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Environmental Studies Conducted at the Fenton Hill Hot Dry Rock Geothermal Development Site

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ENVIRONMENTAL STUDIES CONDUCTED AT THE FENTON HILL HOT DRY ROCK GEOTHERMAL DEVELOPMENT SITE

by

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ABSTRACT

An environmental investigation of Hot Dry Rock (HDR) geothermal development was conducted at Fenton Hill, New Mexico, during 1976-1979. The objective of the environmental program was to evaluate the potential environmental impediments for HDR technologies simultaneously with the development of the energy resource. Activities at the Fenton Hill Site included an evaluation of baseline data for biotic and abiotic ecosystem components. Identification of contaminants produced by HDR processes that had the potential for reaching the surrounding environment is also discussed. This report presents findings for the interim 1976-1979.

Three dominant vegetative communities were identified in the vicinity of the site. These included grass-forb, aspen, and mixed conifer communities. The grass-forb area was identified as having the highest number of species encountered, with *Phleum pratense* and *Dactylis glomerata* being the dominant grass species. Frequency of occurrence and mean coverage values are also given for other species in the three main vegetative complexes. Live trapping of small mammals was conducted to determine species composition, densities, population, and diversity estimates for this component of the ecosystem. The data indicate that *Peromyscus maniculatus* was the dominant species across all trapping sites during the study. Comparisons of relative density of small mammals among the various trapping sites show the grass-forb vegetative community to have had the highest overall density. Comparisons of small mammal diversity for the three main vegetative complexes indicate that the aspen habitat had the highest diversity and the grass-forb habitat had the lowest. The effluent receiving canyon study area, a mixture of vegetative types, had the highest overall diversity. Additionally, meteorological data for the four year period at the site are summarized and presented.

Analyses of waste waters from the closed circulation loop indicate that several trace contaminants (e.g., arsenic, cadmium, fluoride, boron, and lithium) were present at concentrations greater than those reported for surface waters of the region. However, these values were generally within the range of concentrations reported for these elements from thermal springs in the area.

I. INTRODUCTION

To meet increasing national energy needs, geothermal resources are being evaluated as a practical and viable energy source. Three types of geothermal resources are generally recognized: hydrothermal convection systems, geopressured systems, and hot dry rock systems. The Los Alamos National Laboratory has developmental, ongoing research to evaluate the technical and economic feasibility for hot dry rock (HDR) geothermal resources. The near-term goal for this program is to have a power plant on line at the Fenton Hill Site located near Los Alamos, New Mexico, with a capability of generating electricity by 1985. In addition, a second site is currently being selected to further demonstrate the technical feasibility of this tremendous potential energy resource.[1]

Among the criteria established for developing energy technologies is one to demonstrate that the technology is both technically and economically attractive and that it will have minimal adverse impact on the environment.[2] Thus, when the HDR technology development was initiated, an environmental assessment program was simultaneously conducted with the objective of evaluating all phases of development (including exploration, drilling, resource development, and resource utilization). The efforts of this assessment were directed toward identifying and evaluating potential environmental concerns and, where practical, identifying the mitigation measures needed to ensure an environmentally acceptable energy resource. On only a few occasions in the past have environmental studies been initiated as an energy technology was being developed. As a result, unanticipated problems such as emissions or waste disposal have impeded the timely commercialization of energy technologies.

To achieve a comprehensive and integrated assessment of the potential for environmental effects, studies were focused on several essential elements that are required in all environmental assessments of energy technologies. The following relate specifically to the Fenton Hill HDR geothermal site program objectives:

- establish baseline inventories of biotic and abiotic terrestrial and aquatic ecosystem components,
- identify key ecosystem components that may serve as bioindicators of geothermal process effects,
- determine the environmental pathways of the effluents produced by geothermal operations, and
- evaluate the impacts from geothermal site development and operations on ecosystem habitat and natural resources.

As stated previously, the program at Los Alamos is to develop the HDR technology. Thus, the direction of environmental studies is governed, to an extent, by the progress of the technology development. For example, the baseline inventories for the Fenton Hill Site were conducted, and key biotic components of the surrounding ecosystem were identified. In addition, from circulation tests conducted in the closed loop, chemical analyses of the circulating fluid have provided preliminary information on chemical contaminants that can affect the environment should fluid be vented from the system. The purpose of this report is to document the findings for environmental studies that were conducted at the Fenton Hill HDR Site until 1979.

II. DESCRIPTION OF THE STUDY AREA

The Los Alamos HDR facility is situated on the Jemez Plateau in north-central New Mexico, approximately 35 km west of Los Alamos (Fig. 1). The surface of the Plateau was formed by volcanic ash extruded during the volcanic activity that produced the Valles Caldera 1.1 million years ago.[3] The Fenton Hill Site is located at an elevation of 2600 m.

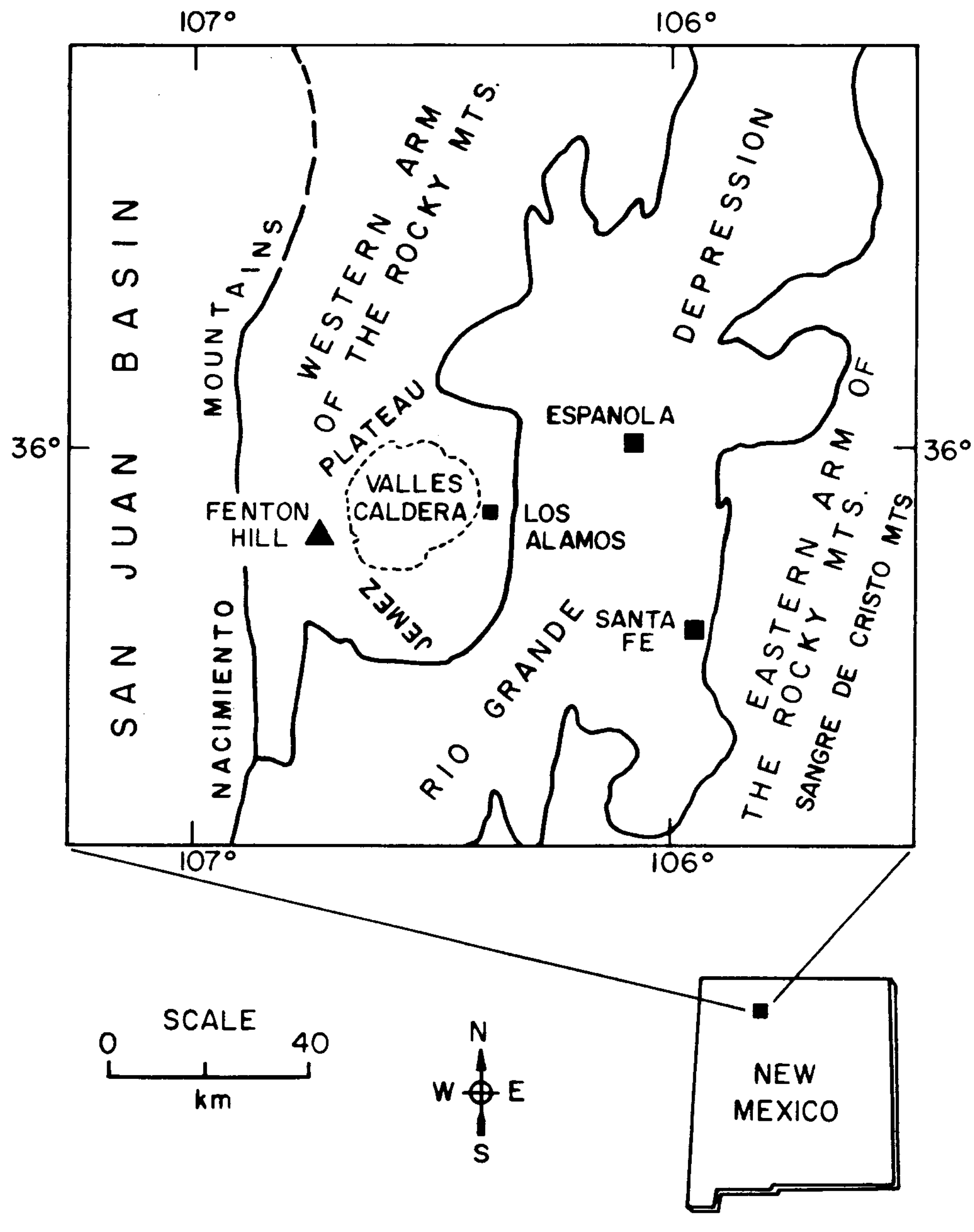

Fig. 1. Hot Dry Rock Site at Fenton Hill.

The overstory vegetation is a mixed coniferous forest, typical of northern New Mexico at this elevation, and is representative of an ecotone between the upper elevational spruce-fir and lower elevational ponderosa pine communities. In 1971, a wildfire swept through the area. It subsequently was aerially reseeded with a mixture of native montane grasses and legumes. A short time later, ponderosa pine seedlings were also planted. Stands of aspen suckers have since developed as secondary succession within the grass-forb community.[4]

The area in which the HDR demonstration project is situated is part of the Santa Fe National Forest. Approximately 0.05 km^2 have been cleared for the phase I and phase II experimental systems. A memorandum of understanding between the US Forest Service (USFS) and the US Department of Energy (DOE) (1979) defines the land, basis of use, and responsibilities of both parties.[5]

In 1976, ecological study sites were established in each of the dominant vegetative communities surrounding the site. The major objective of this initial effort was to evaluate the composition and distribution of the flora and fauna at an early stage of site preparation. The findings of these studies have been presented elsewhere.[4]

The main purpose of this report is to present the results of additional studies through the end of 1979, during which efforts were made to better quantify the composition and distribution of understory vegetation and small mammal communities. In addition, precipitation and temperature were monitored on a monthly basis at the Fenton Hill Site for the period 1976-1979 (Figs. 2 and 3).

III. VEGETATION ANALYSIS FOR THE FENTON HILL SITE

The composition and distribution of understory vegetation were determined for each of the three major vegetative communities surrounding the HDR development site. Five transects were established in the coniferous community, three in the aspen stands, and sixteen in the grass-forb community (Fig. 4). The methods used for vegetation analysis are discussed elsewhere.[4] Briefly, the procedure consisted of marking off a 50-m transect and determining the species composition within 20- by 50-cm plots at 10-m intervals. Determinations were made for composition, density, frequency of occurrence, and mean coverage for each species. A list of all species identified for the Fenton Hill Site is presented in Table I.

Results of the vegetative analyses for 1977 and 1978 are presented in Tables II and III. The vegetative analysis for 1976 was previously discussed by Rea.[4] Only those species that have a frequency of occurrence greater than 1% for all composite plots of a given community type are listed in Table II. These data indicate that the grass-forb community had the highest number (13) of species encountered for both

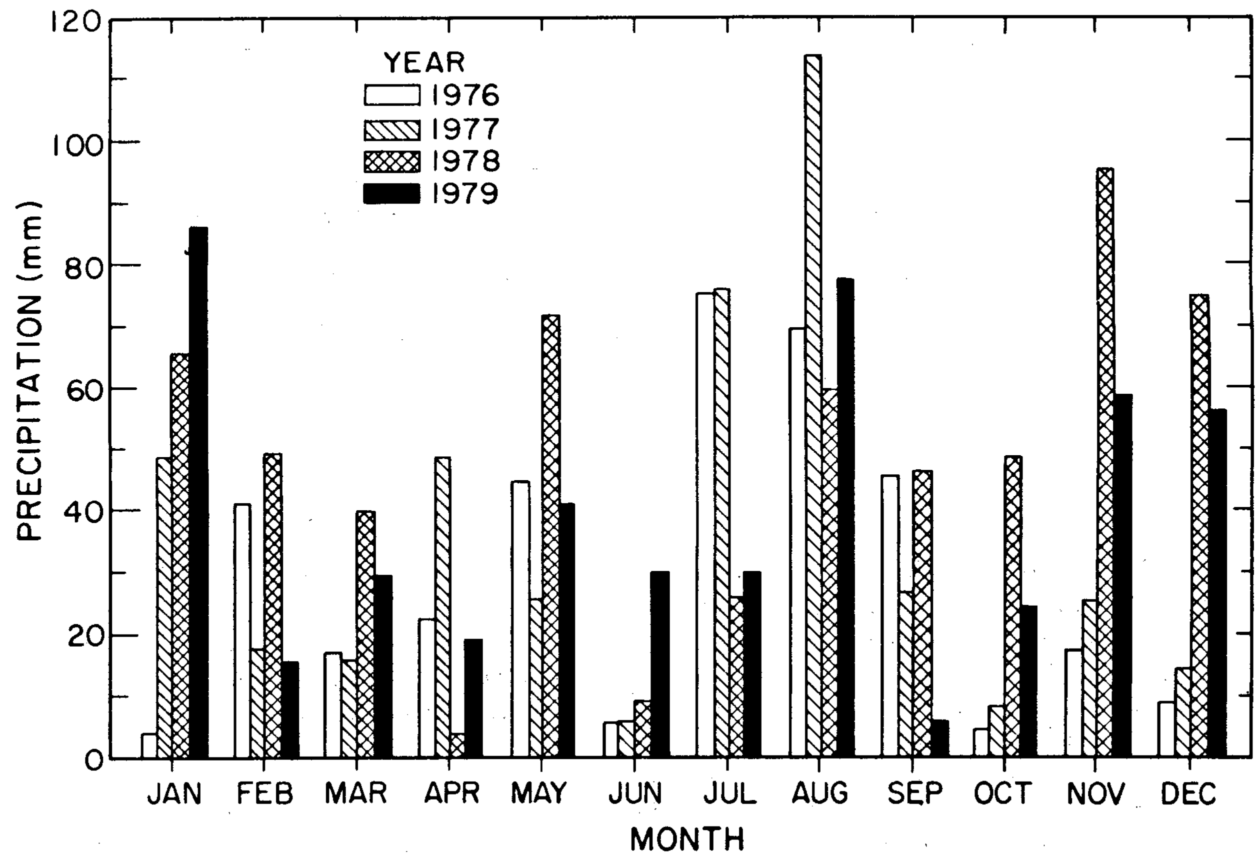

Fig. 2. Precipitation summaries for four years at Fenton Hill.

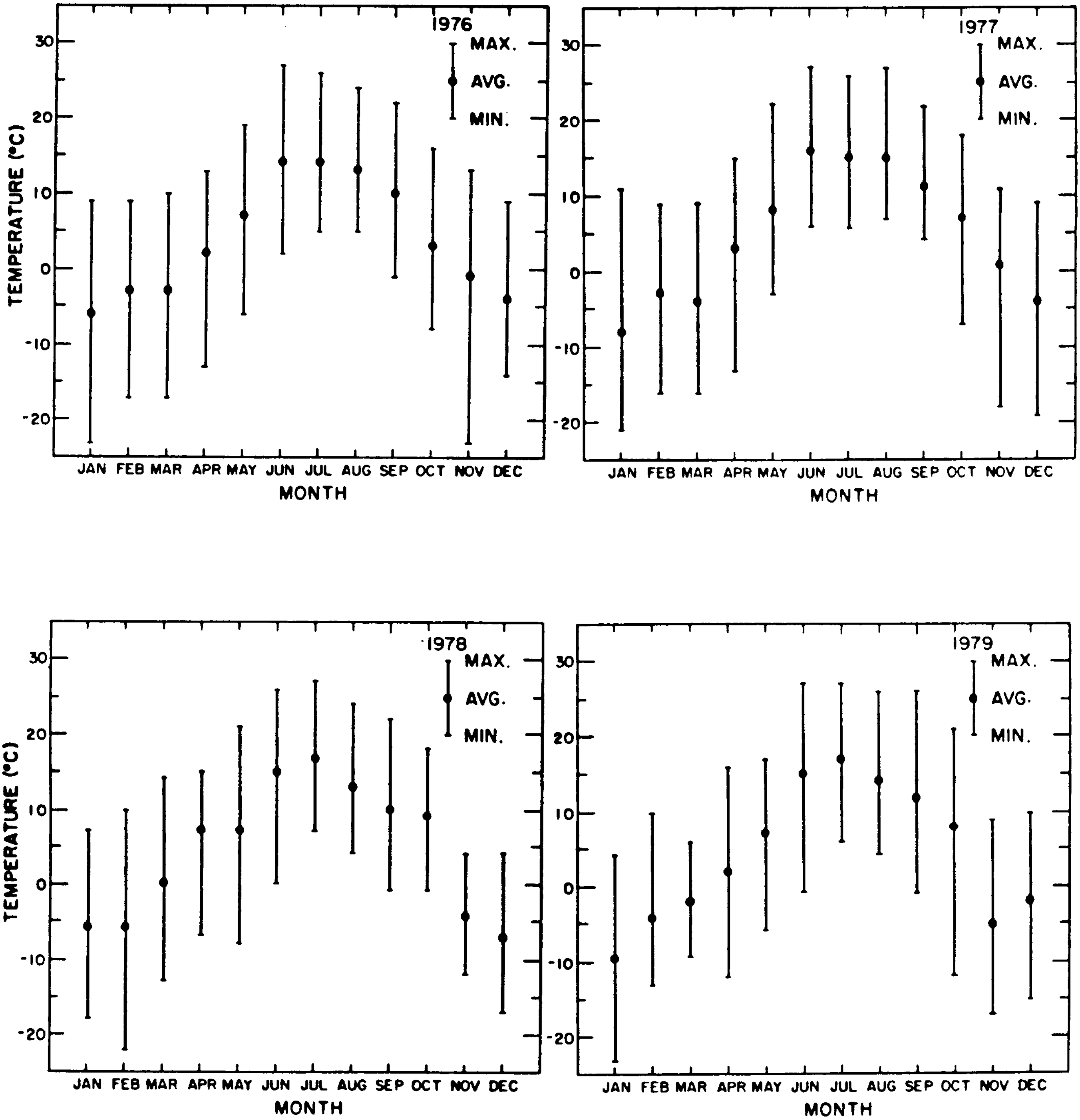

Fig. 3. Monthly summaries for four years (1976-1979) of temperature data at Fenton Hill HDR Site.

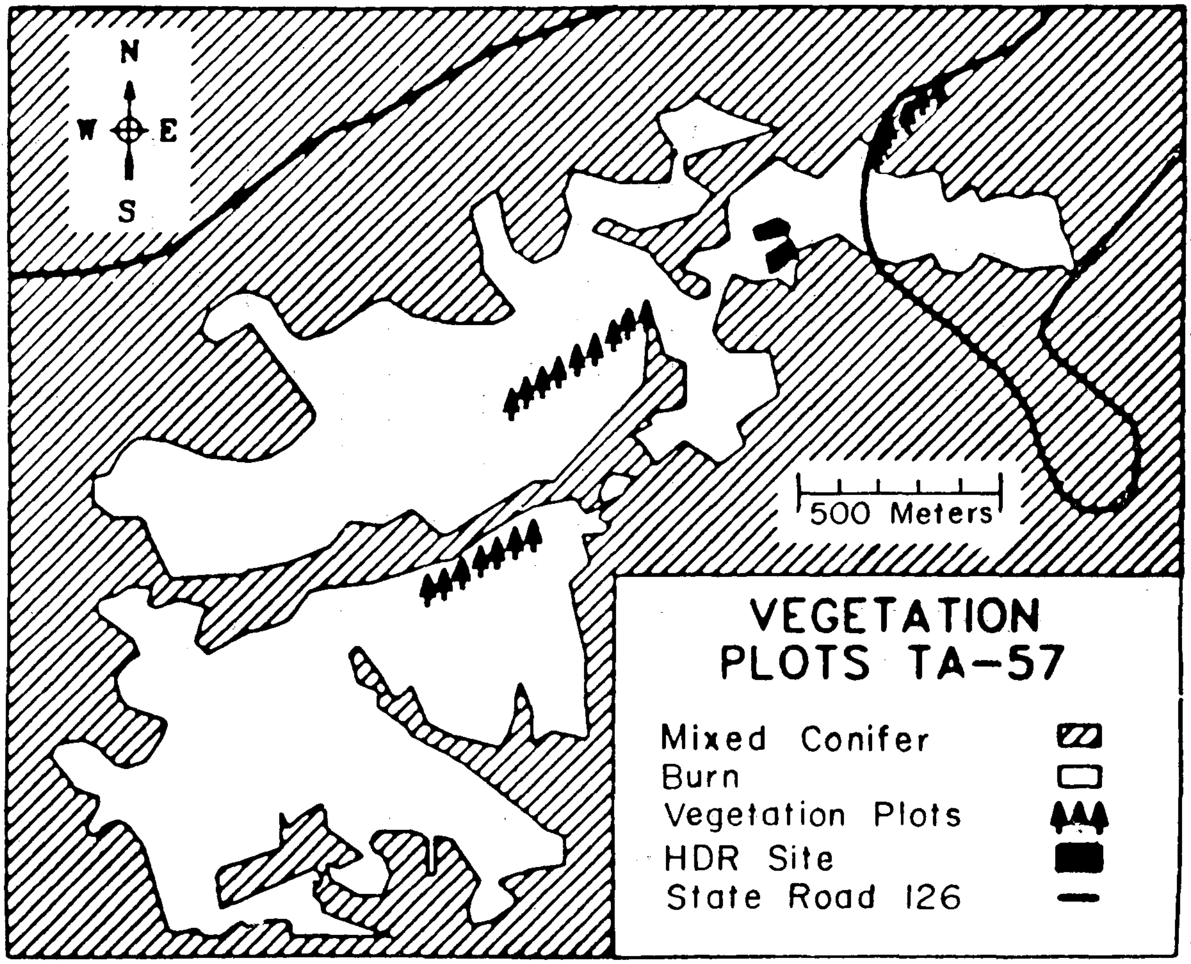

Fig. 4. Locations of vegetation plots at Fenton Hill.

years, that is, the greatest diversity, whereas the aspen stands show the lowest diversity for understory vegetation. Coverage values (Table III) indicate that the grass-forb community was dominated by members of the Graminae family, mostly timothy (*Phleum pratense*) and orchard grass (*Dactylis glomerata*). The mixed conifer and aspen communities exhibited a larger number of shrub and forb species with grasses less dominant. Variances in values for all vegetative types between 1977 and 1978 were attributed to seasonal effects and sampling times.

The occurrence of fires in ecological systems is not an unnatural phenomenon and, if the optimum climatological conditions exist, can lead to rapid successional changes within a community. Our preliminary data indicate that rapid successional processes, encouraged by revegetation, occurred in the Fenton Hill area after the 1971 wildfire. Thus, the potential for determining the effect from HDR technologies, which are anticipated to be minimal based on operations to date, would be masked by the successional processes occurring within the communities. However, the methods used for the vegetation analysis were adequate to perform the stated objectives of this study, that is, determining a baseline inventory and identifying key species in each community type.

TABLE I

SPECIES LIST

Family	Genus	Species	Common Name
Berberidaceae	*Berberis*	*repens*	Creeping mahonia
Compositae	*Achillea*	*lanulosa*	Western yarrow
	Antennaria sp.		Pussytoes
	Artemisia	*franserioides*	Ragweed sagebrush
	Conyza	*schiedeana*	Horseweed
	Gnaphalium	*macounii*	Cudweed
	Haplopappus	*parryi*	Parry goldenweed
	Hieraceum sp.		Hawkweed
	Leucampyx	*newberryi*	Wild cosmos
	Senecio	*wootonii*	Wooton senecio
	Taraxacum	*officinale*	Dandelion
Ericaceae	*Arctostaphylos*	*uva-ursi*	Bearberry
	Chimaphila	*umbellata*	Princepine pipsissewa
Fagacea	*Quercus*	*gambelii*	Gambel oak
Geraniaceae	*Geranium* sp.		Geranium
Gramineae	*Agropyron*	*trachycaulum*	Slender wheatgrass
	Agrostis	*alba*	Redtop
	Bromus	*purgans*	Canada brome
	Dactylis	*glomerata*	Orchard grass
	Koeleria	*cristata*	Prairie Junegrass
	Muhlenbergia	*montana*	Mountain muhly
	Phleum	*pratense*	Timothy
	Sitanion	*hystrix*	Bottlebrush squirreltail
Leguminosae	*Medicago*	*sativa*	Alfalfa
	Melilotus	*albus*	Sweet clover
	Robinia	*neomexicana*	New Mexico locust
Liliaceae	*Smilacina*	*stellata*	Starry Solomonplume
Polemoniaceae	*Gilia*	*aggregata*	Skyrocket gilia
Rosaceae	*Fragaria*	*americana*	Bracted strawberry
	Fragaria	*bracteata*	Strawberry
	Fragaria	*ovalis*	Wild strawberry
	Potentilla sp.		Cinquefoil

TABLE II

PERCENT FREQUENCY OF OCCURRENCE FOR VEGETATION IN STUDY AREAS AT FENTON HILL

Species	Grass Forb		Mixed Conifer		Aspen	
	1977	1978	1977	1978	1977	1978
Achillea lanulosa	12.5	9.0	11.7	9.0	—	2
Agropyron trachycaulum	2.5	—	—	—	—	—
Arctostaphylos uva-ursi	—	3.0	—	24.0	—	—
Berberis repens	—	10.0	—	1.0	—	24.0
Bromus inermis	—	1.0	16.7	—	—	—
Chimaphila umbellata	—	—	—	6.0	—	10.0
Dactylis glomerata	40.0	13.0	—	—	15.0	6.0
Festuca pacifica	—	3.0	—	—	—	—
Fragaria bracteata	—	6.0	—	13.0	—	—
Koeleria cristata	3.8	—	41.7	—	12.0	—
Medicago sativa	1.3	—	—	—	—	—
Melilotus albus	2.5	—	—	—	—	—
Muhlenbergia montana	—	—	10.0	—	—	—
Phleum pratense	41.3	9.0	—	—	9.0	5.0
Potentilla sp.	—	—	—	1.0	—	—
Senecio sp.	—	—	—	3.0	—	—
Sitanion hystrix	—	2.0	—	2.0	—	—
Taraxacum laevigatum	—	—	3.3	—	—	—

IV. SMALL MAMMAL POPULATIONS ASSOCIATED WITH THE VEGETATION COMMUNITIES

Live trapping of small mammals was conducted to determine species composition, densities, population, and diversity estimates for this component of the ecosystem. In 1976, modified North American Census of Small Mammals (NACSM) trapping lines[6] were established in each of the three vegetation communities (Fig. 5). Each trap line was 190-m long and consisted of 20 stations at 10-m intervals. Three additional trapping sites were located in a small effluent-receiving canyon south of the drilling site. (The significance of the effluent-receiving canyon to these studies is discussed in a later section of this report.) Because of the physical barriers imposed by the canyon walls, it was not possible in all cases to transect the canyon bottom with a complete trap line. Trapping grids, which consisted of six stations transecting the canyon bottom and four stations parallel to the canyon bottom (60- by 40-m trapping grid), were used in this area. Stations were spaced at 10-m intervals.

Two trapping sessions were held during the 1976 field season, and one session was held during each of the other field seasons (1977, 1978). Each trapping session consisted of two nights of prebaiting followed by three consecutive days of capture, mark, and release procedures. Data recorded on all animals included capture location, species identification, sex, age class, reproductive condition, and weight.

TABLE III

PERCENT MEAN COVERAGE AND RANGE OF COVERAGE IN STUDY AREAS AT FENTON HILL

Species	Grass-Forb		Mixed Conifer		Aspen	
	1977	1978	1977	1978	1977	1978
Achillea lanulosa	15(<5–30)	17(5–35)	4(<5–10)	7(<5–20)	—	30(20–40)
Agropyron trachycaulum	60(30–90)	—	—	—	—	—
Arctostaphylos uva-ursi	—	30(10–35)	—	27(5–65)	—	—
Berberis repens	—	11(<5–20)	—	5(5)	—	13(<5–40)
Bromus inermis	—	25(25)	6(<5–10)	—	—	—
Chimaphila umbellata	—	—	—	5(5–10)	—	7(<5–25)
Dactylis glomerata	18(5–55)	16(5–35)	—	—	24(10–50)	7(<5–15)
Festuca pacifica	—	5(<5–10)	—	12(<5–30)	—	—
Fragaria bracteata	—	9(5–20)	—	3(<5–5)	—	—
Koeleria cristata	12(10–20)	—	11(5–30)	—	13(5–60)	—
Medicago sativa	20(20)	—	—	—	—	—
Melilotus albus	6(6)	—	—	—	—	—
Muhlenbergia montana	—	—	10(<5–20)	—	—	—
Phleum pratense	18(5–20)	13(5–20)	—	—	14(5–35)	15(<5–45)
Potentilla sp.	—	—	—	5(5)	—	—
Senecio sp.	—	—	—	13(<5–35)	—	—
Sitanion hystrix	—	16(10–20)	—	3(<5–5)	—	—
Taraxacum laevigatum	—	—	3(<5)	—	—	—

Table IV presents a list of the small mammal species captured at the HDR site. A total of eight species were captured for all sites. Six species of mammals were captured in the aspen community, four species in the grass-forb community, five species in the mixed conifer site, and five species in the canyon site. The species captured during this study represent only a small fraction of the mammals that are known to occur in this geographical portion of the state. A list of large and small mammals (excluding order Chiroptera) that have distributions within the geographical and elevational range of the study site is presented in Table V.[7,8] This list does not imply that all species of mammals that could possibly occur in the area are present but instead is representative of the current mammalian species in the area.

A data summary of the small mammals captured is presented in Table VI. *Peromyscus maniculatus* (the white-footed deer mouse) was the dominant small mammal captured at all sites during the study. Of the 944 marked individuals, 675, or $\approx$72%, were *P. maniculatus*. ***Eutamias minimus*** (the least chipmunk) was the second most frequently captured species. This species was captured at all sites during all trapping periods, with the exception of the grass-forb community in 1977. *E. minimus* comprised $\approx$18% of the marked individuals. Captures of *P. maniculatus* and *E. minimus* represented $\approx$90% of the total marked individuals, whereas the remaining six species were captured only occasionally.

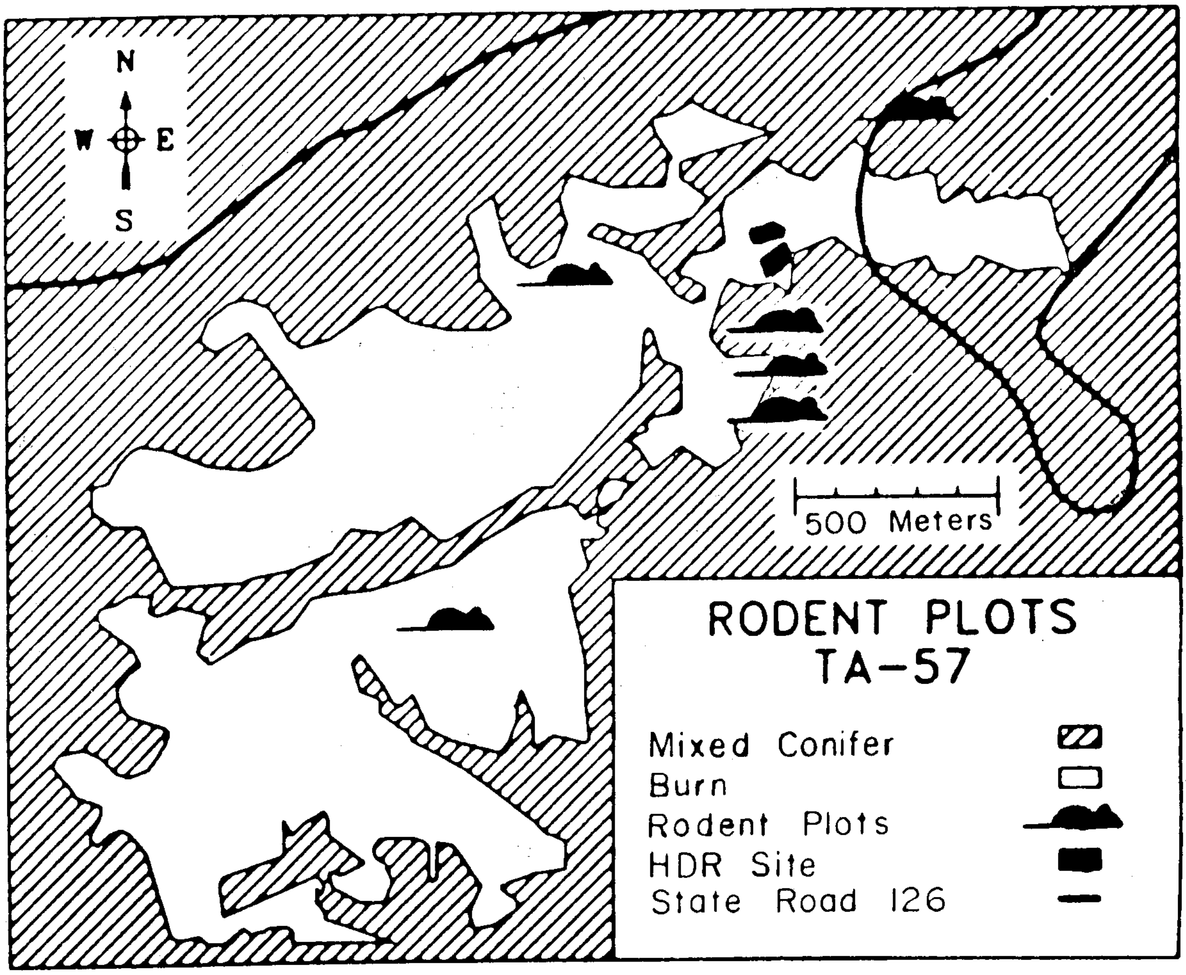

Fig. 5. Locations of small mammal trapping sites at Fenton Hill.

TABLE IV

SPECIES LIST OF SMALL MAMMALS PER TRAPPING AREA CAPTURED AT THE LOS ALAMOS HDR SITE

	Aspen	Grass–Forb	Mixed Conifer	Canyon
Peromyscus maniculatus	x	x	x	x
Eutamias minimus	x	x	x	
Spermophilus lateralis	x	x	x	x
Mustella nixosa	x			
Sylvilagus audubonii	x			
Microtus montanus	x	x	x	x
Sorex sp.				x
Neotoma mexicana			x	

TABLE V

SPECIES LIST OF MAMMALS GENERALLY REPRESENTATIVE OF THE LOS ALAMOS HDR SITE

Scientific Name	Common Name
Order Insectivora	
Sorex nanus	Dwarf shrew
Sorex palustris	Water shrew
Sorex vagrans	Vagrant shrew
Order Lagomorpha	
Sylvilagus audubonii	Desert cottontail
Order Rodenta	
Eutamias minimus	Least chipmunk
Eutamias quadrivittatus	Colorado chipmunk
Spermophilus lateralis	Golden–mantled ground squirrel
Tamiasciurus hudsonicus	Red squirrel
Sciurus aberti	Abert's squirrel
Thomomys talpoides	Northern pocket gopher
Reithrodontomys megalotis	Western harvest mouse
Peromyscus maniculatus	Deer mouse
Peromyscus boylii	Brush mouse
Neotoma mexicana	Mexican woodrat
Neotoma cinerea	Bushy–tailed woodrat
Clethrionomys gapperi	Gapper's red–backed mouse
Microtus montanus	Montane vole
Microtus longicaudus	Long–tailed vole
Erethizon dorsatur	Porcupine
Order Carnivora	
Canis latrans	Coyote
Felis concolor	Mountain lion
Mustella erminea	Ermine
Mustella frenata	Long–tailed weasel
Ursus americanus	Black bear
Order Artiodactyla	
Cervus elaphys	Elk
Odocoileus hemionus	Mule deer

TABLE VI

SMALL MAMMAL TRAPPING SUMMARY FOR THE LOS ALAMOS HDR SITE

Date & Location	Total Species Captured	Total Captures	Total Marked Individuals	Species						
				Eutamias minimus	*Peromyscus maniculatus*	*Spermophilus lateralis*	*Microtus montanus*	*Sylvilagus audubonii*	*Mustella*[a] sp.	Neotoma *mexicana*
June 1976										
Aspen	5	62	36	14	18	2	0	1	1	0
Grass–forb	3	48	30	5	14	1	0	0	0	0
Mixed conifer	4	30	20	7	11	1	1	0	0	0
Canyon (A,B,C)[b]	NT[c]	—	—	—	—	—	—	—	—	—
Sept 1976										
Aspen	4	50	41	18	21	1	0	0	1	0
Grass–forb	2	130	73	1	72	0	0	0	0	0
Mixed conifer	4	42	32	9	20	1	0	0	0	2
Canyon (A,B,C)[b]	3	94	72	20						
Sept 1977										
Aspen	3	72	39	14	24	0	0	1	0	0
Grass–forb	1	112	54	0	54	0	0	0	0	0
Mixed conifer	2	53	28	6	22	0	0	0	0	0
Canyon (A,B,C)[b]	4	175	107	30	67	1	8			
Aug 1978										
Aspen	4	91	59	7	47	2	3	0	0	0
Grass–forb	3	152	98		93	0	2	0	0	0
Mixed conifer	4	97	35	3		1	0	0	0	0
Canyon (A,B,C)[b]	4	373	220	35	145	6	34	0	0	0

[a]Identified as *M. nixosa*, probably *M. frenata*.
[b]Total of three canyon grids.
[c]Not trapped that year.

Comparisons of relative density of small mammals [number of individuals caught ÷ (number of traps × number of trap nights)][9] among the various trapping sites are presented in Table VII. The grass-forb vegetative community had the highest density overall, and the mixed conifer community exhibited the lowest small mammal density among the different trapping sites. Density estimates generally increased over the duration of the study. The increases in density through time in this study were generally attributable to the increased number of *P. maniculatus* captured.

Estimates of population density for the two dominant species, *P. maniculatus* and *E. minimus*, are given in Table VIII. The population estimates (individuals/10 000 m^2) were calculated using the catch per unit area of 50 000 m^2 (Ref. 10). In general, *P. maniculatus* was the numerically dominant species in each of the trapping sites for all trapping sessions. The highest *P. maniculatus* populations were associated with the grass-forb community, and the lowest populations for this species were found in the aspen stand and canyon trapping sites. As pointed out previously, the population estimates indicate a general increase through time for *P. maniculatus* at all trapping sites.

Species diversity indices were also calculated from the small mammal trapping data for each study area. Two indices of diversity were used: (1) Shannon-Weaver information formula H, which typically ranges from 0 (only one species present) to a high of 5 or greater for communities containing many species with small numbers of individuals,[11] and (2) the evenness value J, which ranges from 0 to 1.0 (Ref. 11). A summary of small mammal diversity by trapping site and session is presented in Table IX.

Comparisons of small mammal diversity for the three pure vegetation types (the grass-forb, coniferous forest, and aspen communities) indicate that the aspen habitat had the greatest diversity and that the grass-forb trapping area was the least diverse. Diversity ranged from a low of zero (grass-forb 1977) to a high of 1.07 (aspen in June 1976). The aspen site showed a decline in small mammal diversity from 1976 to 1978. The grass-forb and mixed conifer sites had the lowest diversity values in 1977, exhibiting a reduction from 1976.

TABLE VII

RELATIVE DENSITY[a] OF SMALL MAMMALS AT THE LOS ALAMOS HDR SITE

	Vegetation Type				
Trapping Period	Aspen	Grass-Forb	Mixed Conifer	Canyon[b]	Yearly Mean
June 1976	1.80	1.50	1.00	NT[c]	1.43
Sept 1976	2.05	3.65	1.60	1.20	2.13
Sept 1977	1.95	2.70	1.40	1.78	1.96
Aug 1978	2.95	4.90	1.75	3.67	3.32
Mean by vegetation site	2.19	3.19	1.44	2.22	

[a]Relative density
Number of Individuals Caught/Number of Traps × Number of Trapping Days.
[b]Mean of the three grids in the canyon.
[c]Not trapped that season.

TABLE VIII

POPULATION DENSITY ESTIMATES OF *EUTAMIAS MINIMUS* AND *PEROMYSCUS MANICULATUS* AT THE LOS ALAMOS HDR SITE

Date/Species	Aspen	Grass-Forb	Mixed Conifer	Canyon (A,B,C)[a]
June 1976				
E. minimus	4.73[b]	IC[c]	IC	NT[d]
P. maniculatus	6.89	9.89	IC	NT
Sept 1976				
E. minimus	IC	IC	2.73	IC
P. maniculatus	3.50	21.20	8.3	4.57
Sept 1977				
E. minimus	5.8	IC	IC	2.92
P. maniculatus	7.5	12.93	8.1	6.73
Aug 1978				
E. minimus	4.22	IC	IC	4.64
P. maniculatus	13.12	29.83	20.3	8.73

[a]Average of three canyon grids.
[b]Mammals per hectare.
[c]Insufficient captures.
[d]Not trapped.

TABLE IX

DIVERSITY INDICES OF SMALL MAMMALS AT THE LOS ALAMOS HDR SITE

	1976			
	June	Sept	1977	1978
Aspen	1.07[a]	1.03	0.68	0.53
	0.46[b]	0.45	0.43	0.27
Grass–Forb	0.59	0.07	0.00	0.165
	0.37	0.07	0.00	0.104
Mixed Conifer	1.00	0.76	0.03	0.25
	0.49	0.47	0.03	0.13
Canyon[c]	–	1.02	0.84	0.89
	–	0.59	0.49	0.47

[a]Shannon-Weaver H value.
[b]Evenness value, J.
[c]Average of three sites.

The canyon trapping sites demonstrated greater diversity than the three vegetation sites mentioned above. However, no quantitative vegetation analysis was available for these sites. Qualitative analysis of the area indicated a greater diversity of vegetation types, thus providing a greater number of habitat preferences for small mammal inhabitation. The sides of the effluent canyon provide a northerly and southerly exposure, with predominantly ponderosa overstory on the south-facing slope and a mixed conifer community on the north-facing slope. The canyon bottom exhibits evidence of a somewhat riparian habitat, aided to an extent by liquid effluent releases from the HDR site and storm runoff. In addition, the canyon bottom is interspersed with stands of aspen. This greater diversity of vegetation types, as opposed to the single vegetation sites, is the primary factor contributing to the greater diversity of small mammal species in the canyon sites.

The small mammal diversity values obtained in this study, although low, are consistent with the findings of other investigators.[12]

V. TEMPERATURE AND PRECIPITATION MEASUREMENTS AT THE FENTON HILL SITE

Temperature and precipitation measurements were recorded from 1967-1979 at a weather station located approximately 150-m west of the site. The station consisted of a mechanical weather station and a weighing bucket rain gauge. The mechanical weather station, mounted on top of a collapsible 9-m tower, recorded temperature on a pressure sensitive strip chart. Wind direction and wind run were also collected, and these data have been analyzed and reported.[13] The weighing bucket rain gauge was located about 10 m west of the mechanical weather station. It recorded precipitation on a strip chart, which was attached to a revolving drum. The recorded data were manually reduced into hourly averages and then fed into a computer for statistical analysis as has been described in detail elsewhere.[4]

Although the reduction of these data proved to be a time-consuming and tedious task, the effort was a necessity as no comprehensive records were available for the area. The irregular, rough, mountainous terrain in this area is characterized by localized events, thus making it difficult to extrapolate such parameters as wind and precipitation events over very large regions.

In addition to use for modeling purposes in the Hot Dry Rock program, our data collected from the Fenton Hill Site were also used by DOE, Union Oil, and Public Service Co. of New Mexico in drafting the meteorological implications in the environmental impact statement for the development of hydrothermal resources at the Baca location.[14]

Precipitation patterns for 1976 through 1979 are presented in Fig. 2. The data are presented as monthly totals, and as is evident from the bar graph, precipitation totals were highly variable from year to year for any given month. The lowest annual precipitation level recorded was 35.7 cm in 1976 and the highest annual level was 50.1 cm in 1978. The mean annual precipitation level for the four year period was 44.1 cm, a value that is within the expected range for this elevational and geographical setting.

The mean maximum temperature (°C) and the range from maximum to minimum for each month of each year are presented in Fig. 3. Temperatures at the site were relatively mild: the lowest temperature, -23°C, was recorded during the winter of 1976, and the highest, 27°C, was reached at least once during each of the four years. Large diurnal variations in temperatures were noted, a phenomenon not uncommon to this region.

VI. ASSESSMENT OF HDR IMPACTS ON THE FENTON HILL WATERSHED

In the semiarid southwest, water availability limits technology development and expansion. Ideally, for a technology to be environmentally acceptable in this region, it should have the least possible effect on the quality of water and should minimize depletion of this resource. In concept, HDR geothermal development satisfies both requirements, primarily because of the advantages offered by a closed circulation loop.

As testing of the closed circulation loop of the HDR system was being conducted, the potential effects of releasing waste water produced by the HDR development into the surrounding environment were studied. Several elements in the reservoir rock are known to be relatively soluble and therefore transportable to the surface in the heat-transfer water.[5] Of particular interest and concern were arsenic, cadmium, fluoride, boron, and lithium. These elements pose the potential for adverse environmental effects if the concentrations are sufficiently high in any waters released from the site.

Forming the basis of the evaluation are baseline data established from 1972-74 for surface and ground waters of the area and gathered before completion of initial drilling operations at the Fenton Hill Site.[15] From these studies, permanent water quality monitoring stations were established, and additional data were collected from 1974 and are reported annually.[16–21]

Drilling fluids and circulating waters from the experimental loop are stored in holding ponds located at the Fenton Hill Site. Concentrations of the elements in question in pond effluents are undoubtedly influenced by the activity occurring at the site at any given time. Since the establishment of the Fenton Hill Site, four bore holes have been drilled. In addition, several circulation tests have been conducted, ranging from very short time durations to a maximum of six months. The liquid effluents contained in the holding ponds are periodically released to the environment via the adjacent drainage canyon south of the site.

Table X presents a comparison of trace element levels in three holding ponds on site with levels found in surface and ground waters from natural sources.[19] Results of analyses for the holding pond waters revealed that, although the concentrations of the trace elements were elevated above mean values observed for surface waters at that time, they were generally within the range and more closely reflected values for ground waters. On closer examination, distribution of the concentrations for the various surface and ground water sampling locations was found to be positively skewed; that is, most sample values fell below the mean value for sample groupings. All high values for surface waters were obtained from thermal and mineral spring sampling locations and streams that were fed from these sources.

Records of the volume of effluent released to the effluent canyon are not complete before 1978. Drilling was initiated at the site in late 1974. Liquid effluents released to the canyon are from the pond designated as GTP-3. The mean concentrations for the five elements of concern for all discharges during 1977 were arsenic 0.5 mg/ℓ, boron 9 mg/ℓ, cadmium <0.1 mg/ℓ, fluoride 10 mg/ℓ, and lithium 10 mg/ℓ. No estimate of the total volume of effluents discharged was available.

TABLE X

TRACE ELEMENT CONCENTRATIONS IN HDR EFFLUENTS AND NATURAL WATERS

	Range mg/ℓ				
	Boron	Arsenic	Cadmium	Lithium	Fluoride
Surface Waters	<0.1 – 1.2	<0.005 – 0.007	<0.0005 – 0.001	<0.03 – 1.16	0.72
Ground Waters	0.2 – 11.0	<0.005 – 0.924	<0.0005 – 0.0016	<0.03 – 14.7	1.27
Holding Ponds[a]	6.8	0.23	0.0007	8.2	4.10

[a]Values are mean concentrations (mg/ℓ) for three effluent holding ponds located at the HDR site.

Table XI presents the range and mean of concentrations of each of the five elements for all discharges in 1978 and 1979. The amount of these elements released to the receiving canyon from the holding pond, GTP-3, has been estimated using the volume of yearly discharges and mean concentrations for each element. Boron, fluoride, and lithium were all in excess of 19 kg each year. Arsenic and cadmium occurred at much lower levels.

It has been observed that the effluent does not flow on the surface beyond a distance of 300 m down the canyon and that the effluent is readily absorbed into the stream channel alluvium.[19] During 1979, the stream channel alluvium was sampled at regular intervals to a distance of 1500 m beyond the point of discharge. Samples were processed to allow for evaluation of the horizontal and vertical distribution of each of the five elements in the alluvium. Partial analytical results indicated that there has been some soil loading of these elements.

VII. SUMMARY AND CONCLUSIONS

A baseline biotic inventory, collected from 1976-1979, has been completed for the Fenton Hill Site. A forest fire, which occurred at the site in 1971, and the subsequent revegetation of the area indicated a strong influence on the vegetative communities and small mammal populations associated with them. Three dominant vegetative communities, grass-forb, aspen, and mixed conifer, were identified. The highest species diversity was encountered in the grass-forb community, and the lowest diversity was recorded in the aspen stands. The grass-forb community was found to be dominated by members of the Graminae family, whereas the mixed conifer and aspen communities contained a larger number of forb and shrub species with grasses less dominant. The data from the vegetation analysis at the site indicated that rapid successional changes were occurring. Consequently, it may be difficult to discern environmental effects to these communities that may have been related to HDR operations.

TABLE XI

CONCENTRATION OF ELEMENTS IN POND DISCHARGES[a]

Element	Year	Range (mg/ℓ)	Mean	Estimated Amount Discharged (kg)
As	78	0.300 – <0.500	0.40	1.40
	79	0.02 – 0.49	0.11	0.41
B	78	2.5 – 11.3	6.25	21.88
	79	<0.5 – 63	6.83	25.27
Cd	78	0.0012 – <0.100	0.05	0.18
	79	<0.001 – 0.014	0.002	0.01
Li	78	2.0 – 9.0	6.0	21.00
	79	1.9 – 20	5.8	21.46
F	78	3.8 – 8.0	5.8	20.30
	79	2.8 – 7.3	5.3	19.61

[a]Total volume discharges from GTP-3.
1978 = 3.5×10^6 ℓ.
1979 = 3.7×10^6 ℓ.

A quantitative analysis of the small mammal populations associated with the dominant vegetative communities was also conducted. Parameters measured for each trapping session included relative densities, population densities, and species diversity. The deer mouse, *P. maniculatus*, comprised 72% of all captures and was the dominant species encountered at all trapping sites. The least chipmunk, *Eutamias minimus*, was the second most trappable species. Six other species of small mammals were captured only occasionally and in relatively small numbers.

Mean precipitation and temperature data were collected for the period 1976-1979. The mean annual precipitation level for the four year period was about 44 cm. Several elements including arsenic, cadmium, fluoride, boron, and lithium are known to be relatively soluble from the reservoir rock and thus transportable to the surface in the heat-transfer water. The concern is that these elements could concentrate in sufficiently high amounts in waste waters released from the site to potentially cause adverse environmental effects. In addition, the probability exists that these elements, once released to the environment, may concentrate in abiotic or biotic components of the ecosystem.

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