and a review is currently underway to rescind permits in cases where water has not been used in the past five years. Water consumption in the Amargosa Valley appears to vary considerably over time. Data from Nye County indicate that, from 1985 to 1990, water usage declined from 9,672 acre-feet to 4,109 feet (NYE93b, NYE93c, NYE93d, and NYE93e). State water records show that in 1993, water usage rose to 11,300 acre-feet. Despite these fluctuations, the majority of water use is for irrigation, with the second largest use being mining.

A tour of the Amargosa Valley performed for the preparation of this BID focused on current agricultural activities, inclusive of those with a limited operating history. The first farm visited had grown barley and alfalfa in 1995 with a yield of about 1.5 tons per acre per cutting. With five to six cuttings per year, the yearly yield was estimated at 10 tons per acre. Recently, several pistachio trees have been planted, which are expected to bear nuts within a few years (Photo #1). For the future, the farm owner anticipates raising cattle and estimates that his land could produce 60 head of cattle per year.

A second and much larger farm that was visited (Funeral Mountain Ranch) also raised alfalfa. Alfalfa grown here commercially is utilized as "green chop" for consumption by local dairy farmers, baled and shipped to California (Photo #2), and dried/pelletized for shipment to Japan.

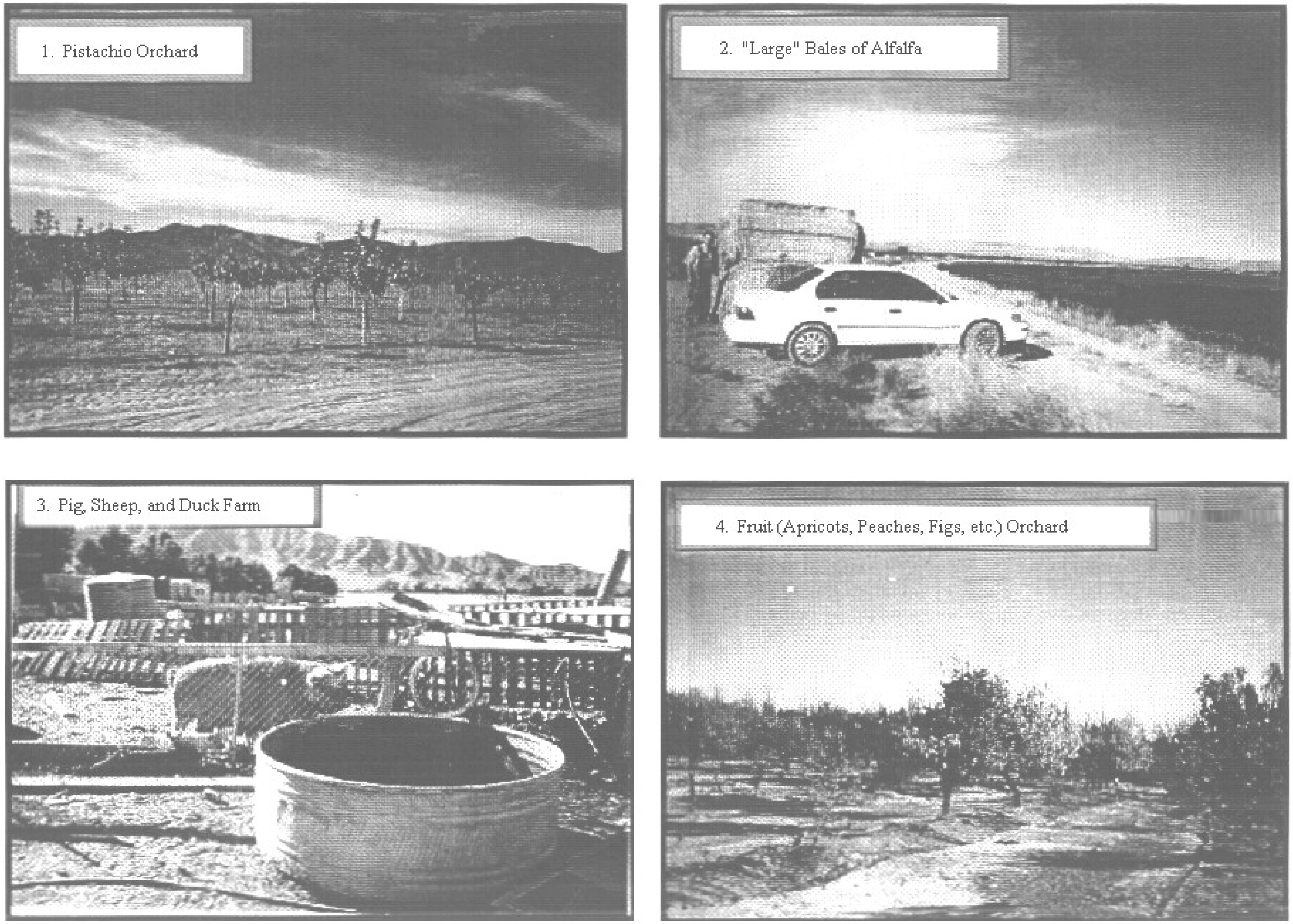
A third farm visited was a large dairy farm with 2,800 cows of which 2,300 are milk producers. This farm has only been in operation for a few years. Its milk is shipped unprocessed into California. Due to the size of the operation, cows do not graze but are fed locally grown “green chop.” Due to the success of this farm, a second and third dairy farm of comparable size are under construction.

The study team visited four additional farms that included the following:

- A small farm raising pigs, sheep, and ducks (Photo #3, Figure 8-10)
- A farm growing primarily vegetables that are sold locally
- A small fruit-tree orchard that was originally planted as an experiment to determine the feasibility of growing apricots, peaches, and figs (Photo #4, Figure 8-10)
- A sod farm, which ships and sells its products outside the Valley

8.2.3.5 New and Unusual Farming Practices

Both ostrich and catfish farming have been identified as current farming enterprises in the Amargosa Valley. Along with hydroponic farming, these new and unusual farming practices are described and assessed in Appendix V to determine their potential impact(s) on human exposure modeling. The following paragraphs summarize the findings for each of these farming practices.



1. Pistachio Orchard

2. "Large" Bales of Alfalfa

3. Pig, Sheep, and Duck Farm

4. Fruit (Apricots, Peaches, Figs, etc.) Orchard

Figure 8-10. Examples of Current Agriculture Activities in the Yucca Mountain Region

For practical and economic reasons, ostrich farmers do not allow their birds to range freely. Rather, they are restricted to a confined area and fed pelletized commercial feed. As a result, the uptake of radionuclides is confined to the consumption of contaminated water. Using radionuclide transfer rates derived for poultry (ostrich-specific values are not available), the concentrations of 19 radionuclides were calculated on a per-unit weight basis. A comparison of these data with radionuclide concentrations in beef indicate that 12 of the 19 radionuclides would be present in lower concentrations in ostrich meat than in beef. Therefore, substituting ostrich meat from farm-raised birds for beef in the dose/risk assessments is not expected to have a significant impact on the results.

Warm climates favor fish farming due to the fact that fish metabolism (and therefore growth rate) increases with increases in ambient water temperature. In arid areas, fish farming is usually conducted in large tanks filled with ground water that is continually filtered and aerated. Food, in the form of commercial pelletized floating feed, is introduced into the tanks daily. The extensive literature on concentration factors for radionuclides in freshwater fish is not considered applicable to the unique conditions of aquaculture. Uptake is limited to direct sorption of radionuclides in the water. Based on bioaccumulation factors adjusted to reflect direct sorption as the only uptake mechanism, it is concluded that substituting catfish for beef in the dose/risk assessments will not significantly affect the results.

In arid regions such as Yucca Mountain, hydroponic farming is conducted in hot-houses to avoid dehydration and damage to the plants and their root systems. A quantitative assessment of the potential impact of substituting hydroponically-grown vegetables for soil-grown vegetables is not possible at this time. However, given that hydroponically-grown vegetables would not be subject to the buildup of radionuclides in soil, it is reasonable to conclude that they would have lower radionuclide concentrations than vegetables grown in soil.

8.3 RADIATION PROTECTION OF INDIVIDUALS

In order to evaluate compliance of the repository system with regulatory requirements, potential radiation doses to humans as a result of releases of radioactivity from the repository must be calculated. This evaluation requires estimating radioactivity releases from the repository; characterizing movement of the radioactivity through the environment; selecting and characterizing the person(s) for whom potential radiation dose is to be evaluated; and characterizing the interaction between the potentially-affected person(s) and the radioactivity in the environment.

Information which provides the basis for estimating potential of radioactivity releases from the repository and their movement through the environment is presented in Chapter 7 of this BID. Information concerning past and present human occupation and use of the environment into which the radioactivity could be released is presented in Section 8.2. This section of the BID is concerned with identifying those individuals for whom the potential radiation dose is to be evaluated, as well as their interaction with any radioactivity released from the repository. This latter information can be used to estimate potential radiation doses to compare these values with established regulatory limits.

Releases of radioactivity from the repository are expected to occur no sooner than several thousands of years in the future; the start of release could be deferred on the order of ten thousand years or more if certain repository design features are used (i.e., those aimed at delaying the start of release) (see Chapter 7). After release from the repository, the radioactivity may transit environmental pathways for long periods of time until it reaches the location of the persons selected for the evaluation of potential doses. Radiation doses might first be incurred many thousands of years in the future, when locations and lifestyles of humans in the vicinity of Yucca Mountain might differ from those of the present. Human locations and lifestyles far in the future cannot, however, be reliably estimated. Therefore, evaluations of future potential radiation doses are based on current patterns of human habitation and activities, as described in Section 8.2 of this BID.

8.3.1 The Critical Group Concept

Individuals in a human population may have widely different responses to radiation exposure given differences in factors such as age and heritage. In addition, their potential to encounter radiation released from a repository at Yucca Mountain will depend on factors such as where they live and what they eat or drink. A wide range of radiation exposures and effects is therefore possible. Means are needed to narrow and characterize the range for which evaluations of compliance with regulatory requirements are to be made. Specification of the exposure conditions to be considered must also be part of the regulations.

The NAS report on the technical basis for EPA's Yucca Mountain standards (NAS95) recommended use of the critical group concept for the development of environmental standards. The critical group concept was first introduced by the International Commission on Radiation Protection (ICRP) in order to account for the variation in dose in a given population which may occur due to differences in age, size, metabolism, habits, and environment. The critical group is defined by the ICRP as a relatively homogeneous group of people whose location and lifestyle are such that they represent those individuals expected to receive the highest doses as a result of radioactive releases (ICR77, ICR85). As part of the critical group definition, the ICRP specifies the following additional criteria:

- Size - The critical group should be small in number and typically include a few to a few tens of persons.
- Homogeneity among members of the critical group - There should be a relatively small difference between those receiving the highest and the lowest doses. It is recommended that the range between the low and high doses not differ by more than a factor of ten or a factor of about three on either side of the critical group average.
- Magnitude of dose/risk - It is suggested that the regulatory limit defined by a standard exceed the calculated average critical group dose by at least a factor of ten.
- Modeling assumptions - In modeling exposure for the critical group, the ICRP recommends that dose estimates be based on cautious, but reasonable assumptions.

The ICRP does not, however, prescribe the lifestyle, habits, or conditions of exposure that may define a critical group into the future. Its generic recommendations suggest use of current knowledge and use of cautious, but reasonable, assumptions for characterizing future exposure scenarios.

According to current understanding, contaminated ground water is the principal pathway by which a release of radionuclides from a repository at Yucca Mountain could cause radiation exposures to humans. To determine the risk resulting from contaminated ground water to exposed individuals requires the development of a comprehensive exposure scenario that specifies discrete pathways and quantifies the intake of individual radionuclides. Depending upon the potential uses of contaminated well water, prominent pathways for human exposure may include internal exposure from the ingestion of contaminated drinking water, vegetables, fruits, dairy products, and meats. For persons engaged in agricultural activities, internal exposure may also result from the inhalation of airborne contaminants resuspended from soil that has been irrigated with contaminated water. Over time, the buildup of soil contaminants could reach levels that also yield significant external doses.

The selection of an exposure scenario that is appropriate for a specified critical group requires a complex array of pathway parameter values that define potential radionuclide concentrations in various media to which individuals may be exposed. Exposure scenarios must also provide quantitative descriptions that include where individuals live, what they eat and drink, and what their sources of food and water are. Many key parameters needed to model human exposures at Yucca Mountain are highly site-specific and reflect the desert conditions of the sparsely-populated Amargosa Valley. For example, the combined impacts of low rainfall, desert temperatures, and soil quality mandate extensive irrigation of farm crops and use of local ground water for cattle. Under these conditions, contaminated well water has the potential for unusually high activity concentrations in all locally-grown food products.

8.3.2 Probabilistic Scenario Modeling

The unique requirements for modeling repository performance and human exposure scenarios over times far into the future highlight the limitations, as well as uncertainties, in dose assessment methodology. The need to provide numerical values for parameters that define human exposure pathways is a major source of uncertainty.

To account explicitly for uncertainties, the NAS (NAS95) offered two probabilistic modeling approaches. The first, described in Appendix C of the NAS report, A Probabilistic Critical Group Approach, uses statistical methods and probability values to characterize members of the critical group. The second, The Subsistence-Farmer Critical Group, described in Appendix D of the report, also employs a probabilistic method, but identifies the subsistence farmer as its principal representative of the critical group. A brief description of these two modeling approaches is presented below.

Approach #1: A Probabilistic Critical Group. In support of ICRP recommendations to use current knowledge and cautious, but reasonable, assumptions to identify the potential future critical group and conditions of exposure, the NAS report (NAS95) suggested the following steps for the Monte Carlo method used to implement a probabilistic assessment:

<u>Step 1</u>:	Identify general lifestyle characteristics of the larger population that includes the critical group.
<u>Step 2</u>:	Quantify important characteristics, distributions of characteristics, and geographic locations of the potentially exposed population.
<u>Step 3</u>:	Based on findings in Steps 1 and 2, model radionuclide transport for estimates of exposures to members of the critical group.

The first and second steps serve to identify the larger exposed population of which the critical group is a subset. As noted previously, human exposure to ground water contaminants may involve several exposure routes. Some routes are likely to be more important than others and reflect the way in which contaminated water is used. Thus, specific information on location, living patterns, lifestyles, and economic activities of potential members of the exposed population can lead to the identity and characterization of the critical group of individuals at greatest risk. Based on current understanding, principal factors affecting the magnitude of individual exposure include (1) distance of residence from the repository, (2) level of dependence on local well water, (3) use of local well water for drinking, crop irrigation, livestock, etc., and (4) personal habits that affect food and water consumption. Consequently, if current population data were to show that individuals at greatest risk involved a cluster of residents whose potable water was supplied by a common well, the critical group might consist of individuals with a variety of lifestyles.

An important component of Step 3 is linking the critical group to future area(s) that will use water from the contaminated aquifer. Potential exposures may range from relatively high levels at locations near the footprint of the repository, because of the lack of dilution of ground water contamination, to lower levels of contamination and correspondingly lower doses at greater distances. Actual exposures will depend on the rate of migration and dilution of contaminated ground water as a function of distance and direction from the repository. For each human habitation location, specific data should be sought to define the slope/topography of the land, quality of soil, depth to ground water, well productivity, and other factors. Taken collectively, data for each location can be used to determine its suitability and probabilistic future use for farming, residential, commercial, industrial, and other purposes that may affect the exposure levels of members of the critical group. To account for probabilistic land use, local ground water dependence, and numerous model parameter uncertainties, the NAS (NAS95) recommended that probabilistic distributions of doses/risks be based on Monte Carlo simulations. In this method, data on the frequency distribution are sampled to provide input to generic model equations. In effect, the Monte Carlo method produces a single predicted value for each set of randomly selected parameter values. The results of numerous (hundreds to thousands) iterations of model solutions are then statistically analyzed to determine their distribution. From the distribution of predicted values, information is extracted that defines the best estimate of an average value (i.e., the most probable value), the range of potential values, and a measure of uncertainty of model predictions that reflects the collective uncertainties of input parameters (HEN92).

Approach #2: The Subsistence Farmer Critical Group. The model described in Appendix D of the NAS report specifies a priori one or more subsistence farmers and makes assumptions designed to define the farmer at maximum risk as representative of the critical group. Subsistence farming does not exclude commercial farmers who, in addition to cash farm products, raise food for personal consumption. The NAS assumed the subsistence farmer of the future would have nutritional needs consistent with those of a present-day person. Like the subsistence farmer of today, most or all drinking water would be obtained from an on-site well that would also be used in the production of all consumed food. The subsistence farmer is also assumed to live his/her entire life at the same location. Thus, the magnitude of the dose to a subsistence farmer will largely be defined by the distribution of radionuclide concentrations in ground water at the point of water withdrawal.

Each of these two approaches to defining the critical group has its advantages and disadvantages. For example, a standard that incorporates the probabilistic critical group would accommodate variabilities, but this approach is relatively complex and difficult to implement. Moreover, the assignment of probability values relating to land use, demands on natural resources, and human activities to the probabilistic critical group may be viewed as subjective and potentially biased by the limitations that define present-day society.

The subsistence farmer approach is relatively simple and easy to use and understand, but it may be formulated to be unrealistically or insufficiently conservative. For example, the subsistence farmer could be assumed to use a well at the repository boundary, where radioactivity contamination levels are highest, even though this location is unsuitable for farming.

Alternatively, the subsistence farmer could be located and characterized such that projections of radiation dose potential are unrealistically low.

8.3.3 Exposed Individuals and Exposure Scenarios for Yucca Mountain

EPA has developed a method for estimating potential radiation doses based on the concept of the reasonably, maximally exposed individual (RMEI). The RMEI concept, which involves estimating the dose to a person assumed to be at greatest risk based on reasonable (i.e., not overly or insufficiently conservative) assumptions, has been used in previous agency programs and guidance (EPA92). For example, the National Emission Standards for Hazardous Air Pollutants (NESHAPS, 40 CFR Part 61), require estimation of dose to a person assumed to reside at a location where the highest dose would be received.

The basic approach for estimating doses to the RMEI is to identify and characterize the most important exposure pathway(s) and input parameters. By using maximum or near-maximum (i.e., 95th percentile) values for one or a few of the most sensitive parameters, while assuming average values for others, it can reasonably be assumed that the resulting dose estimates correspond to the near-maximum exposures that could be received by any member of the exposed population. The ultimate objective of the approach is to define an exposure that is well above average exposures, but within the upper range of possible exposures.

The EPA expects to use the RMEI approach as the basis for radiation protection standards for Yucca Mountain. The concept is consistent with distinct patterns of human lifestyles, locations, and activities currently characteristic of the Yucca Mountain region, as described in Section 8.2 of the BID. The subsistence farmer approach, described in Appendix D of the NAS report and summarized above, is similar to the RMEI approach in that it utilizes specific exposure scenarios and parameters, rather than the probabilistic approach described in Appendix C of the report.

The EPA has defined four basic scenarios for estimating potential exposures to the RMEI in the Yucca Mountain area. These scenarios represent current human habitation patterns and lifestyles in the Yucca Mountain region. They are considered to be scenarios characteristic of the region based on local climatic, geologic, and hydrologic conditions. The four scenarios are summarized below.

(1) *Subsistence (low technology) Farmer*. In this scenario, the farmer is assumed to live in the Yucca Mountain area and to be exposed chronically (both indoors and outdoors) to residual concentrations of radionuclides in soil through all exposure pathways. The location and habits of this individual will be consistent with historical locations, easily accessible water, and new locations based on our current state of knowledge.

(2) *Commercial Farmer.* Based upon economic factors and current technologies, certain areas around Yucca Mountain are suitable for commercial crop production. These areas are either currently being farmed or could be economically viable based upon reasonable assumptions, current technology, and experience in other parts of the arid west. In addition, some parts of the region could possibly support up and coming technologies such as hydroponic applications and fish farming. Exposure pathways in this scenario are the same as those described for the subsistence farmer.

(3) *Rural/Residential Person.* In this scenario, individuals are assumed to live around Yucca Mountain and to be exposed through the same pathways described for the subsistence farmer in Scenario 1. However, in this case the residents are not assumed to be full-time agricultural workers. Instead, it is assumed that these individuals work primarily out of the area and engage only in light farming and recreational activities within. Furthermore, it is assumed that at least 50 percent of the locally-grown produce, meat, milk, and fish consumed by these individuals comes from the vicinity of the site.

(4) *Domestic Use of an Underground Drinking Water Supply*. Based upon current water usage in the arid west, it appears to be reasonable to assume that there could be an hypothetical water supply near or on the Nevada Test Site which could serve a community living near the repository site. In this scenario, sites will be identified which, under reasonable assumptions, could provide drinking water to support a future community.

For each of these four scenarios, the following exposure pathways can be evaluated:

- External radiation from radionuclides in soil
- Inhalation of resuspended soil and dust containing radionuclides
- Inhalation of radon and radon decay products from soil containing radium
- Incidental ingestion of soil containing radionuclides

- Ingestion of drinking water containing radionuclides transported from soil to potable ground water sources

- Ingestion of home-grown produce contaminated with radionuclides taken up from soil

- Ingestion of meat (beef) or milk containing radionuclides taken up by cows grazing on contaminated plants (fodder)

- Ingestion of locally-caught fish containing radionuclides

8.3.4 Details and Analyses for the Subsistence Farmer Scenario

This section provides a detailed discussion of the subsistence farmer scenario. It includes the comparison of results of analyses of this scenario that were obtained by several sources, as well as the comparison of the parameters, methodologies, and assumptions used to conduct the analyses. The purpose of this section is to illustrate the range of factors involved in characterizing a scenario and the variability of analysis input parameters and results for a given scenario.

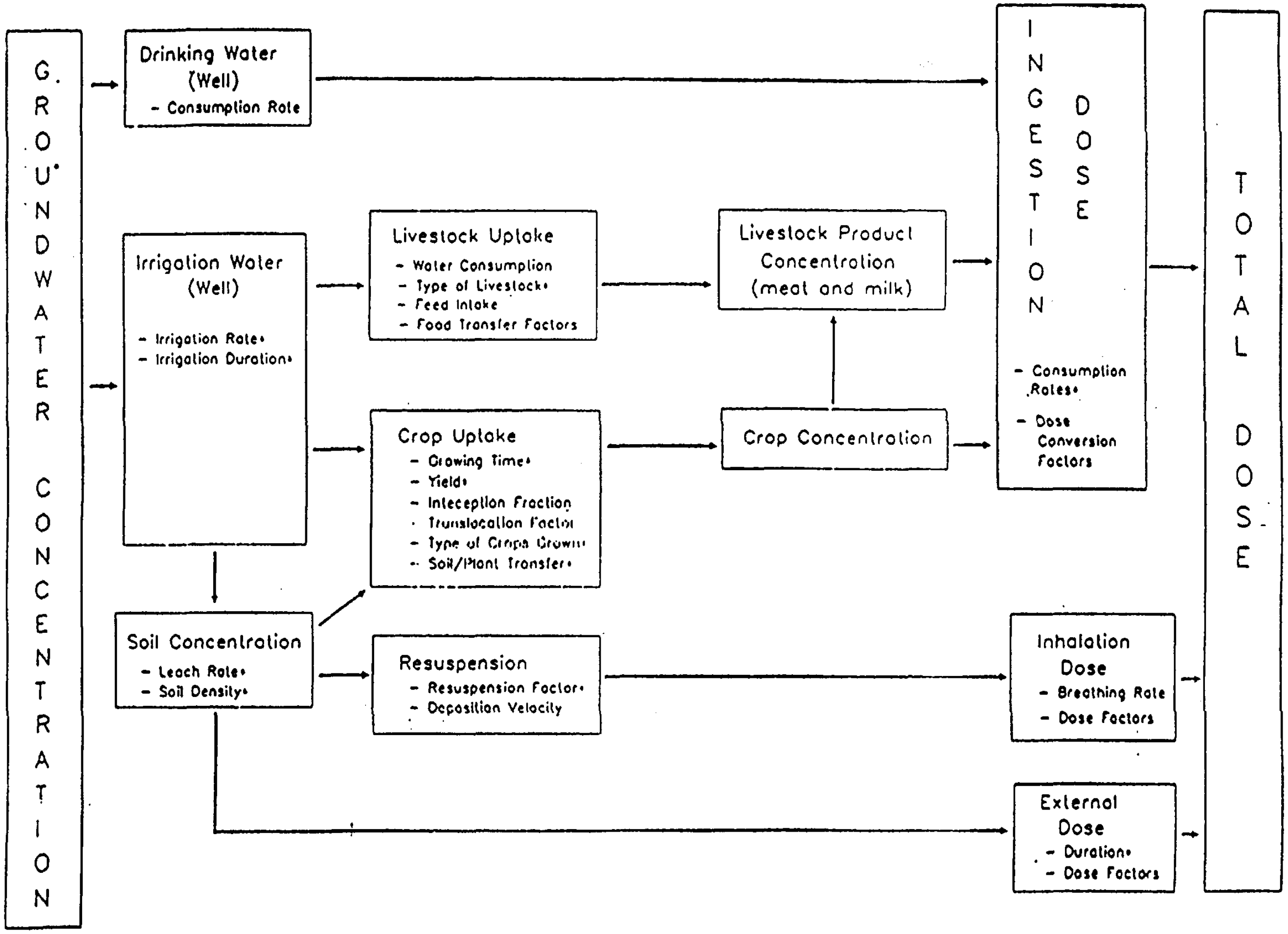
As noted above in Section 8.3.3, the Subsistence Farmer Scenario is one of four scenarios selected by EPA to provide part of the basis for the Yucca Mountain standards. The NAS also described a subsistence farmer scenario in Appendix D of its report (NAS95), and the Center for Nuclear Waste Regulatory Analyses (CNWRA) performed analyses of the “resident farmer” scenario for NRC. These scenarios are highly similar and can be summarily characterized as the self-sufficient farmer scenario. Details of the assumptions used to characterize the scenario vary, but its basic concept is that the farmer grows all of his/her own food and obtains all needed water from a well on his/her property. This scenario corresponds to one type of current lifestyle in the Yucca Mountain region and, depending on assumptions, such as the location of the farm relative to the repository, may correspond to EPA’s RMEI for the site.

In EPA’s version of the scenario, which is reflects current farming activities in the Yucca Mountain region, the farmer is assumed to grow alfalfa which is used as feed for beef cattle and milk cows. The farmer has a garden lot which grows vegetables, fruits, and grain sufficient for home use. In sum, all food consumed by the farmer is assumed to be home-grown. In addition, all water needed for personal consumption, crop irrigation, and drinking by livestock is assumed to be obtained from a single on-site well.

The pathways by which radioactivity released from the repository to the environment can produce radiation doses to this farmer are illustrated in Figure 8-11. As shown, the radioactivity carried from the repository by ground water can distribute in the environment to produce ingestion, inhalation, and external radiation doses to the exposed individual via a variety of environmental pathways.

The relative importance of the three types of dose sources to the total dose incurred will depend on the specific details of the individual's lifestyle in terms of interaction with the environmental pathways, the quantities and types of radionuclides available in each of the pathways, and the rates and means by which the radionuclides move within the pathways. Over many years, extensive research has produced data on how radionuclides move in the environment and the pathways for human exposure. These data are expressed in terms of parameters such as concentration factors and transfer coefficients. These parameters are used as input to computer codes which model radionuclide transport and predict radiation doses.

Quantitative characterization of the pathways and parameters represented in Figure 8-11, for the purpose of estimating radiation dose for the subsistence farmer or any other scenario, has been accomplished using the GENII and GENII-S code. Parameter values were obtained from various sources. As originally developed, the GENII codes implemented the NRC's Regulatory Guide 1.109 and dosimetry models recommended by the ICRP. Parameter values were selected that were appropriate for the Hanford site, but the codes were "...designed with the flexibility to accommodate input parameters for a wide variety of generic sites" (NAP97). The codes have been subjected to rigorous peer review and meet the benchmarking requirement as defined by the American Society of Mechanical Engineers (ASM89a, ASM89b).



• Identifies parameters that are best defined by site-specific values.

Figure 8-11. Ground Water Pathway Model for Subsistence Farmer

The GENII-S codes were originally developed by Sandia National Laboratories for use in performance assessments for the Waste Isolation Pilot Plant (WIPP) (DOE93a). The GENII-S system includes menu-driven programs that assist with scenario generation and input data requirements. Values for parameters can be selected from appropriate sources. An important feature of GENII-S is its versatility in performing either deterministic or stochastic analyses in which probabilistic distributions are assigned to the values of the input parameters. The stochastic analyses provide opportunity to assess sensitivities and uncertainties for results in terms of variations in input parameters. GENII-S is considered by the NAS Committee to be a proven code for dose estimates. As described below in Section 8.3.4.1, it was used by CNWRA to perform illustrative dose assessments for the NRC.

8.3.4.1 The CNWRA Quantification of a Subsistence Farmer Scenario

As part of its development of capability to review a license application from DOE for a repository at Yucca Mountain, NRC, with technical assistance from the CNWRA, has performed analyses of potential radiation doses to receptor groups in the vicinity of Yucca Mountain. The analyses considered an Amargosa Valley resident farmer group, with life style similar to EPA's RMEI subsistence farmer scenario, and a non-farmer receptor group located between five km and 20 km to the south of the proposed repository site. Analysis results were obtained for assumed unit concentrations of radionuclides in ground water and soil (e.g., rem per pCi/l of ground water). Actual doses would depend on actual radionuclide concentrations in these media.

The principal objectives of the analyses were to: (1) summarize and document site-specific characteristics and parameters used to model environmental pathways; (2) assess the relative importance to dose of the pathways identified in Figure 8-11; and (3) provide values for dose conversion factors (DCFs) for use in performance assessments for the Yucca Mountain site. The scope of work also included calculation of the annual total effective dose equivalent (TEDE) for individuals. Results were first reported in 1995 (CNW95) and an update report was issued in 1997 (CNW97).

The 1997 CNWRA report presented updated values for pathway parameters, calculated dose conversion factors based on recent information, and a Monte Carlo-based sensitivity analysis used to identify parameters having the greatest impact on dose evaluations. The GENII-S code was used to make the calculations.

Brief descriptions of the parameters addressed in the CNWRA analyses are presented below. These descriptions illustrate the scope of parameters considered, the means used to quantify the parameters, and the levels of DCF-value results obtained for unit concentrations of the radionuclides and assumed parameter values in the GENII-S code.

All numerical values presented should be considered to be only illustrative. The analyses were done to demonstrate capability and methodology; changes in parameter values and results are to be expected as a result of future updates to the information base for the calculations.

Agricultural Data Used

Subsistence farming, as described in the CNWRA reports, is consistent with present-day agricultural practices for Nye County and incorporates all of the exposure pathways shown in Figure 8-11. Crops likely to be grown in a local vegetable garden were selected (MLS93) and grouped into categories of leafy vegetables, fruits, and root vegetables, as directed by the GENII-S code. Growing times for each group of crops were selected from Chambers and Mays (CHA94) and reflect climatic conditions consistent with those at the Yucca Mountain site.

Conversion of Areal Deposition into Mass Concentration

Contamination of feed and food crops is directly related to the areal deposition of contaminants by water irrigation. To convert the amount deposited by irrigation per unit area (areal concentration, C_A) into the mass concentration, C_M (per units mass) of soil or vegetation, it is necessary to divide the areal concentration by the soil density per unit area or by the mass of vegetation per unit area (termed the vegetation density or, in the case of farm products, the yield or weight per unit area). In soil, it is necessary to specify the depth of interest.

The areal soil density is given by $\rho_A = \rho z$, where ρ is the soil density (typically 1.6 to 2.6 g/cm^3 or 1600 to 2600 kg/m^3) and z is the depth of interest (cm or m). For determining uptake by plants from soil, root depths of 0.15 to 0.2 m are common, so that areal soil densities of 240 to 520 kg/m^2 are reasonable. This calculational process assumes a uniform distribution of the radionuclide with depth, which would be typical of tilled soil used for agriculture.

In the case of vegetation, the mass concentration C_M is obtained by dividing the areal concentration by the vegetation density Y_D (kg/m^2). As the amount of water in vegetation is highly variable and dependent upon collection and storage techniques, use of the dry-weight yield or dry vegetation density [kg(dry)/m^2] is preferable.

For Yucca Mountain, site-specific soil density values suggest a range of 1.2 to 1.8 g/cm^2, which for a 15 cm depth corresponds to a surface areal density of 180 to 270 kg/m^2. While this range of values appears appropriate for most vegetative pathways, alfalfa's tap root can grow to depths of several feet (STI91). The GENII-S code uses a two-compartment soil model that accounts for differences in densities between the tilled layer and the denser lower layer. The higher density of the lower layer has less pore space available to hold water available for root uptake. For alfalfa, a conservative decision was made. A single-compartment soil model represented exclusively by the upper layer was selected.

Crop Yields

Estimates of crop yields were based on data provided by the Nevada Agricultural Statistics Service, which reflect state-wide yields for wheat, barley, potatoes, garlic, and onions. From these data, crop yields for leafy vegetables and root vegetables were assumed to have a range of 0.618 to 6.47 kg/m^2 and 0.769 to 20.8 kg/m^2, respectively. Because fruits are not commercially produced in this region, estimates of yields between 0.3 and 2.0 kg/m^2 were obtained from Snyder et al. (DOE94b).

Crop Interception Fraction

The crop interception fraction refers to the fraction of contaminants in irrigation water deposited on the plant surface. The interception fraction varies among crops and with geographic location. Based on laboratory and field study data that included the Yucca Mountain site (LLL87), values were assumed to range from 0.06 to 1.0 with a best estimate of 0.40. While a value of 1.0 represents a theoretical upper limit, it is not considered excessively conservative in instances of high-density vegetation which is characteristic of home gardens; instances in which irrigation is employed judiciously; and instances of high evaporation rate.

In summary, parameters selected for characterizing Yucca Mountain soil, crop growing times, crop interception fractions, and crop yields are representative of site-specific values or fall within the range of values cited in the scientific literature.

Food Transfer Factors

Food transfer factors quantify the amount of contaminants that may sequentially be transferred from soil to vegetation. When vegetation is used for animal feed, transfer factors must also be used to estimate contamination levels in meat, milk, and other food products. Radionuclide uptake by plants from soil has generally been described by an empirical concentration ratio, CR, which is defined as:

$$CR = \frac{Radionuclide\ activity\ per\ unit\ mass\ of\ plant}{Radionuclide\ activity\ per\ unit\ mass\ of\ soil}$$

The radionuclide soil concentrations are generally expressed in terms of oven-dried soil weight. However, the radionuclide concentrations in crops are reported both in terms of fresh (or wet) weight and dry weight. The relationship between the fresh and dry concentration ratios is:

$$B_{iv} = CR(fresh) = \frac{CR(dry)}{FW/DW}$$

where FW and DW correspond to the fresh and dry weight, respectively. Due to variations in water content, the ratio of fresh to dry weights among leafy vegetables may vary from a low of about seven for Brussels sprouts to a high of 20 for lettuce. For root vegetables, ratios range from four (potatoes) to 18 (radishes) (NRC83).

The feed-to-beef and feed-to-milk transfer factors are also empirically derived constants that establish a relationship between the amount of an element (or radionuclide) that cattle and milk cows ingest daily and the concentration of that element in edible meat or milk at equilibrium. The standard units are expressed as a ratio of pCi/kg of meat or milk to pCi/day of chronic intake contained in feed.

Concentration ratios and food transfer factors are affected by many processes and factors, some of which are site-specific. Empirical data for the area around the Yucca Mountain site were reviewed in the CNWRA 1995 analyses, but are considered to be incomplete. Element-specific transfer factors used in the CNWRA 1997 analyses (Table 8-9) were obtained from data published by the International Atomic Energy Agency (IAE94), the International Union of Radioecologists (IUR89), and by Oak Ridge National Laboratory (ORN82).

Table 8-9. Concentration Ratios and Transfer Coefficients By Element (Source: CNW97)

	Concentration Ratio				**Transfer Coefficient**		
Element	**Leafy Vegetables**	**Other Vegetables**	**Fruit**	**Grain**	**Beef**	**Milk**	**Egg**
Ac	3.5E-03	3.5E-03	3.5E-03	3.5E-03	2.5E-05	2.0E-05	2.0E-03
Am	1.2E-03	4.7E-04	4.7E-04	2.2E-05	4E-05	1.5E-06	4E-03
Cs	1.1E-01	7.2E-02	7.2E-02	1.0E-02	5E0-2	7.9E-03	4E-01
Cm	1.1E-03	5.8E-04	5.8E-04	2.1E-05	3.5E-06	2.0E-05	2.0E-03
I	3.4E-03	2.0E-02	2.0E-02	2.0E-02	4E-02	1.0E-02	3E+00
Pb	1.1E-03	6.4E-03	6.4E-03	4.7E-03	4E-04	2.5E-04	8.0E-01
Mo	8.0E-01	8.0E-01	8.0E-01	8.0E-01	1E-03	2.0E-03	9E-03
Np	6.9E-02	2.7E-02	2.7E-02	2.7E-03	1E-03	5.0E-06	2.0E-03
Ni	1.8E-01	3.0E-02	3.0E-02	3.0E-02	5E-03	1.6E-02	1.0E-01
Nb	5.0E-02	1.7E-02	1.7E-02	1.7E-02	3E-07	4.1E-07	1E-03
Pd	1.5E-01	1.5E-01	1.5E-01	1.5E-01	4.0E-03	1.0E-02	4.0E-03
P	4.0E-00	4.0E-00	4.0E-00	4.0E-00	5.0E-02	1.5E-02	1.0E+01
Pu	3.4E-04	2.3E-04	2.3E-04	8.6E-06	1E-05	1.1E-06	5E-04
Po	1.0E-02	1.0E-02	1.0E-02	1.0E-03	4E-03	1.2E-04	7.0E+00
Pa	2.5E-03	2.5E-03	2.5E-03	2.5E-03	1.0E-05	5.0E-06	2.0E-03
Ra	8.0E-02	1.3E-02	1.3E-02	1.2E-03	9E-04	1.3E-03	2.0E-05
Sm	1.0E-02	1.0E-02	1.0E-02	1.0E-02	5.0E-03	2.0E-05	7.0E-03
Ag	2.7E-04	1.3E-03	8.0E-04	1.5E-01	3E-03	5.0E-05	5.0E-01
Se	2.5E-02	2.5E-02	2.5E-02	2.5E-02	1.5E-02	4.0E-03	9E+00
Sr	1.1E-00	8.6E-01	2.0E-01	1.2E-01	8E-03	3.0E-03	2E-01
Tc	7.6E+01	1.1E+01	1.1E+01	7.3E-01	1E-04	1.4E-04	3E+00
Th	1.1E-02	3.1E-04	3.1E-04	3.4E-05	6.0E-06	5.0E-06	2.0E-03
Sn	3.0E-02	3.0E-02	3.0E-02	3.0E-02	8.0E-02	1.0E-03	8.0E-01
U	2.3E-02	1.1E-02	1.1E-02	1.3E-03	3E-04	4.0E-04	1E+00
Zr	1.0E-03	1.0E-03	1.0E-03	1.0E-03	1E-06	6.0E-07	2E-04

In EPA's reviews of the CNWRA reports, transfer factors selected for analysis by CNWRA were compared to values that are employed by EPA NESHAPs, cited in the literature, or used as default values in other computer codes. Based on this review, it appears that except for iodine, the plant transfer values used by CNWRA are consistent with other values and appear appropriate for modeling the Yucca Mountain site. For iodine, CNWRA’s plant transfer factors appear low by one to two orders of magnitude. With one exception, beef and milk transfer factors values cited for analysis also appear consistent with commonly-used values. There appears to be a substantial discrepancy in the milk transfer factor for technetium. The cited value of 1.4E-4 is nearly 100-fold lower than those recommended by the NRC's NUREG/CR-5512, EPA's NESHAPs, and the computer code PRESTO.

Water Consumption Rates for Drinking and Irrigation

A search for site-specific or representative values failed to yield useful information regarding water consumption rates for hot, dry regions, such as southwestern Nevada. To model potential exposure from drinking contaminated water, CNWRA selected values from a nationwide Food and Drug survey (ROS92). Results indicated that water consumption rates in the United States are distributed log normally, yielding a geometric mean of 349 liters per year (L/yr) and a geometric standard deviation of 1.78.

These values are low when compared to generic values recommended by EPA (EPA89), which assume an average value of 511 L/yr (1.4 liters per day) and a 90th percentile value of 730 L/yr, or 2 liters per day. A 2-liter per day consumption rate is, at the 90th percentile, conservative for most conditions. The consumption rates for inhabitants of arid environments may be nearer to the conservative 2-liters per day rate than the overall average of 1.4 liters per day.

Contaminated water used for irrigation is also a potentially important pathway for human exposure. Previously, it was noted that the Amargosa Valley region south of the Yucca Mountain site currently uses ground water for agricultural irrigation. This supports the likelihood of its future use by a subsistence farmer. However, suitable data do not currently exist for quantifying irrigation rates associated with small-scale or subsistence farming. For surrogate values, the CNWRA relied on water irrigation required for lawn maintenance in Nye County (MLS93). Data suggest a range of values between 26 and 84 inches per year, which corresponds to a growing season of six to 12 months per year.

A comparison of physiological parameters between lawn grasses and edible crops (moisture content, surface to volume ratio, root depth, etc.) suggests that these surrogate values provide a reasonable approximation. The appropriateness of these values is also supported by the fact that the range of irrigation values generally approximates the natural precipitation rates in parts of the country where irrigation is not required.

Buildup of Soil Contaminants

The chronic irrigation of farm land with contaminated water may result in a buildup of contaminants over time. A buildup of soil contaminants affects the ingestion pathways involving edible crops and animal feed, the inhalation exposure from resuspended soil particles, and the external exposure from contaminated ground surfaces.

Estimates of soil buildup are complex and reflect the rate of deposition of a contaminant and its rate of removal. Soil contaminants may be removed by several concurrent processes that include leaching (or washoff), crop uptake (and subsequent harvesting of crop), wind erosion, and radionuclide decay. These biophysical processes can be combined and represented by a simple removal rate constant. Removal rate constants, however, are not easily determined since they are radionuclide-specific and affected by a host of site-specific parameters.

Soil buildup was not modeled in the unit concentration dose estimates for the 20 radionuclides analyzed by CNWRA. Dose estimates, in effect, reflect the combined annual external exposure and committed internal exposures associated with soil irrigation for a period of one year. The potential impact of neglecting soil buildup is likely to vary depending on the radionuclide. When radionuclides are assumed highly soluble and exhibit high leach rates, buildup may be insignificant. For this condition, contamination of food crops may be dominated by external deposition on vegetative (leaf) surfaces.

The EPA evaluated the lack of consideration of soil buildup in the CNWRA analyses. Test runs were performed using leaching removal terms provided by the GENII code. For radionuclides with high leach rates, such as I-129 and Tc-99, dose estimates were unaffected by long-term irrigation, indicating that soil buildup was insignificant. For other radionuclides, doses were not significantly affected for irrigation times of 100 and even up to 1,000 years. With irrigation periods lasting 10,000 years, however, soil buildup for a limited number of radionuclides yielded a ten-fold increase in dose estimates. An irrigation period of 10,000 years is extremely conservative and unrealistic. In addition, the agricultural potential of irrigated land in the arid environment around Yucca Mountain would decrease markedly with time due to build up of salts in the soil from the high evaporation rate.

An independent assessment by the Electric Power Research Institute (EPRI) cited provisional calculations for I-129 and Np-237 (EPR94). The EPRI results confirm that for the ground water release scenario, soil buildup from irrigation is insignificant. EPRI concluded that the need to assess the impact of long-term soil accumulation is limited when radionuclides can be assumed to be relatively soluble.

Inhalation and Soil Exposure Times

In the CNWRA analyses, inhalation and soil exposure times are assumed to be the same. The maximum exposure time of 7,117 hr/yr is based on an individual spending 15 hours per day, seven days per week outdoors in the contaminated area (i.e., a 1.0 exposure factor). The rest of his/her time is spent indoors, exposed to contamination 50 percent of the time (i.e., an exposure factor of 0.5). The minimum exposure time of 5,548 hours per year is based on spending 73 percent of the time indoors with a 0.5 indoor exposure factor and the remaining portion of the time outdoors in the contaminated area. A triangular distribution was assumed, sloping to the minimum value from the maximum value, based on the assumption that the farmer is likely to spend much of the day outdoors.

The CNWRA Selection of Dose Conversion Factors

Estimates of radiation doses that result from the ingestion, inhalation, or external exposure to radioactivity are based on dose conversion factors (DCFs) that make use of contemporary metabolic models and dosimetry methods. A critical choice in selecting DCF-values for dose calculations relates to the solubility of the radionuclide contaminant in aqueous fluids. When ingested, a radionuclide that is highly soluble is readily absorbed from the intestinal tract to the blood stream where it may be metabolized and retained for long periods of time. Similarly, a soluble contaminant that is inhaled may also be quickly removed from the lung and enter the blood stream where its fate is essentially that of an ingested radionuclide. For ingestion and inhalation pathways, DCFs are generally defined in terms of solubility by means of the $\underline{f}_1$ (fractional uptake of nuclides from small intestine) and lung clearance class. Lung clearance, designated as D,W, or Y, refers to "days, weeks, or years" for the radionuclides to be removed from the pulmonary region of the lung.

For insoluble contaminants, the potential for internal exposure through inhalation versus ingestion is quite dissimilar. Inhaled insoluble radionuclides are not readily removed from the lung and may, therefore, result in long-term exposure of the lung and other tissues. Internal dose is minimized, however, when the insoluble contaminant passes through the digestive system without being absorbed.

The GENII code offers a choice of DCFs that correspond to very soluble, soluble, and insoluble states of individual radionuclides. A comparison of GENII DCF values with those in EPA Federal Guidance Reports No. 11 and No. 12 (EPA88, EPA93) shows that, when matched for solubility, there is generally good agreement.

As previously noted, the CNWRA 1997 report (CNW97) presented revisions to some of the pathway parameter values used in the 1995 report and described the basis for the revisions. The parameters were then used to evaluate dose conversion factors for several exposure scenarios, with unit concentration values assumed for the radionuclides. The scenarios considered were the current-day and pluvial-biosphere resident farmer for ground water and soil sources, and the non-farming resident for the same types of scenarios. The GENII-S code was used to make the calculations. Table 8-10 reproduces the set of the results obtained for the resident farmer in the current biosphere with a contaminated ground water source.

The CNWRA 1997 report states that the farmer scenario is conservative in that it is unlikely that there would be a group that would be expected to receive higher exposures. In the CNWRA analyses, the parameter values for calculation of the DCFs were set to average values, so the DCF results obtained, such as those shown in Table 8-9, represent the average member of the most highly-exposed critical group as defined by the ICRP. The approach is described by CNWRA as a shortcut to the computationally-intensive methods that would be required by the concepts put forth by the NAS (NAS95).

To the extent that the details (e.g., lifestyle and pathway parameters) of the CNWRA subsistence farmer scenario correspond to those used by EPA for its subsistence farmer RMEI, the unit-concentration DCF results obtained from the CNWRA analyses correspond to those obtained by EPA. Actual doses predicted to be incurred by the RMEI would depend on actual biosphere concentrations predicted from performance assessments (Chapter 7 of this BID) compared to the unit concentrations used to evaluate the DCFs.

8.3.4.2 Summary of CNWRA Analysis

As previously noted, CNWRA performed an analysis of the subsistence farmer scenario using the GENII-S code. Input parameter values were taken from available sources that compile and

Table 8-10. Dose Conversion Factors for a Resident Farmer in Current Biosphere By Exposure Pathway and Radionuclide for Ground Water Source (rem per pCi/l in ground water) (CNWRA)

Radionuclide	Animal Product Ingestion	Drinking Water Ingestion	External Plume and Groundshine	Inhalation	Terrestrial Crop Ingestion	Total EDE
C 14	3.2E-06	1.5E-06	0.0E-00	0.0E-00	8.9E-06	1.4E-05
Cl 36	2.0E-05	2.2E-06	7.9E-09	1.9E-12	2.3E-05	4.5E-05
Ni 59	6.6E-07	1.5E-07	0.0E-00	2.4E-12	2.0E-07	1.0E-06
Ni 63	1.8E-06	4.0E-07	0.0E-00	6.0E-12	5.3E-07	2.8E-06
Se 79	1.1E-05	6.1E-06	7.3E-10	2.6E-11	8.0E-06	2.5E-05
Sr 90	1.2E-04	8.8E-05	9.3E-09	5.3E-10	1.4E-04	3.4E-04
Zr 93	3.2E-10	1.2E-06	1.6E-09	2.2E-10	1.6E-06	2.8E-06
Nb 94	6.7E-10	5.3E-06	5.3E-05	1.0E-09	7.0E-06	6.6E-05
Mo 93	5.9E-07	1.0E-06	1.7E-07	2.5E-12	1.6E-06	3.4E-06
Tc 99	1.4E-07	1.6E-06	6.8E-10	5.6E-12	3.0E-06	4.8E-06
Pd 107	3.1E-07	1.1E-07	0.0E-00	3.3E-11	1.5E-07	5.7E-07
Ag 110M	3.7E-06	2.4E-05	5.6E-05	1.5E-10	3.0E-05	1.1E-04
Sn 121M	6.9E-06	1.1E-06	1.7E-07	3.0E-11	2.1E-06	1.0E-05
Sn 126	6.4E-05	1.4E-05	6.7E-05	2.5E-10	2.0E-05	1.6E-04
I 129	8.5E-04	1.8E-04	5.3E-07	2.4E-10	2.4E-04	1.3E-03
Cs 135	2.3E-05	5.0E-06	1.2E-09	1.2E-11	6.6E-06	3.5E-05
Cs 137	1.6E-04	3.5E-05	1.9E-05	7.8E-11	4.6E-05	2.6E-04
Sm 151	7.3E-08	2.8E-07	1.8E-10	7.8E-11	3.6E-07	7.1E-07
Pb 210	4.0E-04	3.9E-03	1.3E-07	4.8E-08	5.3E-03	9.6E-03
Ra 226	2.7E-04	7.0E-04	5.6E-05	2.2E-08	9.2E-04	2.0E-03
Ac 227	7.9E-05	1.0E-02	1.3E-05	3.6E-06	1.4E-02	2.4E-02
Th 229	2.9E-05	2.6E-03	1.1E-05	4.6E-06	3.6E-03	6.1E-03
Th 230	6.4E-07	3.9E-04	2.6E-08	7.0E-07	5.2E-04	9.1E-04
Pa 231	1.4E-05	7.8E-03	1.4E-06	2.3E-06	1.0E-02	1.8E-02
U 232	6.8E-06	5.0E-05	7.3E-06	1.8E-06	7.9E-05	1.4E-04
U 233	2.4E-06	1.9E-05	2.5E-08	3.5E-07	2.5E-05	4.7E-05
U 234	2.4E-06	1.9E-05	2.6E-08	3.5E-07	2.5E-05	4.6E-05
U 235	2.5E-06	1.9E-05	5.8E-06	3.2E-07	2.6E-05	5.4E-05
U 236	2.2E-06	1.8E-05	2.3E-08	3.3E-07	2.3E-05	4.4E-05
U 238	2.3E-06	1.7E-05	8.4E-07	3.1E-07	2.9E-05	4.9E-05
Np 237	2.0E-04	3.8E-03	6.3E-06	1.5E-06	5.0E-03	9.1E-03
Pu 239	2.9E-08	3.6E-05	1.3E-08	8.2E-07	4.8E-05	8.5E-05
Pu 240	3.0E-08	3.6E-05	2.8E-08	8.2E-07	4.8E-05	8.5E-05
Pu 242	2.8E-08	3.4E-05	1.1E-07	7.9E-07	4.5E-05	8.0E-05
Am 241	6.6E-06	2.7E-03	9.6E-07	1.2E-06	3.5E-03	6.1E-03
Am 242M	6.3E-06	2.5E-03	7.0E-07	1.1E-06	3.3E-03	5.9E-03
Am 243	6.5E-06	2.6E-03	7.5E-06	1.2E-06	3.5E-03	6.1E-03
Cm 243	9.9E-06	1.8E-03	4.4E-06	8.0E-07	2.4E-03	4.3E-03
Cm 244	7.9E-06	1.5E-03	3.1E-08	6.4E-07	1.9E-03	3.4E-03
Cm 245	1.5E-05	2.7E-03	3.0E-06	1.2E-06	3.6E-03	6.3E-03
Cm 246	1.5E-05	2.7E-03	2.7E-08	1.2E-06	3.6E-03	6.3E-03

interpret past research to develop such values. Variations in input parameter values, which lead in part to variations in analysis results, are also discussed in the CNWRA report.

Table 8-11 shows the CNWRA results for evaluating the arithmetic and geometric means for TEDEs for selected nuclides.

The results shown in Table 8-11 do not imply that the isotopes will actually contribute to dose at these relative levels. Actual levels of concentration in ground water, and the actual relative contributions of various nuclides to dose, will depend on many factors, such as mobility of the nuclide in the environment, solubility in water, time of release of radionuclides from the repository, distance of the exposed individual from the repository, flow rate of ground water in the environment, and the lifestyle of the exposed individual, represented in these results by the subsistence farmer. Performance assessments to date (Chapter 7 of the BID) indicate that Tc-99 and I-129 will be the principal contributors to predicted doses.

Table 8-11. Summary of Mean TEDE Results From CNWRA
Unit Concentration Evaluations for Water

	Annual TEDE, rem/yr per pCi/l	
	Arithmetic Mean	**Geometric Mean**
Radionuclide	**CNWRA**	**CNWRA**
C-14	1.9E-05	1.8E-05
Tc-99	8.4E-06	7.9E-06
I-129	3.1E-03	2.7E-03
Cs-137	7.6E-04	6.6E-04
Ra-226	2.8E-03	2.6E-03
Np-237	1.3E-02	1.2E-02
U-238	7.2E-05	6.8E-05
Pu-239	1.1E-04	1.0E-04
Am-241	7.9E-03	7.4E-03

Potential variability of input parameter values is illustrated by Table 8-12, which shows values of water and food consumption rates used in a variety of dose studies. Included in Table 8-12 are the parameter values used in the CNWRA analyses, values from NRC's Regulatory Guide 1.109, and values used by DOE based on surveys conducted in the Yucca Mountain area.

Table 8-12. Comparison of Inhalation, Drinking Water and Food Consumption Rate Parameter Values From Various Sources

Pathway	Units	CNWRA[1]	BIOMOVS[2]	DOE YM[3]	NRC[4]
Inhalation	m^3/yr	NR	8400	NR	8000/8000
Drinking Water	l/yr	511/730	730	646.16/769.70/769.70	370/730
Leafy vegetables	kg/yr	4.27/11/28.3	62.2	4.39/9.70/63.55	23/64
Root vegetables	kg/yr	11.3/51/231	235	2.13/6.37/28.86	80/217
Fruit	kg/yr	10.2/46/208	NR	4.47/10.54/59.32	42/114
Grain	kg/yr	15.3/69/312	148	0.40/11.01/60.64	46/125
Beef	kg/yr	22.1/59/157	94.9	0.92/8.66/8.97	95/110
Milk	l/yr	20.8/100/482	330	4.84/60.50/119.39	110/310

[1] Except for drinking water, values were taken from CNWRA 97-009, Table 2-4. Middle value is the consumption rate from NUREG/CR-5512, side values are the low and high range values based on log-normal distribution from Hoffman et al. (1982). Drinking water values are the average and 90th percentile values from EPA 540/1-89-002, Exhibit 6-11.

[2] Taken from BIOMOVS II, Technical Report No. 12, Appendix A, Table A-7. These are the values used in the deterministic analysis. Appendix B presents values used in the stochastic analysis; however, stochastic values are not provided for food consumption, drinking water or inhalation rates.

[3] Taken from October 12, 1997 presentation to the Nuclear Waste Technical Review Board. First value is for “Total Population,” middle value is for “Partial Subsistence” population, and last value is for “Subsistence” population. All values are for “Locally Produced Food.”

[4] Taken from NRC’s Regulatory Guide 1.109. First value is for an average adult from Table E-4, while the second value is for the maximum exposed adult from Table E-5.

NR = not reported

The DOE values were developed based on a 1997 survey of over 1,000 households in the Yucca Mountain region. Note that most of the DOE values are substantially lower than the values from the other sources. This is at least partly due to the fact that the DOE values are for “Locally Produced Food,” whereas the other sources are reporting total consumption values. EPA 540/1-89-002 reports that, on average, the fraction of food that is “home grown” is 0.20 for fruits, 0.25 for vegetables, 0.44 for beef, and 0.40 for milk; worst case fractions are 0.30 for fruits, 0.40 for vegetables, and 0.75 for beef and milk. Using these “home grown” fractions, DOE’s leafy vegetable “Total Population” consumption rate is consistent with the average leafy vegetable values from the other sources. However, for the other pathways, the DOE values remain lower than the rates from the other sources. This is consistent with the arid nature of the Yucca Mountain region, which makes farming difficult, and the fact that what agriculture there is is mostly commercial (e.g., alfalfa, milk) with products shipped out of the region.

Of special interest in Table 8-12 is the column of data from Biosphere Model Validation Study (BIOMOVS), which represents parameter values derived from data sources in nations other than the United States. The BIOMOVS is an international cooperative study to test models designed to quantify the transfer and bioaccumulation of radionuclides and other trace substances in the environment. Participating nations include Sweden, the Netherlands, France, Belgium, Switzerland, Canada, Spain, and the United Kingdom. Technical Report No. 12 (BIO96) specifically addresses biosphere modeling for dose assessment for radioactive waste repositories.

A detailed review of the BIOMOVS II Technical Report No. 12 was conducted as a means of comparing BIOMOVS parameter values with those from other sources. Findings can be summarized as follows:

- The BIOMOVS data are “broadly representative of a valley in central Switzerland,” not Nevada’s Amargosa Valley. Therefore, for parameters such as the irrigation rate, for which CNWRA developed data specific to Amargosa Valley, the CNWRA values would be more appropriate than the BIOMOVS data.

- The only stochastic food transfer factor given in BIOMOVS are for I-129 and the Np-237 chain. For all other radionuclides, only deterministic values are given. Both BIOMOVS and CNWRA used IAEA’s *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments* (Technical Report Series No. 364, 1994) as their primary source of food transfer factors.

- In BIOMOVS, the annual drinking water consumption is not a stochastic parameter -- its deterministic value is given as 0.73 m^3/y. This deterministic value is identical with the average water consumption rate used by CNWRA.

- The BIOMOVS residential dust loading central value is given as 5×10^{-5} g/m^3. The BIOMOVS suggested using a log-triangular distribution with the maximum/minimum values plus/minus one order of magnitude from the central value. The lower/upper limit suggested by BIOMOVS is only a factor of two lower/higher than the value used in the CNWRA analysis.

- In addition to residential dust loading, BIOMOVS utilizes an occupational (farming) dust loading central value of 10^{-2} g/m^3, a central value exposure time of 300 hr/y, and the same distributions as the residential dust loading. No reference is provided for these values, although the dust loading appears to be at the OSHA Permissible Exposure Limit (PEL) for nuisance dust (note the upper limit of the stochastic range is an order of magnitude above the OSHA PEL). The BIOMOVS average (residential and occupational) dust loading central value is 3.88 x 10^{-4} g/m^3. The CNWRA analysis did not include occupational dust loading.

- The BIOMOVS does not provide a range of values for consumption rates, only a fixed deterministic value. Most of the BIOMOVS deterministic values tend to be towards the high end of the stochastic values provided by other sources.

These findings indicate that BIOMOVS parameter values could be used in the Yucca Mountain dose evaluations where appropriate. They also tend to confirm the validity of the parameter values used in analyses to date. Values may be revised and refined (e.g., better characterization of values and uncertainty distributions), as characterization of the Yucca Mountain region continues in the future.

8.3.5 Alternative Exposure Scenarios For Consideration at Yucca Mountain

In Section 8.3.4, the subsistence farmer was characterized and modeled as the individual most likely to receive the highest dose among the exposed population. It was noted that the results of the CNWRA evaluations of DCFs might correspond to those for EPA's criteria for the RMEI. At Yucca Mountain, however, the qualification of the subsistence farmer as the RMEI is conditional.

One factor important to characterizing the Yucca Mountain RMEI is his/her location relative to the repository. For example, a subsistence farmer who derives all drinking water and home-grown food from contaminated ground water at a location 10 miles from the repository may be exposed to lower doses than persons whose exposure pathways are limited to drinking water, or fractional quantities of contaminated home-grown food products, residing close to the repository boundary. This is due to the fact that radioactivity concentrations in ground water are expected to decrease with increasing distance from the repository boundary as a result of dilution and dispersion.

The RMEI could also be represented by a commercial farmer, a rural resident, or someone simply using contaminated ground water for domestic uses. For example, slope of terrain and poor soil quality are factors that could potentially preclude farming, but not rural residency, near the repository boundary. Alternatively, commercial farming might economically justify the one-time high cost of drilling a deep well near the repository boundary.

The availability and cost of extracting ground water may also impact the type of farming. While some farming in a desert environment would require extensive use of ground water, certain highly specialized farming may require only modest amounts of water.

A discussion of the alternative RMEI scenarios identified in Section 8.3.3 is presented below.

8.3.5.1 Commercial Farming Scenario

To maximize efficiency and monetary profit, farmers tend to specialize within a particular sector of agriculture. As a result of local conditions, commercial farming in Nevada tends to be focused in the following sectors:

- <u>Dairy Products</u> - Principal activities include milk production and/or breeding of dairy cows. Feed for dairy cows may involve some grazing, but most is either purchased or produced by the dairy farmer.

- <u>Livestock</u> - The largest percentage of livestock is represented by cattle ranchers. Based on range and pasture conditions, grazing may be supplemented to varying degrees by cattle feed that is either purchased or produced by the rancher. (A smaller percentage of livestock farmers specialize in poultry, hogs, etc. In general, feed for these animals is either obtained commercially or from source(s) not likely to be affected by contaminated ground water.)

- <u>Field Crops</u> - Primary field crops in Nevada include wheat, barley, alfalfa, and hay.

- <u>Produce and Specialty Crops</u> - Included in this category are leafy vegetables, root crops, and a <u>limited</u> variety of fruits/nuts.

For the purpose of modeling potential exposure pathways, the commercial farmer is assumed to utilize contaminated ground water for personal use and all activities associated with farming (i.e., irrigation of crop, animal feed, produce, etc. and watering of livestock). Accordingly, the basic model parameters previously identified in the subsistence farm model also apply to the commercial farmer.

There are significant differences in potential radiation dose estimates between the subsistence farmer and the commercial farmer because the commercial farmer is expected to derive only a fraction of consumed food from home-grown/contaminated food products; the specialized farm activities of a commercial farmer may in some instances exclude pathways generically assumed for the subsistence farmer. The variability and uncertainty for modeling a commercial farmer is due to the unlimited number of combinations of contaminated food groupings and the variable ratio or fractions of contaminated food products to the total quantity consumed. For most food categories, fractional quantities have the potential to range from zero to one. For illustration, the following sample scenarios are cited:

<u>Scenario #1: Contaminated Food Intake Approaches Zero</u>. In this sample scenario, the commercial farmer's activity is limited to growing alfalfa for animal feed that is shipped, pelletized, and sold on the open market. Food ingested by the farmer is assumed not to be contaminated and exposure pathways are limited to drinking water, soil/dust inhalation, and external exposure. The latter two pathways are the result of field irrigation and ground contamination.

<u>Scenario #2: Low to Moderate Levels of Contaminated Food Intake</u>. This scenario would represent a commercial farmer who engages in a <u>single</u> activity that may involve livestock, milk, field crops, produce <u>or</u> fruit production. Based on the farming activity selected, the farmer may be reasonably assumed to consume his/her home-grown food product. However, the home-grown/contaminated food category may represent a highly variable fraction of the total quantity consumed. (While it is reasonable to assume that a dairy farmer consumes milk that is 100 percent derived from personal milk production, it is not reasonable to assume that a potato farmer's diet of root vegetables is limited to home-grown potatoes.)

<u>Scenario #3: Medium to High Levels of Contaminated Food Intake</u>. This scenario would represent a commercial farmer engaged in multiple activities. For example, a large dairy farm, in addition to milk production, may also raise alfalfa/hay for its own animal feed. To maintain or increase milk production, dairy farms commonly breed their own stock, leaving aged-/poor-milk producers and male calves available for slaughter. If, in addition

to these activities, a sizeable home-garden is added for personal food production, contaminated food consumption by this commercial farmer approaches that of the subsistence farmer.

The above-cited examples illustrate the difficulty in characterizing a "typical commercial farmer." No single set of model parameters that specify individual food categories and quantify the fractions of contaminated food products can represent the range of conditions.

8.3.5.2 The Rural Residential Scenario

Consideration must be given to the possibility that a rural resident may be the RMEI. The possibility may occur if subsistence and commercial farming close to the repository side are excluded by geophysical limitations (e.g., soil quality, slope of terrain, etc.), but rural residency is not. As was previously noted, using a lower amount of contaminated water drawn from a well close to the repository can lead to greater exposure than using a greater amount of contaminated water drawn from a well farther away from the repository.

A rural residential scenario may reasonably include the drinking water pathway and fractional intakes from ingestion of contaminated home-grown vegetables, produce, and other food products. Consequently, at or near the footprint of the repository, where contamination levels are likely to be greatest, the restricted or unrestricted use of well water for drinking and limited food production may result in exposures greater than those to commercial, and even subsistence farmers, residing at more distant locations. The scope of home-grown food production for rural residents is highly variable and may range from a few kilograms for a single food category to substantial quantities that represent nearly all major food categories.

8.3.5.3 Domestic Use of Contaminated Water Scenario

A community well is a common way to provide domestic water in instances where conventional municipal water supplies are not available. Domestic use implies all normal household uses of water such as bathing, washing, sewage, and human consumption.

Exposure for this scenario is, therefore, limited to the drinking water pathway that has been previously defined. On average, for the 20 radionuclides considered, drinking water contributes about one-fifth of the maximum total dose from all pathways.

8.4 THE REPOSITORY INTRUSION SCENARIO: A SPECIAL CASE

Inadvertent human intrusion into the repository could occur if future generations were to attempt to extract minerals, oil and gas, water or other resources from the site. Such intrusion could result in a breach of the repository's geologic and engineered barriers, thus releasing radionuclides into the atmosphere or ground water. Such a release could pose a risk for future residents of the area. This section examines the possibility of finding resources at the site and the incentive for future exploration.

With regard to the human intrusion issue, the National Academy of Sciences (NAS95) in its report, "Technical Basis for Yucca Mountain Standards," reached the following conclusions:

- There is no technical basis for predicting either the nature or the frequency of intrusions.
- There is no scientific basis for making projections over the long term of the social, institutional, or technological status of future societies.
- There is no scientific basis from which to project the durability of government institutions over the period of interest, which exceeds that of all recorded human history.
- Some degree of continuity of institutions, and hence of the potential for effective active institutional controls, into the future might be expected; but there is no basis in experience for such an assumption beyond a time scale of centuries. There is no scientific basis for assuming the long-term effectiveness of active institutional controls to protect against human intrusion.
- There is no technical basis for making forecasts about the reliability of passive institutional controls.
- There is no scientific basis for estimating the probability of inadvertent, willful, or malicious human action.

Based on these findings, the NAS made the following observations:

- Although it can not be proven, it is believed that a collection of prescriptive requirements, including active institutional controls, record keeping, and passive barriers and markers, will help to reduce the risk of human intrusion, at least in the near term. The degree of benefit is likely to decrease over time.

- Because it is not technically feasible to assess the probability of human intrusion into a repository over the long term, it is not scientifically justified to incorporate alternative scenarios of human intrusion into a fully risk-based compliance assessment that requires knowledge of the character and frequency of various intrusion scenarios. However, it is possible to carry out calculations of the consequences for particular types of intrusion events. Such calculations might be informative in the sense that they can provide useful insight into the degree to which the ability of a repository to protect public health would be degraded by intrusion.

The NAS made the following recommendations for the approach to addressing the human intrusion issue:

- *...the repository developer should be required to provide a reasonable system of active and passive controls to reduce the risk of intrusion in the near term.*

- *EPA should specify in its standard a typical intrusion scenario to be analyzed for its impact on the performance of the repository.*

This section of the BID presents background information relevant to human intrusion scenarios that can be developed for the Yucca Mountain Repository site. The assumptions made about the intrusion scenarios follow the guidelines provided by the NAS. This discussion is organized as follows:

- The potential causes of intrusion are first discussed by summarizing the current resource potential in the vicinity of Yucca Mountain and how that may influence future intrusion.

- Possible intrusion scenarios are presented for each of the resources that are likely to occur in the vicinity of Yucca Mountain.

- The assumptions that apply to each scenario and the parameters that would be used to calculate the consequences of each intrusion scenario are provided.

8.4.1 Site Resources as Potential Cause for Intrusion

Extensive exploration, development, and mining have occurred in the Great Basin of Nevada and extensive histories and lists of mineral deposits are available. Predicting future economic conditions and what materials in the vicinity of the site may be considered resources, or how they may be explored or produced, is not feasible. However, the consequences of an intrusion scenario based on exploration and/or production of a present-day resource can be evaluated using current methods and technologies and by assuming similar types of intrusion in the future. The information on current and historic natural resources in the vicinity of Yucca Mountain is presented to establish plausible background data for scenarios based on current resource exploration and/or production.

The discussion of mineral resources, based on information from Miklas and Fiero (MIK92; FIE86), is focused on oil, natural gas, geothermal resources, and metallic ores. Other mineral resources that are or may be present at or in the vicinity of the Yucca Mountain site, such as gravel, building stone, and pumice, are excluded from this discussion. Such minerals are abundantly present in other parts of the region. Moreover, since they have a low bulk value, they can only be profitably extracted from large-scale, shallow surface workings.

8.4.1.1 Petroleum and Natural Gas Resources

The Great Basin of Nevada, in which Yucca Mountain is located, has the potential for petroleum deposits. Excellent reservoir rocks and structures (faults and folds) exist and source beds (rocks in which petroleum might have formed) are also present. However, the complexity of the geology, due to deformation resulting from tectonic forces, makes exploration difficult and costly. Also, the potential size of such reservoirs is limited due to the high degree of faulting in the region.

Oil and natural gas have been produced in Nye County (Railroad Valley) and Eureka County (Pine Valley). Both sites are about 100 to 300 km northeast of the Yucca Mountain site. The fields are relatively small and production is on the order of several hundred to a few thousand barrels per day. Given that all production to date has come from Tertiary basins in the Sevier mountainous belt between the Devonian/Mississippian Antler highland and the Paleozoic continental shelf, the potential for petroleum resources in the vicinity of Yucca Mountain is rated as low.

8.4.1.2 Geothermal Resources

In general, the Basin and Range Province, which contains the Great Basin subprovince, is an area of elevated heat flow (about two heat flow units [HFU]) relative to other continental settings (about one HFU). This is believed to be due to the thin crust and near melting conditions at the crust/mantle boundary. In Nevada alone, there are nearly 300 thermal springs and warm water wells. However, the hot spring activity is concentrated in the west-central and north-central parts of the state. Yucca Mountain is located in an area of moderately elevated heat flow (1.5 to 2.5 HFU). The Eureka heat flow, on the order of 0.75 to 1.5 HFU, is immediately to the north of Yucca Mountain and is thought to be below the average heat-flow values for the region due to underflow of intrabasinal ground water. A geothermal test well drilled on Pahute Mesa, approximately 40 km north of Yucca Mountain, found maximum water temperatures on the order of 60 to 90°C, well below current geothermal resource values. Warmer temperatures (125°C) were found at a depth of 3,700 m; however, this is below the 1,000 meter depth considered to be economical for low temperature geothermal production (MIK92).

8.4.1.3 Mineral Resources

Disseminated Gold/Silver and Uranium Deposits

Disseminated gold/silver deposits have fueled the Nevada precious metals boom over the past 15 years. These are low-grade deposits (0.01 to 0.1 ounce per ton (oz/ton) cutoff grade) worked by open pit operations involving minimal milling and cyanide leaching technologies. Base metal concentrations are generally low in these deposits, while mercury, arsenic, thallium, and antimony concentrations are elevated. In the Great Basin subprovince, these deposits occur in both sedimentary and volcanic host rocks.

Sedimentary rock that hosts disseminated gold/silver deposits is located predominately in the northern and western portions of the Great Basin, primarily between the Sierra Nevada mountains to the west and the Paleozoic eastern assemblage of the continental shelf. In addition to clustered deposits in sedimentary rock, the Carlin, Getchall, and Cortez metallogenic trends are recognized. Host rock is variable, ranging from calcareous through clastic sedimentary rocks, with some preference for argillaceous or carbonaceous carbonates. The Roberts Mountain thrust of the Antler orogeny, north of the Yucca Mountain site, marks a fairly sharp boundary between gold-bearing deposits northwest of the thrust and barren mineral deposits southeast of the thrust.

While relatively few of the disseminated gold/silver deposits in Nevada are hosted in volcanic rock, those that are have been associated with a magnetic anomaly along the Walker Lane Belt that includes Yucca Mountain. However, the host rock is generally Tertiary andesites, silicic tuffs, and volcaniclastic sedimentary rocks, none of which have been found in the vicinity of Yucca Mountain.

Most of the uranium production in Nevada has been from disseminated tertiary deposits and associated veins at the Apex mine in Lander county north of Yucca Mountain. Volcanic-hosted uranium in sub-economic concentrations is found in silicic volcanics at the McDermitt Caldera in the northwest corner of Nevada.

Porphyry Deposits of Copper, Molybdenum, and Gold/Silver

Porphyry deposits are igneous rocks in which large crystals are enclosed in a very fine-grained matrix. Calc-alkaline porphyry deposits associated with fossil hydrothermal systems contain many of the richest copper and molybdenum deposits in the Great Basin. While ore grades are generally low (0.5 to 1.0 percent copper, 0.01 to 0.1 percent molybdenum), there is typically a high-grade enriched cap. Although concentrations of gold and silver are very low, byproduct recovery from the large volumes of ore processed for copper and/or molybdenum is economic.

Porphyry intrusions are typically 0.5 to 3 km in diameter and lie at depths of one km. The deposits in the province generally date from 50 to 70 million years, although the deposits at Battle Mountain, NV and Bingham, UT are dated from 35 to 40 million years. The relatively few copper and molybdenum deposits in the Great Basin lie far north of Yucca Mountain. The richest porphyry deposits in the Basin and Range Province are south of the Great Basin in southern Arizona and New Mexico. Given the relatively young age of Yucca Mountain, less than 17 million years, it is unlikely that porphyry deposits are to be found in the area.

Skarn and Carbonate-Hosted Deposits

Skarn and carbonate-hosted deposits in the Great Basin have been exploited for a variety of base and precious metals, including iron, tin, tungsten, copper, zinc, lead, molybdenum, gold, and silver. However, these deposits are largely limited to the northern Great Basin and the Porphyry Copper Block of Arizona/New Mexico.

Epithermal Vein Deposits

In the Great Basin, through-going normal faults and associated fracture sets are clearly correlated with mineralization trends for a variety of metals. Veining is largely controlled by normal and slip-strike faulting resulting from caldera formation, although thrust faulting has also played a role.

Many of the historic mining districts in the Great Basin, including Comstock, Bodie, and Tonopah, exploit polymetallic vein deposits. These deposits are usually mined for high-grade gold and silver, but economic concentrations of antimony, lead, zinc, copper, manganese, and uranium have also been developed. Near Yucca Mountain, gold and silver have been produced from vein deposits in the Wahmonie District (25 km east), Bare Mountain (15 km west), and in the Bullfrog Hills (30 km west).

Breccias (Gold/Silver)

Breccia deposits (in pipes, stockwork fractures, and brecciated fault zones) of gold, silver, and base metals are widely dispersed in the Great Basin. Such deposits have been identified at Paradise Peak, Borealis, Victoria, and Ortiz in Nevada, northwest of the Yucca Mountain site. While such deposits are widespread, it should be noted that they contain only a small fraction of the total reserves of the region.

Massive Sulfide (Copper, Lead, Zinc)

Small deposits are found throughout the southern Basin and Range in Arizona and in the north-central Great Basin at Big Mike and Mountain City in Elko County, NV. Of volcanic origin, such deposits are believed to form at tectonic plate margins where seawater circulates near the vents of submarine hydrothermal systems.

Roll-Front (Silver, Uranium)

While roll-front uranium deposits are associated with much of the uranium that has been discovered and mined on the Colorado Plateau, no such deposits have been discovered in the Great Basin subprovince. Indeed, only a single sandstone roll-front deposit of silver (at Silver Reef, UT) has been discovered in the subprovince.

Placer (Gold, Platinum)

Placer deposits in the Great Basin are fairly common, and, due to limited lateral transport, are almost always found in close proximity to the parent deposit. Exceptions include the Snake River, ID and Spring Valley, NV placers, which are not associated with a lode deposit. Gold and platinum placers in Nevada are found north of the Yucca Mountain site at Round Mountain, Battle Mountain, and Manhattan.

8.4.1.4 Other Materials

Other materials found in the Great Basin include barite, manganese, borax, mercury, beryllium, gallium/germanium, zeolites, and fluorspar. Of these, only zeolites and fluorspar are believed to occur in significant deposits near the Yucca Mountain site.

The unique ion exchange and sorptive properties of zeolite minerals find numerous practical applications, including molecular sieves and water softeners. While thick zeolite beds are present in the vicinity of Yucca Mountain, they are found only at great depth. Because of the low value of the resource, economic recovery currently relies on surface-mining techniques. Fluorspar also has a number of industrial applications, primarily in the chemical, ceramic, and metallurgical industries. The largest fluorspar-producing region of Nevada is the Bare Mountains, about 15 km west of Yucca Mountain.

8.4.1.5 Ground Water

Ground water is currently the only source of water in the area and is used for domestic, agricultural, and industrial purposes. Water for site investigation requirements is obtained from two wells (J-12 and J-13) located approximately five km from the proposed repository footprint. Currently, the J-12 and J-13 wells are the closest production wells to Yucca Mountain; there are no production wells situated on Yucca Mountain itself. These wells are completed in the welded Tertiary volcanic rocks (Topopah Spring Member of the Paintbrush Tuff). Wells in the tuff aquifer range in depth from 850 to 3,500 feet and are capable of producing from 370 to 770 gallons per minute (gpm) based on testing performed in 1967 and reported in U.S. Geological Survey Water Supply Paper No. 1938. The water table beneath the proposed repository site is located within the Calico Hills and Crater Flat formations. The Crater Flat hosts the lower volcanic flow system, with the Calico Hills acting as an aquitard between the Crater Flat formation and the upper volcanic flow system within the Topopah Spring. Ground water quality in the volcanic aquifers is variable, being a complex function of many factors. The primary factor governing water quality in the volcanic rocks is the residence time of the water within the aquifer. Wells completed near recharge areas are likely to produce better quality water than those completed in areas with a long residence time. The two existing water supply wells, J-12 and J-13, are completed within the recharge area of Forty Mile Wash and thus produce water of good quality. Water beneath Yucca Mountain is generally found to be older and of poorer quality. (See Section 8.2.3.1.) The latest available data compiled by Lyles and Mihevc in 1994 (DRI94) identify over 500 domestic, agricultural, and monitoring wells in the Amargosa Valley. Past hydrogeologic studies were conducted to: (1) evaluate the water resources potential of the area; (2) evaluate the impact of ground water pumping; (3) estimate the ground water recharge; and (4) evaluate regional ground water flow. These studies are referenced in the Lyles report.

8.4.1.6 Resource Summary

Within a 30-km radius of the Yucca Mountain site, there are six active gold- and silver-producing properties in the Bullfrog and Bare Mountain mining districts to the west of Yucca Mountain. Fluorspar is also produced from the Daisy Mine in the Bare Mountain district. A small amount of mercury has been produced, at both the Thompson Mine on the north end of Yucca Mountain and at Bare Mountain. Borax is produced in the Amargosa Valley due south of the site near the California border. Uranium, geothermal, and hydrocarbon resources have not been exploited in the vicinity of Yucca Mountain; however, hydrocarbon exploration (wildcat) wells have been drilled within 20 km of the site.

Ground water in the vicinity of Yucca Mountain is currently produced from the Tertiary volcanic welded tuff units. Yields from wells constructed in fractured volcanic rocks are generally high. Ground water is also found within the underlying Paleozoic carbonate unit, but the relatively great depths and poor quality of this water preclude it from being utilized as a resource at present. The resource value of ground water in this area depends on the depth to the water (as reflected in drilling costs) and water quality. Beneath Yucca Mountain the resource value of ground water is considerably lower than in the adjacent valleys, due to the increased depth to water and somewhat poorer ground water quality.

8.4.2 Types of Human Intrusion

The NAS recommended that EPA require that the consequences of human intrusion on repository performance be analyzed and that the Agency’s standards specify a typical intrusion scenario to be used for this purpose. Selecting a scenario entails judgment. To provide for the broadest consideration of what scenario or scenarios might be most appropriate, the NAS recommended that EPA make this determination in its rulemaking. As a starting point, the NAS suggested a stylized intrusion scenario consisting of one borehole of a specified diameter drilled from the surface through a canister of waste into the underlying aquifer.

As background for selecting a scenario, the types of human intrusion scenarios that may be considered, based on current knowledge of the area’s resource potential and exploration technologies in use today, are discussed below. Table 8-13 lists likely scenarios for each type of resource currently found in the vicinity of Yucca Mountain. Further discussions of these likely scenarios follow the table.

Table 8-13. Likely Human Intrusion Scenarios for Different Types of Resources

Nature of Human Intrusion	**Petroleum or Geothermal**	**Minerals**	**Tuff Aquifer**	**Carbonate Aquifer**
(1) Borehole completed into repository		X		
(2) Borehole completed into tuff aquifer beneath repository			X	
(3) Borehole completed into carbonate aquifer and tuff aquifer beneath repository	X	X		X
(4) Aquifer testing with uncased borehole or test well			X	X
(5) Production well completed and placed into service			X	

8.4.2.1 Petroleum/Geothermal-Related Intrusion

Human intrusion resulting from the exploration for petroleum or geothermal resources would be comparable due to the depth at which the resources are expected to be found in the area around Yucca Mountain. Petroleum typically is found in the Paleozoic carbonates and the geothermal temperatures that make recovery economic are in the Precambrian basement rocks. Both resources are at depths that would require drilling through the repository horizon elevation and the tuff aquifer, and into or through the Paleozoic carbonate aquifer (Scenario No. 3, Table 8-13).

Typically, petroleum and geothermal exploration holes are cased into competent rock (unfractured and minimal porosity) to provide a seal at the surface in the event that high pressure gases or liquids are encountered during drilling. The seal is expected to withstand the pressures anticipated. It is usually a 14- to 30-inch diameter pipe, depending on the largest drill bit expected to be used, which is set and cemented in the initial borehole advanced into unfractured rock. Once the cement has set, a drill bit slightly smaller than the surface casing, typically 12 to 24 inches in diameter, is lowered to the bottom of the casing and the drill string advanced. Drilling is usually continued in the open hole (no casing) with cuttings or core samples being collected to identify the rock type being penetrated and to evaluate resource content or potential. Excess cuttings are collected in a pit adjacent to the drill rig and the fluid recirculated to flush more cuttings to the surface. In the case of air drilling methods, which are common in geothermal exploration, the air from the cutting return stream is discharged directly to the atmosphere above the cuttings pit.

There are two ways in which release of radionuclides could result from petroleum and geothermal exploration. The first involves potential releases resulting from the drill passing through the repository and associated waste, entraining or dissolving radioactive waste products, and carrying waste products to: (1) the surface in the cuttings return; (2) the tuff aquifer, once it is reached, through the drilling fluid circulation path; and (3) to the deeper carbonate aquifer, once it is reached, through the drilling-fluid circulation path. The primary mechanism for contaminating the aquifer would be the circulation of contaminated drilling fluid. Petroleum exploration drilling commonly uses the direct rotary drilling method, which pumps the drilling fluid down the center of the drill pipe, exits the bit, and flushes the cuttings up the annular space between the hole and the drill pipe to the surface. The cuttings are collected on the surface in pits.

Direct rotary air drilling methods, used to drill geothermal wells, would also discharge the cuttings to a pit, but would not recirculate contamination as readily because they do not recirculate the returning fluid. In both types of drilling, contamination can also be spread when the drill string is removed from the hole to change bits, test the formation, or abandon the hole.

The second possibility of releasing radionuclides occurs when the borehole is being abandoned and is not being sealed. In this instance, material from the breached waste area could fall through the open borehole to the aquifer zones, where it can be dissolved and transported to the environment. If the borehole fills with water, material from the repository horizon could still sink through the water column; contamination also could be circulated by density and/or thermal effects.

8.4.2.2 Mineral Exploration-Related Intrusion

Mineral exploration drilling has the potential to result in more than one intrusion scenario, as illustrated in Table 8-13. The difference among the scenarios is the depth drilled, due to the high degree of uncertainty with respect to what might be considered a mineral resource in the future. Completion of an exploratory borehole into the repository horizon (Scenario No. 1, Table 8-13) is conceivable because the radioactivity released from the repository might be detected using remote sensing instruments and be mistaken as an indication of mineral deposits. Further exploration that would require drilling might thus be undertaken.

Typically, mineral exploration drilling is performed using relatively small diameter (nominally three- to seven-inch) drills or coring bits with air or rotary wash. Mineral exploration holes are not cased, except when the near-surface materials are very unstable which could preclude keeping the top of the hole open. The potential pathways to the environment are very similar to those discussed for petroleum or geothermal exploration, with the primary difference being the size of the borehole and the associated quantity of material potentially removed and circulated. Coring is a frequently used method which provides direct visual identification of the material being penetrated and permits the evaluation of ore grade. If coring were done when the drill is penetrating the repository horizon, it would be possible for a sample of the waste material or contaminated materials from the repository to be brought to the surface.

Considering the known occurrences of mineral resources in the vicinity of Yucca Mountain, it is likely that an exploration borehole would be completed in the Paleozoic and older rocks that are beneath the volcanics that contain the repository horizon and the tuff aquifer zone (Scenario No. 3, Table 8-13). Improper abandonment (e.g., a borehole left open with no backfilling) of a borehole could create a contamination circulation route similar to that described for an abandoned petroleum or geothermal exploration hole.

8.4.2.3 Ground Water Resource-Related Intrusion

The intrusion scenarios developed for ground water resources, shown in Table 8-14, relate to exploration, aquifer testing, and well development and production.

Ground Water Exploration Drilling

Table 8-13 shows the possible borehole scenarios for the tuff aquifer (Scenario No. 2) and carbonate aquifer (Scenario No. 3). The exploration for ground water resources would probably involve a direct rotary-air or water-configured rig using a drill bit or pneumatic hammer on the order of six to eight inches in diameter. In arid regions, like the Yucca Mountain area, air drilling is commonly used to minimize the amount of water required. The exploration borehole would be advanced as rapidly as possible until the first water is noted in the return air, or an increased flow rate is identified from the annular space if water or drilling mud were used. In this case, where the repository horizon is above the aquifer, the repository materials could be penetrated and circulated to the surface for several minutes and would probably not be noticed until ground water began to be emitted from the return line or annulus. Even at this time, it is not likely that the waste material would be recognized unless some type of radiation detector were being used at the drilling site. As described in Section 8.5.2.1, the contamination would be circulated to the surface with the flow up the annular space and, if water were used, returned to the aquifer by the mud pump taking water from the settling pit. If air were used, the recirculated air would not be as contaminated, unless the compressor intake were in close proximity to the discharge line (bloey line), which would be discharging the contaminated return air and cuttings.

Additional releases of the repository waste material and mixing with the aquifer fluids could result from removing the drill string from the hole and reinserting it (tripping). This is done when drill collars need to be added or the bit must be changed. This random action depends on the depth of drilling, bit wear, and rock type and could be exacerbated by drilling through repository waste containers (creating the need for a bit change). A more common tripping of the drill string is done to recover core when a fixed core barrel is used. In this case, the drill string is removed every 30 to 48 inches of drilling, depending on the length of the core barrel, to recover the cored rock. In some instances, a wire-line coring device is used to preclude the necessity of removing the entire drill string from the hole. The core barrel is lowered inside the drill rod, attached to the bit and, once the core barrel is full, pulled to the surface using a wire line on a hoist. Wire-line coring is most frequently used in mineral exploration drilling due to the smaller core diameters (typically less than 2.5 inches) needed for mineral identification.

An improperly abandoned borehole would have consequences similar to those described in previous sections.

Aquifer Testing

Scenarios which entail aquifer testing are shown in Table 8-13 (Scenario No. 4) for the tuff and carbonate aquifers. Aquifer testing could be performed during drilling in the uncased borehole, typically done when drilling is performed using an air rotary rig. More extensive aquifer testing would be performed in a well constructed in the exploratory borehole.

Testing in the open (uncased) borehole is referred to as drill-stem testing. It is performed using the air flow from the compressor(s) to lift the water from the aquifer zone, by inserting the drill pipe near the bottom of the hole and injecting air, causing the fluid column to rise to the surface and/or entraining the water in the air stream to remove it from the borehole. This method creates a scouring action in the open borehole due to up-hole air/water mixtures reaching velocities on the order of 3,000 feet per minute (ft/min). A fluid stream moving this fast would produce erosion in the repository zone penetrated, increasing the material carried to the surface or falling into the borehole. Testing in this manner is usually of shorter duration (several minutes to a few hours) than aquifer tests performed in cased holes. In some cases, an air-lift pumping system (a pipe or drill rod with an internal air line suspended to beneath the water table but not to the end of the pipe) can be lowered into the open hole and used to test the flow.

The second testing-related scenario consists of a well constructed in the exploratory borehole for testing the potential yield and evaluating the storage capacity of an aquifer. Aquifer depths in the vicinity of Yucca Mountain are currently in excess of 244 m and would require a well of at least 12 inches in diameter to set a pump that would be capable of testing the aquifer adequately. Exploratory boreholes are not typically drilled large enough to facilitate constructing a well of this diameter, therefore, conducting a test would require increasing the size of the borehole. This action would remove more material from the breached repository area and allow it to circulate, dissolve, or slough into the borehole. Once the borehole is enlarged, a casing with well screen in the aquifer zone would be set into the borehole, gravel packed in the aquifer zone, a cement plug placed on top of the gravel pack, a bentonite slurry placed around the casing to the surface, and a cement plug placed around the upper few feet of casing to form a surface seal. This well would be constructed in the same manner as a production well, which is discussed in the next scenario. Testing would be performed by placing a pump in the screened zone of the casing and varying the pumping rate to evaluate the aquifer parameters and, after an optimum rate is selected, pumping the aquifer at that rate for several hours or days. During testing, the only release of radioactive contaminants from repository materials to the aquifer would be prior to or during well construction. After the well is constructed, the breached repository horizon would be cased with solid pipe and isolated from the fluid stream.

Ground Water Production

As shown in Table 8-13, the ground water production scenario (Scenario No. 5) is identified only with the tuff aquifer because of the depth and reported poor water quality of the carbonate aquifer. If the production of the carbonate aquifer were to be considered, the scenario would differ only in terms of drilling depth.

The construction of a production well is similar to the process described above for test-well construction, except that a production well is larger in diameter. A reverse rotary drill rig may be used for drilling production wells. In reverse rotary drilling, the fluid flows into the annular space at the surface and maintains a static head of water in the hole. The mud pump draws a suction on the drill rod and the fluid is pumped from the drill rod to the mud pit, where the

cuttings settle out and the fluid flows back into the hole. In this scenario, a potential release of radionuclides to the environment could occur during the drilling of the well as contaminated fluid is circulated from, and later past, the repository horizon, into the mud pit, and ultimately into the aquifer zone. Once the well is constructed, the repository horizon is isolated by packings and the primary source of contamination would be residual fluids in the well and aquifer.
After well construction is completed, the casing is pumped and surged to remove residual drilling fluids from the aquifer and to develop a loose aggregate at the pumping level. This removes the residual fluids from the casing. Well testing may be conducted to confirm a well's performance prior to placing it into production. This will also flush the aquifer zone, with the fluids from all testing typically being discharged to a natural drainage feature, the mud pit, or the ground surface in the vicinity of the well. After all testing is completed, the well is connected to a distribution system and placed into service. Well water could be a sole source supply for a commercial application or combined with several other wells in a large facility or municipal supply system.

8.4.3 Parameters and Assumptions Associated with Ground Water Withdrawal

The potential exposure to radiation associated with ground water withdrawal results from the contamination of the aquifer being pumped. The aquifer considered for ground water withdrawal in the vicinity of Yucca Mountain is the tuff aquifer. The primary parameters necessary to assess the consequences of intrusion are the aquifer pumping rate, the duration of pumping, aquifer properties, the degree to which the aquifer has been contaminated, and the nature of the contaminants.

Production wells are typically large in diameter (16 to 36 inches) to accommodate multistage turbine pumps that can lift water from the aquifer zone at the optimum flow rate, which can range from 500 to 1,500 gpm. For example, the intrusion scenario used by Sandia National Laboratories in TSPA-93 (DOE94a) assumed that a production well drilled using a 24-inch bit intersected the repository.

Pumping rates ranging from 300 to 700 gpm were used for USGS tests at the Nevada Test Site. The tuff aquifer was pumped at 370 gpm for four days at one well location and 697 gpm for four days at another well (USG72).

The assumed pumping duration for a production well would be based on how many gallons per day would be necessary to supply the user. This value would determine the duty cycle of the pump required. For example, pumping a well at 770 gpm continuously would produce one million gallons per day. In a production or test well, the screened zone would be the only source of contamination because the repository horizon above the aquifer would be cased with pipe to facilitate transporting water to the surface. Assumptions would be required for the well-drilling scenarios (air or water) to assess the amount and nature of residual contamination in the aquifer zone, if the well were eventually used as a supply. Significant factors would include the nature of the permeability (i.e., primary porosity or fractures), physical and chemical properties of the tuff aquifer (i.e., adsorption and redox potential), and secondary mineralization and its influence on radionuclide transport. Assumptions regarding the contaminants that have been introduced into the aquifer either as solids or in solution would be equally important.

8.4.4 Parameters and Assumptions Associated with Human Intrusion

There are three categories of future human intrusion events:

- Inadvertent intrusion in which the intruder does not recognize that a hazardous situation has been created. This category has been the focus of discussion in the context of standard-setting and licensing.

- Inadvertent intrusion in which the intruder recognizes that a radioactive waste repository has been disrupted and takes corrective actions. On the assumption that the corrective measures taken are effective and the repository is sealed, this category is not of concern. If, however, corrective actions are not taken or are ineffective, this type of intrusion is operationally the same as the above category.

- Intentional intrusion for either beneficial or malicious purposes. The NAS report considers it presumptuous to try to protect against the risks arising from the conscious activities of future human activities. However, given the potential energy value of the wastes intended for Yucca Mountain, this category of intrusion scenarios might be likely.

Two broad categories of risk could result from the release of radioactive material due to an intrusion into the repository of the type characterized by borehole scenarios. These categories are:

- Risks from materials brought directly to the surface by the intrusive activity.

- Risks that arise from improper abandonment of an exploratory borehole that could compromise the integrity of the repository's engineered or geologic barriers.

Radioactive materials brought directly to the surface by intrusive activity would likely pose hazards to the intruders themselves and to the public. The NAS concluded that analyzing these risks is unlikely to provide useful information about a specific repository site or design and, therefore, should not provide a basis for judging the resilience of the proposed repository to intrusion (NAS95). Accordingly, the NAS recommended that these risks not be considered in the compliance analysis. For these reasons, discussions of parameters and assumptions associated with these types of scenarios are not presented in the BID.

Long-term consequences would result from the abandonment of a borehole that had intersected repository waste without plugging it with impermeable material. The importance of this scenario, as suggested by the NAS, is that it could create enhanced pathways to the environment (both air and ground water). The fact that the scenario could also breach a waste canister is less significant because this will happen eventually even without human intrusion (NAS95).

8.4.4.1 Factors of Consideration

To evaluate the human intrusion scenarios, the following factors or parameters must be evaluated and the associated assumptions made.

Institutional Controls

According to the NAS report, there is no scientific basis for making projections over the long-term of either the social, institutional, or technological status of future societies. There is no scientific basis from which to project the durability of government institutions over the period of interest, which exceeds that of all recorded human history. Some degree of continuity of institutions, and hence of the potential for active institutional controls, into the future might be expected, but there is no basis in experience for such an assumption beyond a time scale of centuries. Similarly, there is no scientific basis for assuming the long-term effectiveness of active institutional controls to protect against human intrusion.

Furthermore, according to the NAS report, there is no scientific basis for making forecasts about the reliability of passive institutional controls. The likelihood that markers or barriers would persist, be understood, and deter intrusion cannot be assessed from a technical basis (NAS95).

Drill Depth and Hole Size

As noted by the NAS, it is not feasible to predict which natural resources will be discovered or will become valuable enough to be the object of an intruder's activity. The characteristics of future technologies for resource exploration and extraction also cannot be predicted (NAS95). The availability of such information would affect the assumptions of drill depth and hole size.

Based on current practice, typical diameters of exploration boreholes and depths of penetration are as shown in Table 8-14.

Table 8-14. Typical Borehole Characteristics (Source: CNW96)

Types of Exploration	Hole Size (inch)	Drill Depth
Petroleum/Geothermal	12 - 24	carbonate aquifer
Mineral	3 - 7	carbonate aquifer
Ground Water	6 - 8	tuff or carbonate aquifer

Number of Boreholes and Borehole Location

Generally, resource exploration utilizes remote sensing, topographic, and geologic information to select drilling locations. However, when investigating a broad area like the Yucca Mountain region, the spacing of exploration boreholes will vary for the various types of resources. Petroleum and geothermal resource exploration is performed to detect regional or structural trends that can extend for tens or hundreds of miles. Thus exploration drilling typically involves a single hole in a region or within a geologic structural trend. Mineral exploration is carried out in an orderly manner, usually employing a grid. The initial grid size, when regional resources are being evaluated (instead of localized vein-type deposits), may be a mile or more on center for boreholes. The grid spacing is decreased only if economic levels of target minerals are detected, which is not expected to be the case in the immediate vicinity of Yucca Mountain. Borehole locations could be on mountain tops or in the low areas.

Exploration for ground water resources can be focused based on surface features or convenience to a user and, in such case, the exploration wells are typically clustered or linearly spaced a mile or more apart. For regional investigations of ground water resource potential, randomly and widely-spaced boreholes are commonly used. In such case, a density of one well per 2,000 km^2 is reasonable; this provides adequate information on the nature and presence of a ground water resource. In the Yucca Mountain area, the most likely locations for ground water exploration are the drainage basins that surround Yucca Mountain.

In terms of the number of boreholes to be assumed in the scenario, the NAS report suggests a stylized intrusion scenario consisting of only one borehole. A single borehole scenario holds the promise of providing considerable insight into repository performance. Under many conditions, the effect of multiple boreholes presumably would be the sum of the effects of each taken separately, but circumstances when this assumption is invalid can also be conceived. Because construction of the scenario is arbitrary, the NAS report argues for the simplest case that evaluates repository performance (NAS95).

In determining the location of the borehole, the stylized single borehole scenario suggested by the NAS postulates drilling from the surface through a canister of waste to the underlying aquifer. The emphasis would be on the creation of enhanced pathways to the environment as opposed to breaching the canister, which will happen eventually even without human intrusion.

Borehole Sealing

According to the NAS report, the characteristics of future technologies for resource exploration and extraction, and whether future practice will include sealing of physical intrusions such as boreholes, cannot be predicted (NAS95).

A common practice in current exploration drilling is to leave the borehole open and allow it to backfill naturally or assume the mud drilling fluid will act as a sealant. For air rotary drilling, there is no drilling fluid filler. For mud rotary drilling, the mud drilling fluid may lose its effectiveness as a sealant if the mud shrinks excessively as it dehydrates.

In an open abandoned borehole, the most likely materials to cause natural backfilling are the loose granular surface materials or friable or loose tuffaceous formations. The only way that the tuffaceous material could be loosened to fall into the open borehole would be by erosion (running water), mechanical impact (scraping, etc.), or shock (seismic waves). If loose surficial materials were washed or ran into the open hole, backfilling of an abandoned borehole could take place relatively quickly. On the other hand, if the loose surface materials or materials from the borehole wall were too large to fall freely, they could plug or bridge (stick together) in the borehole. In such case, the top of the hole could be plugged, precluding backfilling.

Time of Drilling

According to the NAS report, the predictions for how long into the future institutional controls might survive and remain effective are arguable. The probability that an intrusion would occur in a given future time period, such as in any one year, cannot be assessed from a technical basis (NAS95).

Detection of Repository

Two drilling companies were contacted to determine the likelihood that an intact waste canister could be penetrated with a drill being used in a conventional drilling operation. Mr. Leroy Jochum (VIC96) stated that, irrespective of bit type (carbide, diamond, etc.) the drill would not penetrate the canister but would most likely be deflected. If the driller wanted to penetrate the canister, tools could be fabricated to cut the steel, but deliberate effort would be needed and it would take a long time.

Mr. John Horton (LAY96) also indicated that special effort would be required to penetrate the canister. It would require a concerted effort by the driller, possibly involving modification of the bit and a considerable amount of time. He mentioned laser/plasma drilling technology that is being developed by companies involved with DOE’s Hanford Site in Washington State, and stated that future technology might be able to penetrate a waste canister if adequate energy could be applied to the drilling face.

These professional opinions indicate that present-day drilling technology could only penetrate a waste canister if the driller was dedicated to doing so. Conventional drilling methods, without special tools or spending an inordinate amount of time and effort, would not be able to breach the canister. The possibility does exist that future technologies could do so, but it is not likely to be easy. It is conceivable that the radioactivity produced by the repository could be detected using remote sensing instruments and prompt further investigation.

In summarizing this issue, the NAS report concluded that the probability that a future intrusion would be detected and remediated, either when it occurs or later, cannot be assessed from a technical basis (NAS95).

Mechanism for Waste to Reach the Aquifer

In addition to the assumptions regarding the borehole, the contamination conditions intercepted by the borehole mechanism by which the contamination is transported to the aquifer must also be assumed in order to assess the source term.

8.4.4.2 Scenario Examples

As mentioned previously, the NAS report suggested a stylized intrusion scenario consisting of one borehole of a specified diameter drilled from the surface through a canister of waste to the underlying aquifer (NAS95). Two examples of such a scenario are described below.

Example 1

The NAS report provided an example of a scenario which postulates current drilling technology, but assumes sloppy practice, such as not plugging the hole carefully when abandoning it. It is assumed that the intrusion occurs during a period in which some of the canisters will have failed, but the released materials would not otherwise have had time to reach the ground water. In this example, the original hole size, the modification of hole size by natural processes, and the mechanism and processes for waste to reach the aquifer must be assumed or analyzed.

Example 2

A hypothetical, non-mechanistic scenario is another example. In this scenario, the entire content of a single waste canister is emptied through the abandoned borehole into the aquifer. Evaluation of drilling technology, drill size, modification of hole size by natural processes, and the mechanism and processes for waste to reach the aquifer is unnecessary for this scenario.

8.4.4.3 Consequence Analysis

Having defined the reference scenario, the principal questions remaining are: (1) What consequences should be assessed? and (2) How should the results be interpreted?
According to the NAS, the consideration of human intrusion cannot be integrated into a fully risk-based standard because the results of any analysis of increased risk as a consequence of intrusion events would be driven mainly by unknowable factors. The numerical value of the risk of adverse health effects due to intrusion is the product of the frequency of an intrusion scenario

and the measure of consequences. However, the frequency of an intrusion scenario in the distant future cannot be determined in a technically-rigorous and defensible manner.

The NAS recommended that the Yucca Mountain standard require a consequence-only analysis, without attempting to determine an associated probability for the analyzed scenario. The calculations of consequences would provide useful information about how well a repository might perform after an intrusion occurs. Such an analysis would evaluate whether the repository would continue to be able to isolate wastes from the biosphere, or if its performance would be substantially degraded as a consequence of an intrusion of the type postulated.

According to the NAS report, the performance of the disturbed repository should be assessed using the same analytical methods and assumptions (including those about the biosphere and critical groups) as those used in the assessment of the performance for the undisturbed case. This analysis should be carried out to determine how the hypothesized intrusion event affects the risk to the appropriate critical groups. The results of this calculation, however, constitute a conditional risk, that is, one based on the occurrence of a hypothetical intrusion.

Because the probability of intrusion is inherently unknowable, the most useful purpose of this type of analysis is to evaluate the incremental consequences resulting from an assumed scenario. Since human intrusion of some type may be likely to occur in the future, the design of a repository should be resilient to at least modest inadvertent intrusions. In other words, a repository that is suitable for safe, long-term disposal of waste should be able to provide acceptable waste isolation despite some type of intrusive event.

The NAS report recommends that EPA require that the conditional risk resulting from the assumed intrusion scenario should be no greater than the risk levels that would be acceptable for the undisturbed repository case. It is further recommended that compliance analysis not include risks to the intruder or those arising from the material brought directly to the surface as a consequence of the intrusion.

The following sections discuss the potential pathways of exposure that could occur using a borehole scenario, as well as the consequences of intrusion occurring during specific time periods of repository performance.

Ground Water Pathway from Abandoned Borehole

The location of the assumed borehole is a very important factor in evaluating its effects on repository performance and radionuclide transport through ground water. The closer the borehole location is to the boundary of the repository footprint and the location of the critical group, the less time would be required for radioactive materials to travel to the critical group. Consequently, a specific exposure scenario, with an appropriate critical group, would be required for evaluating the ground water pathway from an abandoned borehole.

Air Pathway from Abandoned Borehole

In addition to the ground water pathway, an uncapped, abandoned borehole that penetrates into the repository could provide a path for waste materials to be released to the atmosphere. The radionuclide of primary concern for this air release pathway is carbon-14 (^{14}C). The travel time for gaseous releases would depend on the location of failed waste canisters in relation to the abandoned borehole and the manner in which the repository's openings have been backfilled.

Maximum exposures would occur from ^{14}C released from waste canisters that fail relatively early. In comparison with natural pathways that exist at the Yucca Mountain site, an uncapped, abandoned borehole would have an insignificant incremental effect on gaseous transport routes to the surface. Although the presence of a borehole would not change the total release of ^{14}C to the surface, it could affect the routes used. Consequently, the effect of the borehole on potential exposures to the public would be highly dependent on the assumed location of an exposed individual(s) relative to the borehole and the time at which nearby waste canisters failed.

For these reasons, it is concluded that the air pathway need not be considered as a measure of repository performance in evaluating human intrusion scenarios.

Waste Materials Brought to the Surface by Human Action

The radioactive materials brought directly to the surface by the intrusive activity would pose hazards to the intruders themselves and to the public. According to the NAS report, whenever highly dangerous materials are gathered into one location and an intruder inadvertently breaks in, that intruder runs an inevitable risk. Therefore, it would not be feasible to take regulatory actions today to protect future intruders from the risk of their actions. However, requirements for active or passive institutional controls may provide some protection by decreasing the likelihood of inadvertent intrusion.

The DOE containment and isolation strategy defines three post-emplacement time periods: the containment period, in which the waste canisters remain intact; the transition period, during which canister failure and waste mobilization are gradually increasing; and the peak dose period, in which the canisters have failed and seepage of water into the repository is mobilizing the waste radioactivity and transporting it to the environment. The physical condition of the repository will change throughout these time periods and affect the circumstances of an intrusion scenario, as outlined below.

Intrusion During the Containment Period

During the containment period, the waste containers remain intact. An intrusion of the repository by drilling will either intercept an intact container or miss completely. If there is no interception of a container, there will be no evidence to the drillers that a waste repository has been penetrated. If an intact container is intercepted, it is unlikely that the drill bit will be able to penetrate the container easily. Advance of the drill bit will be stopped or severely slowed, leading to investigation of the cause for the resistance. If drilling persists, metal will be evident in the cuttings and it will suggest that something unusual has occurred. Drilling may continue as part of an investigation of the circumstances encountered, in which case portions of the container and the waste form intercepted by the drill bit will be brought to the surface and exposure of workers may occur. Alternatively, the drilling effort at that location may be abandoned with no radiological consequences.

Intrusion After Initiation of Container Degradation

During the transition period, containment degradation is occurring as a result of corrosion of the container and waste form caused by infiltration of water to the repository. A drilling intrusion of the repository might encounter an intact container, a partially degraded container, materials between the containers that contain no radioactivity and thus give no evidence of the existence of the repository, or materials between containers that contain radioactive waste material that has been mobilized and has migrated some distance from the emplacement location.

This latter type of encounter would give no indication of the existence of the repository unless the drilling cuttings were being monitored for radioactivity. An encounter with an intact or partially-degraded container would produce circumstances such as those described above for the containment period, i.e., an effect on drilling progress, metal in the cuttings, and investigation of the situation or abandonment of the drill hole.

Intrusion During the Peak Dose Period

In the peak dose period, it can be assumed that all containers have failed and all metals have oxidized. The repository conditions will be similar to that of an ore body, with pockets of radioactive materials at locations where containers used to be and radioactivity dispersed throughout the repository. Depending on the extent of lateral migration and dispersion of mobilized radioactivity from the waste, there may still be areas between the emplacement locations where no radioactivity is present.

Under these circumstances, there may be nothing to suggest to a drilling operation that a radioactive waste repository has been penetrated. Evidence might be available if cuttings are being monitored for radioactivity or if it is noticed that some of the cutting materials are composed of oxides of waste package materials. If neither of these pieces of evidence is recognized, drilling operations will proceed as planned.

In summary, the consequences of intrusion, as an incremental effect on expected repository performance, will depend on when the intrusion is assumed to occur. If, for example, intrusion is assumed to occur late in the containment period, the effect on expected waste isolation performance could be relatively significant because no releases are otherwise expected to occur. However, the risks (probabilities and consequences) associated with such a scenario could be extremely small. If the intrusion is assumed to occur in the peak dose period as defined by DOE's waste isolation strategy, it may have an incrementally insignificant impact on repository performance because radionuclide release is already occurring as a result of ongoing degradation, release, and transport processes.

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