NUREG-1710
Vol. 1

History of Water Development in the Amargosa Desert Area: A Literature Review

U.S. Nuclear Regulatory Commission
Advisory Committee on Nuclear Waste
Washington, DC 20555-0001

AVAILABILITY OF REFERENCE MATERIALS IN NRC PUBLICATIONS

NRC Reference Material

As of November 1999, you may electronically access NUREG-series publications and other NRC records at NRC's Public Electronic Reading Room at http://www.nrc.gov/reading-rm.html. Publicly released records include, to name a few, NUREG-series publications; *Federal Register* notices; applicant, licensee, and vendor documents and correspondence; NRC correspondence and internal memoranda; bulletins and information notices; inspection and investigative reports; licensee event reports; and Commission papers and their attachments.

NRC publications in the NUREG series, NRC regulations, and *Title 10, Energy*, in the Code of *Federal Regulations* may also be purchased from one of these two sources.

1. The Superintendent of Documents
   U.S. Government Printing Office
   Mail Stop SSOP
   Washington, DC 20402–0001
   Internet: bookstore.gpo.gov
   Telephone: 202-512-1800
   Fax: 202-512-2250
2. The National Technical Information Service
   Springfield, VA 22161–0002
   www.ntis.gov
   1–800–553–6847 or, locally, 703–605–6000

A single copy of each NRC draft report for comment is available free, to the extent of supply, upon written request as follows:

Address: Office of the Chief Information Officer,
Reproduction and Distribution
Services Section
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
E-mail: DISTRIBUTION@nrc.gov
Facsimile: 301–415–2289

Some publications in the NUREG series that are posted at NRC's Web site address http://www.nrc.gov/reading-rm/doc-collections/nuregs are updated periodically and may differ from the last printed version. Although references to material found on a Web site bear the date the material was accessed, the material available on the date cited may subsequently be removed from the site.

Non-NRC Reference Material

Documents available from public and special technical libraries include all open literature items, such as books, journal articles, and transactions, *Federal Register* notices, Federal and State legislation, and congressional reports. Such documents as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings may be purchased from their sponsoring organization.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at—

The NRC Technical Library
Two White Flint North
11545 Rockville Pike
Rockville, MD 20852–2738

These standards are available in the library for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from—

American National Standards Institute
11 West 42nd Street
New York, NY 10036–8002
www.ansi.org
212–642–4900

Legally binding regulatory requirements are stated only in laws; NRC regulations; licenses, including technical specifications; or orders, not in NUREG-series publications. The views expressed in contractor-prepared publications in this series are not necessarily those of the NRC.

The NUREG series comprises (1) technical and administrative reports and books prepared by the staff (NUREG–XXXX) or agency contractors (NUREG/CR–XXXX), (2) proceedings of conferences (NUREG/CP–XXXX), (3) reports resulting from international agreements (NUREG/IA–XXXX), (4) brochures (NUREG/BR–XXXX), and (5) compilations of legal decisions and orders of the Commission and Atomic and Safety Licensing Boards and of Directors' decisions under Section 2.206 of NRC's regulations (NUREG–0750).

NUREG-1710
Vol. 1

History of Water Development in the Amargosa Desert Area: A Literature Review

Manuscript Completed: May 2004
Date Published: February 2005

Prepared by
M.P. Lee*, N.M. Coleman*, and T.J. Nicholson**

* Advisory Committee on Nuclear Waste Staff

** Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research

U.S. Nuclear Regulatory Commission
Advisory Committee on Nuclear Waste Staff
Washington, DC 20555-0001

NUREG-1710, Volume 1, has been reproduced from the best available copy.

ABSTRACT

Historic accounts, geologic treatises, and other key literature sources were used to identify factors that contributed to the development of local ground-water resources in the Amargosa Desert area during the past 150 years. The literature suggests that the earliest sources of fresh water supply were the abundant, naturally occurring artesian springs in *Ash Meadows*. The first hand-dug well in the area was the *Franklin Well*; it was dug in 1852 for workers performing a survey of the California-Nevada State line. The first mechanically bored wells were drilled in valley-fill (alluvial) deposits for local railroads, along their respective alignments, sometime between 1905-07. About 1917, the first irrigation well was drilled for an experimental farm - the *T&T Ranch*. In the late 1940s-early 1950s, permanent interest in the area was established, in large measure because of Federally-sponsored desert reclamation programs. However, designation of local aquifers as "protected," in 1979; limiting soil conditions; and other factors have curtailed local agricultural development. Because of economic and technical factors, alluvial aquifers have historically been the most important sources of ground-water supply. In general, drilling activity historically preceded geologic understanding of the ground-water resource.

This report is the first volume in the NUREG-1710 series.

CONTENTS

FIGURES

TABLES

APPENDICES

CONVERSION FACTORS

The preferred system of measurement today is the metric system, or the "Systèm Internationale (SI)." However, for some physical quantities, many scientists and engineers (as well as drillers) prefer the familiar, and continue to use inch/pound units (the so-called U.S. customary system). Therefore, for ease of comparison with existing drilling practice, in this regard, inch/pound units will be used in this report.

Multiply	By	To obtain
inch (in)	2.54	centimeter
feet (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
gallon	0.00379	cubic meter
acre	0.04047	hectare
gallons per day (gpd)	0.00379	cubic meters per day
barrel (31 gallons)	0.11924	cubic meter
acre-foot (acre-ft)	1233	cubic meter
acre-foot per year (acre-ft/yr)	1233	cubic meter per year
gallons per minute (gpm)	0.00379	cubic meters per minute
short ton (2000 pounds)	6.350	kilograms

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C = (°F - 32)/1.8.

ACKNOWLEDGMENTS

The authors wish to thank several individuals who provided useful information, comments, and reviews that have enhanced the substance of this report as it was being developed. These individuals include:

John Bradbury (NMSS)
David Brooks (NMSS)
Jeff Ciocco (NMSS)
Brett Leslie (NMSS)
Latif Hamdan (NMSS)
Larry McKague (CNWRA)
Gordon Wittmeyer (CNWRA)

In addition, several individuals were helpful in locating some of the references cited in this report. They include Harold Drollinger (Desert Research Institute/Las Vegas), Chad Glenn (NMSS), Charles Gorday (NRC Library Services Branch/Office of the Chief Information Officer), Tim Gunter (DOE), Darlene Higgs (NMSS), Vivian Mehrhoff (NMSS), and Eric Smistad (DOE). Ellen Kraus (NMSS) provided editorial guidance.

Lastly, the authors also appreciate the conversations and assistance provided by Jackie Gratton, of the Bureau of Land Management (BLM — Las Vegas), who provided information on BLM planning activities in Southern Nevada.

These individuals do not necessarily approve, disapprove, or endorse the views expressed in this report. The views expressed herein are the authors' and do not reflect an NRC staff position, or any judgment or determination by the Advisory Committee on Nuclear Waste or the NRC, regarding the matters addressed or the acceptability of a license application for a geologic repository at Yucca Mountain.

ABBREVIATIONS

ACNW	Advisory Committee on Nuclear Waste
AEC	Atomic Energy Commission
BLM	Bureau of Land Management
CNWRA	Center for Nuclear Waste Regulatory Analyses
CRWMS M&O	Civilian Radioactive Waste Management System Management and Operating (contractor to DOE)
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ERDA	Energy Research & Development Administration
EWDP	Early Warning Drilling Program (of Nye County, Nevada)
FEIS	Final Environmental Impact Statement
LV&T	Las Vegas and Tonopah Railroad
NAFR	Nellis Air Force Range Complex
NDWR	Nevada Division of Water Resources
NMSS	Office of Nuclear Material Safety and Safeguards
NRC	U.S. Nuclear Regulatory Commission
NPS	National Park Service
NRDS	Nuclear Rocket Development Station
NTS	Nevada Test Site
SCP	Site Characterization Plan
SCS	Soil Conservation Service
TEI	Technical Evaluation Investigation
T&T	Tonopah and Tidewater Railroad
T and R	township and range
URL	uniform resource locator (on the Internet)
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

1. INTRODUCTION

In 1878, American explorer John Wesley Powell prepared the *Report on the Lands of the Arid Region of the United States* (Powell, 1878).[1] During the preceding two decades, Powell had cris-crossed portions of the Nation, west of the 100th meridian, as part of his geologic, geographic, and ethnologic reconnaissances. He noted that most of these lands were arid, receiving less than 20 in of rain annually. Moreover, he noted that most of the lands were public, and private interests had already claimed most of the favorable irrigable sites for farming. Shortly thereafter, Powell conceived of the notion to reclaim the estimated "... 1,300,000 square miles of these arid lands through irrigation" for beneficial use. Empirically, he knew that society possessed a great deal of practical knowledge about hydraulic engineering (e.g., Rouse and Ince, 1957; Mabry, 1996), and there were many historic as well as archeological examples of where hydraulic works were constructed to divert water for household and agricultural use (Landels, 1978; Scarborough, 2003). To achieve similar results in the Western United States, Powell believed that what was needed was an irrigation survey. The survey would consist of topographic mapping to plot the catchment basins (i.e., drainage systems), followed by hydrographic measurements of stream flow, and finally an engineering analysis to determine the feasibility of constructing hydraulic structures to manage water supplies.

After a number of water-related adversities in the Great Plains, in the 1870s and the early 1880s (Reisner, 1986; pp. 104-119), Congress ultimately agreed to Powell's proposal in 1888, with the creation of a Federal *Irrigation Survey*[2] (Frazier and Heckler, 1972; p. 5). During the Western drought of 1892-1904 (Gatewood and others, 1964; p. B28), Congress passed additional legislation in the form of the *Federal Reclamation Act of 1902*, which established the forerunner of the U.S. Bureau of Reclamation, to continue such work.

Water availability has been a long-standing issue in the history of the arid regions of the United States (Reisner, 1986). Natural rainfall is generally insufficient for farming. Most western water supplies originate as precipitation in the Sierra Nevada Mountains with little, if any, precipitation generated in the lowlands. There are few perennial or intermittent streams present. In Southern Nevada, for example, the only major occurrences of surface water are cold artesian springs and the *Colorado River* (and its impoundments). There are many ephemeral stream channels present that are associated with the major drainage systems, such as the *Amargosa River*. Storm runoff occurs irregularly between October and May in response to convective weather fronts that begin in the subpolar North Pacific Ocean (Burbey and Prudic, 1991; p. D7). As a consequence, stream discharge rates for drainage systems can vary greatly in magnitude. Some drainage systems, such as the Amargosa River, are almost always dry.[3]

On arriving in the arid Southwest, Euro-American pioneers initially adopted Native American practices to obtain fresh water. Later, during the Industrial Revolution, water-management practices from the mining industry were modified to supply the agricultural and municipal water

[1]Also see Stegner (1962).

[2]The predecessor of the current U.S. Geological Survey (USGS).

[3]The Amargosa River has flowed uninterrupted from its headwaters on and around the Nevada Test Site (NTS) to its distal end in Death Valley (California) only twice since 1995 (Stonestrom and others 2003; p. 19). Springs cause short reaches of the Amargosa River (i.e., the *Carson Slough*) to be perennial to intermittent in their flow.

requirements of growing western communities. Advances in drilling and pumping technology were adopted from the petroleum and natural gas industry at the beginning of this century. These advances, combined with increased geologic knowledge, were ultimately instrumental in exploiting heretofore inaccessible ground water. The history of water development in the Amargosa Desert area generally follows this model.

1.1 Purpose of Report

The purpose of this report is to summarize the history of water development in the Amargosa Desert area. Current residents in the area acquire their drinking water almost exclusively from local ground-water supplies. Previous studies (Duguid and others, 1994; National Research Council, 1995; Mackin and others, 1997; and U.S. Environmental Protection Agency – EPA, 1999) suggest that a potential exposure scenario for a receptor population near Yucca Mountain is at some point hydrologically down-gradient from the site, in the rural community of Amargosa Valley, to the south, through the ground-water/food-ingestion pathway. Although factors affecting the development and use of ground water have been examined in the past for several arid Western states (e.g., Clark, 1987; Hundley, 1992; Kupel, 2003), based on a review of the literature, such factors have not been examined for Nevada, in general, and the Amargosa Desert area[4] in particular. Consequently, the primary authors (Lee and Coleman), while formerly members of the U.S. Nuclear Regulatory Commission (NRC) staff, performed a review of the literature, both printed and electronic, to identify key references. After completion of that review, it was determined that it would be useful to summarize this information in a synthesis report, as a way to preserve institutional knowledge on this subject.

The history of the area has been the subject of previous studies, for other reasons [e.g., Steward (1938); Worman (1969); Pippin and Zerga (1983); Lingenfelter (1986); McCracken (1990a, 1992a, 1992b); Stoffle and others (1990); Myrick (1992); Drollinger and others (1999); and Hartwell and Valentine (2002)].The Energy Research & Development Administration (ERDA – 1977) and the U.S. Department of Energy (DOE) conducted environmental assessments over the years (DOE, 1984, 1986, 1996, 2002a), for which some information on local water use was reported. Land and water-use practices were the subject of preliminary study by DOE (1988a) following the designation of Yucca Mountain by Congress as a candidate site for a geologic repository for the disposal of radioactive waste. More recently, EPA (1999) continued to examine land and water-use practices as part of the development of its radiation protection standards for the potential geologic repository. In preparing this report, the authors relied on these and other key sources to construct a chronological framework for crafting the discussions.

Other key sources included the following: *The History of Technology* series, published by the Cambridge University Press, provided information on archetypical developments in pumping and drilling technology; mineral resource and water supply reports prepared by both the Nevada Department of Mines, Nevada Department of Conservation and Natural Resources, and the USGS; and archeologic reports prepared by the Desert Research Institute and the Los Alamos National Laboratory. These sources were also quite helpful in reconstructing the history described in the following pages. Drilling records maintained by the Nevada State Engineer and the USGS were another source of information that was used. No proprietary or unpublished data sources were reviewed – only information in the public domain has been cited.

Finally the views expressed herein are the authors'. They do not reflect an NRC staff

[4]Sometimes more commonly referred to as the *Amargosa Valley*.

position, or any judgment or determination by the Advisory Committee on Nuclear Waste or the NRC, regarding the matters addressed or the acceptability of a license application for a geologic repository at Yucca Mountain.

The use of firm, trade, and brand names in this NUREG is for identification purposes and does not constitute endorsement by the NRC.

1.2 Geographic Setting

The Amargosa Desert is a valley located in Southern Nye County, Nevada. It is bounded by Clark County to the east and Lincoln County to the west. To the south is Inyo County, California. The valley geographically satisfies the definition of a "desert" because of high local temperatures and low precipitation. This valley occurs at the northern margin of the greater *Mojave* (or *Mohave*) *Desert* of Southern Nevada where it transitions to *the Great Basin Desert*, to the north (Jaeger, 1957; pp. 123-158). This valley covers an area of about 900 mi^2 in Nye County and 470 mi^2 in Inyo County, and is a subbasin of the generally larger *Death Valley drainage basin*. A large part of the area is dominated by the Nellis Air Force Range Complex (NAFR) and NTS; public access to both is restricted. See Figure 1. The valley also corresponds approximately to the *Amargosa Desert hydrographic basin* (Rush, 1968), used to delineate areas or regions or subject to water-resource investigations in Nevada.

Interstate Highway 95 traverses the area and connects the city of Las Vegas (Clark County), in the east, with the major population centers found in the northwestern portions of the State (e.g., Beatty, Goldfield, and Tonopah). State Highways 16, 29, and 58 extend southward from Highway 95, in whole or in part, and connect the interstate with the California highway system. The area also contains lesser paved and unpaved roads that are connected to these highways. There are no longer railroads in the area, although some communities, including NTS, do have small airfields.

Nye County is largely rural (less than 1 person per square mile) and occupies about 16 percent of the State (in terms of area). The population distribution is uneven and confined to discrete rural locations. A few communities have populations in excess of 1000 people; however, these "communities" are in fact collections of isolated farms and ranches, mining settlements, or commercial centers. Nevertheless, some of these may be regarded as "commuter or bedroom" communities. All of these communities are located within the system of roads described above. Approximately 13,000 people live within 62 mi of NTS. About 70 percent of the local population live in four major communities — *Beatty*, *Indian Springs*, *Amargosa Farms*, and *Amargosa Valley* (including *Lathrop Wells*). About 1500 individuals (DOE, 1999; p. 3-80) reside in about 500 households in the Amargosa Farms-Amargosa Valley communities [Civilian Radioactive Waste Management System (CRWMS) Management and Operating (M&O) Contractor, 2000; p. 10]. A significant percentage of the local population may be transient (e.g., seasonal workers) – in the past reportedly ranging from 20 to 25 percent (DOE, 1986; p. 3-102).

Before the Second World War, the area was sparsely inhabited. Since then, the size of the population in the area has been most influenced by the level of activity at the two largest regional employers — NTS and NAFR. However, over the past two decades, tourism and leisure, together, have fast become a major industry in the southern portion of the State, particularly in the Las Vegas area, and many local residents now earn a living in this growing sector of the economy.

The climate in the region is caused by the *rain shadow effect* from the Sierra Nevada Mountains and the Transverse Range. As noted earlier, the area is classified as a mid-

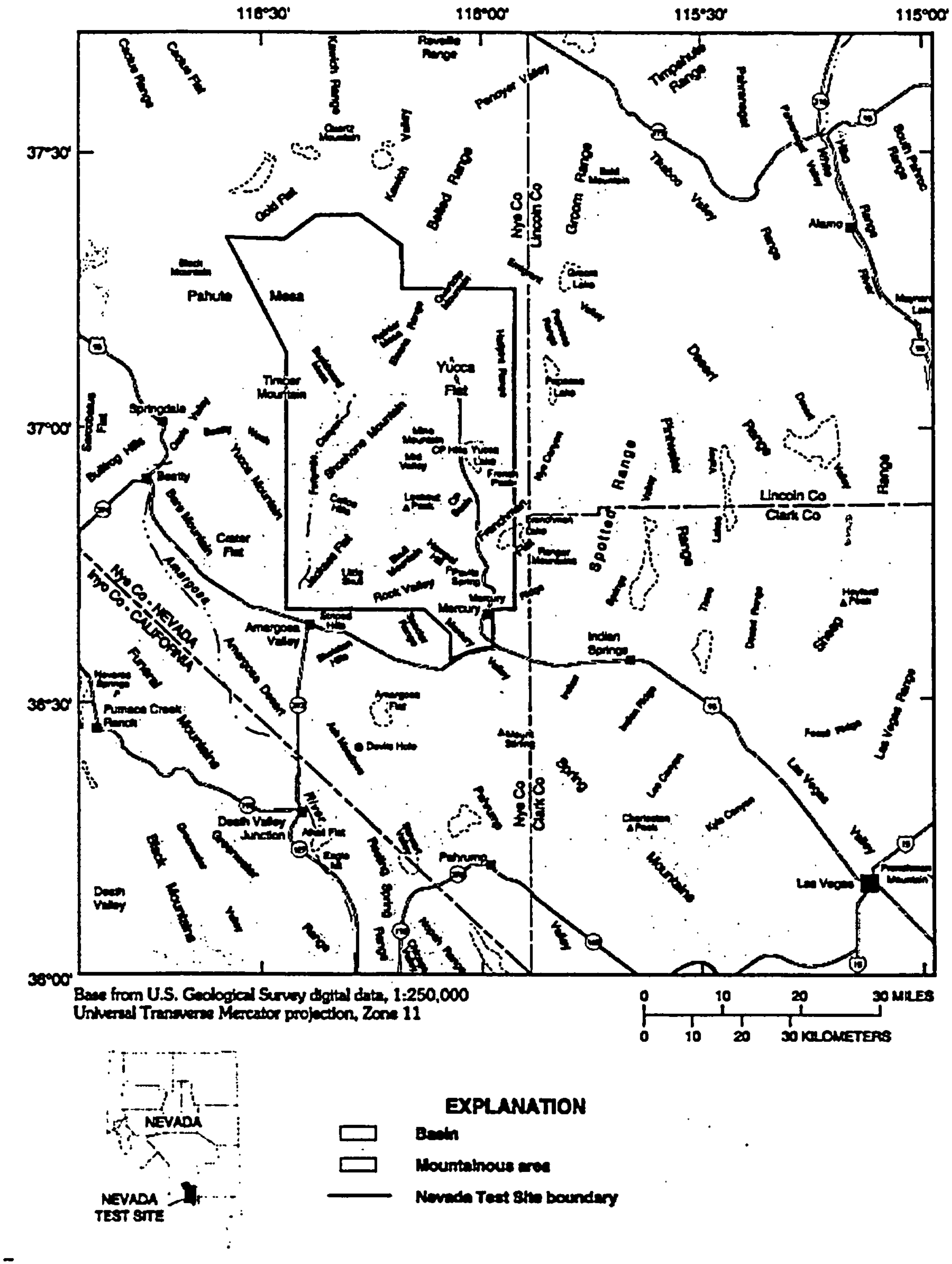


Figure 1. Location Map of the Amargosa Desert Area. Taken from Laczniak and others (1996).

latitude desert because of its high temperatures and low annual rainfall, thus making it one of the most arid regions in the conterminous United States (Geraghty and others, 1973; Plate 3). Local temperatures range from an average daily minimum of about 27 degrees Fahrenheit (°F), in January, to an average daily maximum of over 99°F in July, with wide daily and seasonal variations. The humidity is low and wind movement moderate most of the year. Rainfall distribution is related to the elevation of the land surface and the latitude. Rainfall is usually lower in the valley and higher in the surrounding mountains (ranges, hills, and mesas). For example, rainfall averages less than 4 in/yr in the low-lying valleys of the Mohave Desert. In the high-altitude areas of the Great Basin Desert, rainfall can average more than 20 in/yr. Most rainfall occurs in the winter and is associated with frontal systems that cover large areas (many square miles) of constant and less variable precipitation. Snowfall is confined chiefly to the higher elevations (mountains). Winter storms account for about two-thirds to three-quarters of annual precipitation. By contrast, summer convective cells are highly localized and often more intense with fairly short duration (hours). Summer thunderstorms are common. Precipitation in the area ranges from 3 to 8 in/yr (Prudic and others, 1995; p. 8). In some years, at some locations, there has been no measurable precipitation (Hunt and others, 1966; p. 5).

It is worth noting that temperature, rainfall, and other factors result in distinctive vegetation patterns that can be used to further describe local geography. See Romney and others (1973) and Beatley (1974, 1975). For example, high temperatures and low rainfall within the valley itself favor the growth of so-called "desert scrub" - mostly creosote bush (*Larrea divaricata*) and white bursage (*Ambrosia dumosa*). More moderate temperatures and increased rainfall in the surrounding highlands results in a different suite of flora that forms open woodlands containing sagebrush (*Artemisia tridentata*), piñon pine (*Pinus monophylla*), and Utah juniper (*Juniperus osteoperma*). Although natural vegetation is generally sparse throughout most of the region, the creosote-bursage association has the greatest areal extent, especially at the lower elevations (Figure 2). Table 1 describes the primary vegetation associations.

Lastly, the primary vegetation associations in the Amargosa Desert area create habitats for a variety of reptiles (32 species), birds (66 species), and mammals (46 species). See Collins and others (1982). Small numbers of wild horses and feral burros may also be found locally.

Additional information on local biosphere characteristics can be found in DOE (2002a).

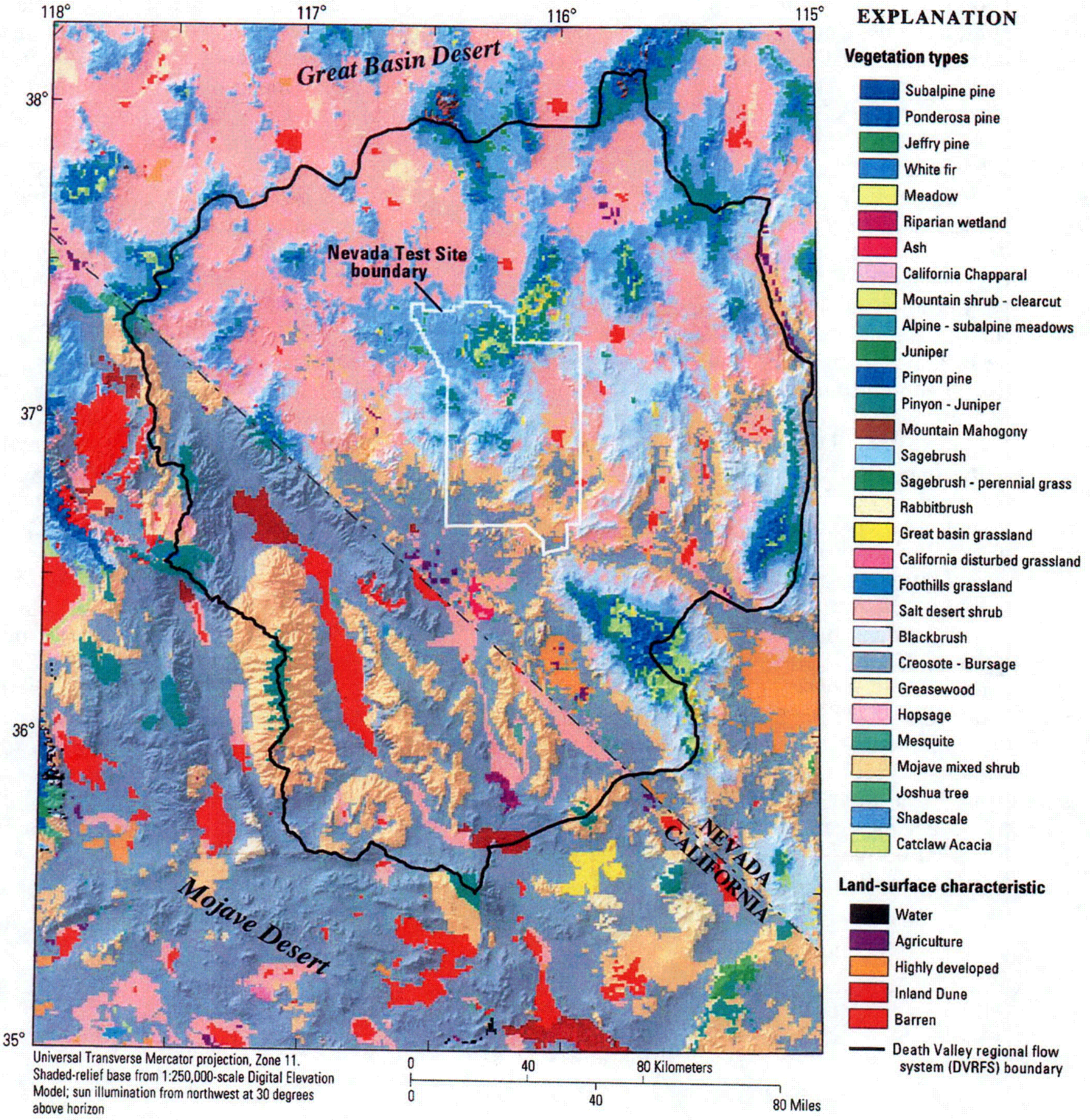


Figure 2. **Principal Vegetation Associations in the Amargosa Desert Area.** Scientific names for plants cited can be found in Appendix A. Taken from Hevesi and others (2003, p. 18). See the USGS URL site at *http://water.usgs.gov/pubs/wri/wri034090/*.

C01

Table 1. **Primary Vegetation Associations in Amargosa Desert Geographic Zones.** Taken from Collins and others (1982). Collins and others (p. 6) also describe an intermediary or transitional zone between the two deserts. Common vegetation names can be found in Appendix A.

Geographic Zone	Primary Vegetation Association	Elevation (ft)	Mean Temperature (°F)		Rainfall Range (in/yr)	Soil Type
			Maximum	Minimum		
Mohave Desert	*Larrea-Ambrosia*	< 3500	High		Low	Loose, sandy soils of lower alluvial plains.
	Larrea-Lycium-Grayia	3500–4000	81–88	28–40	5–7	Rocky surface pavement.
Transitional	*Coleogyne*	4000–5000	83–84	34–36	9–9½	Shallow, sandy-to-gravelly soils of upper alluvial plains.
Great Basin Desert	*Artemisia*	5000–6000	81	29	8	Deep soil profiles found on slopes and ridges of local mountains.
	Artemisia-Pinus-Juniperus	> 6000	72–79	25–29	10–11	

Because the Amargosa River and it tributaries are almost always dry, before 1900, local cold springs, seeps, and natural tanks[5] played an important role in the early history of the area. The indigenous Native American population was the first to benefit from the accessibility of these supply sources as part of their subsistence lifestyle. Later, explorers sought out these resources as part of the Western expansion movement. With the arrival of Euro-American prospectors and pioneers, most of the major springs and seeps were appropriated to provide reliable sources of water for newly introduced mining, ranching, and farming activities. Appropriation might include diverting the spring discharge many miles or tens of miles, using pipes or ditches.

Because the success of many early ranches and farms in the area was tied to the strength of the local mining economy, all experienced the same "bo om or bust" cycles characteristic of fluctuating mineral prices at the time. A well-intended homesteading program sponsored by the Federal government proved initially ineffective because of the absence of surface streams and a limit in the number and location of high-discharge springs. Thus, before 1900, most historical developments in the area were restricted to the locations of existing springs, seeps, and tanks.

2.1 Native American Occupation[6]

In historic times, Southern Nevada (including the Amargosa Desert area) was occupied by two Native American cultures – the *Western Shoshone* and *Southern Paiute*. These peoples were descendants of earlier-Paleo-Native American cultures believed to have occupied the region during the preceding 10,000 years. They were regarded as nomadic hunter-foragers who relied on the numerous springs for water found throughout the area as well as for the local animals the springs attracted and the vegetation they sustained (Stoffle and others, 1990). Thordarson and Robinson (1971, Table 4) identified about 80 artesian springs of various sizes in Southern Nye County, in and around NTS (south of the 37 ° 15' parallel). Ball (1907, pp. 22–23) notes that the placement of many of the early Indian trails in the area was influenced by the locations of these springs and tanks, and the distance between these sites rarely exceeded 40 mi. Ball (1907, p. 27) also notes that many local springs, or directions thereto, were identified using stone monuments (*cairns*) and petroglyphs.

The indigenous Native American population was traditionally organized into geographically distinct groups, usually with unique linguistic patterns and designated foraging areas. In numbers, the Southern Paiute are believed to have been the largest of the two native populations. In the mid- to late-1800s, the total population in the greater Las Vegas area was estimated to have been less than 450 (Steward, 1938; p. 182).[7]

Most Southern Paiute groups were believed to reside in areas of major spring concentrations — *Ash Meadows, Indian Springs, Manse, Pahrump, Tule* (Figure 3) – or along reaches of the Amargosa River itself

[5]Tanks are naturally occurring cisterns found at the surface of an impervious rock.

[6]Much of the discussion in this section is based on Steward (1938), who prepared the earliest and most comprehensive ethnographic reconnaissances of the Southwest United States. Review of information on Paleo-Native American cultures, who also occupied the area at one time, is beyond the scope of this report.

[7]Steward's estimates were based on published and unpublished estimates first made in the 1860s and 1870s.

(Steward, 1938; p. 182).[8] Smaller groups lived at the more isolated springs, including portions of what is now NTS. Local tribes relied on a combination of hunting, foraging, and farming for sustenance. Sustenance could be found in both the lowlands (valley) and the surrounding highlands. Subsistence strategies revolved around moving between the three geographic zones (Table 1) depending on the adequacy of the seasonal harvest (*Op cit.*, pp. 95–97). Staples were mesquite and screw beans, and piñon nuts. These staples were supplemented by seeds of sand bunchgrass, Hopi rye, and Devil' s pin cushion, as well as by cactus fruit and stems, wild grapes, mariposa bulbs, Joshua tree buds, and squaw cabbage beans. Harvesting strategies also included the collection of medicinal plants. Local reeds and grass stems were used to make storage baskets. Insects and their pupae were an important source of protein and were integral to the diet (Jaeger, 1957; p. 167; Hartwell and Valentine, 2002, p. 30).

At the time, Kit fox, mountain lion, bobcat, mule deer, pronghorn antelope, bighorn sheep, and game birds were also indigenous to the area. Small game included jack rabbits, squirrels, pack rats, quail, ducks, snakes, lizards, and tortoises. See Appendix A. However, meat (from large game) was only occasionally taken (Jaeger, 1957; p. 136). Steward (1938) frequently notes that rabbit drives and antelope hunts, when conducted, also served as a special social function within tribal communities.

Popular foraging areas were reported to have included *Ash Meadows*, *Big Dune*, the *Spring Mountains*, the *Funeral Mountains*, the *Shoshone Mountains*, *Calico Hills*, and the *Spector Range* (Figure 2). The normal foraging range was about 20 mi from the primary residential camp, although, for some resources (such as piñon nuts, in high altitude areas), the ranges could be as great as 50 mi (Drollinger and others, 1999; pp. 20–21). Criteria for the location of the primary residential base were proximity to water; wood (for fuel and use in shelter construction); closeness to food caches; and moderate winter temperatures (Steward, 1938; pp. 232–233). Housing thus consisted of lightweight, temporary shelters that could be moved to coincide with seasonal food-gathering practices (Stoffle and others, 1990; p. 40). Several spring locations in NTS had permanent housing made from local country rock and included food caches; but these locations have been interpreted as mainly for use during seasonal harvesting/hunting excursions (Worman, 1969; Stoffle and others, 1990).

Before colonization, Hohokam and Puebloan native cultures practiced irrigation-based agriculture along the flood plains of major rivers in Arizona (Davis, 1897), Colorado (Baker and others, 1973), and New Mexico (Harris, 1984). So-called "dry farming" was not possible because of the low rainfall rates. Crop irrigation was generally achieved by taking advantage of the seasonal water-level fluctuation of rivers and streams within flood plains (Bryan, 1929). Earlier reported theories (Baker and others, 1973; pp. 10–12) suggested that Spanish missionaries were responsible for introducing more sophisticated irrigation techniques to collect and divert surface water. However, Hundley (1992; pp. 16–23) reports that *Owens Valley Paiutes* in Eastern California were using elaborate systems of earthen dams and canals as early as A.D. 1000. Steward (1938)reports that the Southern Paiute also used such systems to diverted spring water in both Ash Meadows and in Pahrump Valley. Manly (1927, p. 151), for example, notes that California-bound miners encountered Southern Paiute practicing irrigation farming at *Cane Springs* in 1849.

[8] Archeological investigation of NTS shows evidence of the Southern Paiute culture in caches of artifacts (beads, pottery, etc.) at camp sites, rock shelters, or stone circles within the current boundaries. Close to Yucca Mountain itself, the terraces adjacent to Fortymile Wash contain abundant artifacts in the form of projectile points, blanks, and flakes (Worman, 1969; Pippin and Zerga, 1983).

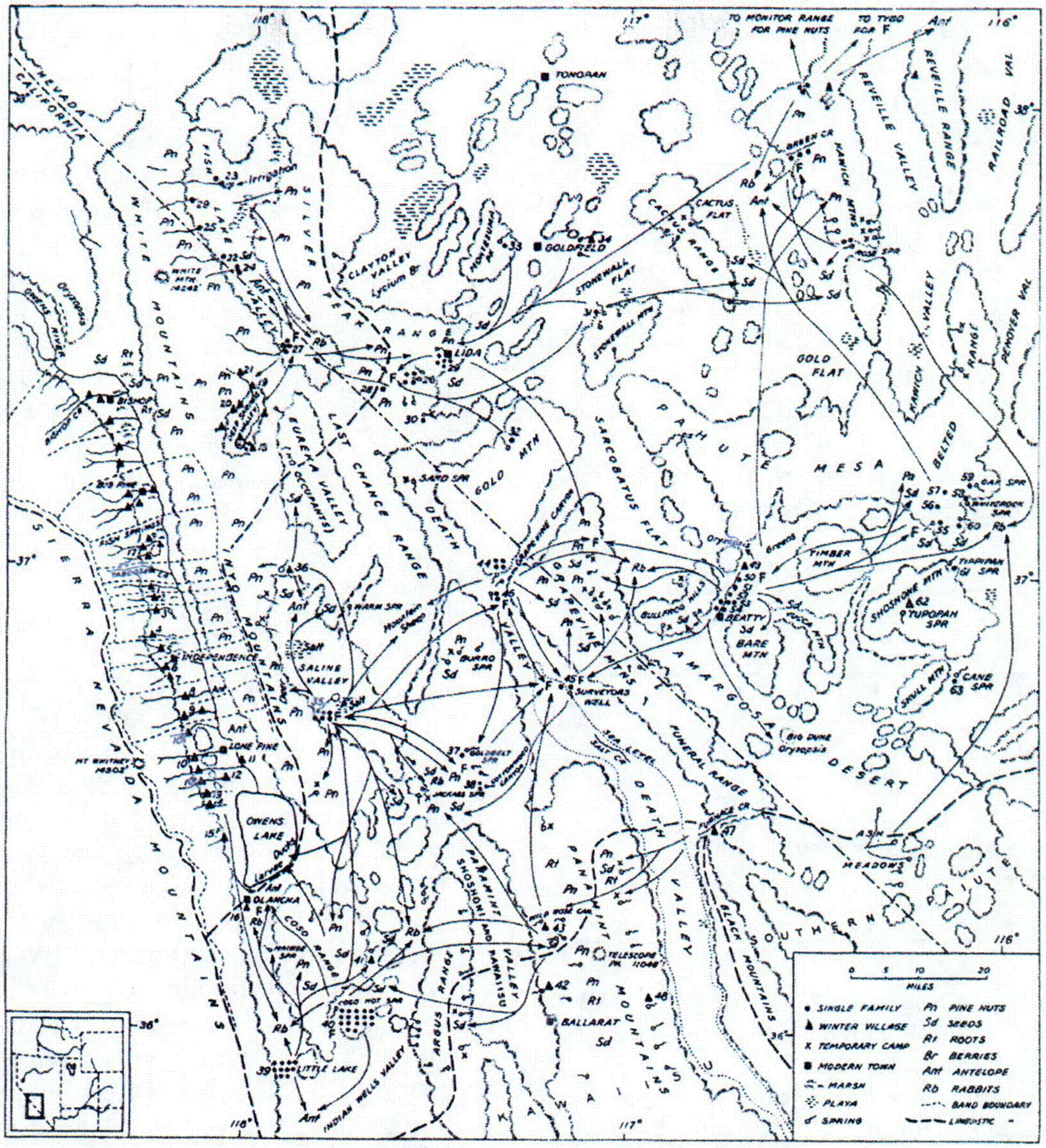


FIGURE 7.—Villages and subsistence areas of the Death Valley and Owens Valley regions.
60285—38 (Face p. 58)

Figure 3. **Portion of Steward's 1938 Map Showing Native American Villages and Subsistence Areas in the Death Valley Area.** Based on published and unpublished estimates first made in the 1860s and 1870s. Map shows that most aboriginal camps and villages identified at the time were in close proximity to the many springs found throughout the area. Dashed lines show food-gathering routes. No camps or villages are shown in the Ash Meadows area, which suggests that the Ash Meadows Paiutes may have been displaced by or assimilated with Euro-American homesteaders by the time the Stewart's compilation was prepared.

Locally fewer in number, the Western Shoshone occupied the northern portions of the area. They are reported to have hunted and foraged in higher elevation areas — around *Beatty* and the *Belted Mountains*. Steward (pp. 93–99, 182–185) reports that at least nine Shoshone families (or family groups) maintained winter camps within current NTS boundaries in the 1870s and 1880s. With the exception of aboriginal farming, the Western Shoshone lifestyle was not unlike that of the Southern Paiute. Overall, the Western Shoshone are believed to have occupied a migratory area greater than that of the Southern Paiute.

C02

Initially, the primary crops grown were indigenous plants - mostly grasses, tubers, and local corns. Melons, maize, pumpkins, squash, and beans were later introduced by missionaries (Hundley, 1992; p. 17). Plots were irrigated in alternate years in a practice similar to fallowing to promote increased crop yields and prevent encroachment of nuisance vegetation (*Op cit.*). Despite these efforts, there was never enough cultivated food to rely solely on farming (Manly, 1927; p. 183).[9] The delicate balance found within the Southern Nevada desert ecosystem could not sustain a large indigenous population (Alley, 1997; p. 3). This was confirmed by Steward's 1938 (p. 49) population estimates compiled for Southern Nevada, summarized below:

Location	Population	Area (mi^2)	Population Density ($persons/mi^2$)
Beatty	29	1300	45
Belted Mountains	42	1300	31
Death Valley	42	1260	30
Las Vegas Valley (and vicinity)	332	9450	28
Kawich Mountains	90 - 120	2025	22 - 17

In reviewing Steward's data, the following points are noteworthy:

- Many of the population estimates were based on Native Americans accounts obtained during the 1860s-70s and were believed to have been subject to some degree of bias (*Op cit.*, pp. 46–48). Moreover, because the population estimates reflected post-Euro-American contact, the estimates were considered low.[10]

- It was not possible to differentiate between the respective Native American groups (and the size of the populations) because subsistence areas were geographically approximate, although it is generally believed that the Western Shoshone were locally fewer in number.

- The local variations in population density were tied to the fertility of the resource area claimed by a particular ethnographic group (*Op cit.*, p. 48). Forage and game were generally more abundant at higher topographic elevations (in mountains) as compared with lower elevations (in valleys).

Despite uncertainty in the estimates, it is generally believed that the local indigenous population outnumbered that of the Euro-Americans before 1900 (Stoffle and others, 1990; p. 37). As a consequence, Native Americans were able to maintain traditional lifestyles, which included control of most of the core spring locations and foraging areas. However, the mining booms of the early 1900s generated a large influx of miners and thus proportions between the two populations changed. The indigenous population became a numerical minority and as a result, most of the major springs were "appropriated" to supply the water needs for mining camps and mineral processing sites and, later, small farms.[11] In addition, newly introduced domestic livestock were allowed to free-range, thereby depleting natural forage that were traditional foodstuffs (or medicinal plants). Because of the absence of identified mineral resources, certain areas — such as Ash Meadows, Oasis Valley, Pahrump Valley, and NTS became so-called "refuge"

[9]In the 1830s, horsemeat became a regular part of the diet once the *Old Spanish Trail* became established, about 90 mi to the southwest of Yucca Mountain.

[10]At the time of the reporting, it was generally known that the size of the indigenous population was declining, principally because of newly introduced contagious diseases. Other lesser factors included inter-racial marriage, armed conflicts, homicide, and infrequent slave raids.

[11]There is archeological evidence of a water rights claim, dated 1919, to *Twin Springs* (in Fortymile Canyon) by Frank L. Lathrop (the namesake of *Lathrop Wells*). See Hartwell and Valentine (2002, p. 65).

areas (*Op cit.*, p. 55). Although displaced from some of their core camp sites, most Native Americans continued to engage in traditional hunting, foraging, and farming in these refuge areas. Produce grown on independently owned, small-scale Native American farms was often marketed in the mining camps (*Op cit.*, pp. 38, 64).

Despite the waxing and waning of mining, the indigenous population was able to coexist with the growing Euro-American population. McCracken (1990b, p. 11), for example, notes that the first *rancherias* established in Pahrump Valley were by Paiutes - at *Manse Springs* (late 1860s) and *Pahrump Springs* (*ca.* 1875). Ball's geologic reconnaissance map (dated 1906) identifies an "Indian camp" within Oasis Valley to the west of NTS, which was probably a Western Shoshone community (McCraken, 1992b; p. 99). Citing U.S. Census data for 1910, Stoffle and others (1990, p. 64) notes several Native American households (probably Southern Paiute) owned rancherias in Ash Meadows and Pahrump. When citing 1937 Bureau of Indian Affairs data, Stoffle and others (p. 72) continues to note Native American households in major spring locations in Ash Meadows and Pahrump, as well as in Beatty and Oasis Valley (where they comprised a significant proportion of the local population). Stoffle and others (p. 72) also identified Native Americans in remote locations of what is now NTS, likely *Captain Jack* and *White Rock Springs*, and possibly other unspecified sites. Census data at the time indicate that most Native Americans were self-employed as farmers, ranchers, prospectors, or miners. A few worked intermittent jobs as teamsters, laundresses, or seasonal help (farming, ranching) to supplement the more traditional subsistence lifestyle. Several individuals were able to establish legal rights to spring-fed lands in local courts outside of what is now NTS (*Op cit.*, pp. 63-64, 73-74). However, withdrawal of what are now NTS lands, from public use in the late 1930s, precluded further Native American access, causing some individuals or families residing therein to relocate (*Op cit.*, pp. 76-77). McCraken (1992a, p. 99) notes that many Native Americans also worked for the regional railroads prior to the Depression. A high percentage of the local population were also employed by the *Works Progress Administration*. When that program ended and the local railroads ceased to operate, McCraken reports that Beatty's Native American community disbanded (*Op cit.*).

2.2 Western Expansion

Many western migration routes coincided with the (limited) occurrence of surface water. For example, exploration of Southern Nevada before the 1880s appears to have been restricted to the Colorado River and to the vicinity of *Las Vegas Meadows*. Because of its great springs, the Old Spanish Trail passed through Las Vegas, connecting Sante Fe (New Mexico) and San Gabriel (California) - see USGS (1970).

In historic times, Nevada is the last State to have been entered by Euro-Americans (National Geographic Society, 1953). Trappers and missionaries traveled along the Old Spanish Trail as early as 1829 (Hafen and Hafen, 1954). The first geographical surveys and mapping expeditions were conducted by U.S. Army topographic engineers - J.C. Frémont (in the mid-1840s) and G.M. Wheeler (in the 1870s). Wheeler's expeditions were the first to explore the present NTS, along portions of Fortymile Wash. Over the next six decades these excursions were followed by expeditions of scientists and naturalists, as well as boundary surveys to run township (T), range (R), and section lines for the territories. However, it wasn't until 1849 that the California gold rush led to a precipitous increase in Western migration and the search for emigration routes and mineral resources in Nevada.

It was standard practice at the time for expeditions to follow existing Indian and game trails, with their established sources of drinking water, or to look for other natural signs of water (phreatophyte vegetation as well as wildlife) to maintain supplies. Historical as well as archeological information suggests that the Amargosa Desert area (consisting of Southern Nevada and Eastern California) was regularly traversed in the late 1840s by emigrant wagons and others on their way to California who took advantage of the abundant springs. See summaries in Long (1950), Worman (1969, pp. 3, 5–8), Pippin and Zerga (1983, pp. 51–54, 66–68), Hattori and McLane (1981), and Drollinger and others (1999, pp. 20–24). Evidence suggesting Euro-American exploration and subsequent habitation of present NTS for the first time may have been in 1847. A stone block engraved with the name "R.J. Byor" and the date "1847" was found near a cabin at *Cane Spring*. Long (1950, p. 104) has suggested that it may have been left there by one or more discharged members of the Mormon Battalion.[12]

Before 1900, the principal migratory route from Las Vegas to California was through Ash Meadows to Death Valley, following the line of springs that existed in the region at the time. About 1849, a second shorter migratory route came into existence – the so-called *Emigrant Trail* described by Long (1950). Rather than wintering in Salt Lake City, a few pioneers decided to strike a southern route to California through what is now NTS (Lingenfelter, 1986; p. 32), north of the Old Spanish Trail. The Emigrant Trail through present NTS had three different legs, coincident with the locations of the principal springs (Figure 4). These springs also happened to be camp sites for the Western Shoshone (Steward, 1938; p. 95). Later stage, freight, and mail lines briefly operated along one or more of these routes. Relay stations were known to have been constructed at several spring locations within current NTS boundaries. Relay station construction frequently included improvements to the spring discharge points as well as the construction of wooden cabins and corrals (Worman, 1969). Some likely relay station locations (*Cane* and *Tippipah Springs*) have stone cabins made from locally-available country rock (*Op cit.*). However, the use of these facilities for their intended purpose is believed to have been short-lived – lasting no later than 1910 (Pippin and Zerga, 1983; p. 54). The reason for abandonment is unclear but probably was because of fluctuations in local mining activity, and the establishment of railroads creating more direct thoroughfares West.

2.3 Early Mineral Exploration and Mining

After the discovery of placer gold at Sutter's Mill (on the *America River* in California), the lure of mineral wealth opened the West to extensive exploration and prospecting. At this time, Nevada was part of the Utah Territory (van Zandt, 1976; pp. 158–160), and a modest level of lead, zinc, and silver mining was taking place in the *Silver City District* of Lyon County (Lincoln, 1923; p. 131). However, it wasn't until 1855, after the discovery of the gold-silver bonanzas in the Nevada Territory, that mining began earnestly (Nevada Bureau of Mines, 1964; p. 3). Prospecting intensified after the 1859 discovery of the *Comstock Lode* in *Virginia City* by the backwash of miners and emigrants following the playing-out of some California gold districts. In light of the newly discovered mineral endowment, Nevada achieved separate Territorial status by Act of Congress in 1861, and Statehood on October 31, 1864. Nye County was created at this time from one of the nine original counties (Esmeralda) in the Territory.

[12]This U.S. Army unit was formed in July 1846 as a home guard to protect migrating settlers during the Mexican-American War of 1846-48. The 500-man reserve unit was disbanded in 1846, and many of its members later migrated west from Utah through Southern Nevada to California (*Op cit.*).

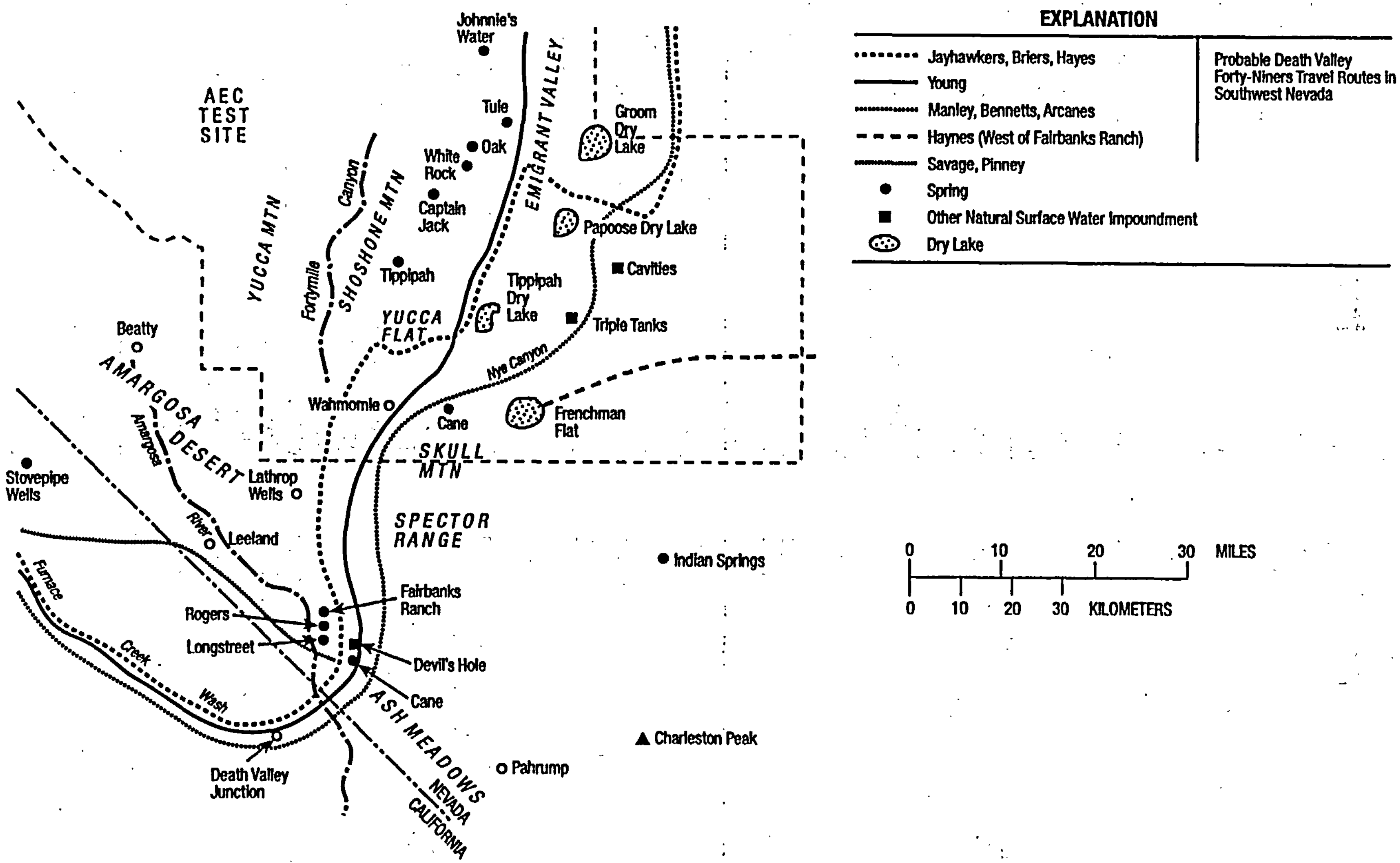


Figure 4. **Approximate Location of Emigrant Trail Routes through Current NTS Boundaries.** The Emigrant Trail (*ca.* mid-1800s) through present NTS had three different legs (Long, 1950), coincident with the locations of the principal springs. Overall, the use of NTS as a thoroughfare had no impact on the development of water resources within the site. Taken from Fehner and Gosling (2000; p. 9), citing Koenig (1984).

The state's first census was conducted the same year Territorial status was achieved. The census reported a population of 14,404, with the greatest portion (4581 individuals) residing in environs of Virginia City.[13] Before the late 1850s, there was little interest in the Territory. As new ore bodies were discovered, mining camps sprang up. In Southern Nevada, there were at least 23 mining districts that were discovered by the early 1900s (e.g., Kral, 1951). By 1880, the State's population had grown to 62,000,owing to the additional discovery of the *Ely Mining District* (*Eureka* and *Austin* mines). In general, during the first 50 years of Statehood, before the First World War, Nevada's economy depended chiefly upon mining (State of Nevada, 1964; p. 273).

Prospecting was somewhat elementary by today's standards. It mainly consisted of walking the terrain, seeking outcrops, and looking for native metals or other recognized signs of mineralization as a guide to locating ore bodies. (Another prospecting technique was to locate and work abandoned Spanish mines.) Most prospectors were self-schooled, with no formal training. There was little scientific documentation of known mining districts based on what are now commonly recognized ore deposit models (Wilburn and others, 2001). Because of their unique knowledge of local geography and resources, Native Americans were often employed in prospecting efforts (Stoffle and others, 1990; pp. 36, 47, 49). Some Native Americans also prospected on their own behalf and staked their own mining claims (*Op cit.*, p. 64).

Once discovered, ore bodies were typically mined by hand, using pick and shovel, aided by explosives when necessary. Depending on the mineral commodity, refining would sometimes needed to separate the valuable ores from the host rock. This would be achieved by crushing the ore and using water to separate the fines. Dibner (1958, p. 86) notes that Georgius Agricola's 1556 classic mining treatise *De Re Metallica* goes into considerable detail on the subject of washing and separating mineral ores. Many of these techniques have not fundamentally changed from when they were first described by Agricola in the 1500s. See Vogely (1985).

However, the large amounts of water needed for the ore separation phase were not always available from local sources. Consequently, before the early 1900s, reduction of the mineral ores to concentrated metals usually took place outside of Southern Nevada. Typically, unrefined ores were transported by pack animal or wagon to the nearest railroad depot (either Las Vegas or Tonopah at the time) - which was many tens of miles away. Consequently, only high-grade mineral deposits were initially sought and exploited because they proved to be the most profitable to mine at the time - that is to say, high-grade ores were the easiest to recover; they required little to no processing; and the cheapest to ship given their weight per unit value. However, such rich mineral deposits are generally rare in nature.[14] Thus, given the general lack of water and transportation infrastructure, there was only a modest level of prospecting and mining in and around the Amargosa Desert before 1900.

For the most part, early prospectors were looking for gold. Then, as now, gold was the principal medium of monetary exchange. The type of gold most often sought was native gold in placer deposits. This form of gold occurs when the precious metal weathers from an ore body and is concentrated by geologic processes down-slope from the source rock. At the time, placer mining could be performed relatively inexpensively, and was well-suited to the individual prospector. It required very little in the way of materiel, and no special mining

[13]By 1863, the population was 10,000. Production at the Comstock Lode peaked in 1877.

[14]In a geostatistical sense, rich deposits of secondary ore minerals occur less frequently in nature than primary ore deposits with lower metal content. See Lasky (1950) and DeYoung (1981).

training. In general, because of differences in density, the gold could be washed-out of stream sands by agitation using pans or sluice boxes in conjunction with water. When water was not available, a dry form of mining could take place also with pans, or rockers, but these mining methods were not very efficient.

Prospecting is reported to have begun in the vicinity of *Tucki Mountain* (now *Silver Mountain*) in 1849 (Lingenfelter, 1986; p. 43), after the unexpected discovery of silver ore along one of the legs of the Emigrant Trail. However, it is difficult to estimate the true magnitude of these past efforts because exploration statistics are rarely published and there are few historic accounts. One way to indirectly infer some information about the magnitude of early mining in the area would be to examine topographic quadrangle maps of the area published by the USGS, which record physical conditions found in the field. Many of the maps for the area show numerous "dog holes" and possibly "pocket mines" that bear testimony to the frenzy of prospecting activity that must have taken place over the years. Throughout the State there are varying estimates of physical signs of current and former mining and exploration activity, ranging from about 200,000 to 310,000 locations. See Price and others (1995, p. 3) and (1999, p. 362).

Another way is to examine the estimates of resident population shown in Table 2. Based on the account of French and others (1981, p. 70), in the late 1800s, prospecting and mining in the Nevada Territory were reported to be at its highest in the spring and early summer months, when surface water supplies were the greatest. During the rest of the year, miners and prospectors were reported to have returned to California owing to the cyclic depletion of such supplies (*Op cit.*).[15] Based on this behavior, therefore, it isn't clear whether the population estimates shown in Table 2 are average or peak annual estimates.

Nonetheless, early exploration efforts did meet with some initial successes and a number of major deposits were discovered (and reported), many of which were in Eastern California. For example, Pleistocene-age borax lake deposits were discovered in Death Valley in 1873 and later worked in 1882. The ore was hauled by the famed 20-mule teams 165 mi southwest to the Southern Pacific railhead at Mojave (California). Silver was mined in the *Panamint City District*, in the Panamint Mountains, from 1873-76. A gold district was discovered in 1890 in the northwest flank of the Spring Mountains.

With the influx of miners, stagecoach and carriage travel became more commonplace throughout the area, and water stops along travel routes became a necessity for both draft animals and man. In general, the abundant springs and tanks throughout the area influenced the location of early thoroughfares between the mining camps and tent towns that developed within these mining districts. Indian and game trails evolved to wagon trails and later to finished carriage ways. The location of these thoroughfares, in relation to known surface water supplies and signs of mining activity, can be found on USGS topographic quadrangle maps of the area, particularly on the now discontinued 1:62,500-scale editions. For example, the *Las Vegas-Bullfrog Stage* was established in 1905 to serve the growing community of Beatty, along a trail to the south of Yucca Mountain. It is estimated that up to 1000 draft animals used this route daily (Hartwell and Valentine, 2002; p. 61). Local Water

[15]Also, during the spring and early summer (March - June), there are more tolerant working temperatures than in mid-summer to early fall (July-September).

Table 2. **Resident Population in Nevada and Nye County, 1861-2000.** The last column in the table shows the Nye County percentage contribution to the overall State population. Population data taken from U.S. Census Bureau.

Year	State Population	Nye County	
		Population	Percentage of State
1861	14,404	Not reported	—
1870	42,491	1087	2.56
1880	62,266	1875	3.01
1890	45,761	1290	2.82
1900	42,355	1140	2.69
1910	81,875	7513	9.18
1920	77,407	6504	8.40
1930	91,058	3989	4.38
1940	110,247	3606	3.27
1950	160,083	3101	1.94
1960	285,278	4375	1.53
1970	488,738	5599	1.15
1980	800,493	9048	1.13
1990	1,236,130	18,190	1.47
2000	1,998,258	32,485	1.63

stops were at *Miller's Well No. 1*[16]; *Fairbanks (Blacks) Ranch; Longstreet Ranch; Miller's Well No. 2*; *Rosewell;* and *(Old) Whitney's Well* (Hattori and McLane, 1981; p. 5). These sites can be found on the *Ash Meadows* and *Lathrop Wells* topographic quadrangle maps (1952 and 1961 editions, respectively).

The increase in human activity placed demands for water far above that which could be supplied by the local springs and tanks.[17] In general, water development practices were far from scientific. Overall, the intent was to discover flowing artesian water (e.g., water under sufficient hydraulic pressure or *head* to flow at the ground surface). This is suggested by Mendenhall (1909), where it was noted that the location of early

[16]Mendenhall (1909, p. 91) reports that this 200-ft well, with a capacity of about 200 barrels per day, was abandoned sometime in 1905.

[17]Before 1880, domestic per-capita water consumption was estimated to be about 3 to 5 gpd. By 1900, domestic per capita water consumption increased by two orders of magnitude to about 100 gpd owing to improved sanitation practices (Tarr and McMichael, 1977; p. 25). However, per capita water consumption is assumed to be generally higher in arid regions. In Arizona, for example, per capita water consumption is estimated to range from 160 to 267 gpd (Duguid and others, 1994; p. A-2).

homesteads in Eastern California and Southern Nevada could be correlated with the occurrence of such springs. McCracken (1992, p. 120) notes that by the late 1870s, most of these favorable watering locations in the area had been occupied (and likely appropriated from Native Americans).

2.4 The Homesteading Movement [18]

Mining in the west generally followed a boom and bust cycle. Economic and technologic developments changed what minerals were being sought and how they were mined. Despite these cycles, some mining camps and communities in Southern Nevada continued to prosper because of the quality of the ores and the size of the deposits. By contrast, other mining districts faltered as known ore bodies became exhausted, and new and richer districts were discovered. Mines could continue to make profits on lower-grade ores so long as metal prices remained high.

At the time, both gold and silver were in circulation as legal tender in the United States. However, production from California gold deposits was beginning to decline and there was an increase in the demand for silver. Western mining interests (and others) wanted more silver coinage in domestic circulation. To offset declining domestic gold production, Congress passed the *Bland-Allison Silver Purchase Act of 1878* to keep mines with lower-grade deposits in operation and increase the amount of silver in circulation. The act required the U.S. Treasury to purchase not less than $2 million nor more than $4 million worth of domestically mined silver bullion for coins each month, at market prices (Rabbitt, 1980; p. 5). However, because declining ore quality affects mine profitability, some Nevada mines continued to close even with this Federal purchase incentive. In 1890, Congress supplanted *Bland-Allison* with the *Sherman Silver Purchase Act* that required the Treasury to purchase nearly twice as much silver bullion as before. Immediately following its passage, there was a short-term increase in the price of silver bullion that was later reversed by market forces. For a variety of reasons, Congress repealed the *Sherman Silver Act* in 1893. Congress later passed the *Gold Standard Act,* in 1900, making gold bullion the standard for the Nation's currency. This action resulted in a further drop in the price of silver bullion. With silver prices dropping, those mining camps and tent towns that relied primarily on silver ores ceased to exist. These locations are considered ghost towns today.

Thus, as the profit from mining began to decline in a particular cycle, many miners turned to farming or ranching to help feed the growing local population. The pattern of farming in the Southwest varies from State to State and reflects factors such as the availability of surface water and suitable soils, length of growing season, elevation, and topography. As noted earlier, there are few perennial streams and rivers, so most farming typically took place in the rich soils found in the lower-elevation flood plains.

By the end of the 1870s, the first wave of homesteaders had staked claims at most of the major springs and seeps from Beatty south, extending along the Amargosa River into Ash Meadows, and beyond to Pahrump Valley (Lingenfelter, 1986; p. 168).. The land was public at the time and managed by the General Land Office within the Department of the Treasury. These lands were subject to private claims consistent with the homesteading laws. Many of the local springs bear the names of the first homesteaders. Some homesteaders also intermarried with the local Ash Meadows Paiute.

Most homesteads had less than 100 head of cattle that grazed on *Larrea*, *Ambrosia*, and *Hilaria*. Depending on what the local

[18] The are several accounts of local homesteading efforts. Summaries have been prepared by Lingenfelter (1986) and McCracken (1990a, 1992b) which, in turn, have been relied on extensively in preparing this section of the report.

markets required, they also successfully raised crops such as alfalfa, barley, vegetables, fruits, and nuts (McCracken, 1990a; p. 29). Using Native American farming methods, irrigation was achieved by diverting a portion of the spring flow, downslope, through hand-dug, lateral ditches, into cultivated fields. Although the claims were 160 acres in size (as required initially by the *Homestead Act of 1862*), they usually were only able to irrigate a fraction of that land, owing to unfavorable soil conditions and low spring discharge.

Because the principal market for locally-grown produce were miners, early homesteading success was uniquely tied to the strength of the local mining economy. Thus, when mining operations ceased in the *Ivanpah* and *Tecopa (California) Mining Districts* in the 1880s, about half of the Amargosa Valley homesteaders abandoned their claims. The only remaining claims were in the Ash Meadows and Pahrump areas (Lingenfelter, 1986; p. 168).

The first reported pioneer settler in Amargosa Valley was *Charles King* (McCracken, 1990a; p. 28). He free-ranged about 1300 head of beef cattle in Ash Meadows around 1873, which he sold to local miners, including those in the Panamint City District. In the Amargosa Desert area, Ash Meadows contains the largest concentration of springs. This location is a veritable oasis watered by dozens of springs and seeps. Several of the springs discharge an even flow rate of more than 720,000 gpd (Dudley and Larson, 1976; p. 1). Total discharge for all Ash Meadows springs is reportedly about 16 million gpd (*Op cit.*). Although the boundaries of this area are poorly defined, Ash Meadows covers approximately 63 mi^2 (Figure 5) and is characterized by dense to moderate growths of natural forage comprised mostly of mesquite, saltbush, and saltgrass. Table 3 describes the major springs of Ash Meadows and provides some recent information on individual spring discharge rates. A more comprehensive list of springs and seeps in the area can be found in Thordarson and Robinson (1971, Table 5).

2.5 Desert Reclamation Programs

Water availability has been a long-standing issue in the development of the arid Southwest. Before the exploitation of ground water, the only major occurrences of perennial water were either springs or certain major western rivers — *Colorado*, *Gila*, *Owens*, *Pecos*, *Rio Grande*, *Sacramento*, *Salt*, and *San Joaquin*. There are many ephemeral stream channels present, including those associated with the drainage systems of the major rivers. Stream runoff occurs irregularly in response to both summer and winter storms. Consequently, early homesteading activities were confined principally to the lowlands where perennial water supplies could be found.

Before 1900, most desert reclamation projects were undertaken privately because capital costs were typically too prohibitive for individual farmers and there were no government policies in this area at the time.[19] However, as a result of State and Federal intervention, it had been recognized that the infrastructure in the Eastern United States had been improved through subsidies for the construction of roads, navigational structures, harbors, railroads, and canals.[20] If some comparable level of success were to be achieved in the reclamation of the arid Southwest, it was soon reasoned that the Federal government would need to intervene. Initially, Congress passed the *Desert Lands*

---

[19]During the 1870s, for example, several corporate irrigation projects, using private monies, were successfully operating in lowland areas of New Mexico (Howell, 1869; Wilson, 1891; Shinkle, 1964) and Colorado (Mack, 1887; Freeman, 1958), where suitable soils and accessible water could be found. In Utah, Morman "cooperatives" had also constructed about 277 canals, totaling some 1043 mi, and were successfully irrigating about 115,000 acres of farmland by the 1870s (Kirby and others, 1956; p. 457).

[20]For example, see Armstrong and others (1976) and Schodek (1987) for descriptions of some of these projects.

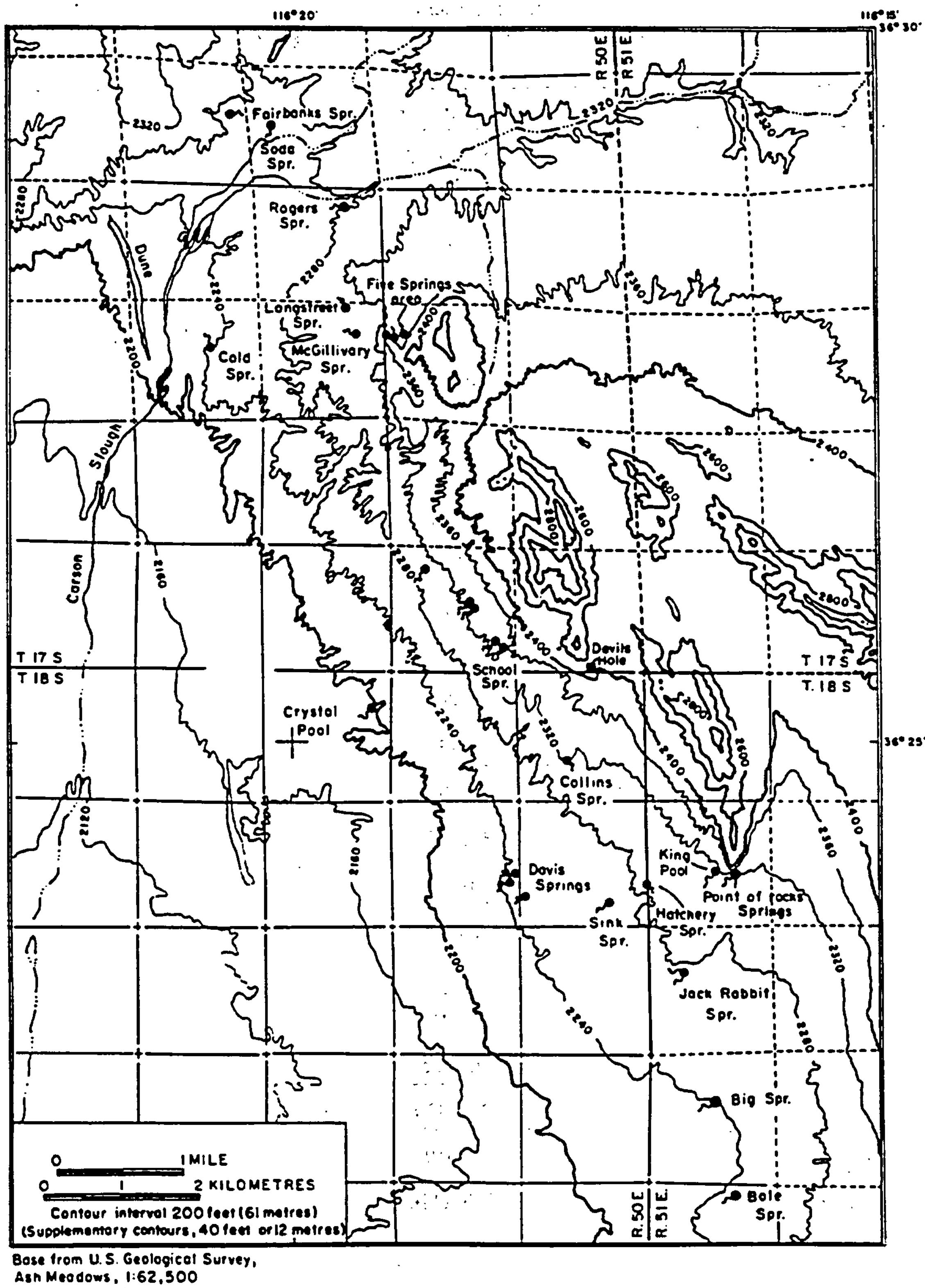


Figure 5. **Springs in the Ash Meadows Area.** From Dudley and Larson (1976, p. 6).

Table 3. Discharge Rates for Springs in the Ash Meadows Area. Taken from Dudley and Larson (1976, pp. 14–15). Note that *QT* means Quaternary- or Tertiary-age alluvial (valley-fill) or lake sediments; *Tr* means travertine or fresh-water limestone; and *Pz* means Paleozoic-age limestone or dolomite.

Name	Discharge Rate (gpm)	Water-Bearing Unit
Fairbanks	1430–2360	Tr
Soda	0–85	QT
Purgatory Spring	9–50	Pz
Rogers	570–735	Tr
Cold	73–80	QT
Longstreet	940–1260	Tr
McGillivary	0–155	QT
Five Springs area 1	0–75	QT
Five Springs area 2	0–60	QT
Five Springs area 3 (8 seeps)	35	QT
Scruggs 1	90–140	QT
Scruggs 2	60	QT
School	6–25	QT
Crystal Pool	1670–3070	Tr
Collins	5–10	QT
Davis 1	395–720	QT
Davis 2	5–175	QT
Davis 3	30–38	QT
Sink	0–25	QT
King Pool	685–2130	Tr
Indian Rock	22–135	Tr
Point of Rocks	290–420	QT/Tr/Pz
Jack Rabbit	0–640	Tr
Big (aka Deep, Ash Meadows)	920–1120	Tr
Bole	12	QT
Last Chance	1	QT
Unnamed (7 total)	1–195	QT

Act of 1877.[21] Desert lands were defined by this act to include those that had neither timber nor mineral resources, nor were capable of agricultural production unless irrigated. This law allowed individuals to claim and purchase 320 acres (½ Section) of public land, provided that, within 3 years they: (a) planted and irrigated 40 acres with "ordinary agricultural crops"; (b) developed a credible plan for irrigating the remaining 280 acres, including securing the necessary water rights (or appropriations); and (c) had demonstrated that they had expended at least $3/acre in making the necessary irrigation improvements and/or acquiring the necessary water rights. (In the Amargosa Desert area, the law also provided that joint water development proposals would be allowed among adjacent tracks of land.[22]) Provided that these terms had been met, within a 4-year time frame, a land patent would be granted. Overall, the act did not achieve the outcome desired. Early homesteaders and corporate concerns were able to monopolize water rights in arable tracts of lowland areas through the *doctrine of riparian rights* (Tank, 1983; p. 82), to the exclusion of all other water rights (Reisner, 1986; p. 43).

In an effort to ensure the beneficial use of water, Congress passed the *Carey Act of 1894.* This act was designed to give Western states and territories additional land if they constructed large-scale, public irrigation and water storage systems. Few States and territories took advantage of this law. Congress next passed the *Federal Reclamation Act of 1902,* which empowered the Department of the Interior (specifically the USGS) to plan, design, and construct irrigation and water storage systems with funds obtained from the sale of public lands in the states and territories mentioned in the Carey Act.[23] Within the USGS, the *Reclamation Service* was created to manage the various water supply projects (Robinson, 1979).

[21]Originally the *Homestead Act of 1862.*

[22]The irrigation plan was assumed to include plans for drilling the necessary number of wells to meet irrigation needs.

[23]Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, North and South Dakota, Utah, Washington, and Wyoming.

3. HISTORICAL DEVELOPMENTS AFTER 1900

From 1890 to 1900, mining was scaled-back greatly in Nevada because the known mineral districts were mined-out and no new ones had been discovered. However, in the early 1900s, a number of major mining districts in Southern Nye County had been discovered. This again caused increased interest in the Amargosa Desert area. After the discovery of the *Tonopah Mining District* about 1900, the first of two regional railroad lines was introduced in 1906. About this time, there were also developments in drilling and pumping technology that permitted the exploitation of ground water, in quantity, for the first time. These developments were also complemented by advances in geologic and fluid mechanics sciences. These advances improved the understanding of the physical occurrence of ground water. In 1915, an experimental farm was established by one of the regional railroads to demonstrate the feasibility of irrigated farming in the valley. By the outbreak of the Second World War, mining had once again waned and the railroads were gone. However, limited farming and ranching persisted in large measure because of the 1915 prototype farm.

3.1 The Second Mining Boom

As noted earlier, mining in the West generally followed a boom and a bust cycle because of the quality of the ores and the size of the deposits being discovered. The Comstock Lode was dying out and other, more promising mining areas never fully materialized (Elliott, 1973; pp. 170-173). By the early 1900s, though, hard-rock mining was thriving once again in Southern Nevada. Improved prospecting techniques led to the identification of new mineral deposit types, and the perfection of new mineral extraction technologies that permitted the mining of larger ore deposits of lesser grade, thereby creating the mining boom. [24] Additionally, miners could rework old tailing dumps and formerly unprofitable mines as commodity prices increased. Other significant silver and gold discoveries were being made at the *Goldfield* (*ca.* 1902) and *Bullfrog-Rhyolite* (*ca.* 1905) *Districts*. With the discovery of these and other new mining districts, syndicates were formed and land speculators began to descend on the major mining centers. In many instances, mining camps or tent towns were created overnight by armies of miners and prospectors. Building booms proceeded in some of these camps, fueled by the influx of the merchant and banking classes. This helped to keep these communities flourishing. At the time, high-value ores containing precious metals (gold and silver), as well as base metals (chiefly copper, iron, lead, and zinc) were known to exist in non-alluvial rocks. Thus, most of the prospecting was taking place outside of the valley, in volcanic and igneous rocks in the surrounding mountain ranges, hills, and mesas.

The history of mining in Eastern California and Southern Nevada has been well-documented in the literature [see respective summaries in Greene (1981), and Tingley and others (1993)] and will not be discussed further other than to note the following points. First, the Nevada mining boom of the early 1900s was largely responsible for the establishment of several communities that continued to exist long after mining had ceased. Second, mining operations now occurred in portions of the State that had little or no apparent sources of water. Mineral deposits were not always coincident with the occurrence of surface water. Despite its scarcity, water availability never

[24] Specifically, the cyanide and flotation processes were combined with crushing, amalgamation, and concentration operations, which led to the increase in the percentage of ore recovery (Chadwick, 1958; pp. 74-76, 95-96).

proved to be a serious impediment to mining and mineral processing. In areas for which there were no sources of supply, private companies built simple water-conveyance systems, or hauled in water to meet the mining community needs (Elliott, 1973; p. 214). Ball (1907, p. 157), for example, noted that the closest source of water for the *Bare Mountain Mining District* were spring-feed portions of the Amargosa River, near Beatty.

Logistically, therefore, the most accessible source of water typically proved to be the many local cold springs. The challenge, albeit simple, was to transmit the water from the spring location to that of the mining operation. This was typically achieved by collecting the spring discharge and delivering it through a pipeline made of metal or wood. The pipeline relied on gravity flow to move water downhill, from the point of occurrence to the point of need, so mechanical pumping was not necessary. In describing early accounts of mining activity, Lingenfelter (1986) has provided some information on local water supply solutions. See summaries in Appendix B.[25] The amounts of water provided by this method depended on the seasonal variations in spring discharge rates, the efficiency of the collecting system at the spring discharge point, and conveyance losses through the pipeline. For most of the smaller mining operations, this method proved to be an effective supply mechanism in the late 1800s and early 1900s.

When there were no nearby springs (or ephemeral streams), another water supply solution would be to haul water in or "import" it from another location, by mule or wagon, or later, by railcar. Again, the amounts of water provided would depend on the frequency and size of replenishment method. For example, *Cane Spring* (in Nye County) was the only source of water for the *Wahmonie Mining District* — the distance between the two locations was about 4 mi. However, because wagons were used to transport supplies,[26] it is likely that they may have done so constantly when the mining community reached its peak population (albeit briefly) of 1500 to 2000. An example of how much water transported by haulage might cost can be derived. In 1907, it is reported that water was being hauled to the mining community of Rawhide (Mineral County) by the *Dead Horse Wells Water Company*. The supply wells were about 8 mi outside of town and the haulage cost per barrel was $2.50 (Batchelor and Batchelor, 1998; p. 69). Using the 1998 consumer price index to adjust for inflation, that would be about $80.00/barrel or $2.50/gallon, in current dollars (Richard Turtil, NRC, personal communication, January 1999).

By contrast, water supplies provided by railcar could be replenished as frequently as the train schedules permitted. The supplies themselves were a function of the railcar's water tank capacity and the number of tank cars per train. In the 1860s, railroads had begun to modify rolling stock to carry water (White, 1993; p. 359). Initial tank designs were made from treated wood, and were either rectangular boxes, oversized barrels, or vats mounted on flat railcars. Because designs varied and were non-standard, the initial capacity of early rolling stock outfitted to carry water can only be estimated to have been about 1700 gallons per flatcar (Forbes, 1958; p. 121). About this time, "fire trains" were also in regular use in the West, including Nevada, for the purpose of extinguishing track fires created by loose embers escaping from locomotives (Solomon, 1998; p. 33). They had greater capacities reaching about 7000 gallons per flatcar (*Op cit.*). By the late 1880s, standardized cast iron tank car designs were introduced with

[25]Although not cited, it is expected that wooden sluices or ditches may have also been used. However, the water supply solutions described in this appendix were relatively simple in comparison to the 20 mi of hydraulic works employed in the *Comstock Mining District* (Shamberger, 1972).

[26]Probably 500-gallon tank wagons (Lingenfelter, 1986; p. 321).

slightly smaller capacities, ranging from about 3400 to 5000 gallons per railcar (White, 1993; p. 373).

When geologic conditions permitted, miners could dig or drill wells to obtain water. As noted later in this report, the depth to the water table in the Amargosa Desert area is quite variable. Before the introduction of drilling technology, wells were dug by hand, using pick and shovel, or excavated, using clamshell or orange-peel buckets. Maintaining or increasing well capacity could be achieved by deepening the well or drifting laterally into the water-bearing strata (Ransome, 1907; p. 24). Wells dug in this manner could be up to 70-ft deep or more, with yields in the range of 4000 to 132,000 gpd (Todd, 1980; pp. 165–167) depending on aquifer properties. The first such reported well in the area was the *Franklin Well* (Inyo County — Section 5 of T26N, R5E). Mendenhall (1909, pp. 36–37) notes that it was dug in 1852 for parties performing a survey of the California-Nevada State line. Miller (1977, p. 11), citing other sources, notes that about 40 wells were hand-dug in the Death Valley-Amargosa Desert areas in the late 1880s and early 1900s, to meet early water-supply needs.

However, this particular supply solution had certain limitations associated with it. First, there was a practical limit to the depth of such wells, owing to stability of the excavation in unconsolidated geologic materials. Consequently, lining or cribbing, using wood or metal, was employed, to prevent the walls of the excavation from caving in (Todd, 1980; p. 168). Second, until the availability of pumping technology, water would have to be hauled to the surface and transported manually to the point of need.

Sometimes, surprisingly, there would be a problem with too much water. A common problem in constructing underground mine workings is the seepage of ground water. When sinking shafts or developing drifts, water-bearing strata are sometimes encountered and ground water seeps into the excavation. This problem was frequently reported in the literature for mines in Southern Nevada, particularly by the turn of the century, when, because of favorable economics and new technologies, deep underground mining had become more common and the mining of lower-grade ores at depth more feasible. As discussed later in Section 3.3, pumps were now in use for mine dewatering. In the *Goldfield Mining District*, for example, when ground water was suitable for use, it was common to pump it out of the mine to the milling location where it was needed. The pumps used were either steam-, gasoline-, or electrically-driven (Ransome, 1907; p. 24).

3.2 Introduction of Railroads

Stage and freight lines were introduced in Southern Nevada as new mining districts were discovered to facilitate commerce and trade among the respective mining camps and the nearest railroads (The Clason Map Company, 1907). For example, by 1905, about 50 freighters were operating between Las Vegas and the Bullfrog Mining District in Beatty (Paher, 1971; p. 87). However, the existing freightage system (consisting of horse or mule teams with about a 22-ton capacity) was soon overwhelmed by the volume of materiel making its way to these communities, and the high tonnage of mineral ores being shipped out (Elliott, 1973; pp. 215–216).

Thus, as the number of new mineral deposits identified continued to grow, and mining activity in the area increased, entrepreneurs soon recognized the potential for small regional railroads. Two regional railroads ultimately served the Amargosa Desert area - the *Las Vegas and Tonopah Railroad* (or the LV&T) and the *Tonopah and Tidewater* (or the T&T).

3.2.1 The Las Vegas and Tonopah Railroad

Located at the north end of the valley, the LV&T was the first rail line introduced to the area (Myrick, 1992; pp. 454–503). It was intended to connect the newly incorporated town of Las Vegas (est. 1905) with the growing mining community of Beatty, to the west. The LV&T began regular operations in 1906. Once completed, full service was also extended to the nearby mining camps in Rhyolite and Goldfield. A one-way, 197-mi trip took about 8 hours to complete, which was faster and more direct than the existing carriage route slightly to the south. By 1907, 50 cars of freight were hauled daily to the mining districts served by the railroad (McCracken, 1992a; p. 37).

Before its construction, the main transportation artery in the area had been an unfinished roadway that existed farther south of the LV&T alignment, approximately contiguous with State Highway 95. It connected the communities of *Las Vegas*, *Indian Springs*, *Ash Meadows*, and *Beatty*. A 1905 map reproduced in Myrick (1992, p. 457), as well as a 1906 geologic reconnaissance map of the area (Ball, 1907), shows its approximate location. The trace of this roadway can also be found on 1:62,500-scale USGS topographic quadrangle maps for the area – *Big Dune* (1952 edition), *Lathrop Wells* (1961 edition), and *Ash Meadows* (1952 edition). The Ash Meadows topographic map shows, for example, that the roadway trace closely follows many of the existing spring locations (e.g., *Fairbanks* and *Longstreet*). In those instances where there were no naturally occurring sources of supply, private wells were dug (e.g., *Franklin, Miller's Nos. 1 and 2, Rosewell*). In the Yucca Mountain area, there were local stops at *Indian Springs* and *Charleston* (to the east of Amargosa Valley). Within Amargosa Valley, local station stops could also be found at *Amargosa* (at the base of the *Spector Range*), *Miller's Station* (at the valley floor), and *Rosewell* (northeast of *Big Dune*).

The second mining boom was beginning to wane in Southern Nevada by the time the second railroad line, the T&T, reached Beatty. Business for the LV&T was helped by the *Carrara marble quarry* (Kral, 1951; p. 63). Operations were suddenly stopped there in 1916, when the power supply to the quarry as abruptly halted (*Op cit.*).[27] Shortly thereafter (about 1918), the LV&T ceased operations because of declines in revenues, and its assets were liquidated. In 1919, the Nevada Department of Highways purchased the right-of-way. In 1920, State Highway 5 (now Interstate 95) was constructed on the track's roadbed (Myrick, 1992; p. 503), thereby connecting Las Vegas and Beatty. Railroad ties were ultimately appropriated by local residents along the route for the construction of homes, barns, shops, and corrals.

3.2.2 The Tonopah and Tidewater Railroad

At the southern end of the valley, construction began on the T&T railroad in 1905 (Myrick, 1992; pp. 545–593). Initially, the T&T was to haul borax ore (in the form of the mineral colemanite) from the *Lila C. mine*, which was located on the eastern flank of the Funeral Mountains. The owners of the LV&T denied the owners of the mine, the Pacific Coast Borax Company, a rail connection. Consequently, after obtaining permission to establish a connection with the *Sante Fe Railroad* system, the Pacific Coast Borax Company decided to construct a second railway line from California, to the south, originating near *Ludlow*. Overall, construction of the T&T line was slow and hampered by labor problems, adverse desert working conditions, and arduous topography in the Amargosa River Canyon (*Op cit.*). Nonetheless, by 1907, the T&T had been extended to *Death Valley Junction*, with a 7-mi spur from there to the Lila C. mine. By 1907, the 250-mi system also had stops as far north as *Gold Center* (to the south of Beatty) and Rhyolite.

However, by the time the T&T line reached Beatty, the mining boom was waning in

[27] In later years, there were attempts at establishing a Portland cement plant at the site using water piped from the upper reaches of the Amargosa River. However, the effort was abandoned and the plant dismantled in 1936.

Southern Nevada, and business for both it and the LV&T began to suffer. Because it had a more-direct route to the west coast, and because of the dedicated borax ore shipments from the Lila C. mine, it is generally believed that the T&T was on sounder economic footing than the LV&T (Myrick, 1992; p. 559). By 1914, the higher-grade ores at the Lila C. mine had been exhausted and production began to fall-off. Mining there ended in 1920 and another nearby mine was subsequently opened — the *Biddy McCarty* (*Op cit.*, p. 586). Overall, though, by the late 1920s, these and other local Pacific Coast Borax Company deposits became depleted, and T&T profits began to deteriorate because of a decline in ore haulage. Business for the T&T was briefly helped by the mining of specialty clays for the petroleum industry in Ash Meadows. The deposits were discovered in 1916 and first mined about 1918 (Cornwall, 1972; p. 35). A spur line was constructed to *Clay Camp* to support mining operations there, which produced about 1200 tons of ore per month. Mining at the site continued until closure of the railroad in 1940.

In 1927, a three-quarter-mile rail spur was constructed to Carrara, southeast of Beatty, but revitalized quarry operations there ceased the same year (Myrick, 1992; pp. 587–588). By the outbreak of the Second World War, the Carrara quarry was essentially abandoned (McCracken, 1992b; p. 47). Other periodic T&T ore haulage during the time included talc (*Tecopa* and *Acme mines*) and some infrequent silver from Beatty (Myrick, 1992; p. 591). By the late 1930s, operators of the line filed to cease operations. Ultimately, abandonment of the line was authorized in July 1940 and the War Department requisitioned the steel rails for scrap, which were removed during 1942-43 (*Op cit.*, p. 593).

3.2.3 Significance of Railroad Siting

In examining the history of water development in the area, a question arises about what impact, if any, did the introduction of these two railroads have on the exploitation of local water supplies in Southern Nevada? The answer is that the railroads had a major impact on the exploitation of heretofore undeveloped ground-water resources. This was in large measure because of the railroad's access to capital and technology. Maxey and Jameson (1948, p. 5), report that the LV&T was the first to drill for ground water in what was then the railroad shop of the *Las Vegas depot*, in 1907. Shortly thereafter, drilling syndicates were formed to drill wells north of railroad-owned property and sell off the land for farming (*Op cit.*).[28] This same drilling expertise was later employed by the local railroads in the Amargosa Valley.

As is the case with modern highways today, railroad engineers at the time tended to favor routes that were as straight and as level as possible, with a minimum of cut and fill. That is to say both the LV&T and the T&T designs emphasized directness and lowest maximum grade between their respective termini. Because the earth's topography is not uniform, railroad designs are typically a series of curves with easements and transitions between the changing curve radii that are a function of the train's proposed operating speed. This classic design approach is apparent when examining the 1954 edition of the USGS 1:250,000-scale topographic map for the *Death Valley, California-Nevada* quadrangle. This map shows a somewhat level LV&T alignment (now State Highway 95), more or less, following the 2800-ft mean-sea-level (msl) topographic contour through most of the

[28]The construction of the LV&T was also instrumental in the establishment of the community of Las Vegas, in 1905. Senator William A. Clark (1839-1925) was the principal owner of the LV&T. He also had financial interests in another railroad line that already passed through Las Vegas – the *San Pedro, Los Angeles, and Salt Lake Line* (Myrick, 1992). When construction began on the LV&T, Clark purchased the two ranches controlling the principal springs in the valley – the *Las Vegas (or Spring) Rancho* and the *Kiel (Kyle) Ranch*. These ranches were later purchased, subdivided, and sold by the railroad (Crampton, 1976; pp. 37–39). In 1909, Clark County was created from portions of Lincoln County and named for the Senator.

valley. This route also happens to be the most direct route to Beatty. By contrast, this same map shows that the T&T alignment closely traces the Amargosa River channel. Although the T&T route is the most direct to Beatty, it may not necessarily be the most level. Because the river channel is the main drainage artery for the basin, it is likely the steepest geomorphic feature within the valley floor. Myrick (1992, p. 546) notes that the T&T relied on an old wagon trail as its road base for most of its route (Figure 6). Nevertheless, the location of either railroad line alignment was not significant for hydrogeologic reasons. As noted earlier, if local water supplies could not be developed, then the railroad would import water from another location.

Again considering the LV&T, the alignment of much of this railroad line took advantage of existing water supplies at *Tule Springs, Corn Creek Springs, Indian Springs, Miller's Station*, and *Rosewell*. Table 4 indicates that the railroad was also able to successfully develop wells at *Corn Creek* and *Amargosa*, although the quality of the ground water at the *Amargosa* location was questionable (Carlson, 1974; p. 37). By contrast, it appears that most of the water supply for T&T station stops in the area were supplied by drilled wells (Table 5), despite the existence of local springs in the Funeral Mountains. In addition, hand-dug wells, all likely pre-dating the T&T, were already known to be adjacent to the train bed, as noted below:

Well Name	Location *	Depth (ft) *
Unnamed (NV)	T15S, R47E**	not reported
Franklin (CA)	Section 5, T26S, R5E	10
Unnamed (CA)	Section 9, T26S, R5E	3
Kelly's (CA)	Section 34, T26S, R5E	19

* Taken from Walker and Eakin (1963; p. 49), unless otherwise specified.
** 1952 edition of the 1:62,500-scale USGS topographic map for the *Big Dune, California-Nevada* quadrangle.

Thus, in all likelihood, railroad planners knew local drilling would yield reliable ground-water supplies. Also, it is important to note that not all local supplies were suitable for locomotive use because of their high mineral content. Large bicarbonate and sulfate concentrations could result in the scaling and ultimately the corrosion of the locomotive's steam boilers. Consequently, local water supplies had to be chemically analyzed to determine their suitability for railroad use (Carpenter, 1915; p. 41).[29]

3.2.4 The T&T Experimental Farm

In its 33-year lifetime, the T&T railroad had only a few years of profitable operation (Myrick, 1992; p. 591). One of the plans to increase the profitability of the line was to demonstrate the feasibility of land reclamation, using local ground-water supplies, in heretofore undeveloped portions of the valley, by establishing an experimental farm. Some limited "back-yard" gardening of vegetables and grains, by resident section crews responsible for track maintenance, had already been taking place at *Leeland Station* (Section 5 of T16S, R48E) —the first T&T stop inside Nevada. See McCraken (1992b, p. 44) and Myrick (1992, pp. 499, 549).[30]

In addition, farming had already been well-established in Pahrump Valley before 1900 at the *Bennett* and *Manse Ranches*. See Mendenhall (1909; p. 91) and McCraken (1990b; pp. 11-20). On learning of these achievements, T&T officials reasoned that if farming could be established in the Amargosa Desert, homesteaders would be attracted and the agricultural products could be shipped by the company. They expected that by expanding the volume of commercial haulage to include agricultural products, the railroad

[29]Based on the recommendations of Dole (1911).

[30] The literature notes that the resident section crews were mostly Mexican nationals and the inference is that these individuals possessed the skills necessary to farm arid land. At the time, Mexican society was largely rural. Many in that society practiced traditional farming methods, on small plots of land, that was essentially subsistence agriculture and under conditions similar to those found at Leeland Station.

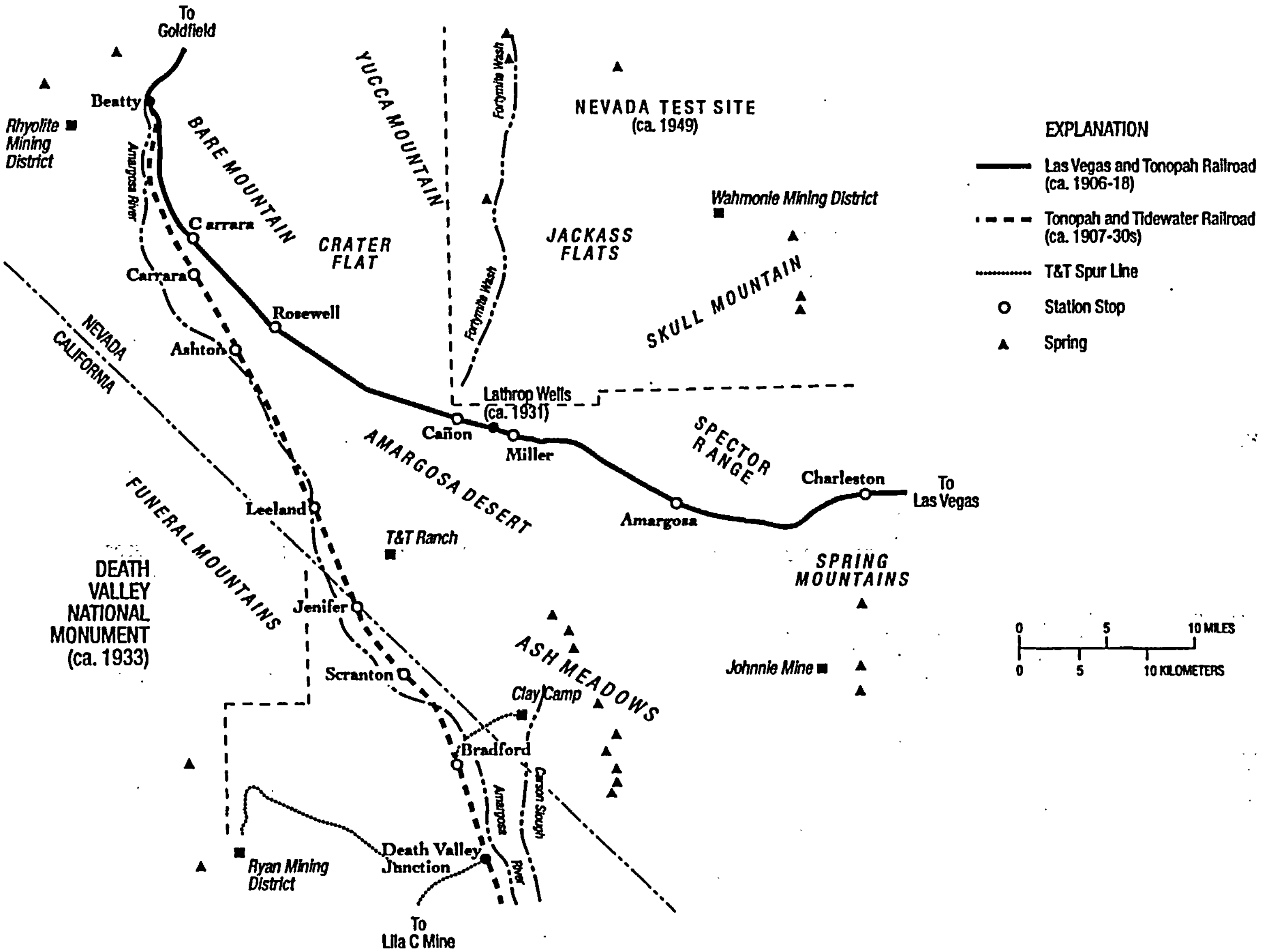


Figure 6. **Approximate Location of the T&T and LV&T Railroads in the Amargosa Desert Area.** Water supply information for the station stops shown can be found in Tables 4 and 5. Detailed information on springs in the Ash Meadows area can be found in Figure 5 and Table 3 of this report. Geographic base is from the 1952 edition of the USGS topographic map for the *Ryan, California-Nevada* quadrangle (1:62,500-scale).

Table 4. **Reported and Inferred Sources of Water Supply for the LV&T Railroad.** Compiled from the references cited. The transformation of the former LV&T railroad grade into what is now State Highway 95 destroyed archeological evidence at some of these sites. Thus, for some of the stations identified (i.e., *Charleston, Point-of-Rocks, Miller, Cañon*), it is likely that their locations can now only be found in the literature.

Location	Elevation (msl – ft)	Milepost from Las Vegas (mi)	Water Source	Type		Comments	Reference(s)
				Depth (ft)	Static Water Level (ft)		
Las Vegas	2030	0	Unspecified LV&T well	< 100 [a]	65	Well also supplied *Corn Creek Station* construction.	Carpenter (1915); Maxey and Jameson (1948, p. 5)
Tule	2495	12	*Tule springs*	Ground level		Early 20th Century homestead; spring yields about "one to two barrels [a day]."	Mendenhall (1909, p. 92)
Corn Creek	2900	21	*Corn Creek Springs* [b] (2930' msl)	Ground level		Early 20th Century homestead; spring discharges 125 gpm.	Clark County Department of Comprehensive Planning (1982, p. 207); Thordarson and Robinson (1971, p. 158)
Owens	3029	28	Not reported.	----	----	Established June 1907 to serve saw mills 12 mi away at Charleston Peak.	Carlson (1974, p. 184)
Indian Springs	3136	44	*Indian Springs* [c] (3175' msl)	Ground level		Early 20th Century homestead.[d] Water piped from spring 1 mi south of station. Spring discharge about 430 gpm.	Carpenter (1915, p. 74); Thordarson and Robinson (1971, Table 5)
Charleston	3629	65.5	Not reported.	----	----	Located at base of Spotted Range, probably served Mercury Valley and points north.	Hattori and McLane (1982)
Point-of-Rocks	3034	[e]	Not reported.	----	----	Station infrequently used.	
Amargosa (*aka* Johnnie Siding)	2790	74.5	Well [f]	179	50	Served *Johnnie Mining District*, 12 mi to the southeast, as well as *Ash Meadows area*.	Walker and Eakin (1963); Paher (1980, p. 325); Hattori and McLane (1982)

Location	Elevation (msl – ft)	Milepost from Las Vegas (mi)	Water Source	Type		Comments	Reference(s)
				Depth (ft)	Static Water Level (ft)		
Miller	2495	85	Well	186	183	Served Death Valley area. Originally part of the *Palmer-Rose* overland freight line between Las Vegas and Beatty.	Ball (1907)
Cañon	e	88	Not reported.	----	----	Station infrequently used.	Carlson (1974, p. 69)
Rosewell	2550	100	Well [g]	210	178	Originally part of the *Palmer-Rose* overland freight line.	Ball (1907); Mendenhall (1909, p. 90); Carlson (1974, p. 205); Hattori and McLane (1982, p. 9)
Carrara	2880	107	Water piped from undefined springs in *Gold Center (Beatty) area* [h]	Ground level		Water supply system consisted of 8-mi pipeline and pumping station.	Lingenfelter (1986, p. 405); Hattori and McLane (1982, p. 11)
Beatty	3284	115	Principally the *Beatty spring group* [i] (3370' msl).	Ground level		Springs approximately 1 mi north of Beatty; 100–200 gpm discharge. Also relied on 11-mi pipeline from *Goss Spring* (125 gpm discharge). Before pipelines, water was hauled by burro at $5/barrel.	Lingenfelter (1986, pp. 218, 222); Malmberg and Eakin (1962, p. 28)

a. 12-in well reported to be "deep."
b. Carpenter (1915; Plate II) also shows 408- and 880-ft wells at the site.
c. Carpenter (1915, p. 74) notes that although four wells had been drilled in the area (ranging in depth from 100 to 700 ft, with a variable water table depth of 16 to 46 ft), the spring was still the preferred source of water supply for the railroad.
d. Originally the *Towner Ranch*, it provided overnight accommodations to travelers to Carson City. The ranch later formed the nucleus of what later became a major terminal for various overland stage routes to *Ash Meadows, Goldfield, Pahranagat* (Maxey and Jameson, 1948; Clark County Department of Comprehensive Planning, 1982 (p. 194).
e. Location not precisely known.
f. Well reported destroyed (Walker and Eakin, 1963; p. 49). Mendenhall (1909, p. 91) also notes that *Miller's Well No. 2*, 6 mi to the south, was also a likely supply source. This 70-ft well yielded about 200 barrels per day of "brackish water" (*Op cit*.).
g. Now dry, the hand-dug well originally yielded about 100 barrels per day (Carlson, 1974; p. 205).
h. *Old Whitney well* is believed to be about 4.7 mi from the site, farther up the former LV&T railroad grade (Hattori and McLane, 1982).
i. Other significant local springs include *Goss, Indian*, and *Terry Springs* (Malmberg and Eakin, 1962).

Table 5. **Reported and Inferred Sources of Water Supply for the T&T Railroad.** Compiled from the references cited. Water supplies at Beatty and Carrara were developed before the arrival of the railroad.

Location[a]	Elevation[a] (msl – ft)	Milepost from Beatty[a] (mi)	Water Source	Type		Comments	Reference
				Depth (ft)	Static Water Level (ft)		
Beatty (NV)	3344	0	Principally the *Beatty spring group*.	Ground level		See Table 4.	
Carrara (NV)[b]	3240	9	Water piped from undefined springs in *Gold Center*.	Ground level		See Table 4.	
Ashton (NV)	2663	14	Well	[c]	?	Served mining districts in Northern Funeral Mountains.	
Leeland (NV)	2380	24	Well	179	?	Served *Lee Mining District* (Funeral Mountains).	Walker and Eakin (1963, p. 46)
Jenifer (CA)[c]	2350	30	None	----	----	No stop. Served mining districts in Northern Funeral Mountains.	
Scranton (CA)	2330	35	Well	23	21	Served mining districts in Northern Funeral Mountains.	Walker and Eakin (1963, p. 49)
Bradford (CA)	2200	41	None	----	----	No stop. Narrow-gauge spur to clay deposits (*Clay Camp*) to the west of Ash Meadows	Lingenfelter (1986, p. 410)
Death Valley Junction (CA)	2037[d]	47	Well	200	63	Major railroad junction/yard serving mining districts in Southern Funeral Mountains and Greenwater Range. Also site of *Pacific Coast Borax Co.* roaster plant.	Lingenfelter (1986)

Location[a]	Elevation[a] (msl – ft)	Milepost from Beatty[a] (mi)	Water Source	Type		Comments	Reference
				Depth (ft)	Static Water Level (ft)		

a. From Myrick (1992, p. 599).
b. Spur to site built in 1927, after dismantlement of T&T railroad.
c. Well depicted on the 1952 edition of the 1:62,500-scale USGS topographic map for the *Ryan, California-Nevada* quadrangle in Section 25 of T27N, R4E.
d. Lingenfelter (1986, p. 391) notes that drinking water was provided to local mining communities from supplies located in Death Valley Junction. Walker and Eakin (1963, p. 49) identified two public wells in the area that are likely the "East" and "West" wells drilled by the *Pacific Coast Borax Co.* These wells are cited in the "Tonopah and Tidewater Railroad Collection" of special papers (Box 1, Folders 5 and 6) located at the *James R. Dickinson Library, University of Nevada (Las Vegas).* French and others (1981, p. 14) note that local residents obtain their water from a distribution system connected to a shallow well that does not meet State drinking water standards because of total dissolved solids (TDS) levels in excess of 1000 mg/L, as well as high fluoride levels.

could also increase revenues (Gower, 1969; p. 28). The concept was sound because farming and ranching had already been well-established in Ash Meadows for many years.

Consequently, between 1915-17, the T&T railroad established a 10-acre experimental farm and dairy. It was named the *T&T Ranch* and was located in Section 25 of T16S, R48E, about 5½ mi southeast from Leeland Station. The farm had a barn, corrals, and other support buildings. Although ostensibly under the technical direction of the University of Nevada (Reno),[31] the farm was operated by railroad personnel (McCracken, 1992b; p. 67). The farm provided fresh vegetables and milk to the *Furnace Creek Inn* (in Death Valley) and the *Amargosa Hotel* (at Death Valley Junction) - both establishments were also owned and operated by the Pacific Coast Borax Company. McCraken (1992b, p. 69) reports that irrigation water was pumped constantly during peak growing season. Although the T&T experimental farm had been in operation since 1915, no new homesteaders had been attracted to the area. In fact, census records indicate that Nevada's population was in decline (Table 2) while the populations of other Western States were expanding. At the time, McCracken (1992b, p. 68) reports that there was the general belief that the conditions imposed by the Homestead Act were too difficult to meet - specifically, developing a surface water supply sufficient to cultivate the requisite 160 acres. In particular, it was thought that Nevada's lack of surface water resources was hindering its agricultural progress (U.S. House of Representatives, 1919; p. 2).

In an effort to encourage more favorable homesteading terms, officials of the T&T railroad persuaded Nevada State Senator Key Pittman (1872-1940) to sponsor new homesteading legislation in 1916. In 1919, Congress passed the *Pittman Underground Water Act*. This homesteading act was intended to "...encourage the reclamation of certain arid lands in the State of Nevada." The act authorized the Secretary of the Interior to issue permits for 160-acre tracts of open, nonmineral public lands in the State known to be irrigable, with permits not to exceed a total of 2560 acres (i.e., one Section). Each permit provided the homesteader with exclusive rights to drill for subsurface water on the tract. If, within two years of receiving the permit, the homesteader was able to locate and develop sufficient ground water to raise crops on at least 20 acres, the homesteader became eligible to receive a patent to the full 160-acre tract. The remaining three-quarters of the tract (480 acres) would thereafter be opened for settlement by others on 160-acre increments as provided for by the 1862 Homestead Act. The primary purpose of the Pittman Act therefore was "...to encourage the discovery of artesian water on the public domain in the State of Nevada without appropriation or expense on the part of the Government," in order to promote "[t] he future development of the agricultural land of the State." (U.S. Senate, 1915; pp. 1–2).

The only homesteaders to take advantage of this new homesteading legislation were themselves officials of the Pacific Coast Borax Company, which owned the T&T Railroad (McCraken, 1992b; p. 68). The claims were centered around the T&T Ranch, forming a contiguous block of land. After drilling, the five claims were eventually patented in 1927 and the homesteaders subsequently consolidated their holdings by forming the *Leeland Water and Land Company*. Soon thereafter, the consolidated land holdings were transferred to the railroad's parent company (McCraken, 1992b; pp. 68–69).

[31] At the time, many States operated "experimental" agricultural stations to improve on local farming practices so this arrangement was not uncommon.

Overall, the Pittman Act failed to significantly advance agricultural development in Nevada, and the Amargosa Valley in particular, and Congress repealed the act in 1964. The T&T Ranch was essentially abandoned by the early 1940s, when railroad operations of its namesake ceased (Bureau of Reclamation, 1975; p. 13). The property remained abandoned until after the Second World War. The lack of commercial success of the ranch may have been caused by the proximity of the site to local markets. At that time, as well as today, Venstrum (1939, p. 82) noted that one of the major impediments to agricultural development in Southern Nevada was the isolation of local farms from major markets.

Although the use of the wells at the T&T Ranch is considered to mark the beginning of land reclamation and modern irrigation in the Amargosa Desert area (Walker and Eakin, 1963; p. 37), it is not clear how many wells were actually in use at this time. Records of the Nevada State Engineer (Carson City), suggest there may have been as many as five observation wells (dated 1921), in addition to one production well. McCraken (1992b, p. 69) reports that initially several wells were drilled to support farm operations, and they ranged in depth from 72 to 88 ft. However, farmers already recognized the potential for ground-water-level declines in Southern Nevada, from irrigation, as early as 1908 (Maxey and Jameson, 1948; p. 6). This "well complex," consisting of a pumping well surrounded by observation wells (Figure 7), may have thus been established by the farm operators after the Pittman Act land patents had been granted to better understand ground-water phenomena in an area heretofore not evaluated.[32]

3.3 Developments in Drilling and Pumping Technology [33]

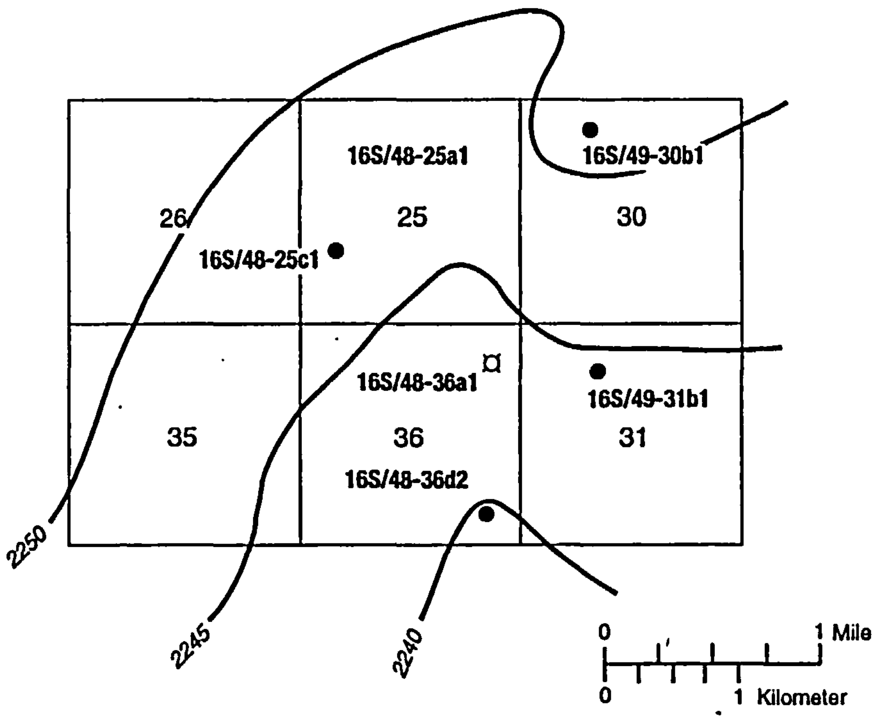
With the arrival of the railroads, more abundant and reliable sources of water had to be located. The locomotives at the time were steam-driven and, given the arid climate and the steep grades to be negotiated, frequent water stops were necessary to maintain boiler supplies. Steam locomotive designs in the 1890s consumed about 80 gallons of water per mile (White, 1998; p. 521) and carried about 2000 gallons of water (*Op cit.*, p. 65). Given these constraints, boiler supplies for operating locomotives are estimated to have been in need of frequent replenishment (i.e., about every 25 miles or so).

Supply methods took on various forms. Usually, the railroad companies attempted to rely on surface water from local springs. Kraus (1969) notes that sometimes railroads would attempt to create man-made springs by drilling horizontally into the sides of mountains, hoping to collect percolating surface water in so-called "infiltration galleries" (Bennett, 1970). At the time, Ball (1907, p. 22) noted that farmers used this technique successfully to recover irrigation water from alluvial fan deposits in California. However, this supply method is not believed to have been relied on in the Amargosa Desert area.

When spring water wasn't available, fresh water was hauled in, or wells were dug or drilled. Ball (1907, p. 21) reports that, in general, shallow wells were typically sunk in the gravel areas found in flats or gulches adjacent to the main travel routes or near the

[32]Empirical evidence indicates that some amount of ground water will always be retained within an aquifer because of physical processes. Thus, it was important to understand how much water a particular geologic unit could actually supply to a production well. To determine just how much water can be supplied by an aquifer, or its *specific yield* (Meinzer, 1923; p. 51), pump tests were devised. Such tests are reported in the literature as early as 1904 (Clark, 1917; p. 84) and were used to determine the general "water-yielding properties" of sands and gravels. Specific yield was first defined by Meinzer (1923, p. 70) as "...the total volume of water pumped by the total volume of sediments drained." It is likely that this well field arrangement, consisting of a pumping well and several observation wells, was established at the T&T Ranch for this purpose.

[33]Unless otherwise noted, much of the discussion in this section on developments in drilling and pumping technology is based on Allen (1958); Bruce (1958); Brantly (1971), and Tanish and Churchfield (1978).



EXPLANATION

¤ 16S/48-36a1	Pumping Well (ca. 1917) and Number
● 16S/48-36b2	Observation Wells (ca. 1921) and Number
—2240—	Water-Level Contour Above Mean Sea Level (in feet)

WELL COMPLEX SUMMARY

Well	Casing Diameter (in)	Depth (ft)	Static Water Level (ft)
16S/48-36a1	Not reported	165	68
16S/48-25a1	16	198	85
16S/49-36d2	16	62	54
16S/49-30b1	16	180	84
16S/49-31b1	$16^1/_2$	153	69
16S/48-25c1	12	203	64

LOCATION MAP

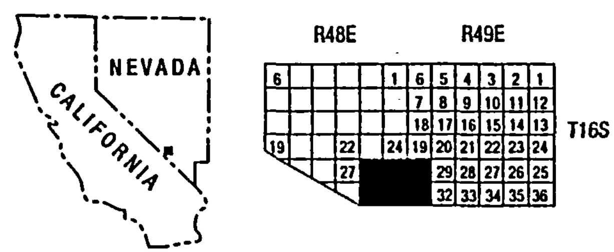


Figure 7. **Well Complex at the T&T Ranch.** Figure shows a pumping well surrounded by a series of observation wells. Data table complied from Walker and Eakin (1963).

respective railroad alignments. Based on a reconstruction of ground-water conditions before 1952, Kilroy (1991) estimates that the depth to water table in some places (*Amargosa Flat*, *Ash Meadows*, and *Franklin Lake playa*) was less that 20 feet. [Also see Czarnecki (1990).] Thus, the digging or drilling of wells would not have proven to be too difficult a technical challenge, at that time.

Hence, it is likely that the first wells in the area were either hand-dug (i.e., *Rosewell, Miller's Well Nos. 1 and 2*) or man-made improvements to existing spring-discharge points. Before 1900 and before the use of mechanical excavation techniques became widespread, it is also likely that early wells were bored by hand-operated augers following the drilling technique known to be used in the Eastern United States at the time.[34] This drilling technique is well suited for shallow water tables in unconsolidated sediments. These conditions can be found in many places in the Amargosa Desert. Moreover, augering did not rely on large amounts of water for lubrication and the removal of cuttings, as is the case with other (modern) drilling methods. Wells developed in this manner were typically lined with a casing of either concrete or metal pipe to prevent the borehole from caving-in. Casing also preserved the hydraulic properties of the well.

Once constructed, various methods were used to lift ground water to the surface. The simplest method was to manually lift water using a bucket and rope. Often, draft animals were used. Later, more sophisticated methods were used, such as windmills[35] – here the breezes were dependable (Murphy, 1901). Although these technologies may have been innovative in their times, they were not capable of providing water in quantities sufficient to meet mining and irrigation needs. However, two major technological developments – the perfection of mechanical cable-tool drilling systems and submersible pumps – changed all this.

Cable-tool Drilling Systems: Cable-tool (or the "yo-yo") is the oldest type of the drilling methods. Drilling is accomplished through the regular lifting and dropping of a string of preferable because they were less likely to be *tools*,[36] consisting of a drill bit, not unlike a chisel, with a relatively sharp edge that breaks the rock by impact (percussion) – that is attached to one or more series of steel bars (cables) called "spring poles." The spring poles added weight to the cutting surface as well as length to the drill so that it would cut rapidly and vertically. During the drilling process, this entire assembly is lifted and released anywhere from 20 to 40 times (strokes) per minute ranging from 1- to 3-foot-lengths per stroke. The drill line is also rotated during the operation, thereby creating a borehole. After the drill bit has cut though 3 to 6 ft of a geologic formation, the string of tools is extracted and the hole is bailed to remove cuttings. Because of the weight of the drill string and spring poles, every cable tool method usually has certain restrictions that depend on borehole depth and borehole diameter. For example, small-diameter boreholes may be drilled relatively deeper than large-diameter boreholes. Collapsing rock formations may also further restrict the initial casing diameter. Generally, casing size decreases as borehole depth increases. Overall, the cable tool drilling method was usually effective for drilling boreholes in consolidated materials, up to 2 ft in diameter,

---

[34] In the 1880s, auger boring was the chief drilling method for developing water wells in the Atlantic and Gulf Coastal Plain areas of the United States (Carlston, 1943).

[35] Windmills are known to have been used in the *Sarcobatus Flat-Oasis Valley areas*, for watering stock (Malmberg and Eakin, 1962; Table 4). Although they are not cited in the literature, it is likely that windmills were also used in the area at one time because of the light-to-moderate winds present.

[36] The full string of cable tool drilling equipment typically consists of five components – a drill bit, drill stem, drilling jars, swivel socket, and cable (Driscoll, 1986; p. 270).

and to depths of about 2000 ft (Todd, 1980; p. 179). With the advent of this new technology, most water wells in the United States were drilled rather than dug. Drilled wells were generally uncontaminated by surface spoils, and more likely to provide reliable water supplies (Bowman, 1911; p. 25). They were also safer to construct.

The standard cable-tool drilling rig was initially developed in the United States. The completion of the first drilled well in Charleston, West Virginia was about 1808 (Carlston, 1943; p.122). Initially, the drill-bits were crude and shaped like fish tails. By the mid-1800s, cable-tool drilling techniques had been improved as a consequence of the industrial revolution and the exploration for petroleum and natural gas. Using a single-cylinder steam engine as a power source, this drilling method was later used to develop the first commercial oil well in the United States - the *Drake Well* in Titusville, Pennsylvania - in 1859 (Brantly, 1971; p. 153). The drilling derrick was adapted from its use as a ship's crane (Derry and Williams, 1961; p. 491) to aid in the withdrawal and storage of drill-pipe and cutting tools. By the end of the century, stand-alone drill rigs were outfitted with wheels for mobility. By the late 1920s-early 1930s, the rigs became truck-mounted. Steam-driven versions were replaced by versions powered by gasoline or diesel fuel. Before the late 1950s, most wells in Southern Nevada were drilled with cable tools (Livingston, 1938; p. 151). The simplicity of their design, ruggedness, and ease of repair and maintenance made the cable-tool systems well-suited for operation in isolated areas (U.S. Bureau of Reclamation, 1977). However, this drilling method was not well-suited for unconsolidated rocks that were water-bearing, so casing of the borehole was often necessary.

Cable drilling costs in the early 1900s were about $1.25/ft, for the first 100 ft; increasing by $0.50/ft for each succeeding 100-ft increment (Carpenter, 1915; p. 40). Drilled wells were usually cased. Drill-pipe and well casing were locally acquired merchant materials. Livingston (1938, pp. 151-152) notes that the usual practice was to drill until the borehole began to cave in and then install casing along the weakened portion of the excavation. Once the casing was installed, drilling would proceed using a smaller diameter drill bit. As a result, most wells in the area have several sizes of overlapping casings. Sometimes gravel packs or perforated casings were used as screens (*Op cit.*, pp. 40, 63). Often no screen would be used.

Some of the early wells in Southern Nevada were uncapped and free-flowing *(artesian)*. This made it easy to exploit local water supplies, but wasted large quantities of it. For example, of the 100 wells sunk in the Las Vegas Valley before 1912, all reached ground water, and 75 were free-flowing (Carpenter, 1915; p. 40). [37] This practice ultimately resulted in early regulation of ground-water supplies by the State Engineer (see Section 3.5). However, unless the ground water was already under sufficient hydraulic head, the water supplies developed using these drilling methods were not free-flowing. Thus, they were only sufficient for a small livestock ranch and not mining and irrigation, because the means for extracting large volumes of ground water were still lacking.[38]

[37]The wells ranged in depth from 150 to 1150 ft, with casing diameters ranging from 3 to 12 in, usually averaging about 8 in.

[38]After its initial development in France in the 1860s, a second drilling method became available - *rotary drilling*. This technology was first introduced to the United States, in the 1880s, in an effort to discover ground-water supplies in remote areas of South Dakota (Brantly, 1971; p. 216). The drilling bits themselves consisted of conical cutting surfaces attached to hollow drill pipe. The pipe is rotated to create a cylindrical cutting motion that excavates geologic formations by fracturing, grinding, and scraping. Unlike cable-tool methods, rotary drilling operates continuously and relies on drilling muds (clay-water mixtures) to lubricate the cutting surface, seal the borehole, and remove cuttings. Additional advantages include a rapid drilling rate and the avoidance of the need to install casing during drilling.

This particular drilling method was found to be well-suited

Centrifugal Pumps: The use of ground water as a source of supply was further helped by the introduction of pumping technology. Beginning in the 1800s, *steam-driven reciprocating (piston) pumps* were already available, mostly in Europe and the Eastern United States, for hydraulic applications. These pumps had already been found useful in dewatering underground mines. The most popular of these was the *Cornish Beam* or *Pumping Engine* (Stowers, 1958).[39] In the mid-1850s, the *rotary or centrifugal pump* was developed. It was mechanically simpler than other pumps for it had fewer moving parts. When compared with other pump designs, the centrifugal pump had been shown to be capable of lifting water against both low- and high-head water conditions (Allen, 1958; p. 524). Also, but more importantly, the centrifugal pump was capable of higher, more constant delivery, with less work (energy) at higher pressures and speeds. See Hood (1898). In the early 1900s, smaller *air-lift pumps* came into fashion for a brief time. These pumps, though, have an uneven delivery.

Thus, once centrifugal pumps had been demonstrated as a practical means for pumping water, designs were soon modified for mobility and powered by coal gas, oil, and gasoline. By the 1910s, pump designs included electric versions adapted for installation under water. Early designs were surface-mounted, on large caissons, with vertical turbine shafts (Carpenter, 1915; pp. 42–43). Later, in the 1930s, electrical versions of the pumps were adapted for submersion in the well bore.

By the 1910s, it was commonplace to find gasoline, diesel, or electric-powered centrifugal pumps, ranging in size from 12 to 30 horsepower,[40] supplying the water needs of Eastern Nevada. Pumps in this power range were capable of irrigating between 5 and 50 acres of farmland (Wilson, 1896; p. 45). When the first reported irrigation well in the area was reported to have been drilled in 1917 (Walker and Eakin, 1963; p. 37), it is likely that it followed the model described by Carpenter (1915), for Eastern Nevada.

Finally, the emergence of innovative drilling and pumping technology did not go unrecognized by the Nevada State Legislature. As early as 1879, an act was approved that permitted the county to pay a bounty of as much as $2/ft for any artesian well drilled (Shamberger, 1991; p. 25).[41] Other types of financial incentives were subsequently passed into State law, between 1887 and 1913, to encourage the private development of ground water for the public good (*Op cit.*, pp. 26–27).

3.4 Role of Hydrogeologic Investigations

The use of ground water in Southern Nevada generally preceded the scientific understanding of its origin and occurrence. As noted earlier in this report, Native Americans, and later, Euro-American homesteaders, were already well-established at the sites of major local springs before the

for unconsolidated alluvial rocks, particularly those that were water (fluid)-bearing (Carpenter, 1915; p. 40). In addition, rotary systems permitted the inspection of drill cuttings to evaluate geologic conditions, while drilling was taking place – unlike cable-tool systems, which required the drilling process to be periodically (and frequently) stopped, to bail cuttings. Nevertheless, it wasn't until 1949 that a rotary system was used to drill a water well in northern Nevada – near *Denio* (Swanson, 1998; p. 96).

[39]By the early 1870s, such pumps were in operation in Nevada. See the account given by Shamberger (1972, pp. 39–41).

[40]A 15-horsepower (gasoline-driven) centrifugal pump, for example, could deliver about 700 gpm of water (Carpenter, 1915; p. 42). Ultimately, pump size was based on water supply needs as well as aquifer-pumping depth and other aquifer hydraulic characteristics.

[41]Under the terms of the act, an individual having to drill and case an artesian well would receive $2/ft for every foot of well drilled beyond 500 ft, provided that a free-flowing well had been developed. Before the passage of the act, if a person already had drilled a well, they received $2/ft for every foot of well drilled beyond 300 ft, provided that a free-flowing well had been developed. The intent of this legislation was to give well owners an incentive to continue with drilling if no water were encountered at the 300- or 500-ft depths (*Op cit.*).

conduct of the first geologic surveys of Southern Nevada. Many of the wells had been drilled and developed before formal scientific investigations were conducted and results documented. Nevertheless, the ability of geologists to prepare system-wide analyses of hydrogeologic conditions has contributed to ground-water development in the Amargosa Desert area and elsewhere in the State. Analyses such as these ultimately improved the quality of earth science information available for public and private decision-making (e.g., Herfindahl, 1969; Bernknopf and others, 1993).

3.4.1 Early Studies

During the late eighteenth and early nineteenth centuries, fundamentals in the geologic sciences were established in Europe (Adams, 1954). These precepts subsequently provided the theoretical basis for evaluating the occurrence and movement of ground water in the United States. Early ground-water resource investigations were conducted by State Geological Surveys and at universities located mostly in the East (Rosenshein and others, 1986). Creation of the USGS, in 1879, was intended to foster an improved understanding of the water resource potential for Western States necessary for irrigation projects. Funding was appropriated, in 1888, for water research that led to the development of the *Water Resources Division* of the USGS (Rabbitt, 1980; pp. 157–161). This division had its first publication appear in 1896 (by Wilson).

Despite the existence of certain basic hydrogeologic theories (i.e., Darcy 1856; Dupuit, 1863), most of the early hydrogeologic investigations were empirical. They relied on the observation and documentation of in-situ conditions found in the field. Many of the early USGS investigations[42] focused on ground-water systems that had produced flowing artesian wells because of the absence of extensive surface water supplies (Meyer and others, 1988; p. 2), as well as no ready access to steam or electrical power to operate pumps.

The first regional overview of water supply in Southern Nevada was prepared by Mendenhall in 1909. Coincidentally, in the same year, one *Carey Land Act* application was received from the *Amargosa Valley Land and Irrigation Company* in Nye County. Although the application was approved, it was subsequently relinquished by the organization (Shamberger, 1991; p. 87). Large tracts of land were covered by irrigation applications for speculative purposes (*Op cit.*, p. 85) by companies with financial backing from the East (Reisner, 1986; p. 108) because there was no filing fee nor price for the land. Shortly thereafter, Carpenter (1915) described drilling and irrigation practices in what were artesian aquifers in the Las Vegas basin. Waring (1921) later described these activities in nearby *Pahrump*, *Mesquite*, and *Ivanpah Valleys*. As a result of the work by Mendenhall and other investigators involved in national mapping efforts, Meinzer (1923) was able to prepare the first comprehensive treatise on the occurrence of ground-water in the principal rock types of the United States, including the local valley-fill deposits considered characteristic of the Basin and Range physiographic province in Southern Nevada (*Op cit.*, pp. 291–303).

The widespread availability of drilling and pumping technology in the 1920s helped to meet the increasing demands for water by a growing western population and reclamation-based agriculture in Southern Nevada. Some of this local activity was described by the *University of Nevada's Agricultural Experimental Station* (Bixby and Hardman, 1928). However, in the arid west, because of the increase in demand on ground water as a source of supply, water tables declined in areas for which natural recharge rates were small in comparison to demand. This led to an increase in the study of well and aquifer hydraulics, during the 1930s and 1940s, to better understand ground-water recharge

[42]Reported in the *Water-Supply Paper series* that succeeded the *Water-Supply and Irrigation Paper series.*

phenomena. As a result of these studies (and others), a series of classic scientific papers describing fundamental geohydrology were published. See Theis (1935,1940) and Jacob (1940, 1947). Freeze and Back (1983), Reilly (2004), and Fetter (2004a, 2004b) summarize this history in more detail.

Although not discussed in detail here, there were parallel advances fluid mechanics science that contributed to improvements in the design of hydraulic machinery, such as pumps and water conveyance systems. See Rouse (1976) for a discussion of this history.

3.4.2 Basin-Wide Studies

There was rapid growth and unregulated use of ground water in the 1920s and 1930s in the greater Las Vegas Valley. This resulted in increased withdrawal of water from local aquifers by pumping, and decreased yields from wells and springs. Although these consequences were recognized as early as 1908 (Maxey and Jameson, 1948; p. 6), it wasn't until 1938 that the Nevada State Engineer became more actively involved in evaluating and managing ground-water resources (*Op cit.*, pp. 7–8).[43] These events led to a comprehensive evaluation of ground water within the State.

In an attempt to determine how the Las Vegas basin would respond to future development, the State Engineers Office entered into a cooperative agreement with the USGS. The results of these investigations were later documented in a series of reports – Livingston (1938); Maxey and Jameson (1946, 1948); Maxey and Robinson (1947); and Robinson and others (1947). Early findings of one particular investigation, Livingston (1938), resulted in the Nevada State legislature determining that immediate changes to its water laws were necessary to better conserve the ground-water resource.[44]

At the time of the Las Vegas artesian basin studies, only a few of the valleys (i.e., hydrographic areas) in Nevada had undergone ground-water development. Although sizable ground-water resources were thought to exist in other basins, their extent was not known because of the absence of data. Consequently, in 1945, the State Engineers Office established a ground-water study program that included a network of 250 observation wells throughout the State (Schamberger, 1991; pp. 68–69). This program was also conducted in cooperation with the USGS, and results were published by the State as *Nevada Water-Resources Bulletins* (*Op cit.*, p. 70). Beginning in 1960, the Nevada Department of Conservation and Natural Resources and the USGS published a ground-water resource *Reconnaissance Series* for basins not previously evaluated in the *Water-Resources Bulletins* (*Op cit.*, pp. 69, 72). This included ground-water resource evaluations for the Amargosa Desert area (Walker and Eakin, 1963) and NTS (Rush, 1970).

There was increased geologic interest in Southern Nevada following the creation of the *Nevada Proving Grounds* (predecessor to NTS) for nuclear activities by the then Atomic Energy Commission (AEC). Following publication of a geologic reconnaissance by Johnson and Hibbard (1957), the USGS initiated a series of regional ground-water studies. These studies were published as *Technical Evaluation Investigations* or TEIs and included the Amargosa Desert area. Exploratory and test wells were sometimes sunk as part of the investigations.

[43]In 1903, the Office of the State Engineer was created to help protect existing water rights and better manage available water resources in Nevada. See Schamberger (1991, p. 17). The early focus of this office was in the management of surface water resources and irrigation concerns. Later, in 1929, the *Nevada Bureau of Mines and Geology* was established, in association with the *Mackay School of Mines*, to provide information on the geology and mineral resources within the state (Tingley, 1988; p. 287).

[44]The *Comprehensive Underground Water Act of 1939* stipulates that all underground water within the State belongs to the public and is subject to appropriation for beneficial use (Schamberger, 1991; pp. 57–58).

The next major evaluation of the ground-water phenomena in the Amargosa Desert area was in the mid-1970s. At this time, the U.S. Bureau of Reclamation (1975) conducted a soil survey as part of its *Inland Basins Program,* to determine the potential for extensive agricultural development of the area. As part of this survey, the Bureau of Reclamation had a test well drilled for pump tests. The 1500-ft well was used to evaluate the thickness and character of the saturated alluvium and to determine the depth to Paleozoic bedrock. The USGS also initiated the *Regional Aquifer-System Analysis Program* during this time in response to a Congressional mandate to develop quantitative appraisals of the major ground-water systems of the United States. The interpretive report of the region including the Amargosa Desert area was published as Burbey and Prudic (1991).

In the early 1980s, in parallel with Congressional passage of the *Nuclear Waste Policy Act* and its implementing regulations, the USGS (in consultation with several states[45]) characterized and evaluated potential hydrogeologic environments for the disposal of high-level radioactive wastes in the Basin and Range physiographic province. The results of these studies were published as eight separate chapters to *USGS Professional Paper 1370.*

Two synthesis reports on regional hydrogeology were prepared in the mid-1990s (Pal Consultants, 1995a and b) in support of the *Death Valley National Park Draft Environmental Impact Statement and General Management Plan* prepared by the National Park Service in 1998. In 1999, the USGS sponsored a conference on the status of geologic investigations in the Death Valley National Park. This annual conference (known as the *Devil's Hole Workshop*) focuses on the regional hydrogeology of Southern Nevada and Eastern California, including the Amargosa Desert area. See Slate (1999), for example.

More recent hydrogeologic studies at NTS have been for the purpose of characterizing the potential Yucca Mountain repository site (e.g., Czarnecki and Waddell, 1984; Luckey and others, 1996; D'Agnese and others, 1997). Many of these studies have been published as *Analysis Model* and *Process Model Reports.* To date, more than 450 boreholes have been drilled in support of various scientific investigations of the Yucca Mountain site (DOE, 2002b; p. 16).

Most recently, and again in association with NTS activities, Nye County initiated its *Early Warning Drilling Program* (EWDP) in the late 1990s with support from DOE. The EWDP has been described as a phased test-well drilling program intended to provide important hydrologic information on the shallow and deep saturated zones down-gradient from the potential repository. This program is described in more detail in Volume 2 (Lee and Coleman, 2005) of this NUREG series.

3.5 Regulation of Water Supply

Because of the arid climate, there appears to have been an early interest in both the development and conservation of ground water within Nevada (Maxey and Jameson, 1948; pp. 4–12). Historically, the only reliable sources of water were the numerous springs, weeps, and seeps, and ground water – to the extent it was accessible.

The State of Nevada legislature began to regulate surface water use as early as 1866, and ground water as early as 1879 (Shamberger, 1991; pp. 6, 25). In 1903, the Office of the State Engineer was created to help protect existing water rights and better manage available water resources. Introduction of subsurface drilling technology in the late 1800s increased interest in the exploitation of ground-water resources. The Nevada legislature subsequently passed additional legislation recognizing that the

[45]Arizona, California, Idaho, Nevada, New Mexico, Texas, and Utah.

ground-water resources would be subject to appropriation by the State Engineer. The legislature also required the adoption of conservation measures to case and cap artesian wells (*Op cit.*, p. 24).

In an effort to conserve the resource, curtail wasteful practices, and protect legitimate water rights, the Nevada State Legislature approved the *Comprehensive Underground Water Act of 1939* (Shamberger, 1991; pp. 57–58). This act declares that "...all underground (ground water) water within the boundaries of the State belongs to the public." To ensure beneficial use of the resource, all water use in Nevada is regulated by the Office of the State Engineer in the Division of Water Resources (NDWR) through permitting or *appropriation*. See Morros (1982, p. 20545) and State of Nevada (1982, pp. 79–83).[46] The maximum amount of ground water that can be appropriated from a given hydrogeologic basin in Nevada is limited to its *perennial* or *safe yield*.[47] For each hydrologic basin in the State, the State Engineer has estimated the perennial yield. These estimates rely on assessments prepared cooperatively by NDWR and the USGS. When ground-water withdrawals exceed recharge, overdrafting or water-mining of the basin can occur. (Water mining can occur even at pumping rates well-below the recharge rate because the water table level reflects a recharge-outflow equilibrium surface. Ground water can also cross hydrographic basin boundaries and thereby also affect equilibrium levels.)

Overdrafting of ground water produces a number of undesirable effects. The most significant is the depletion of the existing resource because overdrafted water comes from storage. Additional undesirable effects include deteriorating water quality, well interference, and land subsidence. Each of these effects are problematic from a cost perspective. Over-appropriation is also prohibited by the State. See Morros (1982; pp. 20467–20557).

The current maximum permissible water-use rate in Southern Nevada is based on the State's perennial yield philosophy. Residential or domestic use is limited to 1800 gpd per single-family unit (State of Nevada, 1982; p. 79), with only one well per household. Agricultural or ranching use is limited to 4 to 5 acre-ft/yr [Tom Gallagher, NDWR (Carson City), personal communication, July 1997]. However, it is generally recognized that *overdrafting* has occurred because of the over appropriation of aquifers, throughout a large portion of Southern Nevada (Maxey and Jameson, 1948; Malmberg, 1967; Nichols and Akers, 1985; Harrill, 1986; Plume, 1989; Morgan and Dittinger, 1996). This has led to some restrictions on development. In instances where it is believed that ground-water withdrawals could exceed ground-water recharge, the State Engineer may issue a statement known as a *designation order*, as a means of protecting the aquifers in a ground-water basin from overuse (DOE, 1988b; p. 3-114). As a *designated basin*, the order defines the area of the overdraft and restricts the issuance of new permits in that area.

Rapid growth in Southern Nevada during the last half-century has resulted in an increased demand for potable water. As a result, there have been documented overdrafts throughout the region. These overdrafts have continued for several decades and are likely a result of the problems associated with determining water budgets, including the estimation of perennial yield (e.g., D'Agnese and others, 1997), for hydrographic areas in Southern Nevada. Because there have been overdrafts, both the Amargosa and Pahrump Valley basins are currently listed as *designated*

[46]Ground water is appropriated by the Nevada State Engineer in the manner described in *Water Supply Report* 2 (State of Nevada, 1982; pp. 79–83).

[47]The State Engineer applies the "safe-yield" philosophy to the allocation of ground water in Nevada. "Safe yield" is a term of art and is generally regarded as the amount of water that can be pumped from an aquifer, on a sustained annual basis, without depleting the reserve or impacting existing legal rights. Any withdrawal in excess of the safe yield can be considered an overdraft (Mann, 1963).

(State of Nevada, 1982; Table 29). The implication of being designated is that the agricultural use of ground water would have the lowest preference of beneficial-use ranking. Under the designation condition, changes in authorization of existing water use or new permitting for domestic and/or quasi-municipal use are favored (Science Applications International Corporation, 1986; pp. 3-5).

Another possible explanation for the overdrafts could be a limitation on the State's 1939 regulatory authority. Ground-water appropriations made before 1913, and used continuously since then, are generally not covered by the State Engineer's 1939 authority. Thus, because there are unregulated ground-water rights in place, it is difficult to evaluate the total amount of ground water available for apportioning throughout the State (State of Nevada, 1982; p. 80).[48]

Traditionally, supply-side solutions such as reservoirs (dams) and canals have been used to meet the growing water needs in the West (Reisner, 1993). However, today such solutions may have become prohibitively expensive (Frederick and others, 1996). In a 1992 report prepared for the State of Nevada, it was noted that the greater Las Vegas area would likely need to adopt a regional solution to its water supply problem (Water Resources Management, Inc., 1992; p. 21). Inasmuch as Nevada already relies on its full allocation from the Colorado River, it has been suggested that a regional supply solution for communities in the Las Vegas valley may include acquiring unallocated ground water in one or more of the neighboring valleys (Basse, 1990; p 24). There was a recent case, in Amargosa Valley, where a private concern petitioned the State Engineer to initiate forfeiture proceedings to acquire unused water rights for the purpose of reallocation (Buqo, 1997; p. 30).

3.6 Agricultural Activity in the Twentieth Century

From the 1920s to the 1940s, there was relatively little development activity in the area. The major population centers were Beatty, Death Valley Junction (because of borax mining); Ash Meadows (because of clay mining and ranching); and the vicinity of the Death Valley National Monument.[49] The State built a highway maintenance facility at what is now Lathrop Wells in 1931 (McCracken, 1992b; p. 72). The *Las Vegas Bombing and Gunnery Range* was created in the early 1940s for the Army Air Corps, to the northeast, using land that is within current NTS boundaries. State Highway 29 was paved from the Lathrop Wells location to Death Valley Junction in the late 1940s (McCracken, 1992b; p. 47). In 1950, the now renamed *Nellis Air Force Range* was selected as the site of the United States continental nuclear test site and the AEC assumed control of operations at the site. These events had little effect, at the time, on the development of ground-water supplies.

In 1948, the abandoned T&T Ranch was reoccupied because of renewed interest in farming at the site. By the mid-1950s, other modern "homesteaders" began to arrive, also intent on farming, owing to the opening of the area to settlement under amended

[48]One of the more well-known examples of the impacts of overdrafting in Southern Nevada was the incident involving the now-present Ash Meadows National Wildlife Refuge. Reduced discharge to some springs in Southern Nye County, in the late 1960s-early 1970s, resulted in the extinction of some late-Pleistocene ancestral fish and the endangerment of others. Overdrafting in Southern Nevada has also resulted in land subsidence and ground failures locally (e.g., Pavelko and others, 1999).

[49]In the late 1920s-early 1930s, several modest desert "resorts" had been created in what is now the Death Valley National Monument. Hoping to attract tourism, some enterprising individuals transformed the living areas at former mining camps – e.g., *Scotty's Castle, Furnace Creek Inn, Saratoga Springs, Death Valley View/ Amargosa Hotel* – see Lingenfelter (1986, pp. 441–467). Shortly thereafter, the Death Valley National Monument itself was established in 1933. During 1933-42, the Civilian Conservation Corps (a *New Deal* unemployment relief measure) maintained camps there during the construction of park infrastructure.

provisions to the Desert Lands Act (McCracken, 1992b; pp. 75–80), now administered by the Bureau of Land Management (BLM).[50] Nuisance vegetation (principally *Larrea-Ambrosia*) was cleared from the irrigation plots and windbreaks were planted to promote soil conservation and protect crops from local wind conditions. Drilling records of the State Engineer confirm the growth in twentieth century homesteading, the trend toward modern land reclamation, and increased ground-water use. Beginning in the early 1950s, and continuing through the 1960s, new drilling permits were issued mostly for irrigation wells.[51] Also during this time, most of the original 1800s-era homesteads were subdivided and sold-off as smaller farms and ranches, which accounted for additional new permitted drilling.

At the beginning of this phase of development (early 1950s), there were about 8000 acres of patented land in the area (Bureau of Reclamation, 1975; p. 13). Following the arrival of electricity, in the early 1960s, an additional 17,000 acres were patented.[52] These more recent homesteading locations can today be easily identified by the stands or rows of an evergreen variety of saltcedar or *Athel tamarisk*[53] used at the time for windbreaks.

Although about 25,000 acres of land have been patented[54] through Desert Land Entry or the Carey Act, in the early 1990s, BLM ceased issuing land patents pending development of a comprehensive resource management plan for the administration of the public lands under its jurisdiction in Southern Nevada. Such a plan (and its attendant Environmental Impact Statement) is required by the *Federal Land Policy and Management Act of 1976* and the *National Environmental Policy Act of 1969*, and would include the Amargosa Desert area. In its proposed resource management plan, BLM recommended that no more than an additional 31,676 acres be made available for discretionary development under Indian Allotment, Desert Land Entry, or the Carey Act. See BLM (1998b, 1998c).

3.6.1 Improvements in Irrigation Delivery Systems

As noted earlier in Section 3.3, after the First World War, there were many new developments in pumping and drilling technology as the demand for petroleum-based products increased. These advances, particularly in the 1930s (Tanish and Churchfield, 1978), also impacted the exploitation and delivery of ground water (Bruce, 1958; pp. 1368–1371). Further impacts were realized by technical improvements in the delivery and application of irrigation water itself.

Most early irrigation methods in the area

[50] In 1946, BLM was formed within the Department of the Interior from the U.S. Grazing Service and the General Land Office.

[51] No water wells were reported to have been drilled for any purpose in the area between the mid-1920s and the early-1950s (Lee and others, 2002).

[52] A major obstacle to expanded water use and agricultural development was the absence of inexpensive sources of power. Initially, the only sources of electricity were diesel- (and some butane-) powered generators, which were expensive and had to run almost constantly during irrigation periods. In 1963, the *Rural Electrification Administration* was instrumental in securing commercial electric power for local residents and businesses (McCracken, 1992b; pp. 84–87). With the arrival of cheaper sources of electric power, there was renewed interest in homesteading and the number of wells in operation grew by about one-third. During the 1960-69 period, for example, there were 217 new drilling permits issued; most were for irrigation.

[53] Athel tamarisk (*Tamarix aphylla*) is a fast-growing, evergreen tree introduced to North America from the Middle East in the early 1800s. It is well adapted to alkaline soils, large temperature extremes, and windy conditions characteristic of the desert Southwest. This tree has numerous slender branches that grow into a dense crown. Leaves are small and scale-like, and gray-green in color. When fully grown, tree heights can range from 33 to 60 feet. In the past, the Athel tree was used for windbreaks, erosion control, and shade. Deciduous varieties of *Tamarix* are considered noxious weeds in the United States.

[54] BLM (1998a, 2000) estimate.

utilized the direct diversion of surface water from springs and streams. Earthen ditches (furrows), sometimes in conjunction with simple hydraulic structures, were used to divert discharged ground water to crops by way of gravity flow. In addition to being somewhat labor-intensive, this passive irrigation technique is both inefficient (conveyance losses, uniformity in application) as well as problematic (erosion control, excess water sediment). Nevertheless, many small farms in the area today still rely on this irrigation method.

Improvements in the delivery and application of irrigation water were achieved through the use of new light-weight materials (plastic and aluminum) as well as automatic control devices. Initially (in the 1950s), the delivery systems were flood siphon tubes and later (in the 1960s), side-roll ("skid-tow") sprinkler systems. Both delivery modes were essentially stationary systems and had to be moved manually from one irrigation location to the next. During the last 20 years, center-pivot sprinklers were perfected and have emerged as the irrigation system of preference, particularly in the West. Such systems are now automated and self-propelled. What is most appealing about this particular irrigation technology is that the light and frequent application of water works well in arid soils with high infiltration rates and correspondingly poor water-holding capacity. It is also regarded as a more efficient and cost-effective irrigation method that is better-suited to soils in places like the Amargosa Desert. See Splinter (1976).

As revealed in Figure 8, center-pivot irrigation systems are popular in the area. They can be easily identified by virtue of their characteristic signature - a *circle* - on aerial photographs and satellite imagery. Center-pivot irrigation systems generally work as follows.[55] The irrigation system consists of water sprinkler nozzles mounted on a 6-in delivery pipe. Water is pumped into the pipe from a source at the center of the field to the sprinklers, which are spaced in such a way that the amount of water applied increases with distance outward from the center of the pivot. This delivery pipe is generally about 8 ft above the ground and is supported by a row of seven or more mobile towers with steel or rubber wheels that are driven with electric or hydraulic motors. Most irrigation systems are designed to fit the conventional unit of agricultural land in the United States - about 160 acres or one quarter-section of land. The circular pattern irrigates about 133 acres of the one quarter-section. These systems are fully electronic (automatic), can apply about 2 in of water in each 12-hr circular traverse, at a rate of 900 gallons/hour (Addink and others, 1975), and can be adapted to apply commercial fertilizers and herbicides. Regular maintenance is required to maintain uniform water applications by the spray nozzles (Briggs and others, 1992).

The use of modern irrigation systems has permitted labor savings as well as economies in the size of acreage farmed. However, the selection of a particular irrigation technique depends on many factors. In general, though, BLM estimates that it would cost in excess of $250,000 to make the necessary irrigation (capital) improvements required by the *Desert Land Entry-Carey Act*.[56]

[55]Taken from Christiansen and Davis (1967).

[56]Estimated capital costs to purchase and construct an irrigation system, and prepare the requisite 320 acres for farming, in current dollars [source: Internet web site at *http://www.blm.gov/nhp/landfacts/DesertLand* (September 2001)]. The National Research Council (1999, p. 66) places the capital costs of center-pivot systems alone at about $300/acre. Capital costs for drilling and finishing the water-supply well, estimated to range from $96/ft to about $500/ft [see EPA (1999) and Wittmeyer and others (2001)], are not included in these estimates. Also omitted is the cost of a water pump needed to lift the water from the water table and deliver it to the irrigation system for crop application. They range in cost from $3000 to $10,000 per system (Gollehon and others, 1994). Lastly, having completed all of the capital improvements necessary to perform irrigation, the operating (energy costs) for the entire system need to be accounted for. Estimates by Scherer (1998) for center-pivot systems are about $644/acre and include well and pump costs. It should be noted that individual estimates will vary by location and whether the equipment is new or used.

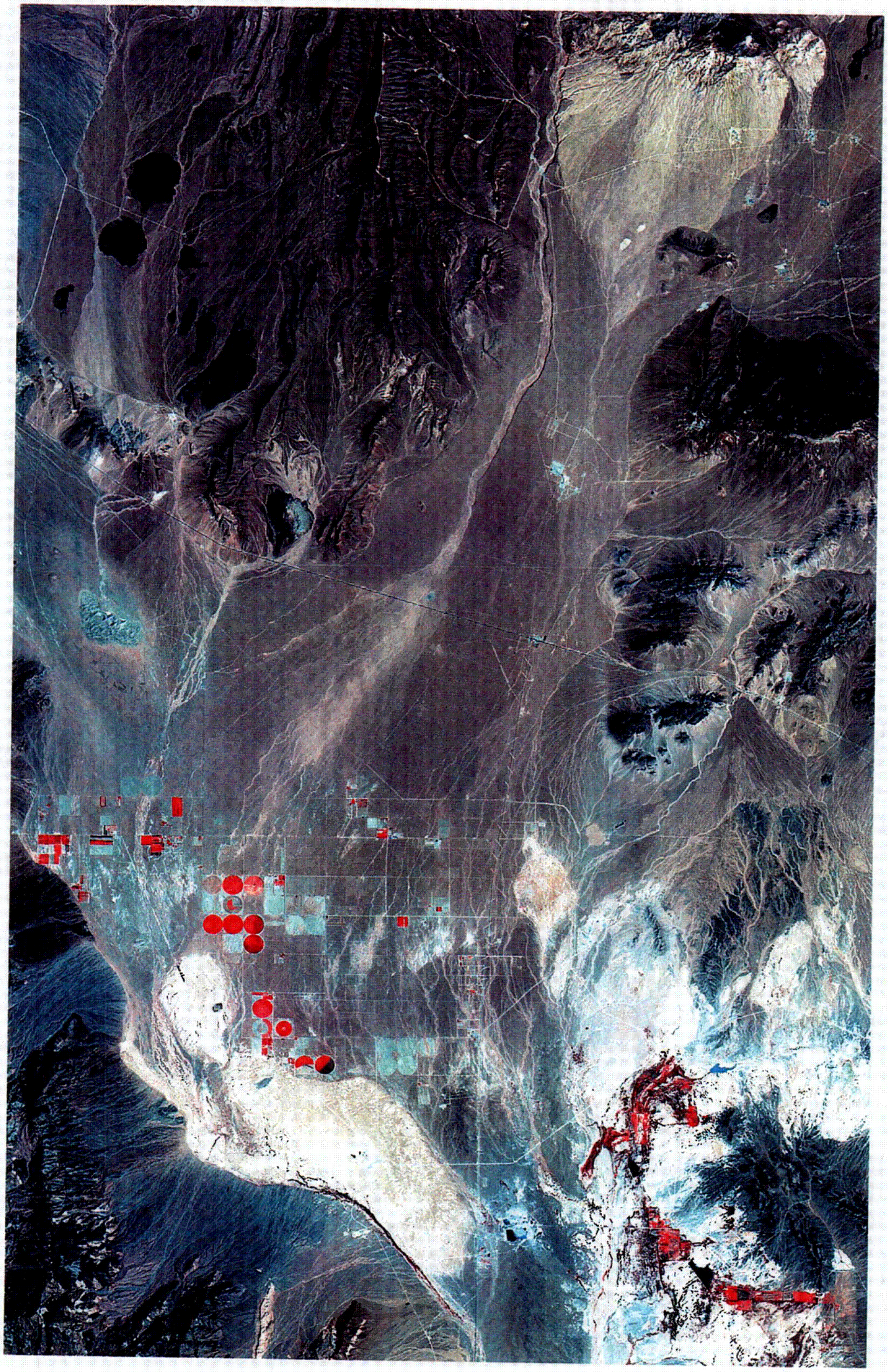


Figure 8. **Landsat Image of the Amargosa Desert Area.** Nominal satellite altitude is approximately 438 miles above the earth's surface.

C03

To meet the growing water supply needs in the area introduced by these modern irrigation systems, about 160 new wells had been drilled by the early 1960s (Walker and Eakin, 1963; Table 3).

3.6.2 Scientific Assessment of Soil Quality

Because of the potential interest in irrigated farming, the Bureau of Reclamation conducted the first of a series of investigations in the late 1960s to evaluate local soil conditions.[57] In summary, these investigations generally report the following. The geologic basin comprising the Amargosa Desert is partially filled with Tertiary- to Quaternary-age sediments derived from the surrounding topographic promontories (mostly volcanic and carbonate sequences) through weathering and erosion. The basin materials are sorted to varying degrees depending on the type of, and distance from, the parent rock. The soils themselves are geologically more recent and were formed on alluvium deposited by the intermittent flow of the Amargosa River and its tributaries. This drainage system reworks and redeposits the basin source material. Source materials are also subject to wind action and dessication due to droughts. As a result, local soils tend to be spatially erratic and lack (vertical) profile uniformity (McCormick and Naphan, 1955). The processes described above yield a coarse class of "soils" (medium- to fine-textured gravels, sands, and silts) that generally hold little water – less than an inch per foot of soil, compared with 2 or more inches for finer-grained soils (Kaser, 1969; pp. 33-26). Evaporation accounts for a considerable amount of (near) surface water loss because of low humidity (30 to 40 percent), abundant sunshine, and light to moderate winds. Evaporation in the area may exceed 120 in of pan evaporation (French and others, 1981; p. 32). Because coarse soils hold little moisture, they also have insufficient capacity for retaining nutrients and are therefore inherently less fertile. Moreover, saline soil conditions exist due to the high concentrations of soluble salts in soil materials as well as a result of the high evaporation rates. This is important because in high enough concentrations, salt compounds can obstruct germination and impede a plant's ability to absorb water and nutrients. Because of these conditions, only salt-tolerant crops (*halophytes*), such as alfalfa, tend to be successful in production. In many areas, soils are also moderately cemented with calcium carbonate that has chemically precipitated from percolating surface waters (McCormick and Naphan, 1955; pp. 15–18). The cemented soil, also known as *hardpan* or *caliché*, generally has the consistency of cured concrete and forms impermeable zones near the ground surface. These zones range in thickness from a few inches to as much as 1 ft in the soil profile (Bureau of Reclamation, 1975; p. 18). The cementation obstructs surface water drainage (percolation) which further contributes to soil salinity. In addition, the caliché creates a physical barrier which restricts the penetration depth of root systems of plants, particularly those with deep root networks like alfalfa.[58] Dynamiting or mechanical plowing (sometimes to depths of up to 5 ft) may be required to render caliché-laden soils workable (Amundson, 2000; p. 9).

Thus, for both geologic and pedogenic reasons, many of the soils in the area have been classified in the past as having properties that "...preclude their use for irrigated agriculture..." or "...have severe limitations that reduce [the] choice of crops or require special conservation practices or both" (Sakamoto and others, 1974).[59] Given

---

[57]Because of their thin soil veneer and variable topography, mountainous areas around the Amargosa Desert basin have been generally excluded from soil surveys.

[58]Alfalfa has a root system that can grow to a depth of 30 ft, when mature. However, it generally needs a minimum of 5–7 ft of soil to develop a root system adequate for production in arid areas (Ogrosky and Mockus, 1964; pp. 21–83).

[59]Based on information prepared by the State Engineer/University of Nevada, it is estimated that at least 60 percent of the soils in the *Amargosa Desert Subbasin* are not considered irrigable; an additional 28 percent of the soils are classified "...severely limited to very

these conditions, many of the Desert Land Entry applicants discontinued crop irrigation after a land patent was granted and some never obtained permanent water rights (Bureau of Reclamation, 1975; p. 48). The principal reason appears to be the absence of 160 acres of contiguous arable land required by the homesteading statutes (*Op cit.*, p. 24).

3.6.3 Ash Meadows Land Withdrawals

In addition to the lands around the former T&T Ranch, another early sought-after homesteading site was the Ash Meadows area. The 22,116 acres of spring-fed wetlands and alkaline desert uplands that initially defined the Ash Meadows location are situated in the southern tip of the Amargosa Desert. They were incorporated into the Death Valley National Monument in 1952 by Presidential Proclamation.

The location provides a habitat for 24 unique flora and fauna. (Four kinds of fish and one plant are currently listed as endangered.) There are about 50 permanent fresh-water springs and seeps that discharge into the refuge. Seven major springs (*Big Springs, Fairbanks, Rogers, Longstreet, Point of Rocks, Jackrabbit,* and *Crystal*) discharge more than 10,000 gpm, year round. Although this discharge area is geologically and hydrologically complex, it is believed that a series of poorly connected gravel, sand, and terrestrial limestone aquifers, supplied by Paleozoic carbonate rocks to the east, provide water to the refuge. See Winograd and Friedman (1972) and Winograd and others (1998). The extensive spring system there, including spring-feed streams, supports a vast riparian zone with abundant natural forage that historically was important to both Native Americans and early pioneers.

During the late 1960s, most of the lands there were still public and managed by BLM. In 1967, on property adjacent to the Ash Meadows portion of the Death Valley National Monument, *Spring Meadows, Inc.*, established a commercial farm and ranch (the *Spring Meadows Ranch*) on 5645 acres of land it obtained through a BLM land exchange.[60] Holdings for the ranch were later increased to 12,000 acres through the private purchase of contiguous, already-patented properties (McCracken, 1992b; pp. 71–72). When necessary, additional local ground-water rights were leased by the ranch operators when land could not be purchased. Besides development of the ranch and farm, about 50 new boreholes were locally drilled and a well field was developed.[61] Other capital improvements included roads, fences, power lines, and the diversion of local streams for irrigation. In summary, when compared to other local farms in operation at that time, the Spring Meadows Ranch was substantial — 4000 acres were under cultivation growing Bermuda grass, alfalfa, wheat, and barley; 1700 to 1800 head of beef cattle grazed; and 100 individuals were employed.

In April 1970, ranch operators sought to further expand pumping operations in the well field, and applied to the State Engineer for changes to permitted water use from several of the wells not currently in production. However, during this time, water-level declines had been observed at the removed Devil's Hole Unit of the Death Valley National Monument. In the view of the National Park Service (NPS), continued or increased pumping of nearby wells was a direct threat to the habitat of the endangered

severely limited..." in their ability to sustain some type of cultivation.

[60]Under Section 8 of the *Taylor Grazing Act of 1934.* In managing public lands, as a matter of long-standing policy, BLM can exchange (i.e., "trade" or "swap") public lands at one location for lands owned by corporations, individuals, States, or local governments at another location. However, the lands to be exchanged must be of equal monetary value and located within the same State. Through exchanges, non-Federal parties can acquire lands with development or economic potential – commercial, industrial, residential, or agricultural. In turn, the Federal Government acquires lands offering public recreation, wildlife, and resource values.

[61]Mostly for operations at the Spring Meadows Ranch. Based on State Engineer records for the period 1967–70.

Devil's Hole pupfish (*Cyprinodon diabolis*) and other species of the genus *Cyprinodon* because of the potential for additional water-level declines.

To resolve the issue, the State Engineer conducted a public hearing in December 1970. NPS commissioned the USGS to determine whether the Spring Meadows' production wells were hydrologically connected to Devil's Hole and, if so, which of those wells could be pumped safely and which should be limited to prevent further water-level declines. At the hearing, NPS requested either that the Spring Meadows' application be denied or that the State's decision on the application be postponed until the USGS studies [later published as Dudley and Larson (1976)] were completed. The Nevada State Engineer declined to postpone a decision, and ruled that the permit would be granted since further economic development of land on the Spring Meadows Ranch would be in the public interest.

In August 1971, the United States filed suit in Federal Court (in Las Vegas) seeking to prevent Spring Meadows, Inc. from pumping (except for domestic purposes) those wells that were known or suspected to have an effect on Devils Hole. Initially, Spring Meadows, Inc. agreed to limit pumping at certain wells; however, the suit was reactivated when pumping resumed in 1972. A subsequent District Court decision led to court-ordered supervision of pumping activity. Appeal of the pumping restrictions was rejected by the Ninth Circuit Court in 1974. In 1975, Spring Meadows, Inc. (now renamed *Cappaert Enterprises*) appealed to the U.S. Supreme Court to review the earlier court decisions because they conflicted with state-assigned water rights (Dudley and Larson, 1976; pp. 1-4). In a June 1976 decision, *Cappaert et al. vs. the United States et al.* (426 U.S. 128), the Supreme Court ordered that high-volume ground-water pumping in the Ash Meadows area be permanently enjoined to prevent further water-level declines within Devil's Hole.[62]

Following the permanent injunction, Cappaert Enterprises sold their operations in the early 1980s to a Pahrump-based land-development company, *Preferred Equities*. Preferred Equities was planning to develop a residential community for about 50,000 at the property which had now grown to about 17,000 acres in holdings. Because of the earlier pupfish controversy and concerns over future impacts to the local ecosystem, *The Nature Conservancy* arranged to purchase 12,600 acres of Preferred Equities land holdings, as well as associated water rights, to preclude future development in the Ash Meadows area (McCracken, 1992b; pp. 71-72). In June 1984, the U.S. Fish and Wildlife Service purchased these holdings and established the *Ash Meadows Wildlife Refuge*.

Today, both the wildlife refuge and the earlier National Monument site encompass more than 22,000 acres. The Ash Meadows Wildlife Refuge is currently undergoing habitat restoration with an overall goal to restore the area to its natural, pre-developed state. This will involve re-directing some spring discharges back into former natural channels, restoring wetlands, removing non-native species (particularly salt cedar, bass, tropical fish, and crayfish), restoring native riparian and upland vegetation, and removing many of the man-made structures.

Drilling records maintained by the State Engineer show that no irrigation well permits were issued in the Ash Meadows area since 1972. Also, in the years since the Supreme Court decision, continuous ground-water monitoring has revealed that the water level in Devil's Hole has recovered to pre-pumping levels [Tim Mayer, U.S. Fish and Wildlife Service (Portland), personal communication, July 1997].

---

[62] An unofficial reprint of the Supreme Court decision for this case can be found on the Internet web site at *http://laws.findlaw.com/us/426/128.html.*

3.6.4 Current Farming Activities

Because of the erratic distribution of arable soils and the Ash Meadows land withdrawals, farming has been generally restricted to scattered tracts of land in southern reaches of the valley. What agricultural activities do occur are confined chiefly to the center of the Amargosa Valley and to the west of Nevada State Route 373. This triangular parcel of land is viewed to have relatively favorable soils and accessible ground water in comparison to other portions of the valley (Horak and Carns, 1997; p. 7). Farming has been successful in the past, due to careful crop selection and special management practices (CRWMS M&O, 1999; p. 10) as well as the application of large quantities of irrigation water (EPA, 1999; p. 8-43). The local growing season averages about 200 days [see Bedinger and others (1985; Table 8, p. G32) and Sakamoto and others (1974)] although some operations may be closer to 300 days (Stonestrom and others, 2003; p. 7). Irrigation methods are flood or sprinkler. The valley is subject to winds of high velocity and duration, creating a sand-blast effect on crops and accelerating soil erosion (Bureau of Reclamation, 1975; p. 21). Consequently, when farming does take place, windbreaks are extensively used. Late frosts can be a problem. Fruit trees grown locally usually bud in February, but a killing frost tends to occur every one in four years – in March.

In 1999, it was estimated that about 2500 acres were under cultivation locally (EPA, 1999; p. 8-40). Alfalfa is the principal commercial agricultural product grown and most of the local growers provide the local dairy operations with a portion of their feedstock.[63] Nine alfalfa farms were reported in production in 1999, ranging in size from 65 to 800 acres and averaging about 255 acres (*Op cit.*). The long growing season permits about seven cuttings per year. However, most irrigation applications need to be properly timed to maintain crop growth. Under current practices, fields are irrigated continuously from February through November. Reported irrigation application rates are variable, ranging from 0.3 to 0.4 in/day (or 6.6 to 8.9 ft/yr – Stonestrom and others, 2003; p. 7).

Other agricultural products grown in the area include lesser amounts of barley, oats, and hay. Winter temperatures are generally too low for the commercial production of winter vegetables. Nevertheless, many local residents maintain *kitchen gardens* and orchards for private use. More than two-dozen fruits, nuts, and vegetables are or have been grown locally (Eisenberg and others, 2001). With few exceptions, most of the farming takes place on a part-time basis, with the owner working full-time in another occupation (Bureau of Reclamation, 1975; p. 13).

All the activities described above rely on some degree of pre-treatment of the soils using commercial fertilizers, sometimes in combination with compost. Despite the effectiveness of these measures, there is information to suggest deterioration of soil conditions in already cultivated areas due to increases in salinity and sodicity levels (CRWMS M&O, 1999; p. 10). Over the long-term, continued increases in salinity and sodicity could lead to reduced agricultural production and possibly abandonment of low-production lands (*Op cit.*).

State Engineer records suggest that only a small percentage of local land is undergoing irrigation at this time and most land users are not using their allocated water rights (Buqo, 1997; p. 30). Overall, current agribusiness in the area is based primarily on a single

[63] Winter hardy, drought-resistant varieties of alfalfa were imported from Russian Turkestan in the early 1900s and proved to be well-suited for the arid climate of the Western United States (Russelle, 2001; p. 259). Nevertheless, because of its inherently low nutritional value (e.g., total digestible nutrients), locally-grown alfalfa is blended with nutritionally-richer alfalfa imported from locations outside of the valley. No more than 10 percent of the production is used locally. Most of the local crop is destined for markets outside of the State [Ken Garey, *Bar-B-Q Ranch* (Amargosa Valley), personal communication, May 1996.]

dairy operation rather than on wide-spread farming. A current herd of about 6000-head supports the *Ponderosa Farms Dairy*. See CRWMS M&O (2000; p. 16). The location of dairy operations here is reported to have more to do with certain economic factors (taxes, permits, state regulations) rather than with agricultural conditions and variables beneficial to bovine well-being (*Op cit.*, p. 17).

3.6.5 Current Water Supply

Today, most Amargosa Desert area residents live in widely spaced farms, ranches, and single-family homes. Although some springs meet (limited) local needs, almost all the water used is provided through either public or private wells. Some of the smaller communities, individual residences, and businesses rely entirely on private (commercial) water suppliers (DOE, 1988b; pp. 3-118 – 3-119). Only a few communities (*Beatty*, *Mercury*, *Tonopah*, and portions of *Pahrump*) have centralized public water systems (DOE, 1986; p. 3-75).

In 1971, the USGS (Thordarson and Robinson, 1971) performed one of the first comprehensive surveys of ground-water availability in the area. The survey was conducted to assist AEC officials in assessing damage claims to water wells and springs possibly resulting from nuclear testing. The USGS reviewed published and unpublished geologic and ground-water data within a 100-mi radius of NTS. The census covered 31,416 mi^2 in portions of six counties in Southern California and Nevada. The types of information collected for the census included aquifer type, water-table depth, yield, and end use. This census identified 6032 wells and 754 springs. Most of the wells identified in the census (98 percent) were located in alluvium. In addition to being the most extensive surficial geologic unit in the region, the alluvial basins are usually the most topographically accessible (occupying physiographic low terrain) and have the highest water-yielding capacity of the aquifer types identified. See Bedinger and others (1989; Figure 1, p. A1). Using USGS data, Fedors and Wittmeyer (2001) describe completion details for typical wells in the area. Water wells are also reported in carbonate and volcanic rocks, but these aquifers generally tend to have lower water yields in the study area. Almost 54 percent of the wells identified in the census were reported to be less than 200-ft deep. Almost 84 percent of the wells were reported to have depths less than 490 ft. Sixty percent of the wells were reported to yield at least 100 gpm. Most of the wells in the census area (56 percent) were reported to be used for domestic purposes. Irrigation (17 percent); municipal and commercial (6 percent each); and stock supply (2 percent), were other end-users of water (Thordarson and Robinson, 1971). (Nine percent of the wells in the 1971 identified in the census area were reportedly no longer in use.)

In a 1988 survey of local wells, for purposes of characterization of the Yucca Mountain site, DOE reported that 50 percent of the wells in the area (199 of 397) were used for domestic use and 41 percent (164 of 397) were used for agricultural irrigation. The remaining 9 percent of the wells were for other uses. See DOE (1988b; p. 3-119). Most of the wells are clustered around the major population centers cited earlier. In DOE's *1986 Environmental Assessment* for Yucca Mountain, the number of local wells reported in operation was 207 (DOE, 1986; p. 3-85).[64] In recent years, the number of domestic and irrigation wells in operation locally is reported to be about 130 (CRWMS M&O, 2000).[65] Well designs are consistent with current standards (Driscoll, 1986).

Agricultural development is currently confined to the southern portion of the Amargosa Desert where ground-water depths range from 33 to 130 ft below the ground surface (Kilroy, 1991), and the gentle topography and suitable soils permit farming.

---

[64] Citing State of Nevada data.

[65] Ibid.

From this location, the depth to the water table increases monotonically along a trajectory extending northward, to more than 980 ft approximately 6 mi from the southernmost perimeter drift of the potential repository. For example, *NTS well J-13*, in Jackass Flats, pumps ground water from a minimum depth of about 980 ft below the ground surface to support Yucca Mountain site characterization activities; however, this may be considered an exception to standard water-supply practice in the area.

In general, water quality throughout the area is adequate for personal consumption, stock, and agricultural purposes. The exceptions are areas in the Southern Amargosa Desert, where evaporites from lacustrine deposits cause the ground water to have TDS concentrations in excess of 10,000 parts/million (Winograd and Thordarson, 1975). Until recently, some ground water was used for processing specialty clays and zeolites mined from lacustrine deposits in Southern Amargosa Desert and in Ash Meadows.

3.6.6 Consumption Rates

DOE has published information on ground-water consumption in the area in several documents: the *1986 Environmental Assessment*; the *1988 Site Characterization Plan* (SCP); in the 1996 *Final Environmental Impact Statement (EIS) for the Nevada Test Site and Off-Site Locations in the State of Nevada* (DOE, 1986, 1988b, and 1996, respectively); and, most recently in technical basis documents providing parameter values for DOE performance assessments for the Yucca Mountain site (CRWMS M&O, 2000).

Using limited consumption data for only 5216 Nye County inhabitants, DOE estimated that the per-capita consumption of water county-wide was 653,000 gpd per 1000 people[66] (DOE, 1986; p. 3-74). Extrapolating this figure county-wide to calendar year 2000 population (Table 2) produces a consumption rate estimate of about 12 million gpd or 37 acre-ft/day. Projected annually, this consumption rate is about 13,400 acre-ft/yr, or more than twice the estimated available perennial-yield amount. Analyses by Fenelon and Moreo (2002, p. 60) place the ground-water withdraw rate in 2000 at 13,000 acre-ft/yr.

DOE has also provided estimated water consumption estimates for selected communities in the Yucca Mountain area (Table 6). This information was first reported in the *Environmental Assessment* (DOE, 1986; p. 3-75), and subsequently updated in the SCP (DOE, 1988b; p. 3-135), and the *Final NTS Environmental Impact Statement* (DOE, 1996; p. 4-132). Table 6 shows that all local communities in the area rely on well water for their supplies. Consequently, certain precautions need to be in place to protect shallow wells from septic contamination. Only a few communities actually have (integrated) public sources of supply.

Finally, it should be noted that several man-made reservoirs have been built in the past to meet the water-supply need for agricultural, mining, or milling purposes, as noted below:

Name	Capacity (acre-ft)	Supply Source	Reference
Crystal Reservoir	1489	*Crystal Spring*	DOE (1988b, p. 3-24)
Clay Camp	43	Local wells	DOE (1988b, p. 3-24)
Death Valley Junction/Point of Rocks	< 40	Not reported	Giampaoli (1986, p. 4)

[66]Estimate based on consumption rate of 3.4 million gpd per 5216 inhabitants.

Table 6. **Water Supply Systems and Rates of Consumption for Major Communities in the Amargosa Desert Area.**

Community	Water-Supply System [a]		Estimated Consumption [b] (10^3 gpd)
	Source	Sewage Treatment	
Amargosa Valley/ Lathrop Wells	Public[c] and private wells	Septic tanks and evaporation ponds	1585
Ash Meadows[c]	Private wells and springs	Septic tanks	40
Beatty	4 municipal wells[c] and spring	Oxidation pond and septic tanks	793
Crystal [c]	Private wells	Septic tanks	61
Death Valley Junction	Private wells [d]	Evaporation pond	17
Indian Springs [c]	Municipal [e] and private wells	Evaporation pond and septic tanks	793
Indian Springs Air Force Base [c]	Wells [c]	Imhoff Tank (sludge disposal in pits)	396
Johnnie [c]	Not reported	Not reported	7
NTS/Mercury [c]	Wells[c]	Oxidation ponds and septic tanks	291
Pahrump [c]	Public[c] and private wells	Evaporation ponds and septic tanks	2480
Rhyolite	Spring-fed storage tank [f]	Septic tank	3

a. From French and others (1981), DOE (1986, p. 3-38), and Science Applications International Corporation (1986, p. 3-6).
b. From DOE (1988b, p. 3-135).
c. Includes piped distribution system. See Gram (1985).
d. Not within Alkali Flat-Furnace Creek Ranch ground-water basin.
e. Water quality does not meet EPA ground-water quality standards.
f. With 20,000 gallon capacity.

7. REFERENCES

Adams, F.D., *The Birth and Development of the Geological Sciences*, New York, Dover Publications, Inc., 1954. [Reprint of the original 1938 edition.]

Addink, J.W., D.L. Miles, and G.V. Skorerboe, "Water Intake under Center-Pivot from Time-Varying Application Rates," *Transactions of the Society of Agricultural Engineers,* 18(3): 523-525 [1975].

Agricola, G., *De Re Metallica [On Metals]*, Basel, 1556. [1950 Dover publication of the 1912 translation by H.C. Hoover and L.C. Hoover.]

Allen, J., "Hydraulic Engineering (in 'Part VI. Civil Engineering')" in C. Singer and others (eds.), *A History of Technology, Volume V: The Late Nineteenth Century - c. 1850 to c. 1900,* Oxford, Clarendon/Oxford University Press, 1958.

Alley, J.R., *The Las Vegas Paiutes: A Short History*, Salt Lake City, University of Utah, 1977. [Prepared by the Las Vegas Tribe of Paiute Indians and University of Utah/American West Center.]

Amundson, R., "Are Soils Endangered?," *California Geology,* 53(4):4-13 [July/August 2000].

Armstrong, E.L., M.C. Robinson, and S.M. Hoy (eds.), *History of Public Works in the United States - 1776-1976,* Chicago, American Public Works Association, 1976.

Baker, T.L., S.R. Rae, J.E. Minor, and S.V. Connor, "Water for the Southwest - Historical Survey and Guide to Historic Sites," Fairfax, American Society of Civil Engineers (ASCE), *ASCE Historical Publication No. 3,* 1973.

Ball, S.H., "A Geologic Reconnaissance in Southwestern Nevada and Eastern California," U.S. Geological Survey Bulletin 308, 1907.

Basse, B., "Water Resources in Southern Nevada," Denver, Adrian Brown Consultants, Inc., August 1990. [Prepared for the Center for Nuclear Waste Regulatory Analyses.]

Batchelor, Y., and D. Batchelor, "Rawhide - Yesterday and Today," *In Focus*, 11(1):57-77 [1997-98]. [Published by the Churchill County Museum Association (Fallon, Nevada).]

Beatley, J.C., "Effects of Rainfall and Temperature on the Distribution and Behavior of *Larrea tridentata* (Creosote-bush) in the Mojave Desert of Nevada," *Ecology*, 55(2):245-261 [1974].

Beatley, J.C., "Climates and Vegetation Patterns Across the Mojave/Great Basin Desert Transition of Southern Nevada," *The American Midland Naturalist,* 93(1):53-70 [1975].

Bedinger, M.S., W.H. Langer, and J.E. Reed, " Synthesis of Hydraulic Properties of Rocks in the Basin and Range Province, Southwestern United States," U.S. Geological Survey Water Supply Paper 2310, 1985.

Bedinger, M.S., K.A. Sargent,, and W.H. Langer, F.B. Sherman, J.E. Reed, and B.T. Brady (eds.), "Studies of Geology and Hydrology in the Basin and Range Province, Southwestern United States, for Isolation of High-Level Radioactive Waste —Basis for Characterization and Evaluation," U.S. Geological Survey Professional Paper 1370-A, 1989.

Bennett, T.W., "On the Design and Construction of Infiltration Galleries," *Ground Water*, 8(3):16-24 [1970].

Bernknopf, R.L., D.S. Brookshire, D.R. Soller, M.J. McKee, J.F. Sutter, J.C. Matti, and R.H. Campbell, "Societal Value of Geologic Maps," U.S. Geological Survey Circular 1111, 1993.

Bixby, F.L., and G. Hardman, "The Development of Water Supplies for Irrigation in Nevada by Pumping from Underground Sources," Las Vegas, University of Nevada Agricultural Experimental Station Bulletin No. 112, 1928.

Bowman, I., "Well-Drilling Methods," U.S. Geological Survey Water-Supply Paper 257, 1911.

Brantly, J.E., *History of Oil Well Drilling*, Houston, Gulf Publishing Co., 1971.

Briggs, B.K., K.J. Fornstrom, and L. Pochop, "Design and Maintenance Factors Affecting Application Uniformity of Low Pressure Center-Pivot Irrigation Systems," in T. Engman (ed.), "Irrigation and Drainage: Saving a Threatened Resource — In Search of Solutions," *Water Forum '92: Proceedings of the 19th American Society of Civil Engineers National Conference, August 2-5, 1992, Baltimore, Maryland*, American Society of Civil Engineers, pp. 257-262 [1992].

Bruce, F.E., "Water Supply (in 'Part VI. Civil Engineering')" in C. Singer and others (eds.), *A History of Technology, Volume V: The Late Nineteenth Century - c. 1850 to c. 1900,* Oxford, Clarendon/Oxford University Press, 1958.

Bryan, K., "Flood-water Farming," *Geographical Review,* 19(3):444–456 [1929].

Burbey, T.J., and D.E. Prudic, "Conceptual Evaluation of Regional Ground-Water Flow in the Carbonate Rock Province of the Great Basin, Nevada, Utah, and Adjacent States: Regional Aquifer-System Analysis — Great Basin, Nevada-Utah," U.S. Geological Survey Professional Paper 1409-D, 1991.

Bureau of Land Management, "Surface Management Status Desert Access Guide, California Desert District —Death Valley Junction," Sacramento, 1 sheet, scale 1:100,000, 1998a.

Bureau of Land Management, "Proposed Las Vegas Resource Management Plan and Final Environmental Impact Statement," Las Vegas Field Office, 2 vols., May 1998b.

Bureau of Land Management, "Rec ord of Decision for the Approved Las Vegas Resource Management Plan and Final Environmental Impact Statement," Las Vegas Field Office, October 1998c.

Bureau of Land Management, "Surface Management Status Desert Access Guide, Nevada (California) Desert District - Beatty," Sacramento, 1 sheet, scale 1:100,000, 2000.

Bureau of Reclamation, " California-Nevada Amargosa Project — Concluding Report," Boulder City, U.S. Department of the Interior, February 1975. [Prepared by the University of Nevada Cooperative Extension Service, Max C. Fleischmann College of Agriculture.]

Buqo, T.S., "Baseline Water Supply and Demand Evaluation of Southern Nye County, Nevada," Blue Diamond, Nevada, [1997]. [Prepared for the Nye County Nuclear Waste Project Office.]

Carslon, H.S., *Nevada Place Names — A Geographical Dictionary,*Reno, University of Nevada Press, 1974. [Cites other primary sources.]

Carlston, C.W., "Notes on the Early History of Water-Well Drilling in the United States," *Economic Geology,* 38:119-136 [1943].

Carpenter, E., "Ground Water in Southeastern Nevada: U.S. Geological Survey Water-Supply Paper 365, 1915.

Chadwick, R., "New Extraction Processes for Metals," in C. Singer and others (eds.), *A History of Technology, Volume V: The Late Nineteenth Century - c. 1850 to c. 1900,* Oxford, Clarendon/Oxford University Press, 1958.

Christiansen, J.E., and J.R. Davis, "Sprinkler Irrigation Systems (Chapter 44)" in R.M. Hagan, H.R. Haise, and T.W. Edminster (eds.), *Irrigation of Agricultural Lands*, Madison, American Society of Agronomy Monograph 11, 1967.

Civilian Radioactive Waste Management System Management and Operating Contractor, "Evaluation of Soils in the Northern Amargosa Valley," North Las Vegas, Nevada, TRW Environmental Safety Systems, Inc., B00000000-01717-5705-00084, February 1999. [Prepared for DOE.]

Civilian Radioactive Waste Management System Management and Operating Contractor, "Ground Water Pumpage Inventory [for 1997] - Amargosa Valley, No. 230 (Attachment II)" in "Groundwater Usage by the Proposed Farming Community," North Las Vegas, Nevada, TRW Environmental Safety Systems, Inc., ANL-NBS-MD-000006 (Rev. 00), February 2000. [Prepared for DOE.]

Clark, I. G., *Water in New Mexico: A History of its Management and Use* , Albuquerque, University of New Mexico Press, 1987.

Clark, W.O., "Ground Water for Irrigation in the Morgan Hill Area, California," in "Contributions to the Hydrology of the United States — 1916," U.S. Geological Survey Water-Supply Paper 400, 1917.

Clark County Department of Comprehensive Planning, "Comprehensive Plan - Clark County, Nevada: Task One, Existing Conditions (Revised)," Las Vegas, Nevada, November 1982.

Collins, E., T.P. O'Farrel l, and W.A. Rhoads, "Biologic Overview for the Nevada Nuclear Waste Storage Investigations, Nevada Test Site, Nye County, Nevada," Goleta, EG&G Energy Measurements, EGG 1183-2460, January 1982. [Prepared for the Sandia National Laboratories.]

Cornwall, H.R., "Geology and Mineral Deposits of Southern Nye County, Nevada," Reno, University of Nevada/Mackay School of Mines, Nevada Bureau of Mines and Geology Bulletin 77, 1972.

Crampton, C.G., *The Complete Las Vegas,* Salt Lake City, Peregrine Smith, 1976.

Czarnecki, J.B., and R.K. Waddell, "Finite-Element Simulation of Ground-Water Flow in the Vicinity of Yucca Mountain, Nevada-California," U.S. Geological Survey Water-Resources Investigations Report, WRI-84-4349, 1984.

Czarnecki, J.B., " Geohydrology and Evapotranspiration at Franklin Lake Playa, Inyo County, California," U.S. Geological Survey Water-Supply Paper 2377, 1990.

D'Agnese, F.A., C.C. Faunt, A.K. Turner, and M.C. Hill, "Hydrogeologic Evaluation and Numerical Simulation of the Death Valley Regional Ground-Water Flow System, Nevada and California, Using Geoscientific Information Systems," U.S. Geological Survey Open-File Report 96-4300, 1997.

Darcy, H., *Les fontaines publiques de la ville de Dijon* [*The Public Fountains of the City of Dijon*], Paris, Victor Dalmont, 1856.

Davis, A.P., "Irrigation Near Phoenix, Arizona," U.S. Geological Survey Water-Supply Paper 2, 1897.

DeYoung, J.H., Jr., "The Lasky Cumulative Tonnage-grade Relationship — A Reexamination," *Economic Geology*, 76[5]:1067–1080 [1981].

Derry, T.K., and T.R. Williams, *A Short History of Technology - From the Earliest Times to A.D. 1900,* New York, Oxford University Press, 1961.

Dibner, B., *Agricola on Metals*, Norwalk, Burndy Library Publication No. 15, 1958.

Dole, R.B., "Rapid Examination of Water," *Economic Geology*, 6(4):353–356 [1911].

Driscoll, F.G., *Groundwater and Wells (2nd ed.)*, St. Paul, Johnson Screens, 1986.

Drollinger, H., C.M. Beck, R. Furlow, and others, "Cultural Resources Management Plan for the Nevada Test Site," Las Vegas, Desert Research Institute, DOE/NV11508-47, June 1999. [Prepared for DOE's Nevada Operations Office.]

Dudley, W.W., Jr., and J.D. Larson, "Effect of Irrigation on Desert Pupfish Habitats in Ash Meadows, Nye County, Nevada," U.S. Geological Survey Professional Paper 927, 1976.

Duguid, J.O., R.W. Andrews, E. Brandstetter, T.F. Dale, and M. Reeves, "Calculations Supporting Evaluation of Potential Environmental Standards for Yucca Mountain," Las Vegas, TRW Environmental Safety Systems, Inc., B00000000-01717-2200-00094-Rev. 01, April 1994.

Dupuit, A.J., *Études théoriques et pratiques sur le mouvement des eaux dans les canaux découverts et á travers less terrains perméables* [*Theoretical and Practical Studies on the Flow of Water in Open Channels and through Permeable Terrains*], Paris, Dunod, 2nd edition, 1863.

Eakin, T.E., S.L. Schoff, and P. Cohen, "Regional Hydrology of a Part of Southern Nevada - A Reconnaissance," U.S. Geological Survey Open File Report, TEI-833, 1963. [Prepared for the AEC.]

Eisenberg, N.A., M.P. Lee, N.M. Coleman, and C. Glenn, "Overview of Farming and Ranching Activities in the Yucca Mountain Area," in T.J. McCartin and M.P. Lee (eds.), "Preliminary Performance-Based Analyses Relevant to Dose-Based Performance Measures for a Proposed Geologic Repository at Yucca Mountain, U.S. Nuclear Regulatory Commission, NUREG-1538, October 2001.

Elliott, R.R., *History of Nevada*, Lincoln, University of Nebraska Press, 1973.

Energy Research & Development Administration [ERDA], "Final Environmental Impact Statement: Nevada Test Site, Nye County, Nevada," Washington, D.C., ERDA-1551, September 1977.

Fedors, R.W., and G.W. Wittmeyer, "Initial Assessment of Dilution Effects Induced by Water Well Pumping in the Yucca Mountain Area," in T.J. McCartin and M.P. Lee (eds.), "Preliminary Performance-Based Analyses Relevant to Dose-Based Performance Measures for a Proposed Geologic Repository at Yucca Mountain," U.S. Nuclear Regulatory Commission, NUREG-1538, October 2001.

Fehner, T.R., and F.G. Gosling, "Origins of the Nevada Test Site," U.S. Department of Energy, DOE/MA-0518, December 2000.

Fenelon, J.M., and M.T. Moreo, "Trend Analysis of Ground-Water Levels and Spring Discharge in the Yucca Mountain Region, Nevada and California, 1960-2000," Carson City, " U.S. Geological Survey Water Resources Investigations Report 02-4178, 2002.

Fetter, C.W., Jr., "Hydrogeology: A Short History, Part 1," *Ground Water*, 42(5):790–TBD [September-October 2004].

Fetter, C.W., Jr., "Hydrogeology: A Short History, Part 2," *Ground Water*, 42(6):949–953 [November-December 2004].

Forbes, R.J., "Petroleum," in C. Singer and others (eds.), *A History of Technology, Volume V: The Late Nineteenth Century — c. 1850 to c. 1900,* Oxford, Clarendon/Oxford University Press, 1958.

Frazier, A.H., and W. Heckler, "Embudo, New Mexico, Birthplace of Systematic Stream Gaging," U.S. Geological Survey Professional Paper 778, 1972.

Frederick, K.D., T. VandenBerg, and J. Hanson, "Economic Values of Fresh Water in the United States," Washington, D.C., *Resources for the Future*, Discussion Paper 97-03, October 1996.

Freeman, I.S., *A History of Montezuma County, Colorado*, Boulder, Johnson Publishing Co., 1958.

Freeze, R.A., and W. Back (eds.), "Physical Geohydrology," Stroudsburg, Hutchinson Ross Publishing Co., *Benchmark Papers in Geology, Vol. 72*, 1983. [Contains 32 papers on the physics of ground-water flow, well and aquifer hydraulics, and regional ground-water flow, plus the editor's comments.]

French, R.H., A. Elzeftawy, J. Bird, and B. Elliot, "Hydr ology and Water Resources Overview for the Nevada Nuclear Waste Storage Investigations, Nevada Test Site, Nye County, Nevada," Las Vegas, Desert Research Institute, NVO-284, June 1981. [Issued June 1984. Prepared for DOE/Nevada Operations Office.]

Gatewood, J.S., A. Wilson, H.E. Thomas, and L.R, Kister, "General Effects of Drought on Water Resources of the Southwest — Drought in the Southwest, 1942-56," U.S. Geological Survey Professional Paper 372-B, 1964.

Geraghty, J.J., D.W. Miller, F. van der Leeden, and F.L. Troise, *Water Atlas of the United States* , Port Washington, Water Information Center Publication, 1973.

Giampaoli, M.E., Inter-Office Memorandum to J. Younker, Science Applications International Corporation, Las Vegas [Subject: "Trip Report: Hydrologic Field Reconnaissance Led by Robert Coache, Water Resources Division, Nevada Department of Natural Resources and Water Conservation, April 24, 1986"], May 7, 1986.

Gollehon, N., M. Aillery, and W. Quinby, "Water Use and Pricing in Agriculture," in U.S. Department of Agriculture, "Agricultu ral Resources and Economic Indicators," Economic Research Service, Natural Resources and Environmental Division, *Agricultural Handbook No. 705*, 1994.

Gower, H.P., *50 Years in Death Valley - Memoirs of a Borax Man*, San Bernardino, Inland Printing and Engraving Co., 1969. [Published as Death Valley '49ers Publication No. 9.]

Gram, A.L., "Development of Water Sources for the Town of Beatty," Altadena, December 1985. [Consultant's report prepared for the Beatty Water and Sanitation District.]

Greene, L.W., "Historic Resource Study - A History of Mining in Death Valley National Monument [California-Nevada]," Denver, National Park Service, Historic Preservation Branch, 2 vols. [4 parts], March 1981.

Hafen, L.R., and A.W. Hafen, *Old Spanish Trail*, Glendal, Arthur H. Clark Co., 1954.

Harrill, J.R., "Ground-Water Storage Depletion in Pahrump Valley, Nevada-California, 1962-75," U.S. Geological Survey Water-Supply Paper 2279, 1986.

Harris, L.G., "New Mexico Water Rights," Las Cruces, New Mexico Water Resources Institute, Miscellaneous Report 25, 1984.

Hartwell, W.T. and D. Valentine, "Reading the Stones: The Archaeology of Yucca Mountain," Las Vegas, Desert Research Institute, Topics in Yucca Mountain Archaeology No. 4, 2002. [Prepared for DOE.]

Hattori, E.M., and A.R. McLane, "An Archeological Survey Between Lathrop Wells, Nye County, and the Indian Springs, Clark County, Nevada," Las Vegas, Desert Research Institute, Technical Report No. 22, August 1981. [Prepared for the Bell Telephone Co.]

Hattori, E.M., and A.R. McLane, "An Archeological Survey Between Beatty, Nye County, Nevada, and the Nevada-California State Line," Las Vegas, Nevada, Desert Research Institute, Technical Report No. 32, November 1982. [Prepared for the Bell Telephone Co.]

Herfindahl, O.C., *Natural Resource Information for Economic Development*, Baltimore, Resources for the Future, 1969.

Hevesi, J.A., A.L. Flint, and L.E. Flint, "Simulation of Net Infiltration and Potential Recharge Using a Distributed-Parameter Watershed Model of the Death Valley Region, Nevada and California," U.S. Geological Survey Water-Resources Investigations Report 03-4090, 2003.

Hundley, N., Jr., *The Great Thirst - Californians and Water, 1770s-1990s*, Berkeley, University of California Press, 1992.

Hunt, C.B., T.W. Robinson, W.A. Bowles, and A.L. Washburn, "Hydrologic Basin, Death Valley, California," U.S. Geological Survey Professional Paper 494-B, 1966.

Hood, O.P., " New Tests of Certain Pumps and Water Lifts Used in Irrigation," U.S. Geological Survey Water-Supply and Irrigation Paper 14, 1898.

Hood, J.W., "Water Wells in Frenchman and Yucca Valleys, Nevada Test Site, Nye County, Nevada," U.S. Geological Survey Open File Report, TEI-788, 1961. [Prepared for the AEC.]

Horak, C., and D. Carns, "Amargosa Focus Group Report: Biosphere Study," Las Vegas, University of Nevada, TIC 241712, 1997. [Prepared by the Cannon

Center for Survey Research.]

Howell, L.B., "The Pecos Valley Irrigation System," *Engineering News*, 36(12):181-183 [1869].

Jacob, C.E., "On the Flow of Water in an Elastic Artesian Aquifer," *Transactions of the American Geophysical Union*, 21: 574-586 [1940].

Jacob, C.E., "Drawdown Test to Determine Effective Radius of Artesian Well," *Transactions of the American Society of Civil Engineers*, 112:1047-1070 [1947].

Jaeger, E.C., "The Mohave Desert," in *The North American Deserts*, Stanford, Stanford University Press, 1957.

Johnson, M.S., and D.E. Hibbard, "Geology of the Atomic Energy Proving Grounds Area, Nevada — A Contribution to General Geology," U.S. Geological Survey Bulletin 1021-K, 1957.

Kaser, R.F., "Irrigation (Section 33)," in C.V. Davis and K.E. Sorensen (eds.), *Handbook of Applied Hydraulics (3rd ed.)*, New York, McGraw-Hill, 1969.

Kilroy, K.C., "Ground-Water Conditions in Amargosa Desert, Nevada-California, 1952-87," U.S. Geological Survey Water-Resources Investigations Report 89-4101, 1991.

Kirby, R.S., S. Withington, A.B. Darling, and F.G. Kilgour, *Engineering in History*, New York, McGraw-Hill, 1956.

Koenig, G., *Beyond This Place There Must Be Dragons: The Routes of the Tragic Trek of the Death Valley 1849ers through Nevada, Death Valley, and on to Southern California*, Glendale, Arthur H. Clark Co., American Trails Series XIV, 1984.

Kral, V.E., "Mineral Resources of Nye County," Reno, University of Nevada Bulletin, Vol. 45, No. 3, *Geology and Mining Series, No. 50*, January 1951.

Kraus, G., *High Road to Promontory: Building the Central Pacific Across the High Sierra*, Palo Alto, American West Publishing Co., 1969.

Kupel, D.E., *Fuel for Growth —Water and Arizona's Urban Environment*, Tucson, University of Arizona Press, 2003.

Landels, J.G., "Water Supplies and Engineering (Chapter 2)," in *Engineering in the Ancient World*, Berkeley, University of California Press, 1978.

Lasky, S.G. "How Tonnage and Grade Relationships Help Predict Ore Reserves," *Mining and Engineering Journal*, 151[4]:81-85 [1950].

Laczniak, R.J., J.C. Cole, D.A. Sawyer, and D.A. Trudeau, "Summary of Hydrologic Controls on Ground-Water Flow at the Nevada Test Site, Nye County, Nevada," U.S. Geological Survey Water-Resources Investigations Report 96-4109, 1996.

Lee, M.P., A.J. Gross, and N.M. Coleman, "Concentration and Distribution of Well Drilling in the Amargosa Desert Area of Southern Nevada," *EOS, Transactions of the American Geophysical Union [Supplement]*, 83[19], S174[2002].

Lee, M.P., and N.M. Coleman, "Histo ry of Water Development in the Nevada Test Site: A Literature Review," U.S. Nuclear Regulatory Commission, NUREG-1710, Vol. 2, February 2005.

Lincoln, F.C., *Mining Districts and Mineral Resources of Nevada*, Reno, Nevada Newsletter Publishing Co., 1923. [1982 reprint by Nevada Publications.]

Lingenfelter, R.E., *Death Valley & the Amargosa: A Land of Illusion*, Berkeley, University of California Press, 1986.

Livingston, P., "Und erground Leakage from Artesian Wells in Las Vegas Area, Nevada" in "Contributions to the Hydrology of the United States —1940," U.S. Geological Survey Water-Supply Paper 849-D, 1938.

Long, M., *The Shadow of the Arrows - Death Valley 1849-1949*, Caldwell, Caxton Printers, 1950 [Revision to the original 1941 edition].

Luckey, R.R., P. Tucci, C.C. Faunt, E.M. Ervin, W.C. Steinkampf, F.A. D'Agnese, and G.L. Patterson, "Status of Understanding of the Saturated-Zone Ground-Water Flow System at Yucca Mountain, as of 1995," U.S. Geological Survey Water-Resources Investigations Report 96-4077, 1996.

Mack, M.J., "Irrigation Engineering in the Former Home of the Aztecs," *Engineering News*, 18:468-469 [1887].

Mackin, P.C., M.P. Lee, M.S. Jarzemba, R.G. Baca, T.J. McCartin, and R.B. Codell, "Activities Related to the Development of the U.S. Environmental Protection Agency Yucca Mountain Standard," in B. Sagar (ed.), "NRC High-Level Radioactive Waste Program Annual Progress Report: Fiscal Year 1996," U.S. Nuclear Regulatory Commission, NUREG/CR-6513, No. 1, January 1997.

Malmberg, G.T., and T.E. Eakin, "Ground-Water Appraisal of Sarcobatus Flat and Oasis Valley, Nye County, Nevada," Carson City, Nevada Department of Conservation and Natural Resources, *Ground-Water Resources - Reconnaissance Series Report 10*, July 1962.

Malmberg, G.T., "Hydrology of the Valley-Fill and Carbonate-Rock Reservoirs, Pahrump Valley, Nevada-California," U.S. Geological Survey Water-Supply Paper 1832, 1967.

Mambry, J.B. (ed.), *Canals and Communities - Small-Scale Irrigation Systems*, Tucson, University of Arizona Press, 1996

Manly, W.L., *Death Valley in '49*, Chicago, Lakeside Press, 1927.

Mann, J.F., "Factors Affecting the Safe Yield of Ground-Water Basins," *Transactions of the American Society of Civil Engineers*, 128 [Part III]: 180–190 [1963].

Maxey, G.B., and C.H. Jameson, "Well Data in Las Vegas and Indian Spring Valleys, Nevada," State of Nevada, Office of the State Engineer, Water Resources Bulletin No. 4, 1946.

Maxey, G.B., and C.H. Jameson, "Geology and Resources of Las Vegas, Pahrump, and Indian Spring Valleys, Clark and Nye Counties, Nevada," State of Nevada, Office of the State Engineer, Water Resources Bulletin No. 5, 1948.

Maxey, G.B., and T.W. Robinson, "Ground Water in Las Vegas, Pahrump, and Indian Spring Valleys, Nevada (A Summary)," State of Nevada, Office of the State Engineer, Water Resources Bulletin No. 6, 1947.

McCracken, R.D., *A History of Amargosa Valley, Nevada*, Tonopah, Nye County Press, 1990a.

McCracken, R.D., *Pahrump —A Valley Waiting to Become a City*, Tonopah, Nye County Press, 1990b.

McCracken, R.D., *The History of Beatty*, Tonopah, Nye County Press, 1992a.

McCracken, R.D., *The Modern Pioneers of the Amargosa Valley* , Tonopah, Nye County Press, 1992b.

McCormick, J.A., and E.D. Naphan, "Understanding the Irrigated Soils of Nevada," University of Nevada, Max C. Fleischmann College of Agriculture, Agricultural Extension Station and U.S. Department of Agriculture, Soil Conservation Service [USDA/SCS], Experiment Station Circular No. 8, February 1955.

Meinzer, O.E., "The Occurrence of Ground Water in the United States (With a Discussion of Principles)," U.S. Geological Survey Water-Supply Paper 489, 1923.

Mendenhall, W.C., "Some Desert Watering Places in Southeastern California and Southwestern Nevada," U.S. Geological Survey Water-Supply Paper 224, 1909.

Meyer, G., G. Davis, and P.E. LaMoreaux, "Historical Perspective (Chapter 1)," in W. Back, J.S. Rosenshein, and P.R. Seaber (eds.), "The Geology of North America - Hydrology," Boulder, *Geological Society of America Centennial Special Volume O-2*, 1988.

Miller, G.A., "Appraisal of the Water Resources of Death Valley, California-Nevada," U.S. Geological Survey, Open File Report 77-728, December 1977.

Morgan, D.S., and M.D. Dettinger, "Ground-Water Conditions in Las Vegas Valley, Clark County, Nevada: Part 2, Hydrogeology and Simulation of Ground-Water Flow," U.S. Geological Survey Water-Supply Paper 2320-B, 1996.

Morros, P.G., "Nevada Water Laws, Title 48 - Water," Carson City, Nevada Department of Conservation and Natural Resources/Division of Water Resources, 1982. [Various chapters complied by the State Engineer.]

Morrow, P.J., and M.N. Machette, "Selected References for the Geology of Death Valley National Park and Surrounding Region," Denver, U.S. Geological Survey, 1999. [Compilation prepared for the Conference on Status of Geologic Research and Mapping in Death Valley National Park," held in Las Vegas, Nevada, on April 9–11, 1999. Available on the Internet at *http://wrgis.wr.usgs.gov/docs/parks/deva/devarefAtoC.html#B*.]

Murphy, C.E., "The Windmill: Its Efficiency and Use," U.S. Geological Survey Water-Supply and Irrigation Paper 41-42, 1901.

Myrick, D.L., *The Railroads of Nevada and Eastern California: Part II — The Southern Railroads* Reno, University of Nevada Press, 1992.

National Geographic Society, "Historical Map of the United States," *National Geographic Magazine*, Vol. CIII, No. 6, 1953.

National Research Council, "Technical Bases for Yucca Mountain Standards," Washington, D.C., National Academy Press, Commission on Geosciences, Environment, and Resources, July 1995.

National Research Council, *A New Era for Irrigation*, Washington, D.C., National Academy Press, Committee on the Future of Irrigation in the Face of Competing Demands, 1996.

Nevada Bureau of Mines, "Mineral and Water Resources of Nevada," Reno, University of Nevada/Mackay School of Mines, Bulletin 65, 1964.

[Prepared by the USGS and the Nevada Bureau of Mines.]

Nichols, W.D., and J.P. Akers, "Water-Level Declines in the Amargosa Valley Area, Nye County, Nevada, 1962-84," U.S. Geological Survey Water Resources Investigations Report, WRI-85-4273, 1985.

Ogrosky, H.O., and V. Mockus, "Hydrology of Agricultural Lands (Section 21)," in V.T. Chow (ed.), *Handbook of Applied Hydrology — A Compendium of Water-Resources Technology*, New York, McGraw-Hill, 1964.

Paher, S.W., *Las Vegas: As it Began – As it Grew*, Las Vegas, Nevada Publications, 1971.

Paher, S.W., *Nevada Ghost Towns and Mining Camps*, San Diego, Howell-North Books, 1980.

Pal Consultants, Inc., "Evaluation of Scientific Literature Pertaining to the Conceptualization of the Death Valley Ground-Water Flow System, Nevada and California," San Jose, October 1995a. [Prepared for the U.S. Department of Interior/National Park Service (DOI/NPS).]

Pal Consultants, Inc., "A Conceptual Model of the Death Valley Ground-Water Flow System, Nevada and California," San Jose, December 1995b. [Prepared for the DOI/NPS.]

Pavelko, M.T., D.B. Wood, and R.J. Laczniak, "Las Vegas – Gambling with Water in the Desert," in D. Galloway, D.R. Jones, and S.E. Ingebritsen (eds.), "Land Subsidence in the United States," U.S. Geological Survey Circular 1182, 1999.

Pippin, L.C. and D.L. Zerga, " Cultural Resources Overview for the Nevada Nuclear Waste Storage Investigations, Nevada Test Site, Nye County, Nevada," University of Nevada System, Desert Research Institute, NVO-266, November 1983. [Prepared for DOE.]

Plume, R.W., "Ground-Water Conditions in Las Vegas Valley, Clark County, Nevada: Part 1, Hydrogeologic Framework," U.S. Geological Survey Water-Supply Paper 2320-A, 1989.

Powell, J.C., *Report on the Lands of the Arid Region of the United States, with a More Detailed Account of the Lands of Utah*, Washington, D.C., U.S. Government Printing Office, 1878.

Price, J.G., L. Shevenell, C.D. Henry, J.G. Rigby, L.G. Christensen, P.J. Lechler, M.O. Desilets, R. Fields, D. Driesner, B. Durbin, and W. Lombardo, "Water Quality at Inactive and Abandoned Mines in Nevada," Reno, University of Nevada/Mackay School of Mines, Nevada Bureau of Mines and Geology Open-File Report 95-4, December 1995.

Price, J.G., C.D. Henry, S.B. Castor, L. Garside, and J.E. Faulds, "Geology of Nevada," *Rocks and Minerals,* 74(6):357–390 [November/December 1999].

Prudic, D.E., J.R. Hatrrill, and T.J. Burbey, "Conceptual Evaluation of Regional Ground-Water Flow in the Carbonate-rock Province of the Great Basin, Nevada, Utah, and Adjacent States," U.S. Geological Survey Professional Paper 1409-D, 1995.

Rabbitt, M.C., "Minerals, Lands, and Geology for the Common Defense and General Welfare – Volume 2, 1879-1904," U.S. Geological Survey, 1980.

Ransome, F.L., "Preliminary Account of Goldfield, Bullfrog, and other Mining Districts in Southern Nevada, with notes on the Manhattan District (by G.H. Garrey and W.H. Emmons)," U.S. Geological Survey Bulletin 303, 1907.

Reisner, M., *Cadillac Desert —The American West and Its Disappearing Water*, New York, Viking-Penguin Books, 1986. [Revised 1993.]

Reilly, T.E., "A Brief History of Contributions to Ground Water Hydrology by the U.S. Geological Survey," *Ground Water*, 42(4): 625–631 [July-August 2004].

Robinson, T.W., and others, "Water Levels and Artesian Pressure in Wells in Las Vegas Valley and in Other Valleys in Nevada – 1943-45," Carson City, State of Nevada, Office of the State Engineer, Water Resources Bulletin No. 3, 1947.

Robinson, M.C., *Water for the West: The Bureau of Reclamation, 1902-1977*, Chicago, Public Works Historical Society, 1979.

Romney, E.M., V.Q. Hale, A. Wallace, O.R. Lunt, J.D. Childress, H. Kaaz, G.V. Alexander, J.E. Kinnear, and T.L. Ackerman, "Some Characteristics of Soil and Perennial Vegetation in Northern Mojave Desert Areas of the Nevada Test Site," Los Angeles, University of California, USAEC Report UCLA12-916, June 1973. [Prepared for the AEC.]

Rosenshein, J.S., J.E. Moore, S.W. Lohman, and E.B. Chase, "Two-hundred Years of Hydrogeology in the United States," U.S. Geological Survey Open-File Report 86-480, 1986.

Rouse, H., and S. Ince, *History of Hydraulics*, Iowa City, Iowa Institute of Hydraulic Research, State University of Iowa, 1957.

Rouse, H., *Hydraulics in the United States 1776-1976*, Iowa City, Iowa Institute of Hydraulic

Research, State University of Iowa, 1976.

Russelle, M.P., "Alfalfa," *American Scientist*, 89(3): 252-261 [May-June 2001].

Rush, F.E., "Regional Ground-Water Systems in the Nevada Test Site Area, Nye, Lincoln, and Clark Counties, Nevada," Carson City, Nevada Department of Conservation and Natural Resources, *Ground-Water Resources - Reconnaissance Series Report 54*, 1970.

Sakamoto, C.M., F.F. Peterson, E.A. Naphan, H.P. Cords, H.R. Guenthner, and R.O. Gifford, "Freeze-Free (32°F) Seasons of the Major Basins and Plateaus of Nevada," in State of Nevada and University of Nevada [Reno], "Water for Nevada: Report 8. Forecasts for the Future - Agriculture," Carson City, Nevada Division of Water Resources/Department of Conservation and Resources, and Division of Agricultural and Resource Economics/Max C. Fleischmann College of Agriculture, 1 sheet, scale 1:750,000, January 1974. [Separate plate dated 1972. Prepared by University of Nevada/The Agriculture Extension Station, NDWR, and the USDA/SCS.]

Scarborough, V.L., "Engineering the Landscape for Water Management (Chapter 4)," in *The Flow of Power —Ancient Water and Landscapes*, Sante Fe, SAR Press, 2003.

Scherer, T., "Selecting an Irrigation System," Fargo, North Dakota State University Extension Service, Publication AE-91, September 1998.

Schodek, D.L., *Landmarks in American Civil Engineering*, Cambridge, MIT Press, 1987.

Science Applications International Corporation [SAIC], "Socioeconomic Profile of Nye County, Nevada: Community Services Inventory," Las Vegas, Nevada Nuclear Waste Storage Investigations Project SAIC-85/8000, June 1986. [Prepared for DOE.]

Shamberger, H.A., "The Story of the Water Supply for The Comstock - Including the Towns of Virginia City, Gold Hill, and Silver City, Nevada (Together with Other Water-Related Events for the Period 1859-1969), U.S. Geological Survey Professional Paper 779, 1972.

Shamberger, H.A., "Evolution of Nevada's Water Laws, as Related to the Development and Evaluation of the State's Water Resources, from 1866 to About 1960," Carson City, Nevada Department of Conservation and Natural Resources/Division of Water Resources, Water-Resources Bulletin 49, 1991. [Prepared by the USGS.]

Shinkle, J.D., *Fifty Years of Rosewell History - 1867-1917*, Rosewell, Hall-Poorbaugh Press, 1964.

Slate, J.L. (ed.), "Proceedings of Conference on the Status of Geologic Research and Mapping, Death Valley National Park," U.S. Geological Survey Open-File Report 99-133, 1999. [Includes a diskette of references compiled by Morrow and Machette.]

Solomon, B., *Trains of the Old West*, New York, Metro Books, 1998.

Splinter, W.E., "Center-Pivot Irrigation," *Scientific American*, 234[6]: 90-99 [1976].

State of Nevada, "Water for Southern Nevada," Carson City, Division of Water Planning/Department of Conservation and Natural Resources, Water Supply Report 2, November 1982. [Prepared by URS and Converse Ward Davis Dixon in cooperation with the Las Vegas Valley Water District.]

Stegner, W.E. (ed.), *Report on the Lands of the Arid Region of the United States, by John Wesley Powell*, Cambridge, Cambridge University Press, 1962.

Steward, J.H., "Basin-Plateau Aboriginal Sociopolitical Groups," *Smithsonian Institution Bureau of American Ethnology Bulletin*, Vol. 120, 1938. [1997 reprint by the University of Utah Press.]

Stoffle, R.W., D.B. Halmo, J.E. Olmsted, and M.J. Evans, "Native American Cultural Resource Studies at Yucca Mountain, Nevada," Ann Arbor, Institute for Social Research, University of Michigan, 1990. [Originally prepared for DOE by SAIC.]

Stonestrom, D.A., D.E. Prudic, R.J. Laczniak, K.C. Akstin, R.A. Boyd, and K.K. Henkelman, "Estimates of Deep Percolation Beneath Native Vegetation, Irrigated Fields, and the Amargosa-River Channel, Amargosa Desert, Nye County, Nevada," U.S. Geological Survey Open-File Report 03-104, 2003.

Stowers, A., "The Stationary Steam Engine, 1830-1900," in C. Singer and others (eds.), *A History of Technology, Volume V: The Late Nineteenth Century — c. 1850 to c. 1900*, Oxford, Clarendon/Oxford University Press, 1958.

Swanson, G.J. (ed.), *Eighty Years of Water Well Drilling: Photos and Folklore*, Westerville, National Ground Water Association, 1998.

Tarr, J.E., and F.C. McMichael, "Historic Turning Points in Municipal Water Supply and Wastewater Disposal, 1850-1932," in "Celebrating ASCE's 125th Anniversary. Turning Points in U.S. Civil Engineering History," *Civil Engineering*, 1977. [Special issue containing journal reprints from years 1975-1977.]

Tanish, H.R., and S.E. Churchfield, "Production of Petroleum Oil and Natural Gas," in T.I. Williams (ed.), *A History of Technology, Volume VI: The Twentieth Century — c. 1900 to c. 1950, Part I*, Oxford, Clarendon/Oxford University Press, 1978.

Tank., R.W., "Water Rights Law (Part II)," in *Legal Aspects of Geology*, New York, Plenum Press, 1983.

The Clason Map Company, "[Map of] Nevada and the Southern Portion of California (3rd ed.)," Denver, 1 sheet, scale unknown, 1907.

Theis, C.V., "The Relation Between the Lowering of the Piezometric Surface and the Rate and Discharge of a Well using Ground-Water Storage," *Transactions of the American Geophysical Union* 16:519-524 [1935].

Theis, C.V., "The Source of Water Derived from Wells," *Civil Engineering*, 10(5): 277-280 [1940].

Thordarson, W., and B.P. Robinson, "Wells and Springs in California and Nevada within 100 Miles of the Point 37 Deg. 15 Min. N., 116 Deg. 25 Min. W., on Nevada Test Site," U.S. Geological Survey, USGS-474-85, 1971. [Prepared for the AEC.]

Tingley, J.V., "History of the Nevada Bureau of Mines and Geology," in A.A. Socolow (ed.), *The State Geological Surveys —A History*, Association of American State Geologists, 1988. [Available from the Florida Geological Survey, Tallahassee.]

Tingley, J.V., R.C. Horton, and F.C. Lincoln, "Outline of Nevada Mining History," Reno, Nevada Bureau of Mines and Geology Special Publication 15, 1993.

Todd, D.K., *Groundwater Hydrology (2nd ed.)*, New York, John Wiley and Sons, 1980.

U.S. Bureau of Reclamation, *Ground Water Manual*, Washington, D.C., 1977.

U.S. Department of Energy, "Draft Environmental Assessment: Yucca Mountain Site, Nevada Research and Development Area, Nevada," Las Vegas, Office of Civilian Radioactive Waste Management, DOE/RW-0012, December 1984.

U.S. Department of Energy, "Environmental Assessment: Yucca Mountain Site, Nevada Research and Development Area, Nevada," Office of Civilian Radioactive Waste Management, Nevada, 3 vols., DOE/RW-0073, May 1986.

U.S. Department of Energy, "Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada," Office of Civilian Radioactive Waste Management, Nevada, DOE/RW-0199, 9 vols., December 1988a.

U.S. Department of Energy, "Chapter 3. Hydrology," in "Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada," Office of Civilian Radioactive Waste Management, Nevada, DOE/RW-0199, Vol. II, Part A, December 1988b.

U.S. Department of Energy, "Final Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada," Nevada Operations Office, DOE/EIS-0243, 3 vols. (and appendices), August 1996.

U.S. Department of Energy, "Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada," Office of Civilian Radioactive Waste Management, DOE/EIS-0250, 4vols., February 2002a.

U.S. Department of Energy, "Recommendation of the Secretary of Energy Regarding the Suitability of the Yucca Mountain Site for a Repository Under the Nuclear Waste Policy Act of 1982," Washington, D.C., Office of Civilian Radioactive Waste Management, February 2002b.

U.S. Environmental Protection Agency, "Environmental Radiation Protection Standards for Yucca Mountain, Nevada — Draft Background Information Document for Proposed 40 CFR 197," Office of Radiation and Indoor Air, EPA 402-R-99-008, August 1999.

U.S. Geological Survey, "The National Atlas of the United States," Washington, D.C., 1970.

U.S. House of Representatives, "Report Number 286, 66th Congress, 1st Session," Washington, D.C., U.S. Government Printing Office, 1919.

U.S. Senate, "Report Number 4, 64 th Congress, 1st Session," Washington, D.C., U.S. Government Printing Office, 1915.

van Zandt, F.K., "Nevada and Utah," in "Boundaries of the United States and the Several States," U.S. Geological Survey Professional Paper 909, 1976.

Venstrum, C., "Economic Study of Southern Nevada: Preliminary Report," Reno, University of Nevada, Agricultural Experiment Station, November 1939. [U.S. Work Projects Administration publication of field investigation conducted in May 1932.]

Vogely, W.A. (ed.), *Economics of the Mineral Industries*, Littleton, Society of Mining Engineers, 1985.

Walker, G.E., and T.E. Eakin, "Geology and Ground-Water of Amargosa Desert, Nevada - California," Carson City, Nevada Department of Conservation and Natural Resources, *Ground-Water Resources - Reconnaissance Series Report 14*, March 1963.

Waring, G.A., "Ground Water in Pahrump, Mesquite, and Ivanpah Valleys, Nevada and California," U.S. Geological Survey Water-Supply Paper 450-C, 1921.

Water Resources Management, Inc., "WRMI Process - Water Supply Planning for the Las Vegas Region," Columbia, May 1992. [Prepared for the Las Vegas Valley Water District.]

White, J.H., Jr., *The American Railroad Freight Car: From the Wood-Car Era to the Coming of Steel*, Baltimore, Johns Hopkins University Press, 1993.

White, J.H., Jr., *American Locomotives: An Engineering History, 1830-1880*, Baltimore, Johns Hopkins University Press, 1998.

Wilburn, D., T. Goonan, and D. Bleiwas, "History of Exploration Technology (Appendix 1)" in "Technological Advancement — Factor in Increasing Resource Use," U.S. Geological Survey Open-File Report 01-197, 2001.

Wilson, H.M., "Pumping Water for Irrigation," U.S. Geological Survey Water-Supply and Irrigation Paper No. 1, 1896.

Winograd, I.J., and I. Friedman, "Deuterium as a Tracer of Regional Ground-Water Flow, Southern Great Basin, Nevada and California," *Geological Society of America Bulletin*, 83(12): 3691–3708 [1972].

Winograd, I.J., and W. Thordarson, "Hydrogeologic and Hydrochemical Framework, South-Central Great Basin, Nevada-California, with Special Reference to the Nevada Test Site (Hydrology of Nuclear Test Sites)," U.S. Geological Survey Professional Paper 712-C, 1975.

Winograd, I.J., A.C. Riggs, and T.B. Coplen, "The Relative Contributions of Summer and Cool-Season Precipitation to Groundwater Recharge, Spring Mountains, Nevada, USA" *Hydrogeology Journal*, 6[1]:77–93 [1998].

Wittmeyer, G.W., M.P. Miklas, R.V. Klar, D. Williams, and D. Balin, "Use of Ground Water in the Arid and Semi-Arid Western United States: Possible Implications for the Yucca Mountain Area," in T.J. McCartin and M.P. Lee (eds.), "Preliminary Performance-Based Analyses Relevant to Dose-Based Performance Measures for a Proposed Geologic Repository at Yucca Mountain," U.S. Nuclear Regulatory Commission, NUREG-1538, October 2001.

Worman, F.C.V., "Arche ological Investigations at the U.S. Atomic Energy Commission's Nevada Test Site and Nuclear Rocket Development Station," Los Alamos, Los Alamos Scientific Laboratory, LA-4125, August 1969. [Prepared for the AEC.]

APPENDIX A

PLANTS AND ANIMALS IN THE AMARGOSA DESERT AREA

Scientific names for plants (flora) and animals (fauna) cited in this report. A more comprehensive listing of local biosphere resources can be found in DOE (1996, 2002). Information on *likely uses* was taken from Jaeger (1957) and Stoffle and others (1990).

Common Name	Scientific Name	Likely Use
	FLORA	
blackbrush	*Coleogyne ramosissima*	
boxthorn	*Lycium andersonii*	
bunchgrass	*Stipa speciosa*	Edible seeds.
creosote bush	*Larrea divaricata*	Fuel, medicinal and/or beverage tea, ceremonial incense, and sap glue. Also, natural forage for domestic cattle.
desert ground-cherry	*Physalis crassifolia*	Edible fruit (when ripe).
desert saltbush	*Atriplex polycarpa*	Edible leaf extract.
desert saltgrass	*Distichlis spicata*	
desert sand grass (Indian rice)	*Oryzopsis hymenoides*	Edible seeds.
Devil's pin-cushion (barrel cactus)	*Echinocactus polycephalus*	Edible cactus, awls, and needles.
galleta grass	*Hilaria rigida*	Natural forage for domestic cattle.
greasewood	*Larrea tridentata*	Fuel, medicinal and/or beverage tea, sap glue, and ceremonial incense.
Hopi (or wild) rye grass	*Leymus triticoides*	Edible seeds.
hopsage	*Grayia spinosa*	
Joshua tree	*Yucca brevifolia*	Edible buds, baskets, and sandals.
mariposa lily	*Calochortus flexuosus*	Edible bulbs.
Mojave yucca	*Yucca schidigera*	Edible cactus and baskets.
honey mesquite	*Prosopis glandulosa*	Edible bean pods. Also, wood used for dwelling construction, fuel, and utilitarian items.
piñon pine	*Pinus monophylla*	Edible nuts, medicinal chew (sap), fuel, baskets, and pitch.
prickly pear cactus	*Opuntia sp.*	Edible fruit and stems (pads).

Common Name	Scientific Name	Likely Use
rabbit brush	*Chrysothamnus puberulus*	Medicinal and/or beverage tea, and dwelling construction.
sagebrush	*Artemisia tridentata*	Medicinal and/or beverage tea, and dwelling construction.
screw bean (or tornillo)	*Prosopis pubescens*	Edible pods, dwelling construction, fuel, and utilitarian items.
squaw cabbage beans	*Streptanthus inflatus*	Edible beans.
Utah juniper	*Juniperus osteoperma*	Edible berries, dwelling construction, fuel, and ceremonial incense.
velvet mesquite (bush)	*Prosopis juliflora*	Edible bean pods.
wild grapes	*Vitis arizonica*	Edible berries.
white bursage	*Ambrosia dumosa*	Natural forage for domestic cattle.
	FAUNA	
bobcat	*Lynx rufus*	
desert bighorn sheep	*Ovis nelsoni*	
desert tortoise	*Gopherus agassizii*	
duck	*Anatidae*	
jack rabbit	*Lepus californicus*	
kit fox	*Vulpes velox*	
mountain lion	*Felis concolor*	
mule deer	*Odocoileus hemionus eremicus*	
pack (wood) rat	*Neotoma lepida*	
pronghorn antelope	*Antilocapra americana*	
squirrel	*Citellius*	

References

Jaeger, E.C., *The North American Deserts*, Stanford, Stanford University Press, 1957.

Stoffle, R.W., D.B. Halmo, J.E. Olmsted, and M.J. Evans, "Native American Cultural Resource Studies at Yucca Mountain, Nevada," Ann Arbor, Institute for Social Research, University of Michigan, 1990.

U.S. Department of Energy, "Final Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada," Las Vegas, Nevada Operations Office, DOE/EIS-0243, Vol. 1, August 1996.

U.S. Department of Energy, "Chapter 3, Affected Environment," in "Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada. Volume I – Impact Analyses," Office of Civilian Radioactive Waste Management, DOE/EIS-0250, February 2002.

APPENDIX B

EARLY SOURCES OF WATER SUPPLY FOR MINING OR MINING-RELATED OPERATIONS IN THE AMARGOSA DESERT AREA

In California (Inyo County) and Nevada (Clark, Esmeralda, Nye , and Pershing Counties), as reported by Lingenfelter (1986), unless otherwise noted.

Location	Year(s)	Source	Comments	Page(s)
		IVANPAH MINING DISTRICT (Inyo County)		
Unspecified	1851, mid-1870s	*Salt Spring*	----	55, 136
		GOLD MOUNTAIN MINING DISTRICT (Inyo County)		
Magruder Mountain	*ca.* 1872	*Mammoth Springs (?)*	$30,000 pipeline.	109
Magruder Mountain (South side)	1880	*Mammoth Springs*	12-mi pipeline consisting of 6-in, spiral -riveted pipe.	149
Unspecified	1902	Springs, stream, and ground water	*Stinking Springs* (later renamed *Thorpe's Well*).	345–347
		PANAMINT MOUNTAIN MINING DISTRICT (Inyo County)		
Unspecified	mid-1870s	Man-made reservoir	Spring-fed, using 1-mi pipeline.	123
Pleasant Canyon	1893	Stream	Pumped water to *Mineral Ranch* from a steam 600 ft below.	195
Ballarat Mine	1899	Undefined spring	5-mi pipeline.	198
Skidoo Mine	*ca.* 1907	Undefined spring	23-mi pipeline.	287

Location	Year(s)	Source	Comments	Page(s)
RESTING SPRING MINING DISTRICT (Inyo County)				
Unspecified	1874	*Resting Spring (?)*	Hills south-southeast of *Resting Spring* on the *Old Spanish Trail.*	137
JOHNNIE MINING DISTRICT (Nye County)				
Chispa Mine	*ca.* 1891	*Horseshutem Springs*	6-mi pipeline.	190
Johnnie Mine	1905	*Horseshutem Springs*	5-mi pipeline, 2 in diameter.	353; Carlson (1974, p. 146)
DEATH VALLEY MINING DISTRICT (Inyo County)				
Confidence Mill	1896	Ground water	Well sunk in Death Valley; later moved mill to spring near the mouth of Pleasant Canyon.	193, 195
Death Valley Junction	1916	Not specified	Water hauled by railroad from undisclosed location.	391
GOLDFIELD MINING DISTRICT (Esmeralda and Nye Counties)				
Columbia Mountain Mill	*ca.* 1905	Ground water	Pumped from 100-ft level of the *Dewdrop shaft.*	Ransome (1907, p. 24)
Spokane Shaft	*ca.* 1905	Ground water	Pumped from100-ft level of mine.	Ransome (1907, p. 24)
January Mine	*ca.* 1905	*Alkali Spring*	10-mi pipeline through which water is pumped for milling.	Ransome (1907, p. 23)
WAHMONIE MINING DISTRICT (Nye County)				
Horn Silver Mine	*ca.* 1905	*Cane Spring*	Water hauled by wagon 4 mi.	Kral (1951); Brady (1975, pp. 8–9)

Location	Year(s)	Source	Comments	Page(s)
BULLFROG-RHYOLITE MINING DISTRICT (Nye County)				
Unspecified	1906	*Beatty, Goss, Indian,* and *Terry Springs*	Water-supply companies using pipelines; 11-mi pipeline from *Goss Spring*; before pipelines, water hauled by burro at $5/barrel.	218, 222
Lee Mine	1907	*Rose Well*	Water hauled 13 mi by burro at $5/barrel.	280
ECHO MINING DISTRICT (Pershing County)				
Unspecified	1906	Stream	1-mi long spring-fed stream in Black Mountains.	329
GREENWATER MINING DISTRICT (Inyo County)				
Unspecified	1907	*Greenwater Springs*	Hauled water at $8/barrel.	335, 460
FUNERAL MOUNTAINS MINING DISTRICT (Inyo County)				
Keane Wonder (mine)	1911	Undefined spring	Funeral Mountains.	306
BARE MOUNTAIN MINING DISTRICT (Nye County)				
American Carrara Marble quarry	1913	Undefined spring	8-mi pipeline from *Gold Center* (Beatty area). Hattori and McLane (1982, p. 11) describe remnants of a pumping station associated with this water supply system.	405
Sterling Mine (Crater Flat)	1970s (?)	Water trucked-in from Beatty	240,000 gpd.	French and others (1981, p. 28)

References

Brady, W.J., "The Early Days at NTS," *NTS News/Bicentennial Issue 1975*, 5(5):7–11 [1975].

Carlson, H.S., *Nevada Place Names – A Geographical Dictionary,* Reno, University of Nevada Press, 1974.

French, R.H., A. Elzeftawy, J. Bird, and B. Elliot, "Hydrology and Water Resources Overview for the Nevada Nuclear Waste Storage Investigations, Nevada Test Site, Nye County, Nevada," Las Vegas, Desert Research Institute, NVO-284, June 1981. [Issued June 1984. Prepared for DOE/Nevada Operations Office.]

Kral, V.E., "Mineral Resources of Nye County," University of Nevada Bulletin, Vol. 45, No. 3, *Geology and Mining Series, No. 50,* January 1951.

Hattori, E.M., and A.R. McLane, "An Archeological Survey Between Beatty, Nye County, and Indian Springs, Clark County, Nevada," Las Vegas, Desert Research Institute, Social Sciences Center Technical Report 32, November 1982. [Prepared for the Bell Telephone Company of Nevada.]

Lingenfelter, R.E., *Death Valley & the Amargosa: A Land of Illusion,* Berkeley, University of California Press, 1986.

Ransome, F.L., "Preliminary Account of Goldfield, Bullfrog, and other Mining Districts in Southern Nevada, with notes on the Manhattan District (by G.H. Garrey and W.H. Emmons)," U.S. Geological Survey Bulletin 303, 1907.

NRC FORM 335 (9-2004) NRCMD 3.7 U.S. NUCLEAR REGULATORY COMMISSION **BIBLIOGRAPHIC DATA SHEET** *(See instructions on the reverse)*	1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.) NUREG-1710, Volume 1
2. TITLE AND SUBTITLE History of Water Development in the Amargosa Desert Area: A Literature Review	3. DATE REPORT PUBLISHED MONTH: February YEAR: 2005 4. FIN OR GRANT NUMBER
5. AUTHOR(S) M.P. Lee*, N.M. Coleman*, and T.J. Nicholson**	6. TYPE OF REPORT Technical 7. PERIOD COVERED *(Inclusive Dates)*

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

* Advisory Committee on Nuclear Waste Staff
** Division of Systems Analysis and Regulatory Effectiveness, Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission, Washington, D.C. 20555-0001

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Same as above.

10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

Historic accounts, geologic treatises, and other key literature sources were used to identify factors that contributed to the development of local ground-water resources in the Amargosa Desert area during the past 150 years. The literature suggests that the earliest sources of fresh water supply were the abundant, naturally occurring artesian springs in Ash Meadows. The first hand-dug well in the area was the Franklin Well; it was dug in 1852 for workers performing a survey of the California-Nevada State line. The first mechanically bored wells were drilled in valley-fill (alluvial) deposits for local railroads, along their respective alignments, sometime between 1905-07. About 1917, the first irrigation well was drilled for an experimental farm – the T&T Ranch. In the late 1940s-early 1950s, permanent interest in the area was established, in large measure because of Federally-sponsored desert reclamation programs. However, designation of local aquifers as "protected," in 1979; limiting soil conditions; and other factors have curtailed local agricultural development. Because of economic and technical factors, alluvial aquifers have historically been the most important sources of ground-water supply. In general, drilling activity historically preceded geologic understanding of the ground-water resource.

This report is the first volume in the NUREG-1710 series.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*		13. AVAILABILITY STATEMENT
Amargosa Valley	water resources	unlimited
Ash Meadows	well drilling	14. SECURITY CLASSIFICATION
biosphere	Yucca Mountain	*(This Page)* unclassified
farming		*(This Report)* unclassified
ground water		15. NUMBER OF PAGES
mining		
Native Americans		16. PRICE
Nevada Test Site		
railroads		
springs		

Printed
on recycled
paper

Federal Recycling Program

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555-0001

OFFICIAL BUSINESS