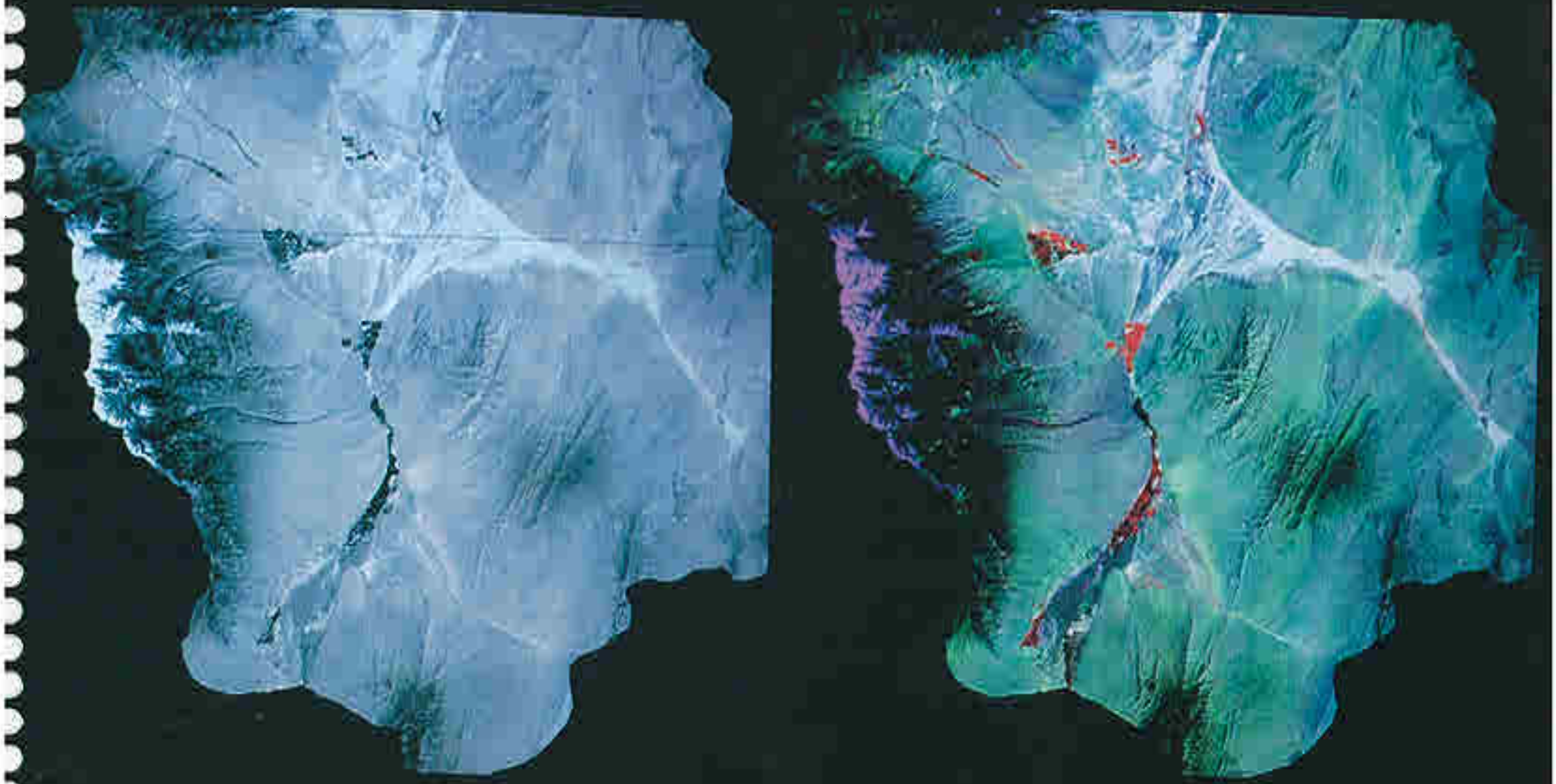

HYDROLOGY AND STEADY STATE GROUND-WATER MODEL OF SNAKE VALLEY, EAST-CENTRAL NEVADA, AND WEST-CENTRAL UTAH

1993

Las Vegas Valley Water District

COOPERATIVE WATER PROJECT
Water for Nevada's Future
Report No. 9
Hydrographic Basin 195

HYDROLOGY AND STEADY STATE GROUND-WATER MODEL OF SNAKE VALLEY, EAST-CENTRAL NEVADA, AND WEST-CENTRAL UTAH

By

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1993

PREFACE

This report on the water resources and development potential of Snake Valley is one of a series of reports on hydrographic basins in southern and eastern Nevada, prepared by the Las Vegas Valley Water District as part of the District's Cooperative Water Project. Kay Brothers and James V. Tracy developed the ground-water flow model and co-authored the report. Thomas S. Buqo performed detailed evaluations of the available data and prepared selected portions of the report. David J. Donovan and Greg A. Febbo, Jr. prepared the report figures. Information used in performing this work was provided by the Nevada State Engineer's office, the U.S. Geological Survey, Summit Engineering, Inc., and the U.S. Air Force. Additional information and technical assistance was provided by the staff of the Research Department of the Las Vegas Valley Water District, under the direction of Terry Katzer, Director.

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Report
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2. Woodward-Clyde Consultants, Dames and Moore, and the Las Vegas Valley Water District, 1992, Environmental report of the Virgin River water resource development project, Clark County, Nevada: Las Vegas Valley Water District, Cooperative Water Project, Series Report No. 2, 130 p.

3. Buqo, T.S., Drici, O., and Goings, D.B., 1992, Hydrology and steady state ground-water model of Coyote Spring Valley, Clark and Lincoln Counties, Nevada: Las Vegas Valley Water District, Cooperative Water Project, Series Report No. 3, 83 p.

4. Buqo, T.S., Drici, O., and Goings, D.B., 1992, Hydrology and steady state ground-water model of Three Lakes South Valley, Clark County, Nevada: Las Vegas Valley Water District, Cooperative Water Project, Series Report No. 4, 80 p.

5. Cole, E., Cernoch, B., Bruce, L., and Rumbaugh, J.O. III, 1992, Hydrology and steady state ground-water model of Three Lakes North Valley, Clark and Lincoln Counties, Nevada: Las Vegas Valley Water District, Cooperative Water Project, Series Report No. 5, 45 p.

6. Cole, E., Cernoch, B., Bruce, L., and Rumbaugh, J.O. III, 1992, Hydrology and steady state ground-water model of Tikaboo Valleys North and South, Clark and Lincoln Counties, Nevada: Las Vegas Valley Water District, Cooperative Water Project, Series Report No. 6, 50 p.

7. Avon, L. and Durbin, T.J., 1992, Evaluation of the Maxey-Eakin Method for Calculating Recharge to Ground-Water Basins in Nevada: Las Vegas Valley Water District, Cooperative Water Project, Series Report No. 7, 44 p.

8. Brothers, K., Buqo, T., and Tracy, J., 1993, Hydrology and steady state ground-water model of Coal and Garden Valleys, Lincoln and Nye Counties, Nevada: Las Vegas Valley Water District, Cooperative Water Project, Series Report No. 8, 52 p.

COOPERATIVE WATER PROJECT SERIES

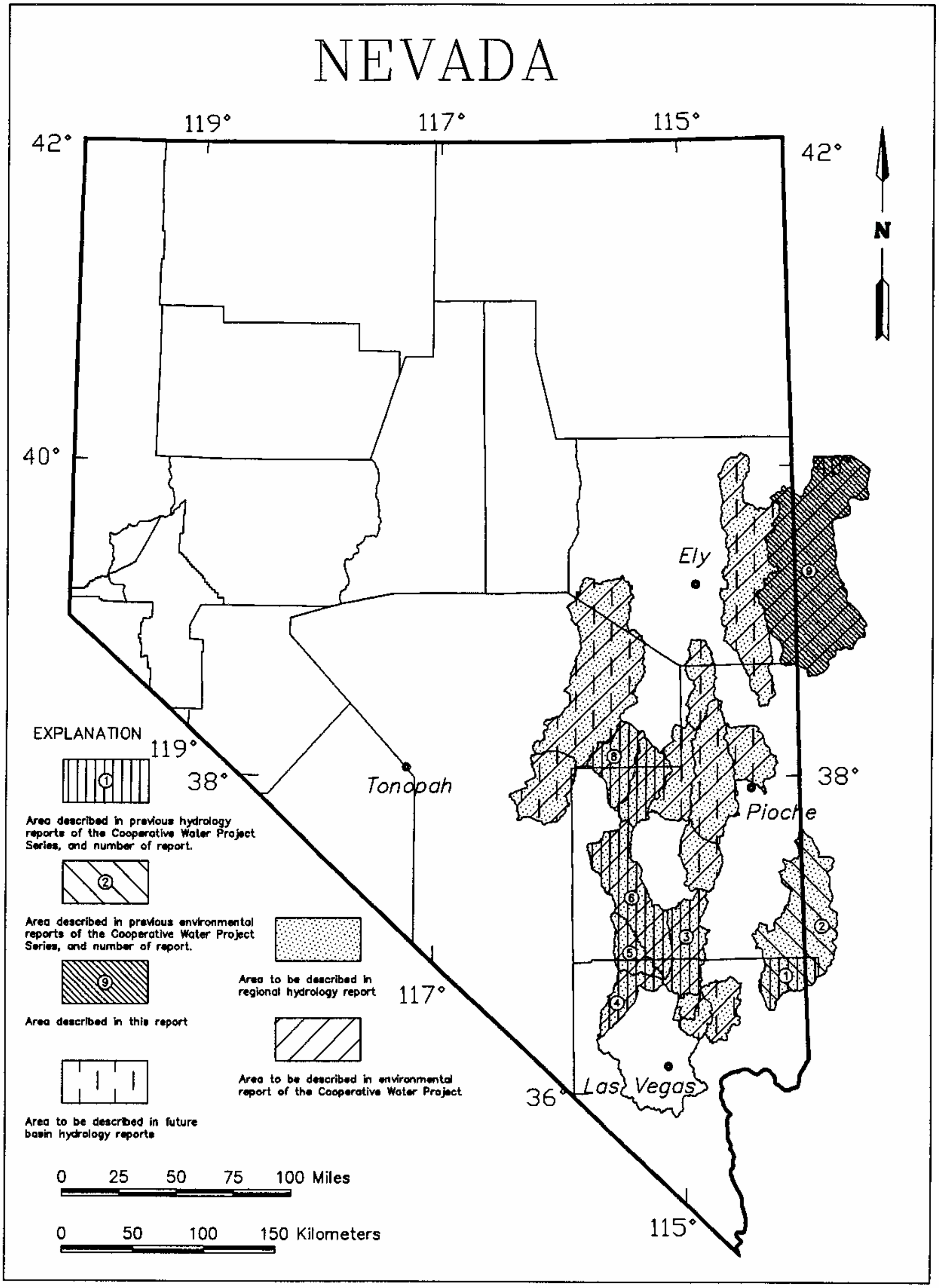
REFERENCES (Continued)

Report
No.

9. Brothers, K., Buqo, T., and Tracy, J., 1993, Hydrology and steady state ground-water model of Snake Valley, East-Central Nevada, and West-Central Utah: Las Vegas Valley Water District, Cooperative Water Project, Series Report No. 9, 66 p.

10. Drici, O., Garey, C., and Buqo, T., 1993, Hydrology and steady state ground-water model of Pahroc Valley, Lincoln and Nye Counties, Nevada: Las Vegas Valley Water District, Cooperative Water Project, Series Report No. 10, 64 p.

11. Brothers, K., Buqo, T.S., Tracy, J., Kaufmann, R.F., Stock M., Bentley, C., Zdon, A., and Kepper, J., 1993 Hydrology and steady state ground-water model of Cave Valley, Lincoln and White Pine Counties, Nevada: Las Vegas Valley Water District, Cooperative Water Project, Series Report No. 11, 48 p.



Areas described in previous reports of this series, the area described in this report and the areas to be described in future reports.

INTRODUCTION

In October 1989, the Las Vegas Valley Water District (District) filed 9 applications to obtain ground-water rights from the Nevada portion of Snake Valley located in White Pine and Lincoln counties. Since the time of these water right filings, the District has conducted extensive investigations of these areas including the collection of basic hydrologic data, a water rights inventory, the synthesis of all published and agency information on the water resources of the area, and the development of conceptual and numerical models of the valleys. This report details the hydrologic assessments of Snake Valley that were conducted, and the steady-state ground-water flow model developed to represent the aquifer systems of the basin.

Background

Snake Valley is an arid basin located about 200 miles north of Las Vegas, Nevada (Figure 1). About one-third of the valley is situated in Nevada while the remaining two-thirds is in Utah. A very small area in the extreme southwestern portion of the basin is located in Lincoln County, Nevada. The rest of the Nevada part of the basin is in White Pine County. Almost 200 production and observation wells have been drilled in Snake Valley; data concerning these wells provides much information about the alluvial aquifer in the basin. Although detailed information on the underlying carbonate aquifer is lacking, much can be inferred on the basis of the regional carbonate aquifer studies that have been conducted throughout the Great Basin. On the basis of the geology of the basin and the hydrogeology of neighboring basins, it is assumed that the regional carbonate aquifer underlies Snake Valley.

Snake Valley is in direct hydraulic communication with Hamlin Valley, located to the south. The two valleys appear to form an open system in terms of both ground water and surface water. Although the District plans no development in Hamlin Valley, it is included within this report because of its proximity and interrelationship with Snake Valley. Similarly, a small subbasin in the northwest part of Snake Valley, Pleasant Valley, is recognized by the Nevada State Engineer as a discrete hydrographic basin but is included within the scope of this report.

The District plans to develop the water resources of Snake Valley through the installation of a well field and distribution system that will convey the water to users in metropolitan areas of Clark County. Preliminary plans call for the drilling of water wells at nine locations; final optimized wellfield designs will be developed in subsequent phases of the development program and will be based upon detailed planning and environmental studies.

To assist its efforts in formulating final plans for developing the water resources of Snake Valley, the District developed a numerical model of the ground-water flow regime of Snake and Hamlin Valleys. A numerical model is a computer code which translates the mechanics of ground-water flow through the earth through a series of mathematical equations. By coupling the available information on the basins (and similar valleys in Nevada) with the predictive capabilities of the model, it is possible to predict the response of the ground water to the proposed water withdrawals by the District.

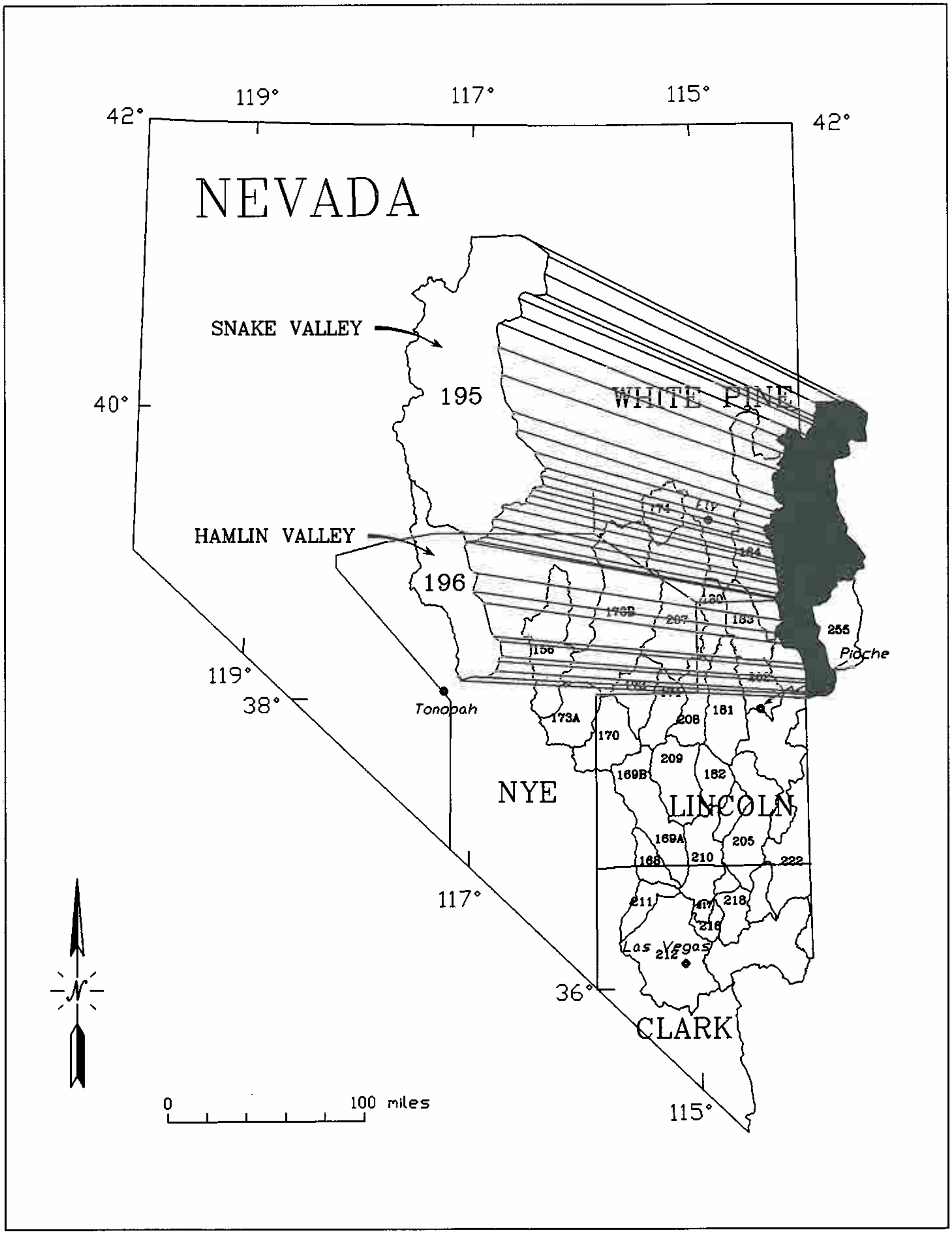


Figure 1. -- Location of the study area

The development of a ground-water flow model for Snake and Hamlin Valleys serves two important purposes. First, it is a useful planning tool in developing well field designs by allowing water supply design experts to simulate the efficiency of different design alternatives; secondly, it allows planners to simulate the potential effects of the water withdrawals, if any, on neighboring water users, or the environment.

Both beneficial and negative impacts may result from ground-water withdrawals from the valley-fill deposits and/or the regional carbonate aquifer in the arid basins of Nevada. The benefits derived from the application of currently unused ground water to beneficial use is, of course, the primary positive impact. The economic impact of large-scale ground-water development programs, such as that proposed by the District, is likely to be appreciable and the project is likely to result in significant short-term and long-term economic benefits. The proposed program will require the cooperative efforts of large teams of scientists, engineers, and water planners, and the services of the water well and construction industries.

Beside the favorable economic impacts expected to result from the proposed development of ground water in Snake Valley, negative impacts can occur. The primary negative impact of ground-water withdrawals is the lowering of ground-water levels in the vicinity of the production wells; this lowering of water levels is commonly referred to as drawdown. If the drawdown near a pumping well, or a wellfield, is significant, then the direction and rate of ground-water flow can be altered and potentially may result in:

- Increased pumping lifts and costs;
- Reductions in spring-flow rates;
- Reductions in surface-water flows; and
- Degradation of water quality.

The magnitude and significance of these impacts depends largely upon the overall hydrologic setting of the basin where the withdrawals occur. In remote, undeveloped or underdeveloped basins with no surface water or large springs, the drawdown that will result from ground-water development may not result in significant adverse impacts within the valley. In other instances, the presence of sensitive environments in a valley may be adversely impacted as a result of the same amount of drawdown. Examples of sensitive environments in Nevada include: 1) wetland areas that provide valuable habitat for many types of wildlife; 2) surface water flows and their associated riparian habitats; 3) springs that either support wildlife or have been developed for ranching, mining, quasi-municipal, or domestic uses; and 4) areas where ground water provides the sole source of drinking water for a community.

Because many of the basins in central and southern Nevada are hydraulically linked, via the regional carbonate aquifer, into vast flow systems, the drawdown that results from the development of ground water in one valley can impact the environment of another valley. Thus, the development of a numerical model of ground-water flow to simulate the impacts of pumping must take into account the environment in peripheral valleys as well as the valley actually being modelled. The District is in the process of preparing a computer model to evaluate these potential regional impacts.

There are a number of springs in Snake and Hamlin Valleys but only Warm and Twin Springs located in Utah in northern Snake Valley are considered to be regional springs. In the Utah portion of the basin, areas of potential concern include the Goshute Indian Reservation in the Deep Creek Range and the Fish Springs National Wildlife Refuge located in the northwest part of Fish Springs Flat and on the east side of the Fish Springs Range which bounds part of Snake Valley. In Nevada, the two key areas of potential concern are the Goshute Indian Range to the north of Snake Valley in Antelope Valley and Great Basin National Park, encompassing much of the south-central portion of the Snake Range on the western side of the basin. The proposed District withdrawals are located far south of those potential areas of concern; however, modelling the hydrogeology of Snake Valley will aid in predicting the effects of withdrawing water on these areas.

The use of numerical methods to simulate water withdrawals in Snake Valley provides a tool for predicting the effects that would be expected to result from proposed District development. Recently, the U.S. Geological Survey (USGS) has reported the findings of a cooperative study of the water resources potential of the carbonate aquifer conducted in cooperation with the U.S. Bureau of Reclamation, state and local agencies, including the District (Dettinger, 1989). This report recommends the effective use of computer models for predicting the site-specific effects of water withdrawals from the carbonate aquifer. The report concluded that increased confidence in such predictions can be achieved through a staged approach to development coupled with adequate monitoring and interpretation. The development of a computer model of the steady-state ground-water flow regime in Snake and Hamlin Valleys, performed as part of this investigation, represents one of the first steps in implementing such a staged approach.

The steady-state ground-water model, described in this report, provides a preliminary representation of the aquifer system based upon the information available at this time. As additional data becomes available through District efforts, the model of the ground-water flow regime for either or both valleys can be updated accordingly to provide a more refined representation of the hydrologic system.

Purpose and Scope

The purpose of this project is twofold: 1) to define the hydrologic conditions of Snake and Hamlin Valleys, and 2) to develop a calibrated steady-state ground-water flow model of the valleys. The specific objectives of these investigations are to:

- Collect land use data in the valleys;
- Compile and review published reports and unpublished data on the basins;
- Interpret the available data and determine the characteristics of the basins; and
- Prepare a computer model to simulate steady-state ground-water flow in the basins.

To achieve these objectives, a detailed investigation of the hydrologic conditions of Snake and Hamlin Valleys was conducted. The scope of work included a review of all available published and unpublished data, the evaluation of the occurrence and movement of ground water and water chemistry, and the development of conceptual and steady-state numerical models of the hydrogeologic regimes of the valleys. The basin characterization information and steady-state flow model discussed in this report will be used by the District to develop a transient regional model including Snake and Hamlin Valleys' ground-water regime.

Location and Physiographic Setting

Snake and Hamlin Valleys lie within the Great Basin Physiographic Region as defined by Fenneman (1931). In this section, the location of the valleys, shown in Figure 2, and their general physiographic setting are presented and discussed.

Snake Valley is located between the Snake Range to the west and the Confusion and Conger Ranges to the east. On the south, Snake Valley is hydraulically connected via both the surface water and the ground-water regime with Hamlin Valley. To the northeast, in Utah, Snake Valley is separated from the Great Salt Lake Desert by a small topographic divide but is, again, hydraulically connected. Snake Valley, within the context of this report, includes all of Pleasant Valley in Nevada and Utah and the Ferguson Desert area of Utah along the southeast margin of Snake Valley.

Snake Valley is approximately 90 miles along its central axis, 20-40 miles wide, and covers 777 square miles in Nevada (Scott, et al., 1971) and about an additional 1900 square miles in Utah. The valley floor ranges in elevation from almost 7,000 feet above mean sea level (AMSL) on the alluvial fans in the Black Horse area of the Snake Range to about 4,750 feet AMSL at the north-central end of the valley in Utah in the Salt Marsh Lake area. The valley floor averages about 5,200 feet AMSL overall in elevation. In Nevada, Snake Valley is bounded on the west by the Snake Range, which rises to a maximum elevation of 13,063 feet AMSL at Wheeler Peak. Further to the north, in the Utah part of Snake Valley, the basin is bounded on the west by the 12,000 ft high Deep Creek Range. On the east, Snake Valley is bounded by the Confusion and Conger ranges, which rise to a maximum elevation of about 9,800 feet AMSL.

The physiography of Snake Valley is similar to that of most valleys in Nevada; mountains rise on the east and west and alluvial fans radiate from the major mountain watersheds forming a somewhat continuous bajada. Unlike many of the valleys in southern Nevada, however, Snake valley has a surface water regime of perennial streams and lakes. On the valley floor, the major features include Pruess Lake, three miles south of Garrison, Utah and Salt Marsh Lake about three miles east of Gandy, Utah. Preuss Lake is fed by perennial flow from Big Spring Creek and a tributary, Lake Creek. Other significant streams include Baker, Lehman, Snake, and Big Wash creeks, all of which originate in Nevada on the east slopes of the Snake Range.

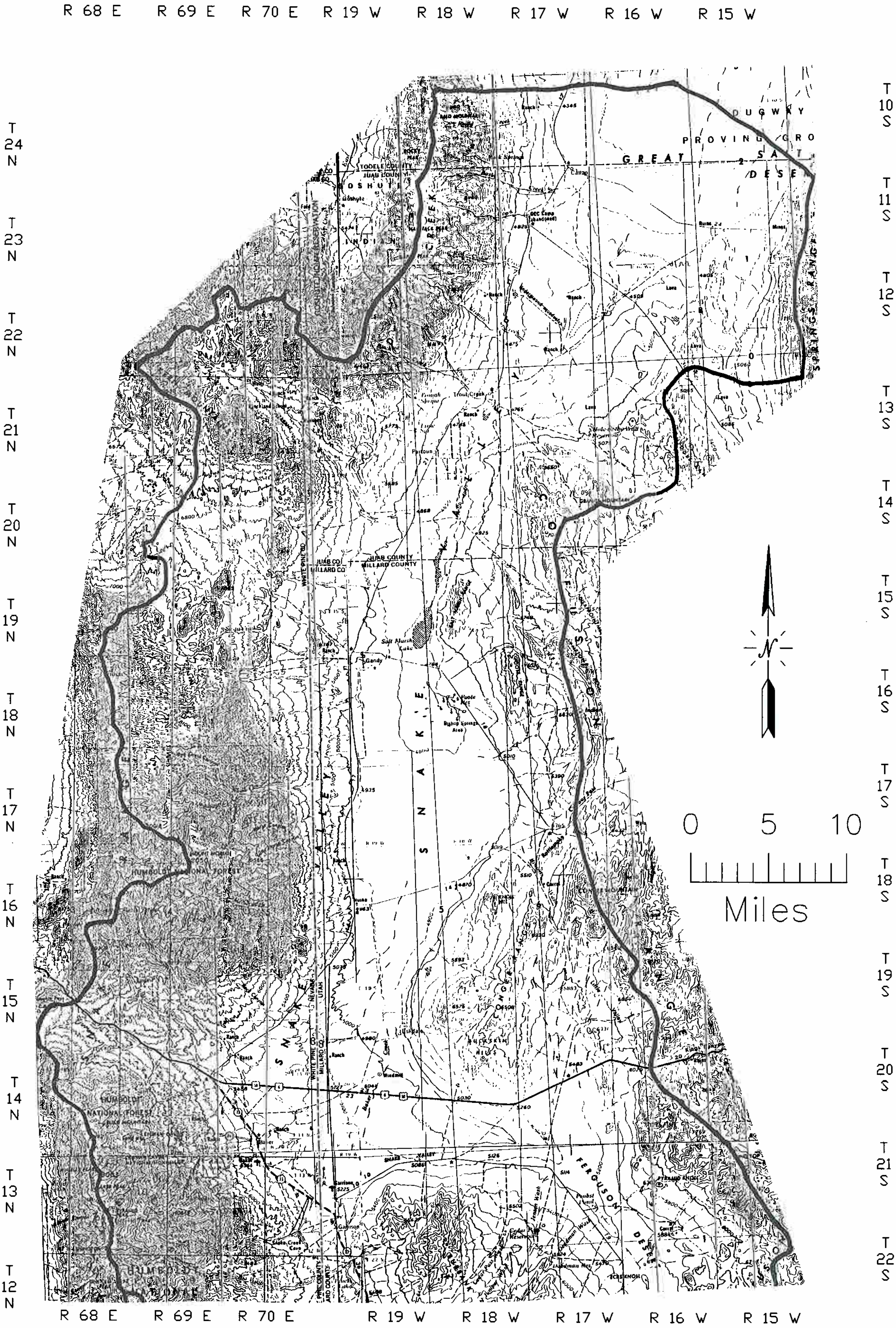


Figure 2. -- Physiography and location of Snake and Hamlin Valleys (Northern Half).

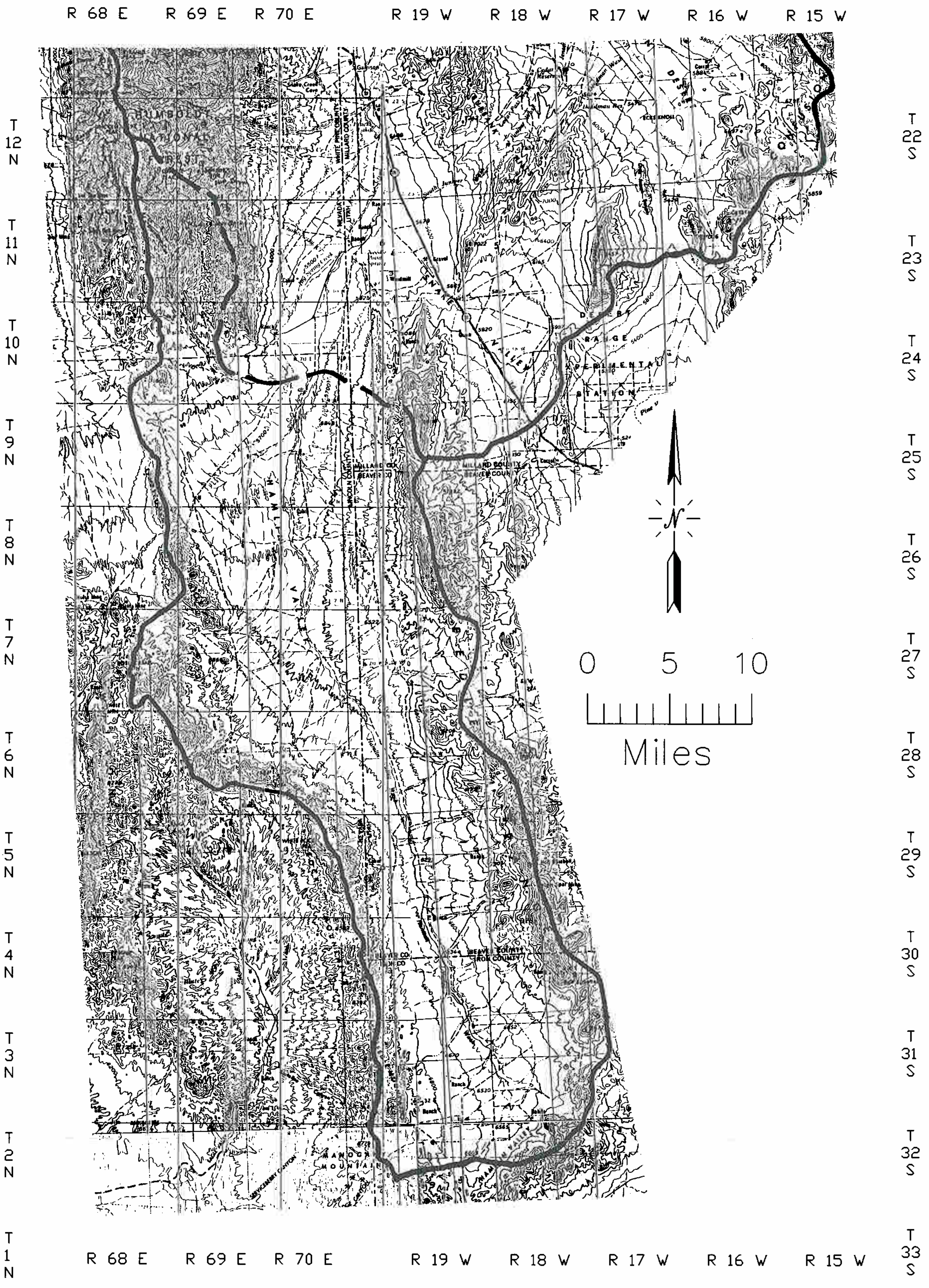


Figure 2a. -- Physiography and location of Snake and Hamlin Valleys (Southern Half).

On the west, from north to south, Hamlin Valley is bounded by the Snake Range, Limestone Hills, Wilson Creek Range, and the White Rock Mountains. In the northeastern most part of the basin, a narrow topographic divide at The Troughs separates Hamlin Valley from Spring Valley. On the north, Hamlin Valley is topographically open to Snake Valley. On the south, the basin is separated from the Escalante Desert by a low topographic divide. On the east, from north to south, Hamlin Valley is bounded by the Mountain Home Range and the Indian Peak Range. A topographic divide along the east-central boundary of the basin separates Hamlin Valley from Pine Valley to the west.

Hamlin Valley is approximately 50 miles in length and averages about 16 miles in width. With a total area of about 1360 square miles, there are about 413 square miles in the Nevada part of the basin (Scott, et al., 1971). The elevation of the valley floor ranges from about 7,500 feet AMSL along the southeastern flanks of the valley to about 5,500 feet AMSL at the north end of the valley along Hamlin Valley Wash. On the west, in Nevada, the elevations in the bounding mountain ranges vary from over 11,000 feet AMSL at Granite Peak in the Snake Range, about to about 7700 feet in the Limestone Hills. On the east, in Utah, the mountains are less imposing, with a maximum elevation of 9784 in the Indian Peak Range and about 8,500 feet in the Mountain Home Range.

The physiography of Hamlin Valley is similar to that of Snake Valley. The major features along the valley floor include Hamlin Valley Wash, Rosecrans Creek, Hyde Wash, and Big Spring Wash.

Availability of Data

Compared to many rural Nevada basins, Snake Valley and Hamlin Valley have been moderately developed and a considerable amount of information is available for the area. Records are available for over 250 production and observation wells that have been drilled in the two basins (Bunch and Harrill, 1984). Other available information includes published reports by the Nevada Bureaus of Mines and Geology, the USGS, and the Utah State Engineer. In the late 1970s and early 1980s, Snake and Hamlin Valleys were also the target of extensive investigations by the U.S. Air Force as part of their MX Water Resources Program. As a result of these previous investigations and the development that has occurred in the valley, the hydrologic conditions have been relatively well defined. Regional data from adjacent valleys are also available to supplement the existing valley-specific data.

The distribution of data points in the valley, although not ideal; does provide for coverage of a significant area. Water level data in Snake Valley is available for much of the basin, particularly the south-central portion of the basin where agricultural development has occurred. One Hundred and four (104) wells located in Snake and Hamlin Valleys were chosen to provide areal coverage and are shown in Table 1. Appendix A provides an explanation of the well location designations used in this report in both Nevada and Utah.

Table 1.-- Selected water level data in Snake and Hamlin Valleys, Nevada and Utah.

NEVADA						
ID NUMBER	LOCATION	LAND ELEV. (in ft. AMSL)	DEPTH TO WATER (in ft.)	WATER ELEV. (in ft.)	DATE MEASURED	SOURCE
1[b]	19N/69E-15C	7180	9.00	7171	07/18/53	1
2	15N/70E-25DD	5080[a]	10.68	5069	09/26/91	1
3	14N/70E-31C	5620	25.00	5595	10/14/50	1
4	14N/70E-27C	5300	89.20	5211	04/04/90	1
5	14N/70E-20	5420	53.00	5367	03/74	2
6	14N/70E-8DC	5500	60.00	5440	03/81	2
7	14N/69E-24DAB	5600	12.00	5588	08/79	2
8	14N/69E-24BDD	5650	32.00	5618	08/79	2
9	14N/69E-24A	5680	27.00	5653	05/07/58	1
10	13N/71E-19B	5160	21.50	5139	04/04/90	1
11	13N/70E-35A	5330	99.50	5231	04/04/90	1
12	13N/70E-16DB	5360	50.00	5310	08/48	2
13	13N/70E-16CC	5470	53.00	5417	03/74	2
14	13N/70E-16C	5435	39.00	5396	05/06/53	2
15[b]	13N/70E-14CCA	5200	FLOWING	5200	05/79	2
16[b]	13N/70E-10CAD	5250	FLOWING	5250	08/79	2
17	13N/70E-10ABA	5200	151.00	5049	08/79	2
18[b]	13N/70E-10A	5220	FLOWING	>5220	04/04/90	2
19	13N/70E-9CA	5300	28.00	5272		2
20	13N/70E-9C	5350	36.40	5314	04/04/90	1
21	13N/70E-9BDD	5300	16.00	5284	08/79	2
22	13N/70E-9B	5350	18.00	5332	07/30/58	1
23	13N/70E-4CDC	5300	28.00	5272	08/79	2
24	13N/70E-4D	5300	30.20	5270	04/04/90	1
25[b]	13N/70E-3D	5350	FLOWING	5350	06/50	2
26[b]	13N/69E-11CBC	6550	25.00	6525	04/58	2
27[b]	13N/69E-11ABC	6400	85.00	6315	04/74	2
28	11N/70E-36BD	5520	66.50	5453	09/26/91	1
29	11N/70E-35BA	5680	141.08	5539	09/26/91	1

Table 1.--Selected water level data in Snake and Hamlin Valleys, Nevada and Utah (continued).

ID NUMBER	LOCATION	LAND ELEV. (in ft. AMSL)	DEPTH TO WATER (in ft.)	WATER ELEV. (in ft.)	DATE MEASURED	SOURCE
30	11N/70E-35AD	5595	69.28	5526	09/26/91	1
31	10N/70E-25D	5525	7.00	5518	08/03/53	1
32	10N/70E-12B	5470	14.00	5456	07/53	2
33	10N/70E-11D	5490	9.00	5481	07/53	2
34	9.5N/70E-33AB	5650	75.00	5575	07/80	2
35	9N/71E-6A	5720	199.00	5521	07/79	2
36	9N/70E-34DCD	5690	110.00	5580	08/79	2
37	9N/70E-14CAB	5620	27.00	5593	07/79	2
38	8N/70E-21AAD	5710	122.00	5588	05/79	2
39	8N/70E-6ABA	5670	88.00	5582	07/79	2
40	8N/69E-36AAA	5816	145.00	5671	08/79	2
41	8N/69E-36A	5770	152.30	5618	03/18/47	1
42	8N/69E-35DC2	5816	156.00	5660	02/81	2
43[b]	8N/69E-35DC1	5834	174.00	5660	02/81	2
44	8N/69E-15BBD	5750	75.00	5675	07/79	2

UTAH

ID NUMBER	LOCATION	LAND ELEV. (in ft. AMSL)	DEPTH TO WATER (in ft.)	WATER ELEV. (in ft.)	DATE MEASURED	SOURCE
45	(C-11-16)36DCB	4420	2.72	4417	09/24/91	1
46	(C-11-17)1BDC	4356[a]	6.68	4349	09/24/91	1
47	(C-11-17)11AAA	4382[a]	47.23	4335	09/24/91	1
48	(C-11-17)12ACC	4350[a]	24.69	4325	09/24/91	1
49	(C-11-17)12CBB	4390	53.73	4336	09/30/91	1
50	(C-12-17)34AAC	4560	76.32	4484	09/26/91	1
51	(C-12-17)35CAC	4570	91.24	4479	09/26/91	1
52	(C-13-18)13CAC	4700	16.84	4683	09/26/91	1
53	(C-13-18)23AAB	4700	14.35	4686	09/26/91	1
54	(C-13-18)28DAB	4780	29.90	4750	09/26/91	1
55	(C-13-18)33DDC	4760	9.69	4750	09/26/91	1
56	(C-13-18)34CCC	4740	0.67	4739	09/26/91	1

Table 1.--Selected water level data in Snake and Hamlin Valleys, Nevada and Utah (continued).

ID NUMBER	LOCATION	LAND ELEV. (in ft. AMSL)	DEPTH TO WATER (in ft.)	WATER ELEV. (in ft.)	DATE MEASURED	SOURCE
57	(C-14-18)18DCC	4870	77.34	4793	03/15/82	1
58	(C-14-18)26DBC	4960	168.57	4791	09/26/91	1
59	(C-15-19)11BCC	4980	88.05	4892	09/26/91	1
60	(C-16-18)26CBA	4880	41.52	4838	09/26/91	1
61	(C-16-19)4BBA	5000	71.95	4928	09/26/91	1
62	(C-17-19)4ADD	4880	41.84	4838	03/13/91	1
63	(C-18-18)31ADB	4980	78.69	4901	09/25/91	1
64	(C-18-19)20DAD	4960	24.70	4935	09/26/91	1
65	(C-18-19)20DDD	4989	25.45	4964	09/26/91	1
66	(C-18-19)28BCC	4970	17.98	4952	09/26/91	1
67	(C-19-19)26ABA	4945	15.18	4930	03/27/90	1
68	(C-19-19)26BDD	4945	16.48	4929	09/26/91	1
69	(C-19-19)35CDD	4980	13.52	4966	03/03/81	1
70	(C-19-19)35DCD	4980	22.39	4958	09/26/91	1
71	(C-19-19)36CDA	5020	68.52	4951	09/26/91	1
72	(C-20-19)14BBC	4995	15.24	4980	09/26/91	1
73	(C-20-19)19DCD	5079	37.41	5042	03/13/91	1
74	(C-20-19)21ACC	5028	27.36	5001	09/25/91	1
75	(C-20-20)12ACC	5120	27.18	5093	09/26/91	1
76	(C-21-18)32ABD	5020	35.54	4984	09/25/91	1
77	(C-21-19)31CCA	5225	42.00	5183	07/51	2
78	(C-22-19)6BCA	5213	37.00	5176	08/79	2
79	(C-22-19)6BAC	5260	58.73	5211	09/25/91	1
80	(C-22-19)6BCC	5276	67.41	5209	09/25/91	1
81	(C-22-19)31CB	5560	187.00	5373	03/81	2
82	(C-22-20)1AAC	5270	60.00	5210	05/44	2
83	(C-22-20)1AAD	5270	63.00	5207	06/48	2
84	(C-22-20)1ABA	5280	70.73	5209	09/25/91	1
85	(C-22-20)1DAA	5270	75.00	5195	07/39	2
86	(C-23-19)8D	5400	3.00	5397	05/76	2
87	(C-23-19)9CDB	5400	8.93	5391	09/25/91	1

Table 1.--Selected water level data in Snake and Hamlin Valleys, Nevada and Utah (continued).

ID NUMBER	LOCATION	LAND ELEV. (in ft. AMSL)	DEPTH TO WATER (in ft.)	WATER ELEV. (in ft.)	DATE MEASURED	SOURCE
88	(C-23-19)10CA	5485	69.00	5416	03/81	2
89	(C-23-19)10DD	5590	163.00	5427	03/81	2
90	(C-23-19)13AAB	5930	476.00	5454		2
91	(C-23-19)20BAC	5400	15.00	5385	03/28/90	1
92	(C-23-19)20BDB	5410	18.00	5392	08/79	2
93	(C-23-19)20DBC	5415	16.00	5399	08/79	2
94	(C-23-19)22B	5405	48.00	5357	03/81	2
95	(C-23-19)24DCC	5780	455.00	5325	06/39	2
96	(C-23-19)28CB	5450	40.00	5410	03/81	2
97	(C-24-19)3CAD	5570	124.42	5446	09/10/87	1
98	(C-24-19)3DA	5570	126.00	5444	03/81	2
99	(C-24-19)4AA	5530	82.00	5448	03/81	2
100	(C-30-19)21CAB	6325	170.00	6155		2
101[b]	(C-32-19)21ABA1	6740	17.00	6723	11/62	2
102[b]	(C-32-19)21ABA2	6740	58.00	6682	11/62	2
103	(C-32-19)22DCB	6640	335.00	6305	12/64	2
104	(C-32-19)27ACC	6650	415.00	6235	09/72	2

1) USGS Data Base
2) Bunch and Harrill (1984)
   a) Corrected elevations
   b) Not used in model calibration or preparation of Figure 7: Either flowing wells, wells representative of perched localized systems, or duplicate wells.

The valley-specific data may be supplemented by regional data. Previous investigations in neighboring valleys have generated a data base of regional information which can be used to help formulate a ground-water model for Snake Valley. These data provide specific measures or estimates of the ground-water conditions at selected points in time and values for key hydrologic parameters. Several of the wells in adjacent valleys that were drilled as part of the Air Force's MX investigations extend through the valley-fill into the underlying carbonate rocks.

The primary source of data for Snake Valley is a reconnaissance report authored by Hood and Rush (1965). Investigators of the regional flow system and adjacent valleys have included Ertec Western (1981); Thomas, et al. (1986); and Dettinger (1989). The sources of recent data available for Snake Valley include: 1) details on water well construction from Well Drillers Reports filed with the Nevada State Engineer Office; 2) water level, spring discharge, and water chemistry data and the results of aquifer tests from the USGS databases; and 3) the results of aquifer tests and exploratory drilling into the carbonate aquifer by the Air Force during 1980 and 1981.

Other available data included technical reports of the Nevada Department of Conservation and Natural Resources, USGS Professional Papers, Water-Supply Papers, and Open-File Reports, and cooperative reports on the regional carbonate aquifer study conducted in 1988. Characterizations of the regional setting, particularly the recent publications by the USGS, provide important, and accepted regional interpretations that are also of considerable use in evaluating Snake Valley.

Information on the status of water rights Snake Valley was made available by Summit Engineering Corporation (SEC) in the form of water right abstracts. According to SEC, these abstracts were based upon a thorough compilation and review of the public documents available from the Nevada State Engineer Office, the regulatory authority governing water rights in Nevada. A detailed listing of the water rights for the Nevada part of Snake Valley are included in Appendix B.

The conceptual and numerical models of Snake Valley, discussed later in the report, were based on the available site-specific and regional data discussed in the previous paragraphs, the observations made during reconnaissance trips to the valley, and the knowledge of the overall regional ground-water setting.

Methods

In assessing the water resources potential of Snake Valley, and developing a steady-state numerical model of the ground-water system of the basin, only standard approaches and procedures were used. In this section, the methods and procedures that were used are identified and discussed, along with a brief introduction to the selected numerical modelling code.

Data Collection and Compilation

Data from the USGS Water Resources Division's databases that included the most recent water level measurements available, along with well drillers reports, published reports, and maps. A literature search was conducted to identify and compile data from available published sources.

The locations and data sources were verified by comparing reported or entered data point locations and parameters with field observations and/or the published source of information. Spatial data sets (e.g., water levels, water chemistry, and water right locations), were plotted at uniform scales and annotated. The resulting maps were inspected for anomalous values and further verification was performed to resolve any anomalous data points.

Numerical Model Development

The model used to simulate the ground-water regime of Snake Valley is a computer code prepared by the USGS and referred to as MODFLOW (for "Modular Three-Dimensional Finite-Difference Ground-Water Flow Model"). The USGS has prepared comprehensive documentation for this code in one of their series of manuals on techniques of water-resources investigations (McDonald and Harbaugh, 1988). An overview of the code, a discussion of the general approach used in modelling, and the specifics of the model developed for the basin are detailed in the "Ground-Water Flow Model Development" section.

GENERAL HYDROGEOLOGIC FEATURES

The development of numerical simulations of the proposed District ground-water withdrawals in Snake Valley requires a thorough understanding of the hydrologic regime of the basin. The information that is available concerning the valley, and adjacent or similar areas, is used to develop a conceptual model of the source of water in the valley, its occurrence and flow in the subsurface, and the relationship between the valley and adjacent areas. In this section, the regional and valley-specific hydrologic conditions in both valleys are described and discussed.

Regional and Basin Hydrogeologic Features

Snake and Hamlin Valleys are situated in the Alluvial Basins Ground-Water Region as defined by Heath (1984). Individual hydrographic basins in this region are characterized by alluvial basins that are underlain by bedrock, and are separated by the bedrock outcrops in the bounding mountain ranges, or, in some instances, by lower divides in alluvial terrain.

When ground-water flows from one basin to another, the basins are considered to be part of a flow system. Snake Valley comprises a portion of the Great Salt Lake Desert Flow System as defined by Harrill, et al. (1988). This flow system comprises 21 individual hydrographic basins and encompasses almost 13,000 square miles, and the southwestern part of the system is shown in Figure 3. It should be noted that Harrill defined Snake Valley as including both Snake Valley, Hamlin Valley, and Pleasant Valley, hydrographic basins 195, 196, and 197, respectively, as defined by the Nevada State Engineer. The discharge from the flow system is to the huge evapotranspiration center in the Great Salt Lake Desert with more limited discharge to the Great Salt Lake.

The overall component of regional ground-water flow is to the northeast in the western parts of the flow system and to the northwest in the eastern parts of the system. Within individual valleys in the flow system, recharge from the bounding mountain ranges results in a local flow component that generally coincides with the topography (i.e, from the mountains toward the axis of the valleys or toward playas with downward vertical hydraulic gradients).

Snake Valley receives a moderate amount of subsurface underflow from adjacent basins in Utah. According to estimates presented by Harrill et al. (1988), Pine Valley discharges 11,000 acre feet per year of ground water into Snake and Wah Wah valleys and about 8,500 acre feet per is discharged from Wah Wah Valley into Snake and Tule Valleys. If it is assumed that the discharge from these basins is evenly distributed, then these two basins contribute an estimated 9,750 acre feet per year of subsurface flow to Snake Valley. However, as discussed under "Model Development" the hydraulic gradients indicate this flow goes from Pine to Wah Wah then to Tule Valleys, not entering Snake Valley. The results of the computer modelling and ground-water level data in the Valleys indicates that the flow into Snake Valley is around 1,000 acre-feet per year. Hamlin Valley receives a small contribution of flow (4,000 acre feet per year) from Spring Valley which then flows northeast into Snake Valley.

Similarly, subsurface flow via underflow into adjacent valleys accounts for a significant amount of discharge from Snake Valley with appreciable subsurface discharge to Tule Valley (between 22,000 and 33,000 acre feet per year), a lesser amount to the Great Salt Lake Desert (about 10,000 acre feet per year), and an unknown, but limited amount probably discharging to Fish Springs Flat, Harrill et al. (1988). Discharge via subsurface flow from Hamlin Valley has not been estimated but is believed to be entirely into Snake Valley.

Lithologic and Hydrologic Features

The hydrostratigraphic units present and their ability to store and transmit ground water are important considerations in developing both conceptual and numerical models of Snake Valley. The type, thickness and depth, and water-bearing properties of the geologic materials in the valley can be used to define the overall water resources potential. In this section, the geologic units present in Snake Valley and their hydraulic properties are described and discussed.

Hydrostratigraphy

The stratigraphy of the Snake Range, Deep Creek Range, and Confusion Range have been well summarized by Hose and Blake (1976) and Hintze (1982) and are shown in Figure 4. On the

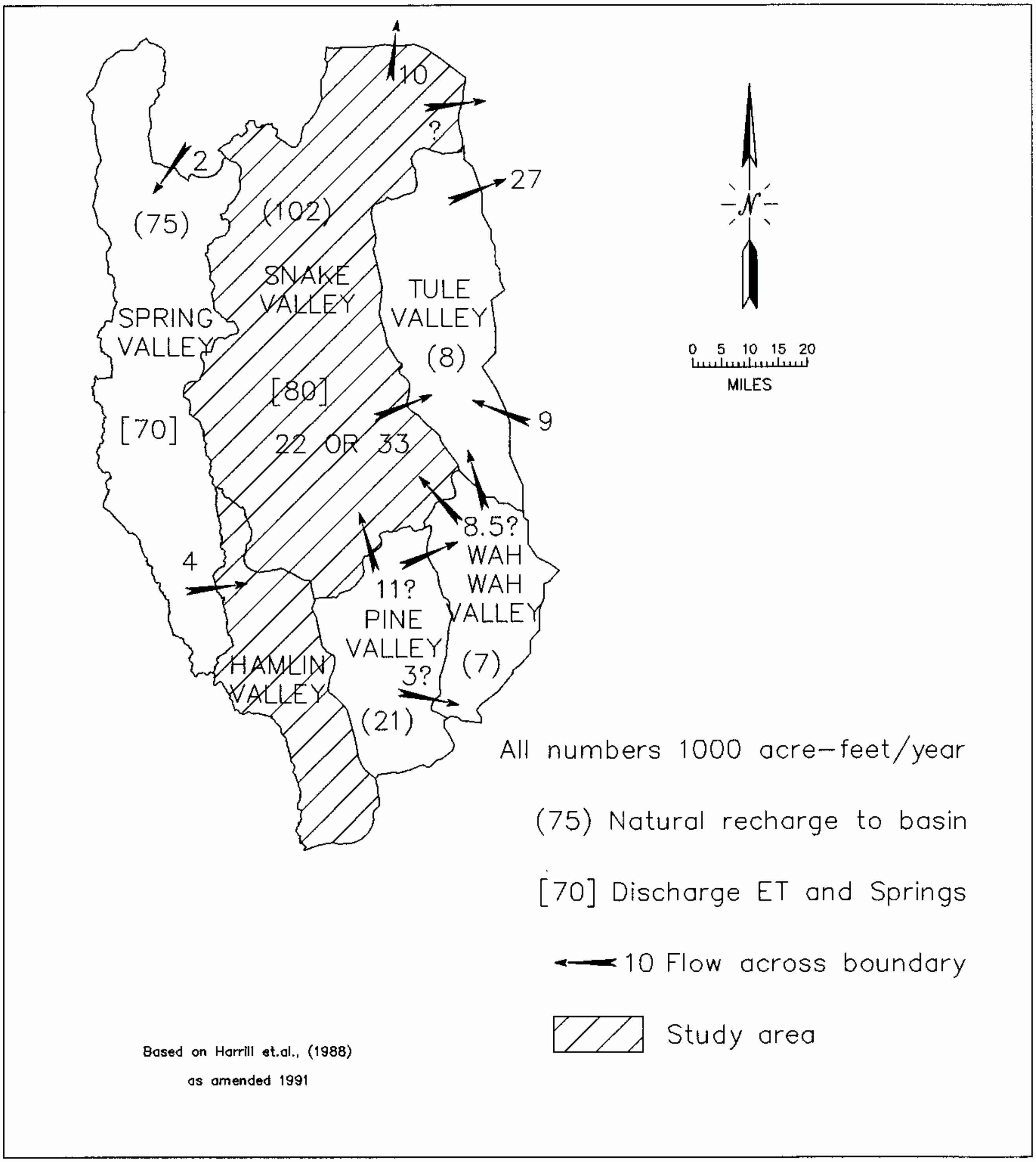


Figure 3. -- Location of Snake and Hamlin Valleys within the southwestern part of the Great Salt Lake Desert Flow System.

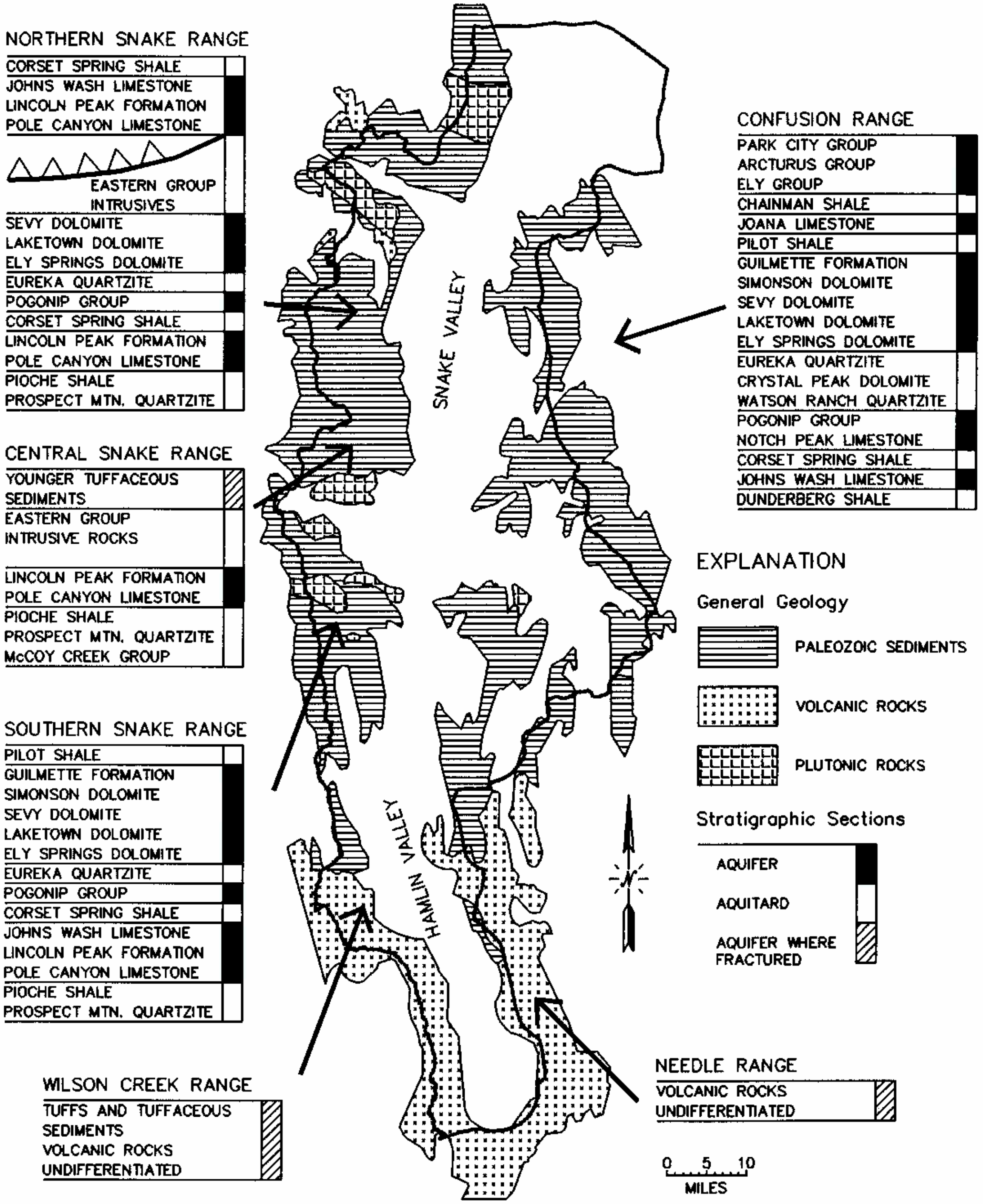


Figure 4. -- Geological and hydrogeological units in Snake and Hamlin Valleys

eastern side of the basin in the Confusion Range, the stratigraphic sequence is almost identical to that identified in east-central parts of Nevada by Ertec Western (1981). The consolidated rock units present, in descending order, include: 1) Tertiary intrusive volcanic rocks (aquitard); 2) more than 8000 feet of the Park City, Arcturus and Ely groups (aquifer); 3) about 1730 feet of the Chainman Shale (aquitard); 4) the Joanna Limestone, ranging in thickness from 10 to 300 feet (aquifer); 5) about 800 feet of Pilot Shale (aquitard); 6) a sequence of over 6000 ft comprising the Guilmette formation and the Simonson, Sevy, Laketown, and Ely Springs dolomites (aquifer); 7) the Eureka Quartzite, Crystal Peak Dolomite and Watson Ranch Quartzite with a combined thickness of 875 feet (aquitard); 8) about 5280 feet of the Pogonip Group and Notch Peak Limestone (aquifer); and 9) the Corset Spring Shale, Johns Wash Limestone and Dunderberg Shale with a total thickness of about 430 feet. These units may be underlain by the Picoche Shale, Prospect Mountain Quartzite, and clastics of Precambrian age but they have not been described in the Confusion Range.

The stratigraphy of the Snake Range is far more complex than that observed in the Confusion Range. The northern part of the range has a low angle fault complex described by Hose and Blake (1976) as "the most important single structural feature of eastern Nevada". Stewart (1980) referred to this feature as the Snake Range Thrust Fault. In the area of this decollement feature, rocks of middle and upper Cambrian age have been faulted over rocks of middle or lower Cambrian age. The lower plate has been extensively intruded by intrusive bodies but the upper plate has not. The net result of the structural activity in this area is a greatly reduced thickness of mid and late Paleozoic rocks (Ordovician and younger).

In the central part of the Snake Range an outcrop of younger tuffaceous sediments is present in the vicinity of U.S. Highway 50. These sediments overly a presumably thin sequence of Paleozoic rocks including the Lincoln Peak formation and the Pole Canyon Limestone. These units are underlain by the Pioche Shale, Prospect Mountain Quartzite, and the Precambrian quartzites and siltstones of the McCoy Creek Group. The southern third of the Snake Range is less disturbed. In this area, a sequence of Paleozoic rocks of Devonian and younger age is present that correlates with the Pilot Shale and underlying units in the Confusion Range and many areas in east-central Nevada.

The hydrostratigraphy of the mountains that bound Hamlin Valley is quite different than that of Snake Valley. The Limestone Hills, on the northwest, are a limited exposure of Silurian and Ordovician carbonates. The Wilson Creek Range and White Rock Mountains on the west, the divide to the south between Hamlin Valley and Escalante Desert, and the southern two thirds of the east-bounding Wah Wah Mountains are an extensive massif of volcanic rocks of Tertiary age. These volcanics comprise welded tuffs, basalts, and extensive rhyolites. Because of the lower transmissive capabilities of these rocks, the volcanic massif effectively isolates Hamlin Valley from adjacent valleys and forms the southwestern and southern boundary of the Great Salt Lake Desert Flow System.

For the unconsolidated sediments that overly the bedrock in the valley, two units of note are present. These units are the valley-fill deposits typical of alluvial valleys in the Great Basin and lacustrine sediments associated with Lake Bonneville. Younger and older alluvial deposits are not differentiated on either the state or county geologic maps nor are any Lake Bonneville deposits shown. However, it is likely that both younger and older alluvium are present in much of the valley and that lacustrine deposits associated with Lake Bonneville are predominantly in Utah. Limited areas of these deposits may also be present in the Baker and Hamlin Valley wash areas of Nevada as well.

Table 2 presents the available data on the hydraulic characteristics of rocks and unconsolidated sediments that are present in Snake and Hamlin Valleys. These parameters,and other features, are discussed for each modelled hydrostratigraphic unit in the following sections.

Table 2.--Summary of transmissivity and hydraulic conductivity values in southern Nevada.

Transmissivity (ft^2/day)

Aquifer	Minimum	Maximum	Median	Number of Samples	Reference
Valley Fill	321 25,920	4,478 259,200	1,470 -	7 2	Winograd and Thordarson (1975) Burbey and Prudic (1985)
Tuff/Volcanic	6.7 259	9,090 -	281 -	5 1	Winograd and Thordarson (1975) Burbey and Prudic (1985)
Carbonate	174 11 86	11,496 250,000 43,200	1,470 2,100 4,320	11 31 5	Winograd and Thordarson (1975) Unpublished USGS Data Burbey and Prudic (1985)

Hydraulic Conductivity (ft/day)

Aquifer	Minimum	Maximum	Median	Number of Samples	Reference
Valley Fill	0.02	140	74[a]	7	Plume and Carlton (1988)
Carbonate	0.01 0.02	940 1.53	5.40 0.18	38 8	Unpublished USGS Data Winograd and Thordarson (1975)
Clastic	0.006	0.10	0.02	4	Unpublished USGS Data

[a] Average value for 18 tests in 14 basins

Valley-Fill Deposits

The valley-fill aquifer is composed of alluvial-fan, fluvial, fanglomerate, lake-bed, and mudflow deposits of Quaternary (Younger Alluvium) and Tertiary (Older Alluvium) age. The Older Alluvium is typically more consolidated than the Younger Alluvium, is more highly cemented, and, where saturated, exhibits lower hydraulic properties. The grain size of these deposits decreases with distance from the source, and away from distributary channels on alluvial fans. Interbedding of fine and coarse-grained materials is common in the valley-fill deposits, which range from gravels and sand, in alluvial fans, to clay-sized material, in mudflows and playa deposits. Caliche deposits, which may impede the downward infiltration of water in the soil zone, may also be common in the valley-fill.

The younger and older alluvium are present throughout the valley floor in Snake Valley. Hose and Blake (1976) did not differentiate Younger and Older Alluvium but it is likely that Older Alluvium is present at depth below the Younger Alluvium. Based upon the available information on Older Alluvium in other Nevada basins, the older alluvium is presumed to be similar, hydraulically, to the valley-fill sediments and, for the purposes of modelling, the older and younger valley-fill may be considered as one hydrostratigraphic unit. The thickness of the valley fill in Snake Valley is appreciable; a thickness of at least 4,200 feet was verified through a petroleum exploration well drilled at T20S-R19W 19d.

The thickness of alluvium in Hamlin Valley has not been well established. According to Ertec (1980), a gravity survey in the western portion of Hamlin Valley (near the Limestone Hills) indicated a thickness of about 10,000 feet. It is considered likely that the alluvium elsewhere in Hamlin Valley is somewhat thinner as evidenced by the much narrower width of alluvium and the scattered outcroppings of volcanic rocks near the valley floor. Extensive lacustrine and sediments occur in northern and central Hamlin Valley according to Ertec (1981).

The flow of ground water through the valley-fill aquifer occurs primarily through the interstitial porosity. However, flow is controlled by the variations in the relative permeabilities of the interbedded materials. The fine-grained sediments of the Lake Bonneville deposits although not tested in Snake or Hamlin valleys, can be expected to exhibit permeabilities several orders of magnitude smaller than sand and gravel. The interbedding of fine grained and coarse-grained sediments in the valley-fill deposits results in horizontal permeabilities that are considerably greater than vertical permeabilities.

On a regional basis, the transmissivity (a measure of the ability of an aquifer to transmit ground water) of the valley-fill ranges from about 321 to about 259,200 ft^2/day according to Burbey and Prudic (1985) and Winograd and Thordarson (1975). As part of the U.S. Air Force's investigations in Snake and Hamlin Valleys, nine aquifer tests were performed for wells in the valley-fill aquifer. Based upon the results of these tests, the transmissivity of the valley-fill aquifer ranges from 58 ft^2/day to about 47,000 ft^2/day (Ertec, 1980).

The transmissivity of the alluvium in a given valley or hydrologic setting is a function of both the permeability and the saturated thickness of the aquifer. Small values of transmissivity (less than 670 ft^2/day) generally indicate fair to poor well yield potential while high transmissivity wells (greater than 6,700 ft^2/day) may be capable of producing wells yields in the hundreds or even thousands of gallons per minute.

Regionally, the hydraulic gradient (slope of the surface of the ground water) in the valley-fill aquifer is often less than 60 ft/mi, and is usually less than 30 ft/mi (Winograd and Thordarson, 1975). Because of the distribution of wells in Snake and Hamlin Valleys, the calculation of gradients must be based upon widely separated wells and the inferred water surface between the wells. These calculations indicate that the gradient in the valley is variable with gradients of about 40 ft/mi in the southern part of the basin and about 14 ft/mi in the northern part of the basin.

Consolidated Rock

The regional carbonate aquifer in Snake Valley consists of thick sequences of Paleozoic limestones and dolomites, although not as thick as elsewhere in the carbonate province of the Great Basin. This unit comprises the numerous individual rock units that were previously discussed, and has an overall thickness of several thousand feet. Flow through the carbonate aquifer is believed to occur primarily through fractures, and is likely to be concentrated in areas of greater fracture frequency. Except in areas of structural or stratigraphic anomalies, the hydraulic gradient in this aquifer is likely to be small because of high transmissivity.

The movement of ground water across the contact between the valley-fill aquifer and the carbonate aquifer depends on the potentiometric heads (elevation of the water table or piezometric surface) in each aquifer. In areas where the head is higher in the valley-fill, the ground water moves principally downward into the underlying carbonate, serving to recharge the regional carbonate aquifer. Where the head in the carbonate aquifer is higher than the valley-fill, ground water in the overlying alluvial material is, in part, derived through upward leakage of water from the carbonate rocks.

The carbonate aquifer presumably underlies the alluvial deposits under most of Snake Valley. This aquifer, because the complex geology of the Snake Range (relative to the Confusion Range) may comprise one or more of the individual aquifers identified by Winograd and Thordarson (1975) for areas in southern Nevada. In most of Snake Valley east of the Snake Range Thrust Fault, these units form a continuous vertical sequence and, for the purposes of modelling, can be considered as a single hydrostratigraphic unit.

In the nearby valleys, the transmissivity of the carbonate aquifer has been found to range from 11 to 250,000 ft^2/day (Winograd and Thordarson (1975); Burbey and Prudic (1985); and unpublished USGS data), with values as high as several hundred thousand ft^2/day possible in fractured areas (Winograd, 1963; Winograd and Thordarson, 1975). Variations in structural setting, proximity to faults, mechanical rock properties, depositional environment, and aquifer thickness are the chief parameters that account for the large variations in the transmissivity of carbonates.

In general, it is inferred that the transmissivity of the carbonate aquifer in Snake Valley is variable with the highest transmissivities occurring in the vicinity of major structural elements such as north-south trending normal faults typical of the Great Basin. In these areas, dissolution of the carbonates results in high secondary porosities and very high transmissivities. Hood and Rush (1965) noted the presence of karst features in the Eskdale area and extensive caverns are present at Lehman Caves. In the relatively undisturbed areas between such structural features the transmissivities are probably appreciably lower because of the inferred lesser degree of development of secondary porosity.

Structural Features

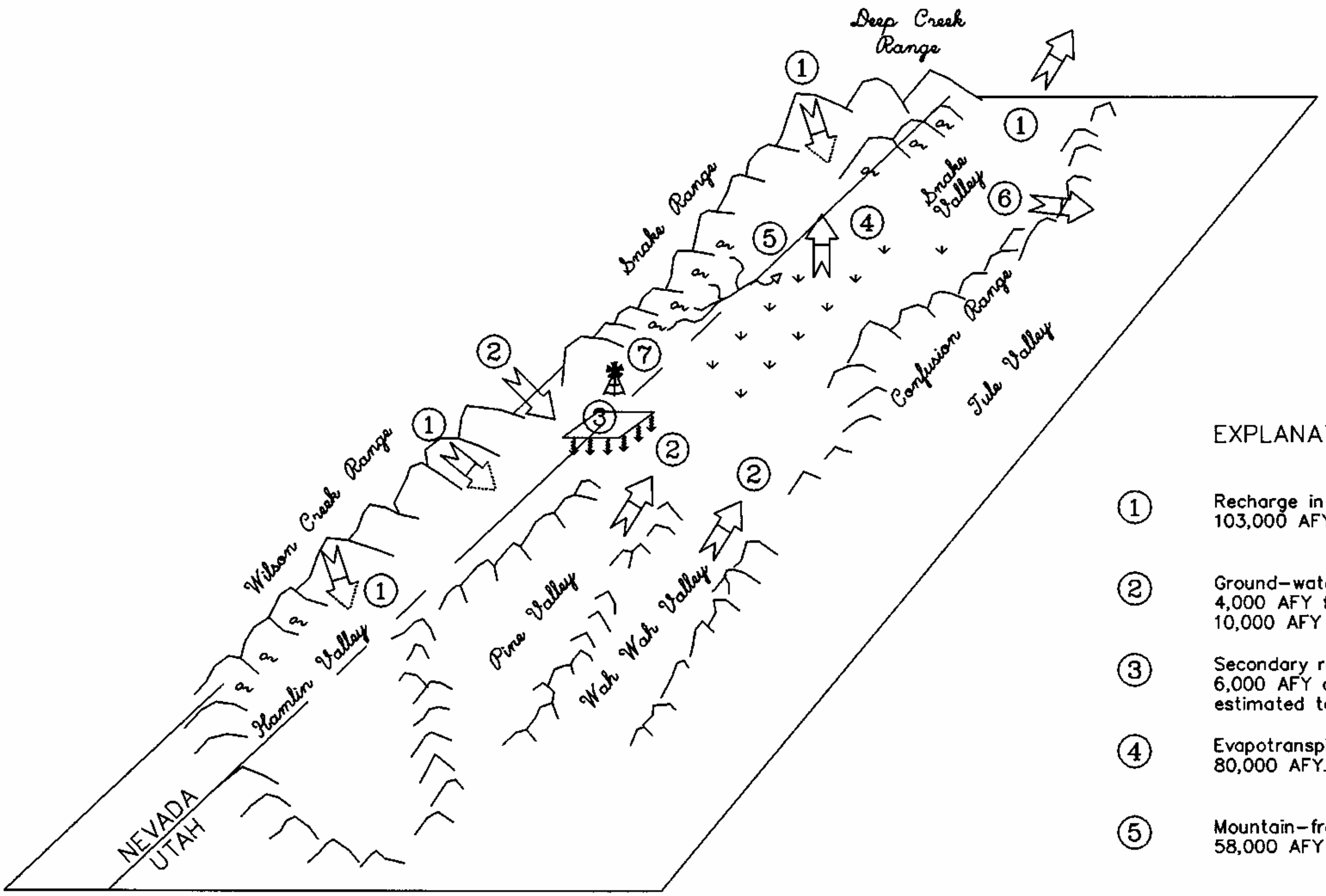
Structures within Snake and Hamlin Valleys are generally consistent with features typical of the Basin and Range Province (i.e., horst and graben structures oriented along north and northeast-trending normal faults). The Basin and Range is dominated by north-south trending fault scarps and lineaments that cut through the alluvium (Tschanz and Pampeyan, 1970). Several periods of regional tectonism have faulted, fractured, and displaced both bedrock and valley-fill materials.

In addition to the Basin and Range style normal faulting, thrust faulting has occurred that likely has a significance with respect to the occurrence and flow of ground water. The Snake Range Thrust Fault, as previously discussed, is a significant geologic structure in this area of Nevada. This feature has resulted in a reduced thickness of carbonate rocks relative to other areas within the region, and presumably, a correspondingly lower transmissivity for the carbonate aquifer.

WATER RESOURCES APPRAISAL

To develop a steady-state ground-water flow model that is representative of the hydrogeologic system of Snake and Hamlin Valleys, it is necessary to define the magnitude of the water resources available in the basins and the basins' development history. Knowledge of the location and magnitude of planned future development is necessary when using the transient model for predictive purposes. The following sections present the available information on the surface and ground-water resources of the valleys.

Figure 5 shows a conceptualization of the overall hydrologic system of Snake and Hamlin Valleys. Each of the major components of the water budget for the basins are discussed in detail in the following sections. It should be noted that although there are numerous wells in these two basins, detailed hydrogeologic studies have not been conducted. Therefore, the development of the conceptual model of the two valleys must rely in part, upon inference based upon the data that are available and analogy to other basins in eastern and southern Nevada that share similar characteristics.



EXPLANATION

① Recharge in upland areas
103,000 AFY

② Ground-water inflow:
4,000 AFY from Spring Valley;
10,000 AFY from Pine and Wah Wah Valleys.

③ Secondary recharge
6,000 AFY of which 2,000 AFY is
estimated to be from ground water.

④ Evapotranspiration
80,000 AFY.

⑤ Mountain-front runoff to valley
58,000 AFY

⑥ Ground-water outflow
10,000 AF to Great Salt Lake Desert
22,000 to 33,000 AFY to Tule Valley

⑦ Permited consumptive ground-
water rights in Snake Valley, Nevada
6,200 AFY

Figure 5. -- Schematic diagram of the water budget for Snake Valley

Surface Water

An accurate simulation of a hydrogeologic system requires an understanding of the surface water conditions and the significance of surface water in the overall water budget for a given hydrographic basin. This section describes the general conditions of the surface water regime of Snake Valley and Hamlin Valley.

General Conditions

Unlike many of the arid basins of eastern and southern Nevada, there are significant surface water resources in Snake and Hamlin Valleys. Hood and Rush (1965) note that there are 14 perennial streams in the basins. Of these, only two, Big Spring Creek and Warm Creek are spring fed; the remainder all have their headwaters high on the east slopes of the Snake Range. Big Wash, Snake, Baker, and Lehman Creeks all drain the eastern slopes of the Snake Range and flow into Snake Valley. Further to the north, Birch, Trout, Granite, Cedar, Thomas, and Basin Creeks drain the southern and eastern slopes of the Deep Creek Range and all flow into Snake Valley.

Surface water flows are derived from snowmelt over the mountain areas, spring discharges, and runoff from winter and summer rainfall events. Numerous springs in the Deep Creek Range, Kern Mountains, Snake Range, Wilson Creek Range, and White Rock Mountains contribute to surface water flows along short reaches of their drainages. Peak discharges along these streams typically occur in the late spring of each year when the spring discharge is augmented by snowmelt. Elsewhere in the basin, most drainages are dry except for ephemeral flow during precipitation events over individual watersheds.

On a basin wide basis, surface water drains from Snake and Hamlin Valleys to the north toward the Great Salt Lake Desert. There are numerous surface water impoundments in these valleys including Baker Reservoir and Silver Creek Reservoir in Nevada and Pruess Lake, Probst Pond, Hole-in-the-Wall Reservoir, Mile Pond, Mud Lake Reservoir, and Roadside Reservoir in Utah, along with numerous unnamed ponds and reservoirs.

Mountain Front Runoff

As part of the USGS hydrologic budgets, the amount of mountain front runoff, or the volume of surface water flowing past the alluvial-bedrock contacts, were estimated for the majority of hydrographic basins. As stated previously and shown in Figure 5, the quantity of runoff from the mountains bounding Snake and Hamlin Valleys total about 58,000 acre feet per year according to Hood and Rush (1965). Of this total, 7,000 acre feet per year is contributed by Hamlin Valley and 50,000 acre feet per year is from the west bounding mountains of Snake Valley. Only an estimated 1,000 acre feet per year is derived from the eastern bounding mountains in Utah according to these investigators. Scott, et al. (1971) estimated that a total of 38,000 acre feet per year of runoff originates in the Nevada part of Snake and Hamlin Valleys and discharges into the Utah part of Snake Valley.

For hydrographic basins where there is significant mountain front runoff, the role of the surface-water component in terms of the calculation of ground-water recharge is unclear. The Maxey-Eakin method (Eakin et al., 1951) was developed using a total of 21 hydrographic basins in eastern and central Nevada (Avon and Durbin, 1992). Many of these valleys do not have a significant surface-water component with most streams being ephemeral, and in many cases percolating into the alluvial fan shortly after exiting the mountain block. Mountain front runoff in valleys in the Great Basin must either recharge the ground-water system or evapotranspire. Does the Maxey-Eakin method account for, in cases where there is significant mountain front runoff, this water recharging in the central part of the valley; does an appreciable amount enter the alluvial system (i.e. the ground water) from the stream channels; is this water rejected ground-water recharge?

Of interest, is the Spring Valley reconnaissance report (Rush and Kazmi, 1965) and the discussion regarding the mountain-front runoff. On page 18, of this report it is stated,

> "During the non growing season over 200 days per year, much of the streamflow of the valley runs to waste. Some of the water flows to the playas and is evaporated, but a large portion seeps into the ground and recharges the ground-water reservoir."

On page 25, the hydrologic components for Spring Valley are listed as,

> "The estimate of ground-water recharge includes (1) recharge by seepage loss from streams both in the mountains and on the alluvial apron and subsurface inflow from the mountains to the alluvium (65,000 acre-feet); and (2) deep infiltration of precipitation on the higher parts of the alluvial apron (10,000 acre-feet). The estimated runoff from the mountains, or at the bedrock-alluvium contact, represents the surface-water inflow to the valley (90,000 acre-feet). As mentioned above, part seeps into the alluvium and part is diverted for irrigation. The remainder, termed rejected recharge, flows into the playas and is lost by evaporation."

Also of interest, is the estimate of ground-water recharge for Skull Valley Utah (Hood and Waddell, 1968). Three methods were used to calculate ground-water recharge, one was the Maxey-Eakin method (Eakin et al., 1951), one was a method by Gates (1963,1965) which estimates the volume of ground-water recharge by deducting the estimated evapotranspiration losses from the precipitation areas in and above the recharge areas, and the other method was based on the water losses in stream channels that cross the recharge area. The Eakin method resulted in a annual ground-water recharge rate of 32,000 acre-feet per year and the other methods resulted in ranges of values of 37,000 to 53,000 and 34,000 to 52,000 acre-feet per year, respectively. In the Gates method (Gates 1963,1965) the range was based on variations in the assumed losses by evaporation, and in the method considering stream losses the range was generated by different assumptions for duration of the major spring runoff season. Regardless, it appears the Maxey-Eakin method is conservative in estimating the amount of water entering the ground-water system.

For the purposes of this report and the computer modeling of the ground-water system, to be conservative, it was assumed that any recharge from mountain front runoff was included in the Maxey Eakin estimate of recharge. It was also assumed that all evapotranspiration was satisfied from the ground-water component and the springflow or drain outflows. Therefore, in Figure 5, the mountain front runoff to the valley is shown because it is part of the complete hydrologic budget presented by Hood and Rush (1965), but is not considered in addition to the estimated ground-water recharge as calculated by the Maxey-Eakin method (Eakin et al., 1951).

Available Records

Data concerning the discharge rates for these streams are available but limited. Hood and Rush (1965) give discharge measurements or estimates for Big Spring (8 cfs), Warm Springs (8 cfs), Baker Creek at Narrows near Baker (3.87 to 19.6 cfs), Lehman Creek near Baker (3.67 to 19.6 cfs), and Trout Creek near Callao, Utah (1.75 to 6.25 cfs). Figure 6 shows the monthly maximums, minimums, and averages of Lehman Creek near Baker for the period of record, 1948 to 1955. This figure illustrates the seasonal variability of surface flows with the peak flows occurring during the late spring and summer resulting from snowmelt. Measurements were taken at six stream locations in Snake Valley and five stream locations in Hamlin Valley in 1979 as part of the MX Water Resources Investigations (Bunch and Harrill, 1974). These measurements were made in July and August and ranged between about 1 and 10 cfs.

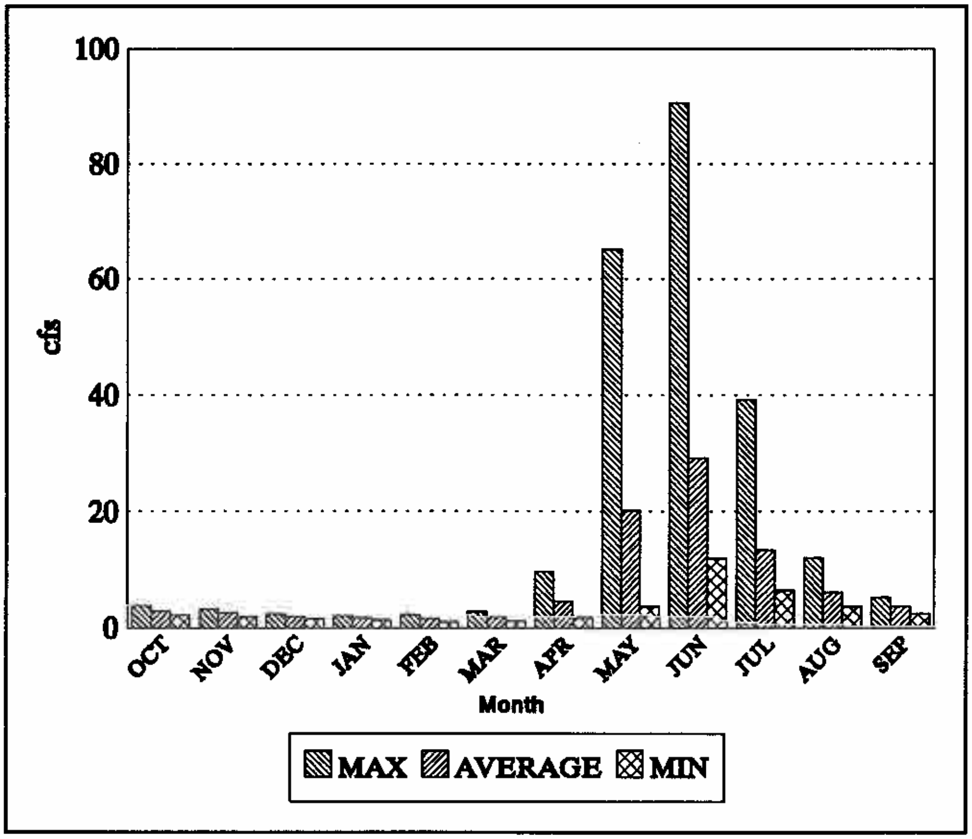


Figure 6.--Select streamflow characteristics for Lehman Creek near Baker, Nevada for the water years 1948-1955.

There are no discharge data for the numerous ephemeral washes throughout Snake and Hamlin Valley. These washes flow in response to the infrequent precipitation over the drainage area. Nevertheless, these are estimates for the total mountain front runoff in Snake and Hamlin Valleys.

Ground Water

It is necessary to understand the conditions and characteristics of the ground water in Snake and Hamlin Valleys to develop an accurate numerical simulation. This section discusses the ground-water occurrence, source, movement, chemical quality, and ground-water budget for these two basins.

Occurrence

Ground water occurs in Snake Valley at depths ranging from above land surface at flowing wells in the Callao, Utah area, at land surface at the many springs discharging in the basin, to more than 200 feet below land surface in some wells. In Hamlin Valley, the depths to water are similar, ranging from above land surface at flowing wells in the Baker Ranch and Mt. Wheeler Ranch areas to more than 400 feet below land surface in the western part of the basin. As stated previously, there are over 250 wells in Snake and Hamlin Valleys and 104 were chosen to areally represent depths to ground water, as shown in Table 1. This water level data was evaluated with spring locations and ten of these wells were deleted because they were flowing or representative of high localized flow systems. Based on this analyses water level data was narrowed to the 94 wells used to produce a potentiometric map as shown in Figure 7. These wells are thought to be the best areal representation of water levels in Snake and Hamlin Valleys considering land surface elevations and well completion depths.

As shown, a significant ground-water mound exists along the entire western portion of Snake and Hamlin Valleys reflecting the significant amounts of recharge that occur in the mountain areas. The elevation of the potentiometric surface ranges from about 6,300 feet AMSL in the highest portions of the mountains to about 5,500 feet AMSL near the contact with the valley-fill deposits. In the valley floor area the potentiometric surface ranges from about 6,000 feet AMSL in the southern portion of Hamlin Valley to less than 4,400 feet AMSL at the northern end of Snake Valley.

Figures 8 and 9 show a total of seven hydrographs for wells in Snake Valley of which six are listed in Table 1. Six of these wells show very little long-term variations in the water levels, with one showing an apparent decline of 40 feet that occurred sometime between 1965 and 1978. However, the water level has increased slightly between 1978 and 1991. The lack of long-term declines in the static water levels, common in the nearby Escalante Desert and Sevier Desert basins, suggests that ground-water withdrawals within the basins are well below the perennial yield.

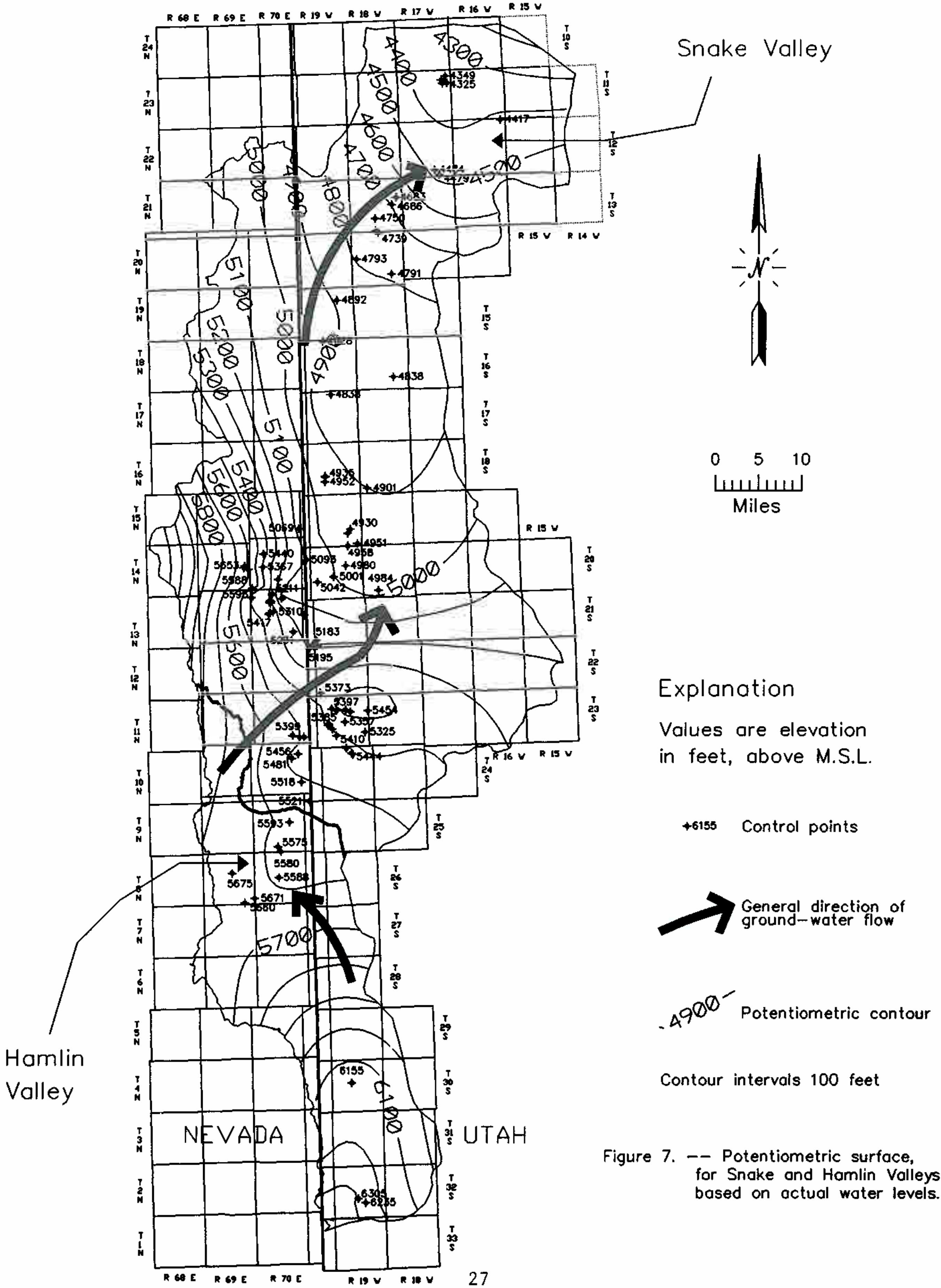


Figure 7. -- Potentiometric surface, for Snake and Hamlin Valleys, based on actual water levels.

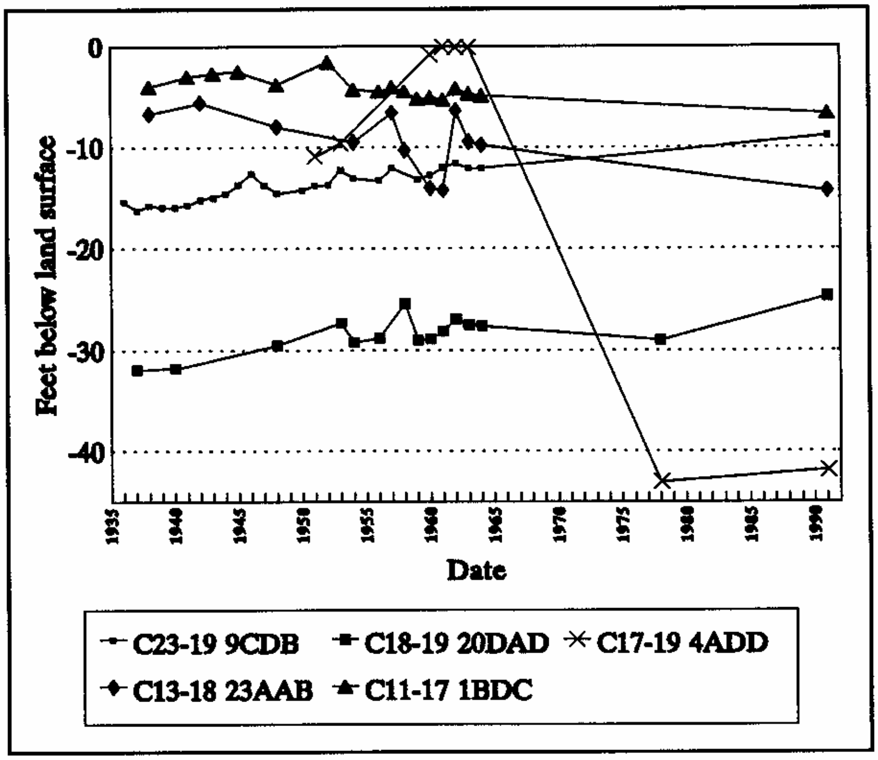


Figure 8.--Hydrographs of five wells in Snake Valley.

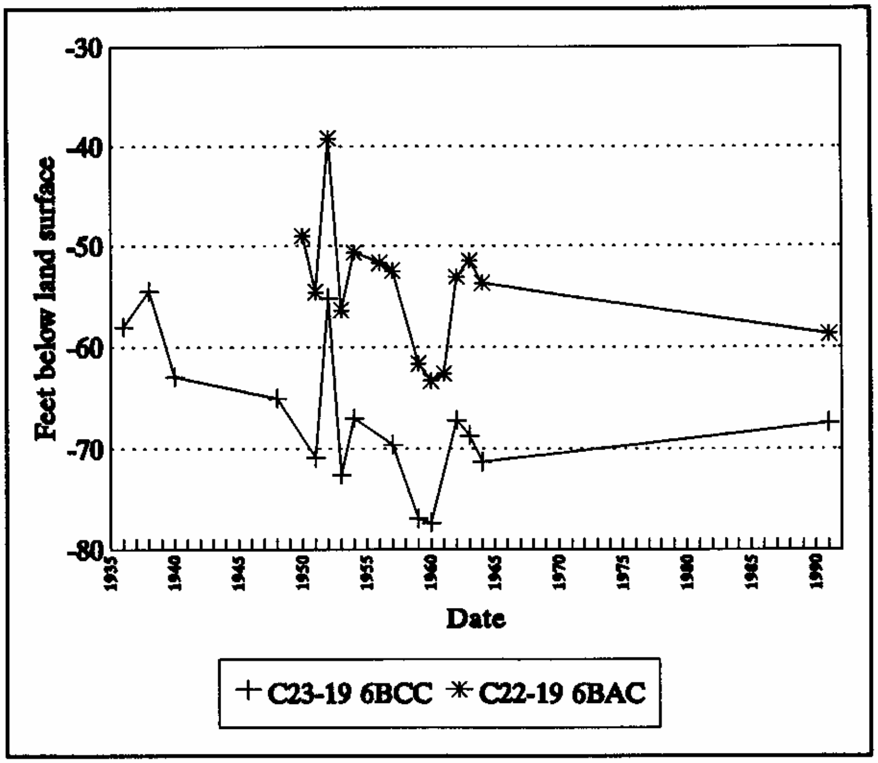


Figure 9.--Hydrographs of two wells in Snake Valley.

No head elevation data are available for wells completed in the carbonate aquifer in Snake Valley. Because of the short flow distances from the recharge areas in carbonate terrane, the relatively thin thickness of carbonates, and the existence of a major regional recharge area along the western portions of the basin, it is believed that the heads in the carbonate aquifer are likely to be the same or close to those observed in the valley-fill aquifer. That there are numerous flowing wells in Snake Valley suggests that there is a strong upward hydraulic gradient. Because of the steep slope of the potentiometric surface on the western flanks of the two basins, this upward gradient is to be expected and is not believed to be an indication of major head differentials between the two aquifers. This inference is supported by the findings of Hood and Rush (1965) who found that the flowing wells were, in some cases, as shallow as 90 feet.

Source

The source of ground water within Snake and Hamlin Valleys is primarily from recharge of precipitation over the western bounding mountain ranges with lesser quantities derived from the eastern bounding mountains and subsurface flow from adjacent basins. As noted previously, about 4,000 acre feet per year enters northern Hamlin Valley from Spring Valley and Pine and Wah Wah valleys in Utah contribute an estimated approximate 9,800 acre feet per year of underflow to eastern Snake Valley.

Movement

Flow from the major recharge area on the west side of Snake and Hamlin Valleys is from the west to the east, toward Utah. In the valley floor area, flow is primarily to the north toward the Great Salt Lake Desert. Data are generally lacking for the eastern flanks of the basins and the eastern bounding mountain ranges, however, it is inferred that a western component of flow predominates in these areas.

Chemical Water Quality

The chemical quality of the ground water in Nevada depends on its location. The chemical concentration in recharge areas is normally very low; however, the ground water comes into contact with soluble rock materials for long periods of time as it moves towards discharge areas where the chemical concentration is higher. The solubility, volume, distribution of rock materials, time of water contact with the rocks, temperature, and pressure in the ground-water system are factors that determine the extent to which the chemical constituents from the rock materials will be dissolved.

Hood and Rush (1965) present the results of chemical analyses for 22 locations in Snake and Hamlin Valleys. These analyses exhibit the expected trend of fresh water in the recharge areas and water with higher total dissolved solids (TDS) in the lowland areas. The occurrence of higher TDS is probably due primarily to the natural concentration of salts in the extensive areas of shallow ground water. In these areas, the evaporation of shallow ground water and evapotranspiration results in increased levels of TDS.

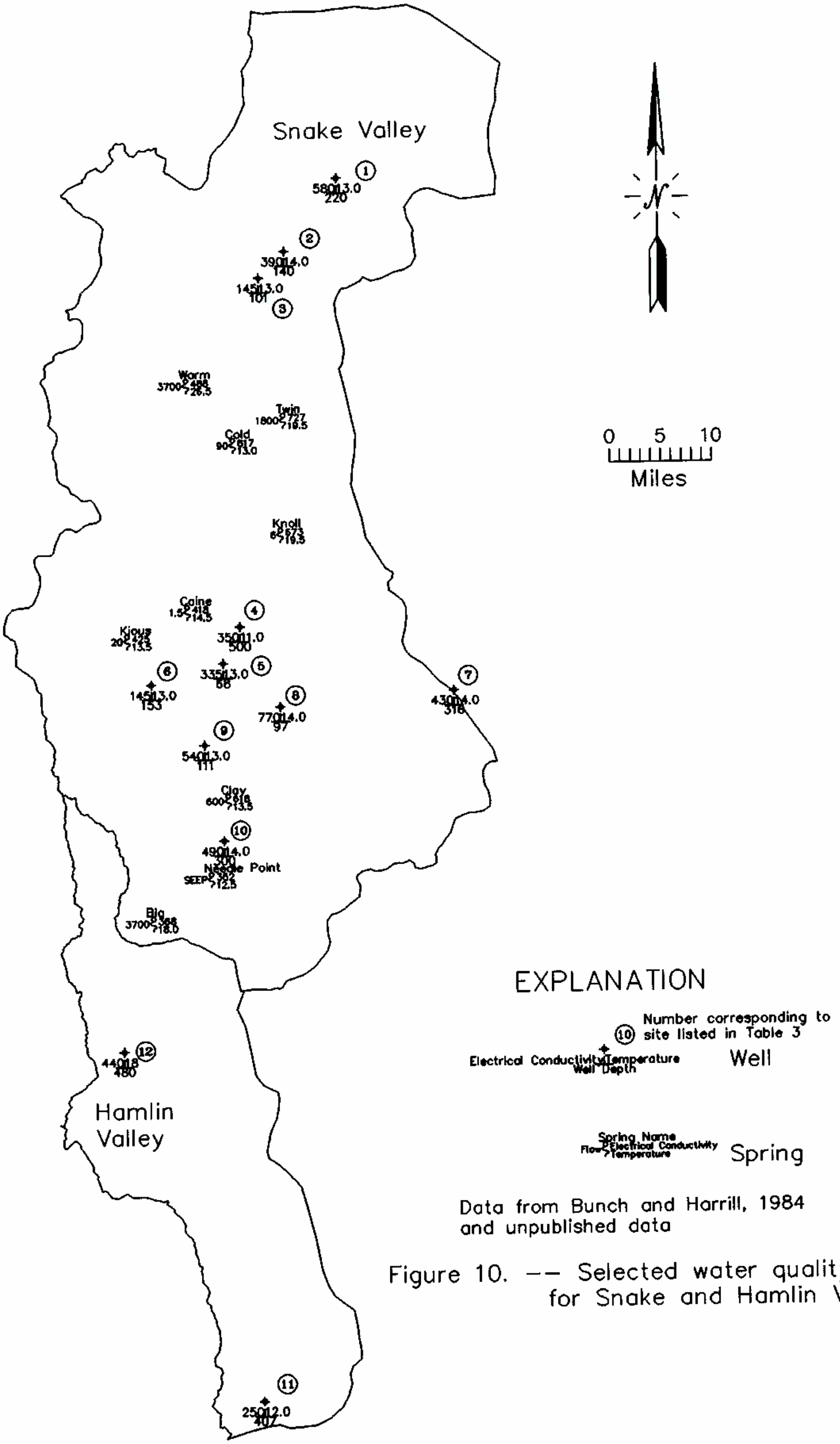
There are three major springs that dominate springflow in the valley. These are Warm Springs with a flow of about 3700 gpm and a temperature of 26.5 °C, Big Springs with flow of 3700 gpm and a temperature of 18 °C, and Twin Springs with a flow of about 1800 gpm and a temperature of 19.5 °C. Figure 10 shows location, flow, temperature, and electrical conductivity (EC) of these springs and other springs in Snake Valley, as well as temperature, EC, and depth of selected well water quality.

The ratios of the Na+K and SO_4+Cl for these three major springs were plotted on a logarithmic graph (modified from Mifflin, 1968) to investigate the regional nature of these springs as shown in Figure 11. Included in the plot are Big, Kious, Knoll, Twin, and Warm Springs which are located in Snake Valley. Kious and Big Springs were sampled as part of a reconnaissance study in October of 1991 by the District and the Desert Research Institute (DRI). Chemistry data for the other springs are found in Hood and Rush (1965) and Bunch and Harrill (1984). Table 3 lists all the chemistry data for the springs and the selected wells shown in Figure 10 and also lists the source.

Mifflin (1968) created a graph of a number of springs located in Nevada in the carbonate terrane, classifying local or regional flowpaths based on chemistry. As this modified graph shows in Figure 11, Warm, Twin, Knoll, and Kious Springs are classified as regional springs considering only the Na+K and Cl+SO_4 ratios, however with evaluating the location, temperature, elevation, and discharge Kious and Knoll are local springs. The graph originally created by Mifflin (1968) was designed to aid in characterizing springs with larger flows than Kious and Knoll. The location of Kious and Knoll on the plot helps point out the necessity of evaluating other aspects of the spring when trying to define flow paths. However, Warm and Twin Springs could be a part of a regional flow system with water coming from Pine and/or Wah Wah Valleys or could also be from the Snake Range to the west. The temperature of Warm Spring indicates a circulating depth of 3,000 to 3,500 feet while the temperatures of Twin and Knoll Springs indicate shallower flow paths. These springs are located in the northern part of Snake Valley a significant distance from any of the proposed District withdrawals.

On the basis of the ion ratios, it appears that the other major spring, Big Spring, is definitely a local spring although it has a slight thermal component. This slightly elevated temperature indicates that, while the spring is part of the basin hydrologic cycle, it also has some component coming from some depth and appears to be brought to the surface by a northeast trending fault structure. The proposed District points of diversion are to the north and east of Big Springs and all would be considered downgradient; therefore, withdrawals should not impact spring flow.

All water quality samples from springs and wells meet the Safe Drinking Water Standards for total dissolved solids and therefore would require little treatment before being used as a potable supply.



Data from Bunch and Harrill, 1984
and unpublished data

Figure 10. –– Selected water quality data for Snake and Hamlin Valleys.

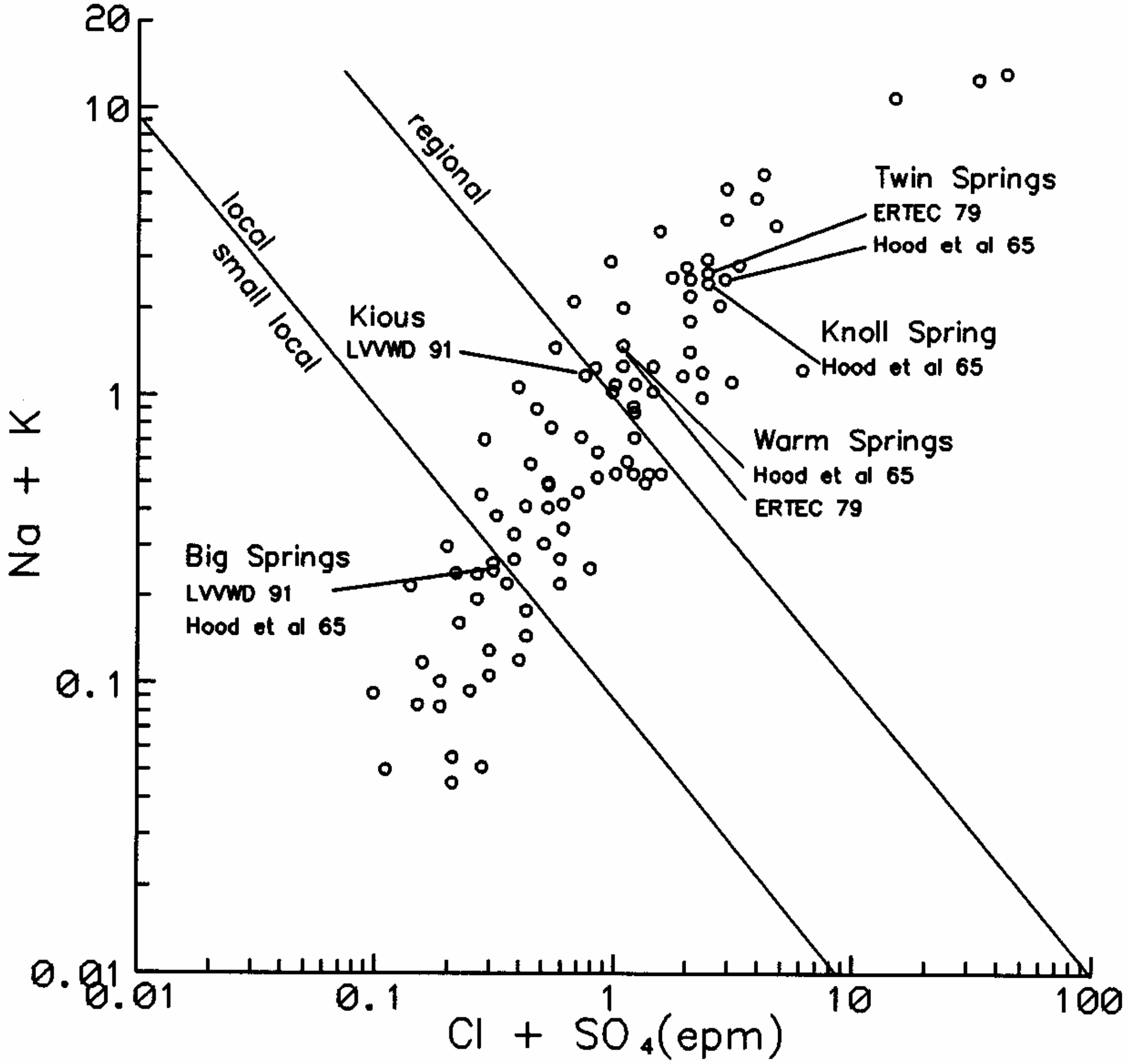


Figure 11.--Plot of the relation between water chemistry and spring classification (modified after Mifflin, 1968)

Table 3.--Chemistry from select wells and springs in Snake and Hamlin Valleys, Nevada and Utah. Values are in mg/l unless otherwise noted.

SAMPLE POINT	EC μmhos/cm	FLOW GPM	pH	TEMP o C	SiO_2	Ca	Mg	Na	K	HCO_3 mg/L	Cl	SO_4	F	N	SOURCE
WARM SPRING	488	—	8.0	26.5	—	50.2	17.1	—	—	203	—	—	—	—	LVVWD 91
	520	—	8.1	26.0	29	51.0	18.0	29.0	3.7	138	24	26	0.5	0.2	ERTEC 79
	505	3600	7.8	27.2	—	50.0	19.0	33.0	—	250	24	24	0.8	2.7	HOOD ET AL 65
TWIN SPRING	520	—	6.8	20.0	21	61.0	30.0	60.0	5.8	297	50	58	0.5	0.6	ERTEC 79
	739	—	7.6	20.0	—	62.0	31.0	61.0	—	312	63	66	—	0.2	HOOD ET AL 65
	727	1800*	7.6	19.5	—	61.3	28.6	—	—	247	—	—	—	—	LVVWD 91
KNOLL SPRING	688	3	7.6	19.4	—	63.0	28.0	57.0	—	317	52	58	—	0.3	HOOD ET AL 65
	673	6	7.5	19.5	—	—	—	—	—	245	—	—	—	—	LVVWD 91
BIG SPRING	401	—	7.8	17.8	—	47.0	20.0	5.9	—	238	3.7	8	0.2	2.2	HOOD ET AL 65
	368	3700	7.7	18.0	—	46.6	19.9	5.5	1.5	244	5.1	7.3	0.15	1.6	LVVWD 91
KIOUS SPRING	425	20	7.5	13.0	—	52.8	7.7	27.2	1.6	198	34	13.8	0.7	2.8	LVVWD 91
CAINE SPRING	418	2	7.8	14.5	—	42.5	17.2	—	—	148	—	—	—	—	LVVWD 91
CLAY SPRING	618	600	7.6	13.5	—	69.7	36.3	—	—	207	—	—	—	—	LVVWD 91
COLD SPRING	817	90	7.6	13.0	—	61.3	21.5	—	—	290	—	—	—	—	LVVWD 91
NEEDLE POINT SPRING	352	SEEP	8.1	12.5	—	29.1	15.4	—	—	111	—	—	—	—	LVVWD 91
WELL 1	580		7.9	13.0	36	47.0	29.0	77.0	4.3	163	75	50	0.5	0.5	ERTEC 79
WELL 2	390		8.2	14.0	35	32.0	20.0	42.0	3.5	233	21	28	0.4	0.3	ERTEC 79
WELL 3	145		8.2	13.0	21	33.0	9.2	20.0	1.8	112	42	19	—	1.1	ERTEC 79
WELL 4	370		—	11.0	31	49.0	22.0	23.0	2.5	238	31	28	0.3	0.1	ERTEC 79
WELL 5	335		7.7	13.0	17	36.0	1.3	21.0	3.2	166	26	32	0.2	0.5	ERTEC 79
WELL 6	145		6.5	13.0	15	20.0	3.1	4.4	0.6	87	13	155	1.9	0.3	ERTEC 79
WELL 7	430		7.4	14.0	30	35.0	33.0	50.0	6.9	191	68	116	2.2	0.2	ERTEC 79
WELL 8	770		7.1	14.0	1.2	60.0	50.0	34.0	3.1	156	18	170	1.6	0.6	ERTEC 79
WELL 9	540		6.8	13.0	18	79.0	3.0	15.0	1.8	388	12	21	0.1	3.6	ERTEC 79
WELL 10	490		7.6	14.0	40	51.0	31.0	35.0	2.1	219	2.5	8	0.1	0.2	ERTEC 79
WELL 11	250		—	12.0	34	35.0	6.4	13.0	2.4	146	11	9	0.2	1.4	ERTEC 79
WELL 12	440		7.8	18.0	—	38.0	1.6	—	—	192	21	36	—	—	HOOD ET AL 65

Ground-Water Budget

A ground-water budget consists of a complete accounting of all components of inflow and outflow for a hydrographic basin. The results of any model developed to simulate flow in a basin are dependent upon the accuracy of the budget. Table 4 summarizes the water budget for Snake and Hamlin Valleys. The following sections present the current estimates for recharge and discharge for these basins.

Table 4.--Ground-water budget for Snake and Hamlin Valleys.

		Published Value Acre-feet/year (rounded)
RECHARGE		
Recharge from precipitation		103,000
Subsurface Inflow		14,000
Secondary Recharge*		6,000
	TOTAL	123,000
DISCHARGE		
Evapotranspiration		80,000
Pumpage* (consumptive)		6,000
Outflow		32,000 - 43,000
	TOTAL	118,000 - 129,000

Source: Hood and Rush (1965), Harrill et al. (1988)
* not considered in steady state model

Estimated Average Annual Recharge

Recharge to a basin usually consists of several components: precipitation, subsurface inflow, and secondary recharge. Estimates for these elements for Snake and Hamlin Valleys are provided in the following sections.

Precipitation

The primary source of recharge to the hydrologic system of Snake and Hamlin Valleys is the infiltration of precipitation over the basins. Hood and Rush (1965) present summary precipitation data for a number of stations in, and adjacent to, the two valleys. Precipitation in the area ranges from about 14 inches per year at Wilson Creek Summit of less than five inches per year at Callao, Utah. Significantly greater precipitation is probable at higher elevations in the Deep Creek, Snake, and Wilson Creek ranges. Hood and Rush (1965) estimated that 2 million acre feet of precipitation fall over Snake and Hamlin Valleys annually. The total precipitation over the Nevada portion of Snake Valley is 624,000 acre-feet per year (including the 54,000 acre feet per year that fall on the Pleasant Valley portion of Snake Valley) while 260,000 acre feet per year occur over the Nevada portions of Hamlin Valley (Scott, et al., 1971). The volume of recharge derived from precipitation is reported by these same authors to be 100,000 acre-feet per year, or about 5 percent of the precipitation. Harrill, et al. (1988) reported the recharge from precipitation in Snake and Hamlin Valleys to be 102,000 acre-feet per year, whle Hood and Rush (1965) reported it to be 103,000 acre-feet per year.

The infiltration of precipitation does not occur evenly over a large area. Rather, as determined by Maxey and Eakin (1949) and Quiring (1965), the distribution of precipitation, and hence, infiltration and recharge, in the desert valleys of Nevada, is primarily a function of elevation and latitude.

Thus, for the purposes of developing a ground-water flow model of Snake Valley, recharge is distributed according to the zones summarized in Table 5.

Table 5.--Recharge distribution zones for Snake and Hamlin Valleys, Hood and Rush (1965).

ELEVATION Feet Above Sea Level	PRECIPITATION ZONE Inches / Year		APPROX. AREA Acres	PRECIPITATION Acre-feet/year	RECHARGE RATE Percentage	RECHARGE FLUX acre-feet/year (rounded)
>9,000	>18	20	83,900	140,000	21	29,200
8,000-9,000	16-18	17	127,000	180,000	14	25,200
7,000-8,000	13-16	14.5	240,000	29,000	8	23,200
6,000-7,000	11-13	12	601,000	331,000	5 Snake	16,600
				270,000	1 Hamlin	2,700
5,000-6,000	8-11	9.5	767,000	606,000	1	6,100
below 5,000	<8	6	412,000	206,000	0	0
				2,000,000	Total (rounded)	103,000

Ground-Water Inflow

The inflow of ground water to Snake and Hamlin Valleys from upgradient basins is not appreciable, totalling only about 14,000 acre feet per year or about 13 percent of the recharge contributed by precipitation. As discussed previously, this inflow is from Spring Valley in Nevada and Pine and Wah Wah Valleys in Utah.

Secondary Recharge

As stated above, there are a number of perennial streams that provide surface water for irrigation. A number of the irrigation wells are used just to supplement surface-water flows in the late summer after the peak runoff season. Also many grassed wetland areas that are fed by surface runoff or spring flows are used for livestock grazing. Satellite data were used to evaluate vegetation coverages and irrigated areas as discussed in more detail below. Using this data the District estimated that in 1990 there were approximately 17,000 acres of wetland and agricultural lands in the area evaluated in Snake Valley (southern and central part of the valley). Of these it is estimated that about 6000 acres are in crop irrigation, probably most of this is irrigated with surface water. However, if conservatively estimated that each acre receives 4 feet per year from either surface or ground water (a total of 24,000 acre-feet per year) and 25 percent of that returns, then secondary recharge could be estimated at least at 6,000 acre-feet per year. Of the total water used for irrigation, one-third (8,000 acre-feet per year) is assumed to be ground water, therefore again assuming a 25 percent return, secondary recharge of ground water would be about 2,000 acre-feet per year. Because the steady state model considers the ground-water budget components only secondary recharge was not estimated since the ground-water component is fairly small and water levels have not declined appreciably in Snake Valley.

Estimated Average Annual Discharge

Components of discharge include evapotranspiration (ET), springs, well pumpage, and subsurface outflow. Estimates of the quantity of these components are included in the following sections.

Evapotranspiration

Evapotranspiration includes transpiration by wetlands and native phreatophytes and evaporation from bare soil and playa areas where the ground-water table is within a certain depth (usually 15-30 feet) below land surface. Because of the relatively shallow depths to the water table, and the presence of expansive areas of native phreatophytes in Snake Valley, ET is a major source of ground-water discharge from the valley. Satellite imagery in conjunction with field reconnaissance were used to estimate the vegetation covers in Snake Valley and compare them with the estimates made by Hood and Rush (1965). Satellite imagery was obtained for most all of Snake Valley, excluding the very northern part. Wetlands and phreatophyte coverages have not changed appreciably from the USGS estimates. Therefore the estimate of about 80,000 acre-feet per year of evapotranspiration by Hood and Rush (1965), as shown in Table 6, still seems reasonable.

Table 6.--Estimated annual natural ground-water discharge by evapotranspiration in the Snake Valley area, Nevada and Utah

Phreatophyte	Area (acres)	Depth to Water (feet)	Evapotranspiration			Acre-feet (rounded)	Acre-feet Difference
			Acre-feet per acre[1]	Acre-feet (rounded)	Acre-feet per acre[2]		
Mixture of meadow grass and rabbitbrush	3,300	2-10	0.5	1,700	0.8	2,640	+940
Wet meadow	11,000	0-5	1.75	19,000			
Mixed greasewood and rabbitbrush	240,000	10-50	.2	50,000	0.7	168,000	+118,000
Evaporation from:							
Playas that are flooded part of year	3,200	0-15	.75	2,400			
Playas (Great Salt Lake Desert) that rarely is flooded, but has shallow water table	60,000	0-30	.1	6,000			
Totals (rounded)	320,000			80,000			119,000

1) Based on Hood and Rush (1965)
2) Based on Nichols (1992)

However, of interest is a recent study by Nichols (1992) which found that the rates for phreatophyte transpiration might be a factor of 3.5 times as high as those used in the USGS reconnaissance studies for northern and eastern Nevada. Applying factors reported by Nichols, as shown in the above Table 6, the calculated evapotranspiration rate for Snake Valley would be about 120,000 acre-feet per year higher or about 200,000 acre-feet per year. If this were the evapotranspiration volume then the recharge estimate or subsurface flow estimate would be in error. A potential explanation is that actual ground-water recharge is higher than that predicted by the Maxey Eakin Method (Eakin, et al., 1951) in valleys where there is significant mountain front runoff, which can enter the aquifer system at and below the bedrock/alluvial contact.

Springs

There are numerous springs in Snake and Hamlin Valleys. Discharge data are lacking for most springs (a few flows are listed in Table 3) but it is known that some springs have appreciable discharge rates (several cubic feet per second). Although no estimates of total spring discharge in the area are available, it is believed that the total is appreciable, probably ten to twenty thousand acre feet per year. This discharge is accounted for in the water budget for the basin and in the numerical model by spring discharge (drains) and evapotranspiration.

Water Wells

More than 250 water wells exist in Snake and Hamlin Valleys. However, as stated above, the majority of irrigation wells in Snake Valley are probably used to supplement surface water, resulting from snowmelt, in late summer and early fall. Total permitted ground-water consumptive use is about 6,200 acre-feet per year in the Nevada part of Snake Valley but is in actuality probably much less since total consumptive use for all Snake and Hamlin Valleys is 6,000 acre-feet per year as estimated below in the "Pumpage" section. As discussed in a previous section and shown in Figures 8 and 9, water levels have remained about the same in Snake Valley for the past 30-40 years.

Ground-Water Outflow

Discharge through subsurface flow is along the northern boundary of Snake Valley into the Great Salt Lake Desert and along the east-central part of Snake Valley into Tule Valley, Utah. Harrill et al. (1988) indicate that outflow to the Great Salt Lake Desert is about 10,000 acre feet per year and outflow to Tule Valley is between 22,000 and 33,000 acre feet per year.

Total Discharge

Based upon the preceding estimates and published values, the total discharge from Snake and Hamlin Valleys is believed to be between 118,000-129,000 acre feet per year as shown in Table 4. Most of this discharge is consumptive use by natural phreatophytes in the central portion of Snake Valley.

Perennial Yield

Scott, et al. (1971) defined perennial yield as "the maximum amount of natural discharge that can be salvaged each year over the long term without depleting the ground-water reservoir." The perennial yield of the Nevada portion of Snake Valley is reported to be greater than 25,000 acre-feet per year (Scott et al., 1971) who also reported perennial yield of 5,000 and 1,500 acre feet per year for the Nevada portions of Hamlin and Pleasant valleys, respectively. The combined perennial yield for Snake and Hamlin Valleys in Nevada is thus greater than 31,500 acre feet per year. For the basins as a whole, the perennial yield, according to Hood and Rush (1965) is about 80,000 acre feet per year.

Storage

The quantity of ground water stored in the geologic units underlying Snake Valley is large; the amount of recoverable ground water in storage in the valley reservoir is estimated to average about 10 percent of the volume of the saturated valley-fill (Scott, et al., 1971). For Snake and Hamlin Valleys, Hood and Rush (1965) estimated the quantity of recoverable ground water to be at least 12 million acre-feet in the upper 100 feet of the valley fill.

No estimates have been made of the amount of ground water that is stored in the carbonate aquifer in Snake Valley. Although the storage capacity of the carbonates is believed to be less than that of the valley-fill, the large saturated thickness and great areal extent of the carbonate aquifer suggests that the quantity of recoverable water from storage may be even greater than that expected from the valley-fill deposits.

Dettinger (1989) reported that the quantities of ground water in the regional carbonate aquifer are "enormous", and estimated that the total quantity of water stored in this regional aquifer south of Pioche and Tonopah is on the order of 800 million acre-feet. However, for practical purposes not all this water can be extracted. Adopting Dettinger's assumption of a total of one percent of the aquifer volume as being recoverable, then a rough estimate of the recoverable ground water in storage in Snake Valley can be made. Based upon this recovery factor, the areal extent of the carbonate aquifer underlying the valley (approximately 3,480 square miles), and an assumed saturated thickness of 1,000 feet (about the limit for economic well drilling), then the total recoverable ground-water storage in Snake Valley is estimated to be approximately 22 million acre-feet. However, the upper 100 feet of the rock aquifer probably contains about only 2 million acre-feet of ground water.

INVENTORY OF WATER RIGHTS, PUMPAGE, AND LAND USE

Currently the State Engineer does not conduct a periodic pumpage inventory in Snake Valley. As stated above, the majority of ground water is used in late summer and early fall when surface-water flows resulting from snow melt are at a low. The following summarizes the water rights for the Nevada part of Snake Valley and estimates the ground-water pumpage and landuse for all of Snake Valley.

Present Development

The level of development of water resources in a basin can be illustrated by the water right allocations and the current water usage within that basin. There has been very little development over what was reported by Hood and Rush (1965). Their estimate of land under irrigation from both spring and ground water are probably still relevant order of magnitude approximations. The following sections discuss the present development.

Water Right Status

Table 7 summarizes the water right status for the Nevada part of Snake Valley which is based on information supplied by SEC. The numbers in the table are consumptive use numbers based on 50 percent for municipal and domestic uses, 75 percent for irrigation uses, and 100 percent for stock watering. Appendix B contains a detailed listing of all the permits and applications. Please note that Desert Land Entries (DLE) are not included in the table since, historically, less than one percent of these water rights are ever developed. A single water right application senior to the Districts applications is pending; this water right will be for a limited quantity of water, probably a duty of 14 acre feet per year.

Table 7.--Water rights (consumptive use) Snake Valley, Nevada, in acre-feet per year.

	Surface	Underground
PERMITS	15,180	6,203
APPLICATIONS	0	14[1)]

[1)] Excludes 15,360 acre-feet per year (consumptive use) Desert Land Entries (DLE) applications

Pumpage

Data on actual water use is not available for ground or surface water in Snake and Hamlin Valley. Hood and Rush (1965) estimated that about 7000 acre-feet per year of ground water was being used in Snake and Hamlin Valleys, with about one half being used south of Gandy and north of U.S. Highway 50 which includes the Eskdale area. The remaining half being used is supplemental to surface water in the remaining developed areas. The actual total acreage irrigated presently appears to be slightly less than the USGS estimate, and is conservatively estimated to be about 6,000 acres requiring 18,000 acre-feet per year consumptive use (24,000 acre-feet per year total) for all of Snake Valley. The distribution between ground and surface water was assumed to be about the same as reported in Hood and Rush (1965) and satellite imagery was used to calculate the acreages south of Gandy and U.S. Highway 50 which was found to be about 640 acres. Based on this estimation of acreages consumptive use pumpage was rounded to 2,000 acre-feet/year south of Gandy and north of U.S. Highway 50. For the remainder of Snake Valley about the same numbers used by Hood and Rush (1965) for ground-water supplementary to surface supplies were used which equals about 4,000 acre-feet per year. Therefore, the total estimated consumptive pumpage was rounded to about 6,000 acre-feet per year, about a third of all consumptive use.

For purposes of the steady state model pumpage was not considered. As discussed in the previous section regarding historical water levels, and shown in Figures 8 and 9, ground-water levels have remained fairly constant over the years in Snake Valley. However, historical pumpage for Snake Valley will be included in the transient simulations which will be included as part of the District's regional modelling effort.

Land Use

Most of the land in Snake Valley is public-domain land administered by the Bureau of Land Management. The primary land use is livestock production with agriculture primarily limited to the irrigation of pastures and alfalfa fields.

As discussed above, satellite imagery (Landsat Thematic Mapper (TM) data) was used to delineate wetlands and irrigated fields. Based on this imagery and field reconnaissance, the District determined that in 1990 there was about 11,000 acres of wetlands and 6000 acres of irrigated fields in central and southern Snake Valley. The very northern area of Snake Valley was not examined with satellite imagery. These agricultural numbers are slightly less than those reported in Hood and Rush (1965). Detailed landuse maps and discussion for Snake Valley are part of the Cooperative Water Project's environmental report.

Future Development

Other than the District's plans for ground-water withdrawal, there is no other development known to be planned in Snake or Hamlin valleys.

MODEL DEVELOPMENT

MODFLOW is a three dimensional ground-water flow model that simulates ground-water movement through gridded layered cell blocks by solving a series of finite difference equations. These equations preserve the quantity of ground water in the modelled area. For any further detail regarding the flow model, the MODFLOW documentation (McDonald and Harbaugh, 1988) should be consulted.

The first step in developing a ground-water flow model is the formulation of a conceptual hydrogeologic model of the area to be mathematically represented. This conceptual model is based upon the available hydrologic data, inferences based on observations of similar hydrologic settings, and assumed conditions or expected ranges of conditions for parameters that have not been measured or are not readily estimated for the subject hydrologic basin.

The first step in the mathematical representation of the conceptual model is the development of a grid system covering the hydrologic basin. The grid system can be either single or multiple layers with each cell in the model being identified by grid row, column, and layer designation. Usually the grid size and number of layers are chosen based on the amount of available hydrologic data for the particular basin. Each cell is given a number of parameters (i.e. transmissivity, storage (in transient scenarios), conductive characteristics for spring flow, recharge where appropriate, and rates of evapotranspiration when the water levels are within a set distance from land surface) which control water flow through the model. The District made the decision to make all the grids for the individual ground-water flow models one mile by one mile and each model two layers, one to represent the alluvial system and the other the consolidated bedrock. In some valleys there were not enough data to warrant this scale; however, preparation of the model on this scale will provide a framework for future data entry resulting in model refinement.

Approach and Assumptions

The approach taken in all the individual basin models was to produce a steady state model which replicated as closely as possible the hydrologic basin budget as defined by the USGS while attempting to match existing ground-water levels. The most important "constant" becomes the amount of water entering the system or the recharge and of course water levels which serve as calibration points. Hood and Rush (1965) established the hydrologic budget for Snake and Hamlin Valleys. As discussed previously, there are data for over 250 wells in Snake and Hamlin Valleys, which provides a good areal data base for model calibration, however there are no known wells completed in consolidated rock.

A one square mile grid, 145 rows by 53 columns as shown in Figure 12, consisting of two layers was constructed to simulate ground-water flow in Snake and Hamlin Valleys. Both the upper alluvial fill and surrounding consolidated rock outcroppings and the lower consolidated rocks were modelled as confined fixed transmissivity units. Parameter selection (i.e. transmissivity and vertical leakance) was keyed to rock type. Figures 13 and 14 shows the

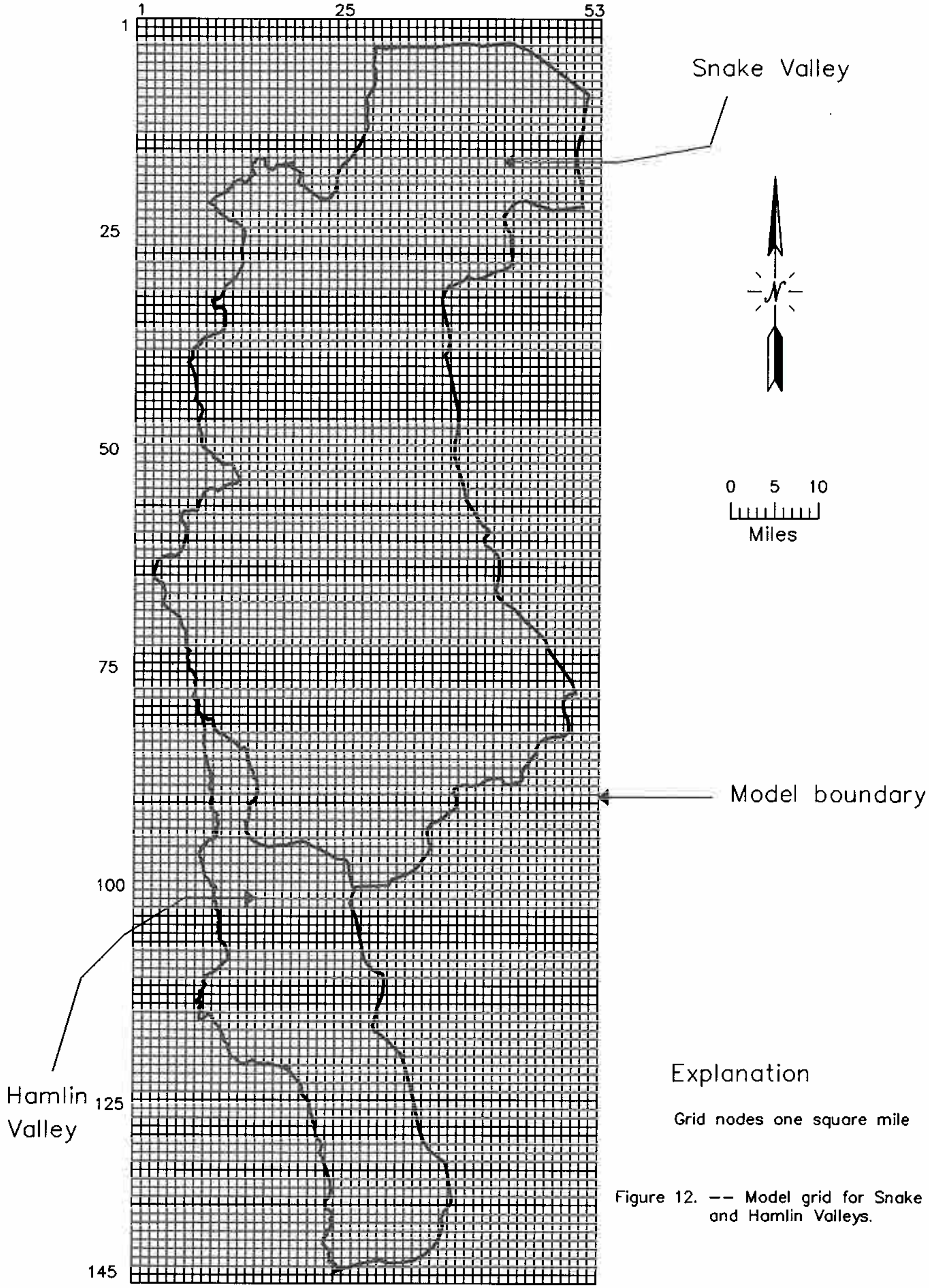


Figure 12. -- Model grid for Snake and Hamlin Valleys.

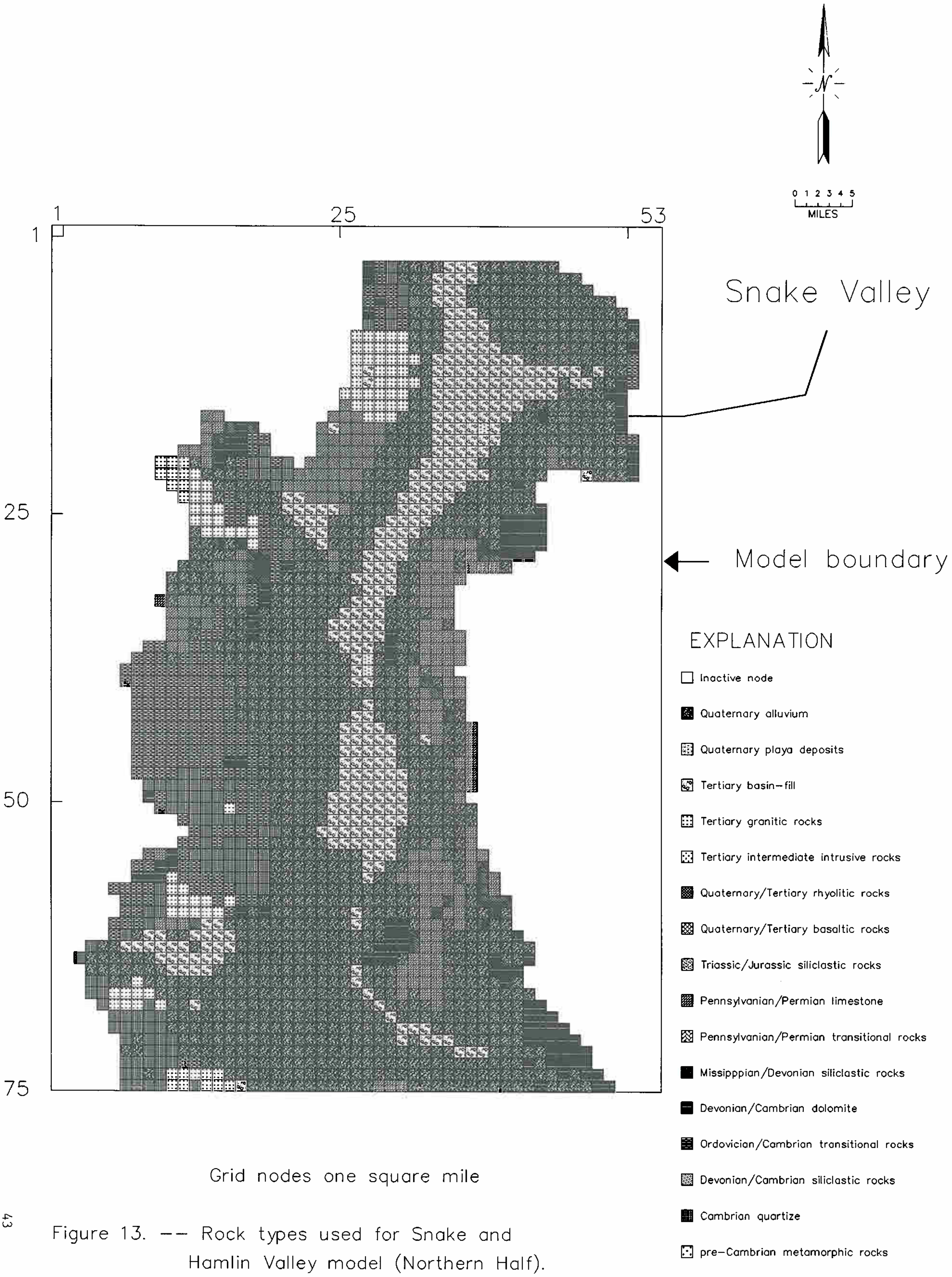


Figure 13. -- Rock types used for Snake and Hamlin Valley model (Northern Half).

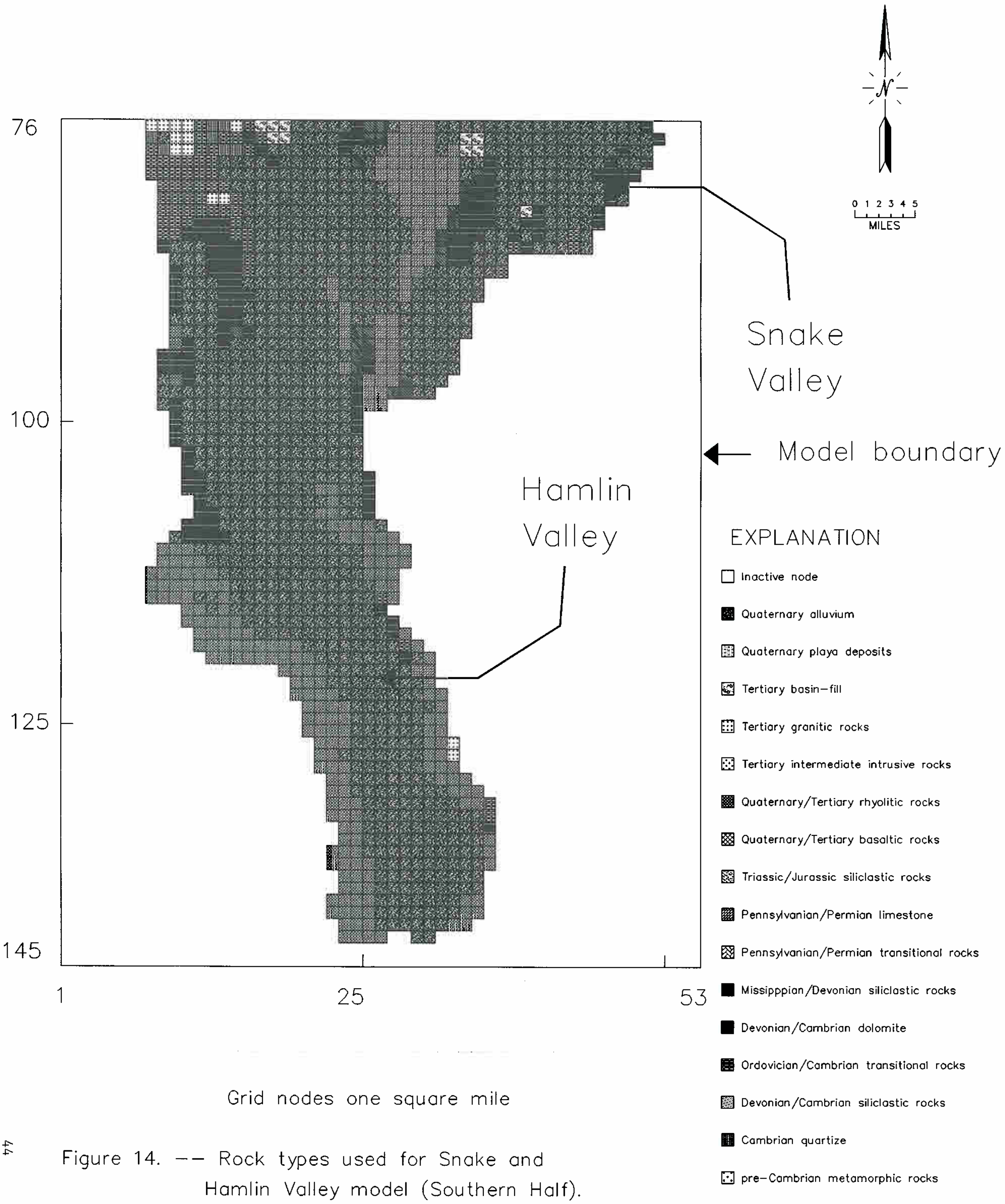


Figure 14. -- Rock types used for Snake and Hamlin Valley model (Southern Half).

lithology distribution for the upper layer, specifying alluvium and rock type based on the digital representation of the Nevada 1:500,000 scale geology map (Stewart and Carlson, 1978) prepared by Turner and Bawiec (1992). The lower layer or underlying consolidated rocks were assumed to be carbonates with some overlying volcanics which were simulated by using the vertical conductance between layers.

Parameter Estimates

Recharge and Discharge

Hood and Rush (1965) estimate the recharge, based on the method described by Eakin et al. (1951), to Snake and Hamlin Valleys to be about 103,000 acre-feet per year. Hood and Rush also estimated the total discharge from evapotranspiration to be about 80,000 acre-feet per year, the majority in Snake Valley. The amount of ground-water consumption was estimated to be about 7,000 acre-feet per year in the early 1960's. A recent assessment of land use and water rights permits in these valleys confirmed that well pumpage has not changed dramatically in the past thirty years and is estimated slightly lower at about 6000 acre-feet per year consumptive use, instead of the Hood and Rush (1965) estimate of 7000 acre-feet per year.

Primary Recharge

Primary recharge in Snake and Hamlin Valleys occurs from the infiltration of precipitation into the ground-water system occurring in the higher elevations as well as from some infiltration of surface water runoff and spring flow. Snake Valley receives a large part of its recharge from the Snake Range bordering the valley on the west side, in Nevada. Other ranges contributing to Snake Valley recharge are the Confusion Range on the east side and the Deep Creek Range in the north. The Wilson Creek Range on the west side of Hamlin Valley also contributes some recharge to the area.

Digital elevation data were used to computer generate and distribute recharge based on the Maxey-Eakin method (Eakin et al., 1951) with the factors listed for Snake and Hamlin Valleys in the report by Hood and Rush (1965) and shown in Table 5. Digital elevations were obtained for the complete Cooperative Water Project (CWP) area from the USGS, which are based on the 1:250,000 scale Army Map Series (AMS) maps and contain an elevation every 90 meters. This data was smoothed by finding the nearest neighbor then resampling at 150 meter intervals. The file was then subset for the Snake and Hamlin Valley grid area. It should be noted that even after smoothing the digital elevations, the playa area in the northeastern part of Snake Valley had erroneous elevation values, values lower than the water table. This area was corrected by extracting actual points from the USGS 1:100000 maps, gridding these points using a minimum curvature gridding package, then inserting this subset into the digital elevation file for Snake and Hamlin Valleys.

Dr. James Tracy developed a program to calculate recharge based on these digital elevations for each grid cell using the Eakin factors (precipitation and percentage infiltrating the ground-water system) listed in the various USGS reconnaissance reports. The product of the program is a matrix corresponding to the grid which specifies recharge rates for each cell. This program was used to generate such a matrix for the Snake and Hamlin Valley area.

Figure 15 is a graphical representation of the recharge distribution used in the Snake and Hamlin Valley model. Based on this method, the recharge for Snake and Hamlin Valleys was calculated to be about 110,000 acre-feet per year, about seven percent greater than that calculated by Hood and Rush (1965). Since the factors used to calculate recharge were the same, the difference in recharge could be due, in part, to the difference in total area calculations for the hydrographic basins. The hydrographic basins were digitized then using the ARCInfo gridding package a raster file was subset based on a half a mile grid. Therefore, in a quarter of a square mile area, if over 50 percent of the polygon was in the basin the total area was considered part of the basin. However the difference of seven percent is well within the accuracy of the estimation of natural recharge.

Secondary Recharge

Secondary recharge is due to infiltration of water from anthropogenic uses such as irrigation or septic disposal systems. As stated above and discussed in more detail below, secondary recharge from irrigation was estimated to be about 6000 acre-feet per year (a combination of both surface and ground water) in Snake Valley and negligible in Hamlin Valley. The majority of this is from surface water. Ground water is used only to supplement surface water in most cases. Because ground-water levels have not declined significantly as shown in Figures 8 and 9, the decision was made not to include irrigation pumpage or secondary recharge in the steady state model. The transient runs that will be simulated as part of the District's regional model will include pumpage based on land use.

Discharge

Evapotranspiration

Evapotranspiration (ET) was simulated in Snake and Hamlin Valleys by using the MODFLOW ET module. Maximum rates and extinction depths are specified and ET is calculated linearly, based on depth to water, with zero ET at the specified extinction depth and maximum ET occurring when the water table is at land surface.

Hood and Rush (1965) estimate ET in Snake Valley for three different types of phreatophytic zones based on types of phreatophytes and depths to water and two different zones for playa or bare soil evaporation, these are shown in Table 6. To incorporate these zones in the model, the map delineating these zones was digitized and using the ARC Info gridding function a matrix was established specifying a certain number for a specific zone corresponding to the appropriate grid row and column. The two different zones for playa or bare soil evaporation were combined into one overall zone which estimates bare soil evaporation. Figure 16 shows the four zones, final rates and extinction depths used in the model.

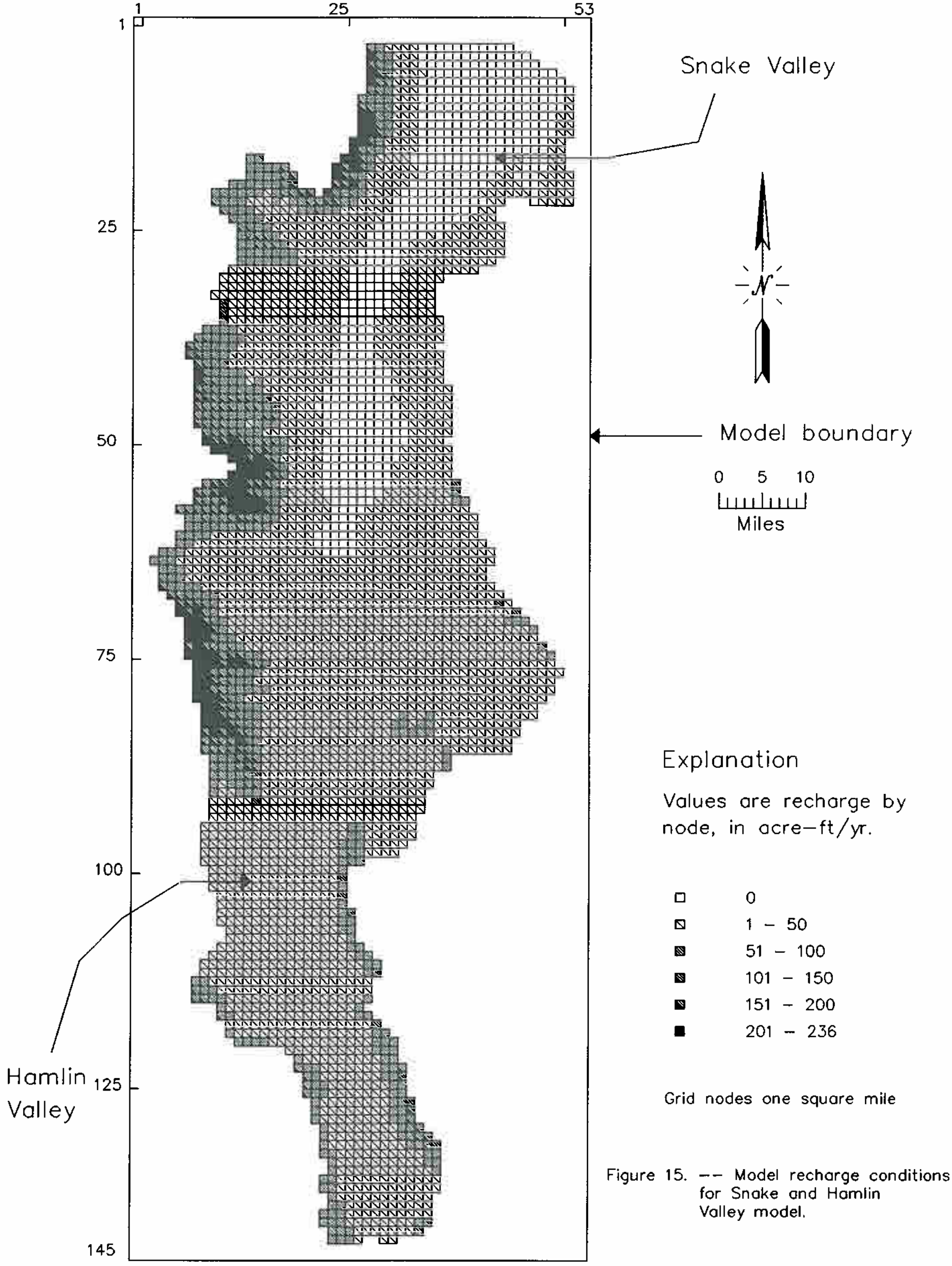
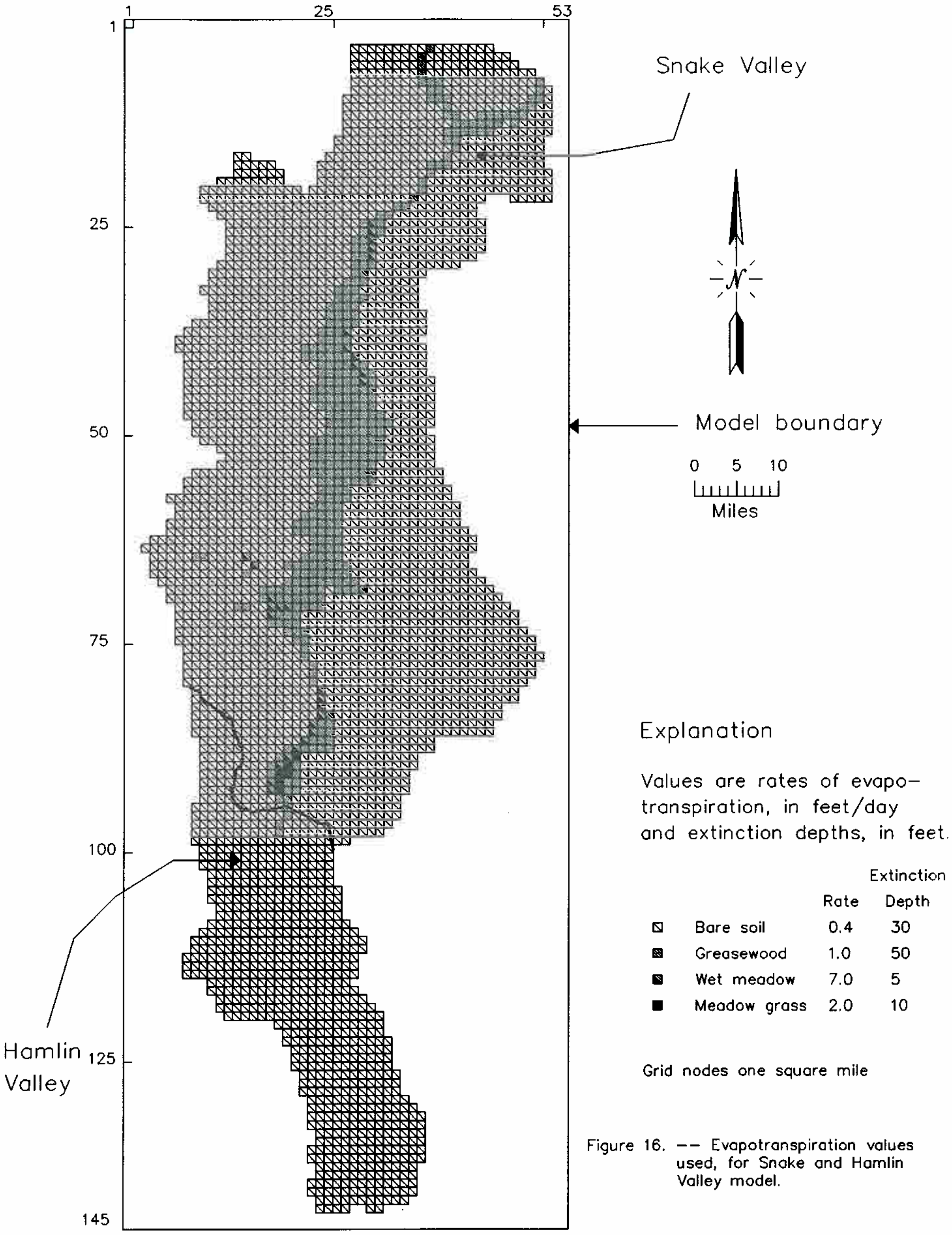


Figure 15. -- Model recharge conditions for Snake and Hamlin Valley model.



Explanation

Values are rates of evapotranspiration, in feet/day and extinction depths, in feet.

		Rate	Extinction Depth
▧	Bare soil	0.4	30
▨	Greasewood	1.0	50
▩	Wet meadow	7.0	5
■	Meadow grass	2.0	10

Grid nodes one square mile

Figure 16. -- Evapotranspiration values used, for Snake and Hamlin Valley model.

Because the rates assumed by Hood and Rush (1965) were constant for each zone regardless of the actual variable depth to water, greater potential ET rates have to be estimates of actual ET rates and were specified for the phreatophyte zones to calculate volumes corresponding to the estimated volumes, since the MODFLOW ET module calculates the rate of ET based on the simulated depth to water. Initially, extinction depths specified in Hood and Rush (1965) were used with rates twice those listed to compensate for the overall rate regardless of depth to water, as shown in this report in Table 6. Therefore, when the model simulated depth to water was one half the listed depth to water range or extinction depth specified by Hood and Rush (1965), the rate was equal to that listed in Hood and Rush (1965). These rates resulted in insufficient ET causing water levels to be higher than land surface. Finally, rates four times as great as that specified in Hood and Rush (1965) with the same extinction depths were used in the ET module and produced a total ET of about 80,000 acre-feet per year and a spring flow of about 7,000 acre-feet per year. The percentages of ET occurring in each zone are near the USGS designations with that for greasewood being slightly higher (76% compared to 63%). However, Hood and Rush (1965) did not estimate spring flow, but just took into account wet meadow areas as those areas near the springs.

In initial model runs extensive ET was occurring in northern Hamlin Valley in the area of Hamlin Wash. To increase simulated depth to water in this area, therefore significantly reduce ET, it was necessary to create a zone of higher transmissivity in the lower layer. This resulted in lowering water levels in this area as well as allowing this water to reach southern Snake Valley and ET and discharge as springs (simulated as drains) in the Big Spring area. This is discussed in more detail under the "Transmissivity" section.

Springs

Drains were used to simulate flow in the Big Spring area in southern Snake Valley and in the Warm and Twin spring areas in northern Snake Valley. Five drains were input to simulate the spring line from Big Spring north and one for Warm and one for Twin Springs. Conductances of 10,000 feet per day with corresponding land surface elevations were input. The location of the nodes for the Big Spring area were chosen using Landsat TM imagery, highlighting the infrared band. The nodes with row and columns 93/17, 92/17, 91/17, 90/18, 89/18, 40/21, and 30/44 were most representative of spring areas and extremely high ET areas. The model simulated a flow of about 7,000 acre-feet per year for spring flow. This in conjunction with the estimated ET volume of 80,000 results in a overall estimate of ET of about 87,000 acre-feet per year.

Hydraulic Characteristics

The hydraulic characteristics govern how the water introduced by recharge or interbasin flow moves through the modelled area to the areas of discharge. For a steady state simulation the important hydraulic characteristics are transmissivity, boundary conditions (conductances) and, since this is a two layer model, vertical leakance. These parameters are discussed below:

Boundary Conditions

Each individual basin was modelled as a "free body" tied to general head boundaries outside the existing basin boundary. The water levels specified for the general head boundaries were based on Thomas et al. (1986) for each layer. Conductances were established to simulate the USGS estimates for inflow and outflow in each layer, as well as match existing water levels. Figures 17 and 18 show the location of the general head boundaries and the conductances used in each layer.

Inflow

Harrill et al. (1988) estimate that about 4000 acre-feet per year enter Hamlin Valley from Spring Valley through a trough area just south of the Snake Range. This water then flows north east into Snake Valley. They also show some potential inflow to Snake Valley from Pine and Wah Wah Valleys. There is some question as to the flowpath. Does this water enter Snake Valley directly from Pine Valley or flow through Wah Wah Valley from Pine Valley, then to Snake Valley, or flow directly from Pine Valley into Wah Wah Valley then to Tule Valley? As discussed under the section entitled "Regional and Basin Hydrogeologic Features", it was assumed that about a half of the 19,500 acre-feet per year contribution from Pine and Wah Wah Valleys reaches Snake, or about 10,000 acre-feet per year (rounded). When looking at the gradient between Snake Valley and Pine and Wah Wah Valleys (Thomas et al., 1986) there is a low gradient, which makes it difficult to simulate such flow. Because of this gradient it was not possible with the model to simulate this amount of water flowing into Snake Valley from Pine or Wah Wah Valleys. The gradient would support this water flowing from Pine Valley into Wah Wah Valley then to Tule Valley, not flowing through Snake Valley. The modelled amount of inflow was about 1,000 acre-feet per year.

Outflow

Hood and Rush (1965) and Harrill et al. (1988) estimate that about 10,000 acre-feet per year exit northeastern Snake Valley in the alluvial system to the Great Salt Lake Desert. Harrill et al. (1988) also estimate between 22,000 and 33,000 acre-feet per year exit eastern Snake Valley in the consolidated rock aquifer into Tule Valley. This actual budget amount is dependent on the flowpath and the distribution of the water eventually entering Tule Valley from Pine and Wah Wah Valleys via Snake Valley or directly.

The boundary conditions established for the model resulted in about 29,000 acre feet per year leaving Snake Valley, about 14,000 in the alluvial system and 15,000 in the consolidated system. As stated above the model simulates very little ground water (only about 1000 acre-feet per year) enter Snake Valley from the southeastern boundary connecting Snake to Pine and Wah Wah Valleys.

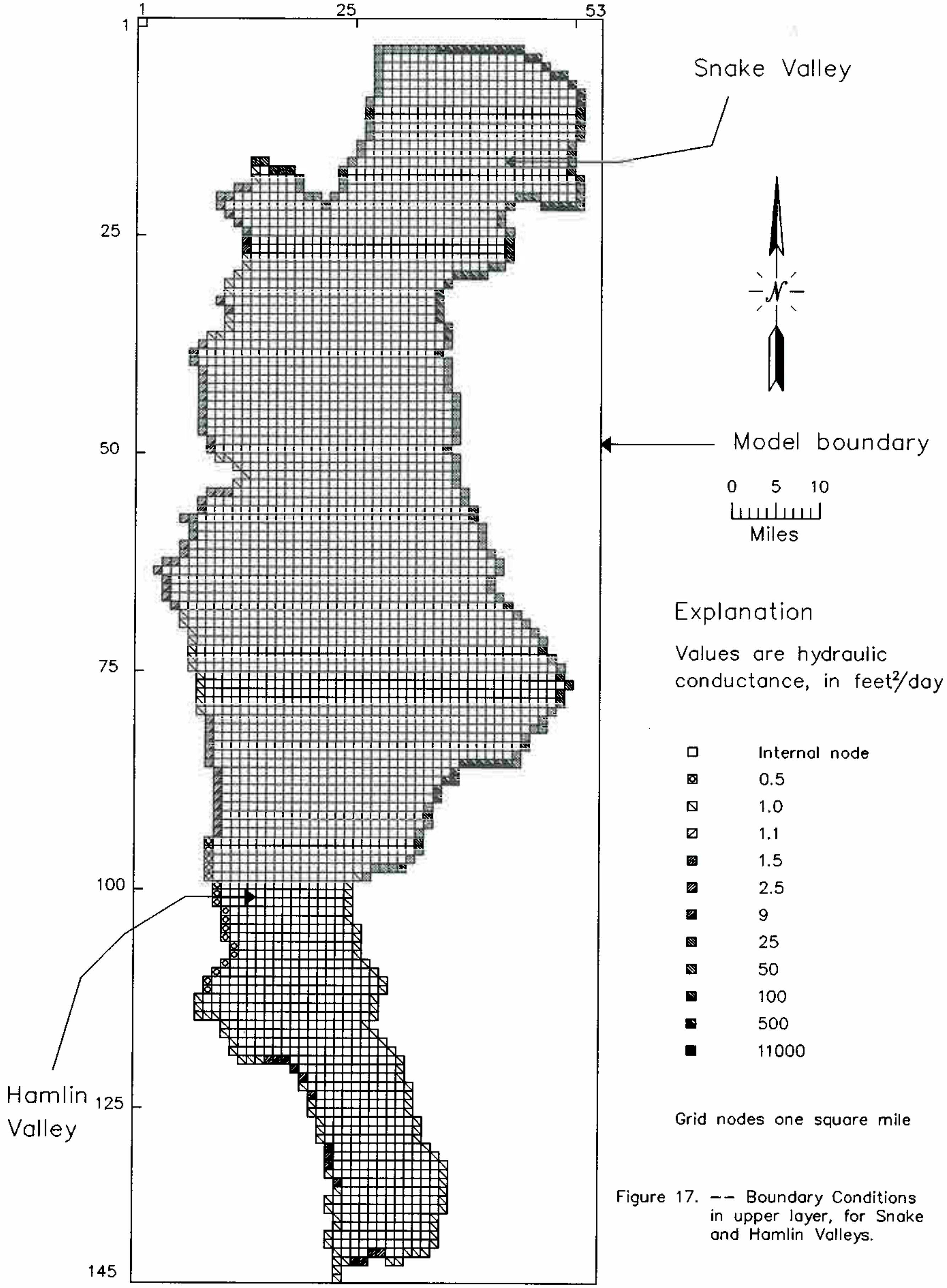


Figure 17. -- Boundary Conditions in upper layer, for Snake and Hamlin Valleys.

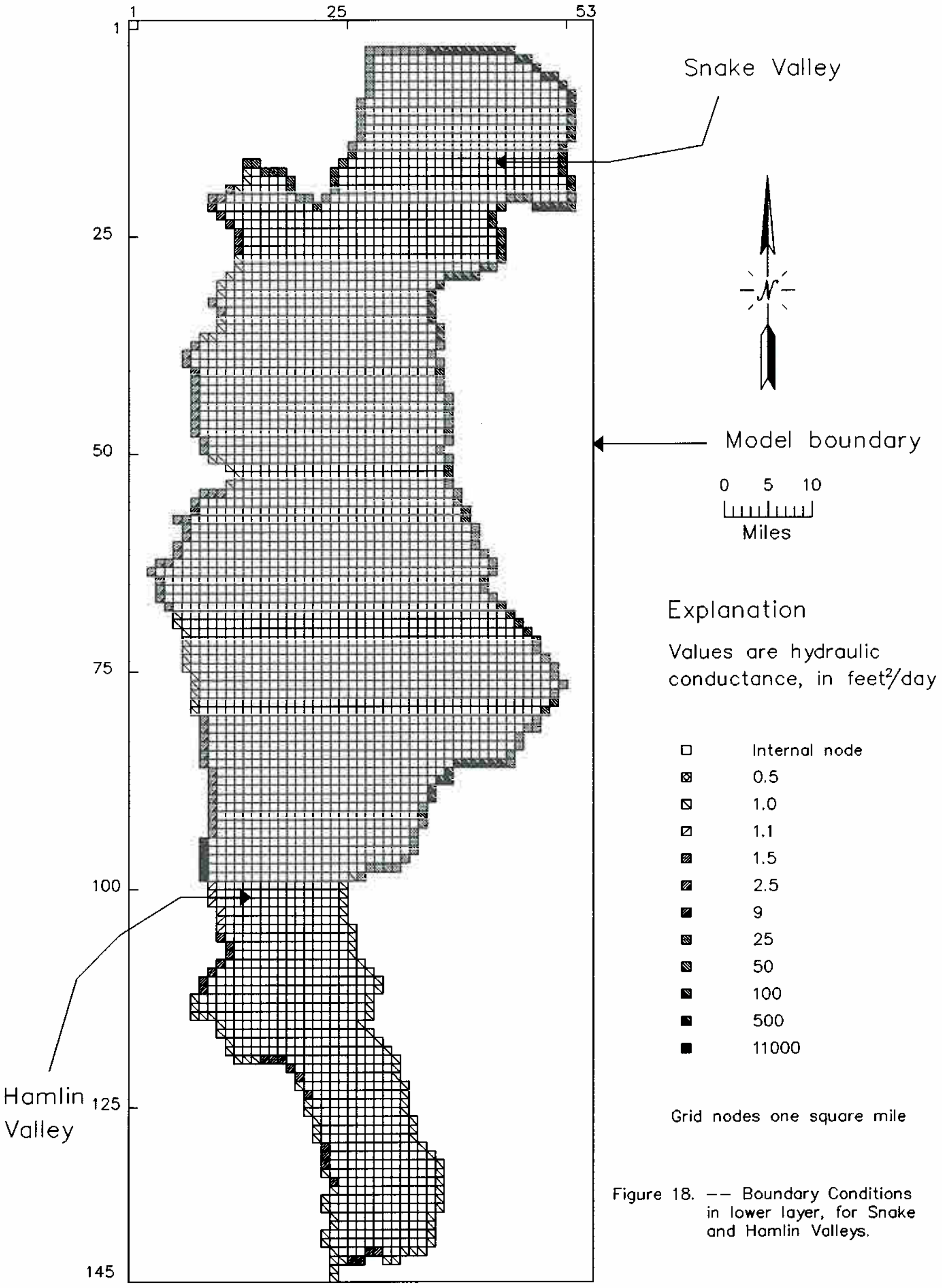


Figure 18. -- Boundary Conditions in lower layer, for Snake and Hamlin Valleys.

Transmissivity

Transmissivity values were assigned based on rock type. The USGS digital representation of the 1:500,000 scale Nevada Geology (Turner and Bawiec, 1992) was used to classify rock types into transmissivity zones. A raster file of the geology was created from the digital map by using the gridding function in ARC Info, subsetting a number corresponding to the geology type every half a mile for the complete CWP regional model area. This grid was then subset on mile nodes for the area corresponding to the Snake and Hamlin Valley model, which included sixteen different geologic classifications as shown in Figures 13 and 14.

As discussed above, as part of the MX Missile siting investigation nine aquifer tests were conducted in the alluvium in Snake and Hamlin Valleys. These transmissivity values ranged from 58 to 47,000 ft^2 per day. Initially in the upper layer the transmissivity values of 5000 ft^2 per day was assigned to alluvium, about 2000 ft^2 per day for playa deposits, around 1000 ft^2 per day for the carbonate rock types, and about 250ft^2 per day or slightly lower for clastics and volcanic rock classifications. In calibrating the model, over 100 wells were evaluated, and considered to provide an areal coverage of depth to water, and 94 were used in the model calibration, which are all completed in the alluvium. It became apparent that the transmissivities of the alluvium and playa deposits were too high because the majority of the simulated water levels were much lower than the observed values. To match water levels it was necessary to use lower transmissivity values for most all the units in the upper layer. These values are shown in Figure 19. Calibration to these existing water levels is discussed in more detail in the following section entitled, "Steady State Simulation".

There are no wells completed in the consolidated rocks in Snake or Hamlin Valleys, therefore initial estimates of transmissivities for the lower layer were based on other consolidated rock wells as well as other models prepared for valleys within the carbonate rock province. Carbonate rocks were assumed to be underlying the alluvium and playa deposits and a values of 500 ft^2 per day were initially assigned to those. In the area just south of the Snake Range these low values restricted flow causing water to rise above land surface and not allowing enough water to reach ET areas. A zone of high transmissivity was required in the lower layer to transmit sufficient water under the alluvium to discharge areas (ET and spring areas) resulting in ET values of about 87,000 acre-feet per year slightly higher than the Hood and Rush (1965) value of 80,000 acre-feet/year. A higher value of 2,250 ft^2 per day was used for the remaining lower layer. The final calibrated transmissivity values used for the lower layer are shown in Figure 20. The high transmissivity zone of 80,000 ft^2 per day is within the range of values for aquifer tests preformed for wells in the carbonates (Bunch and Harrill, 1984).

Vertical Leakance

The vertical leakance value establishes the connection between the upper and lower model layers and were calculated as specified by McDonald and Harbaugh (1988) based on assumptions of an overall general thicknesses of 4,500 feet for the alluvium and 15,000 feet for the bedrock. Recalculation was done as transmissivity values varied significantly during calibration. For the

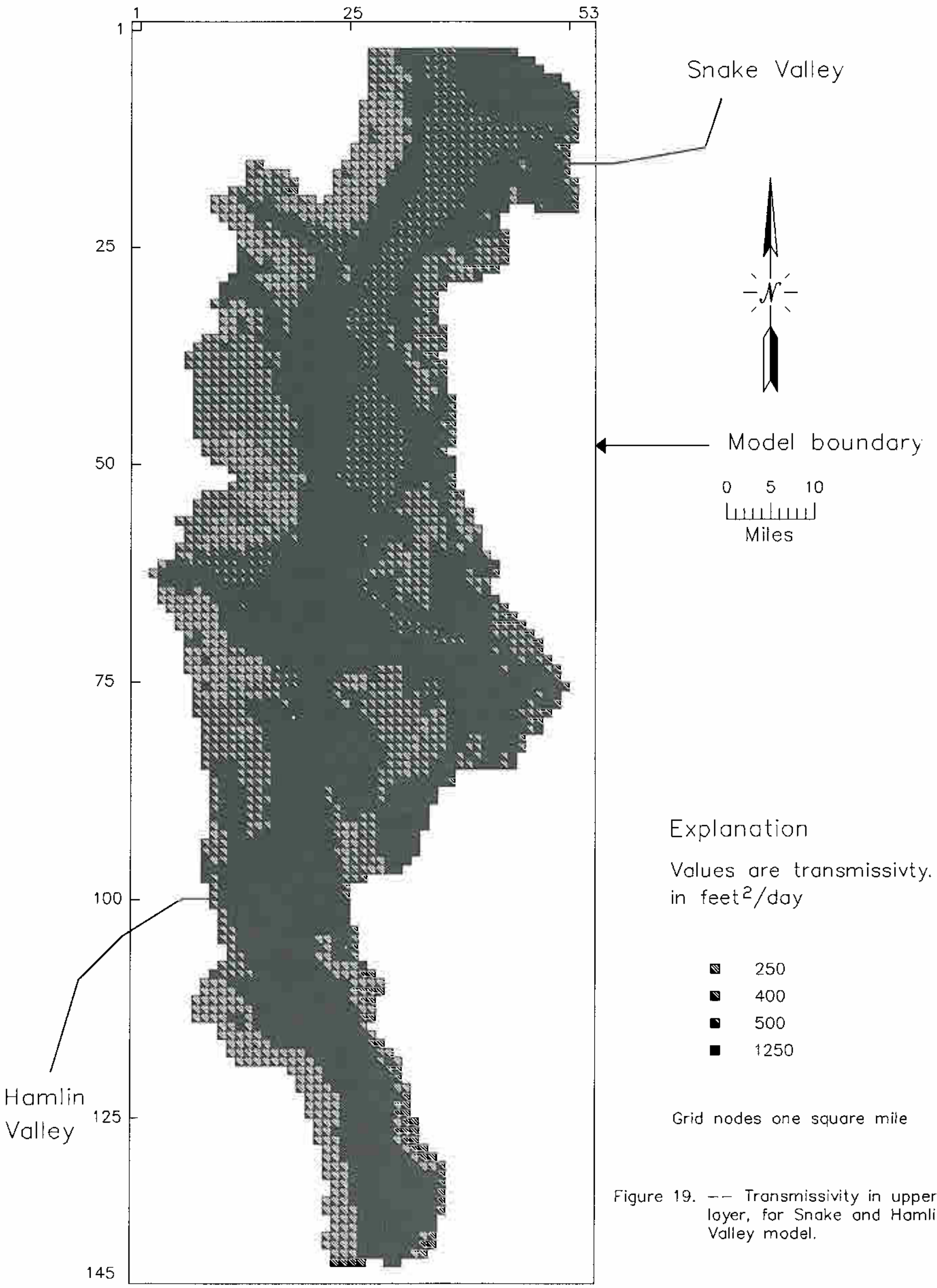


Figure 19. -- Transmissivity in upper layer, for Snake and Hamlin Valley model.

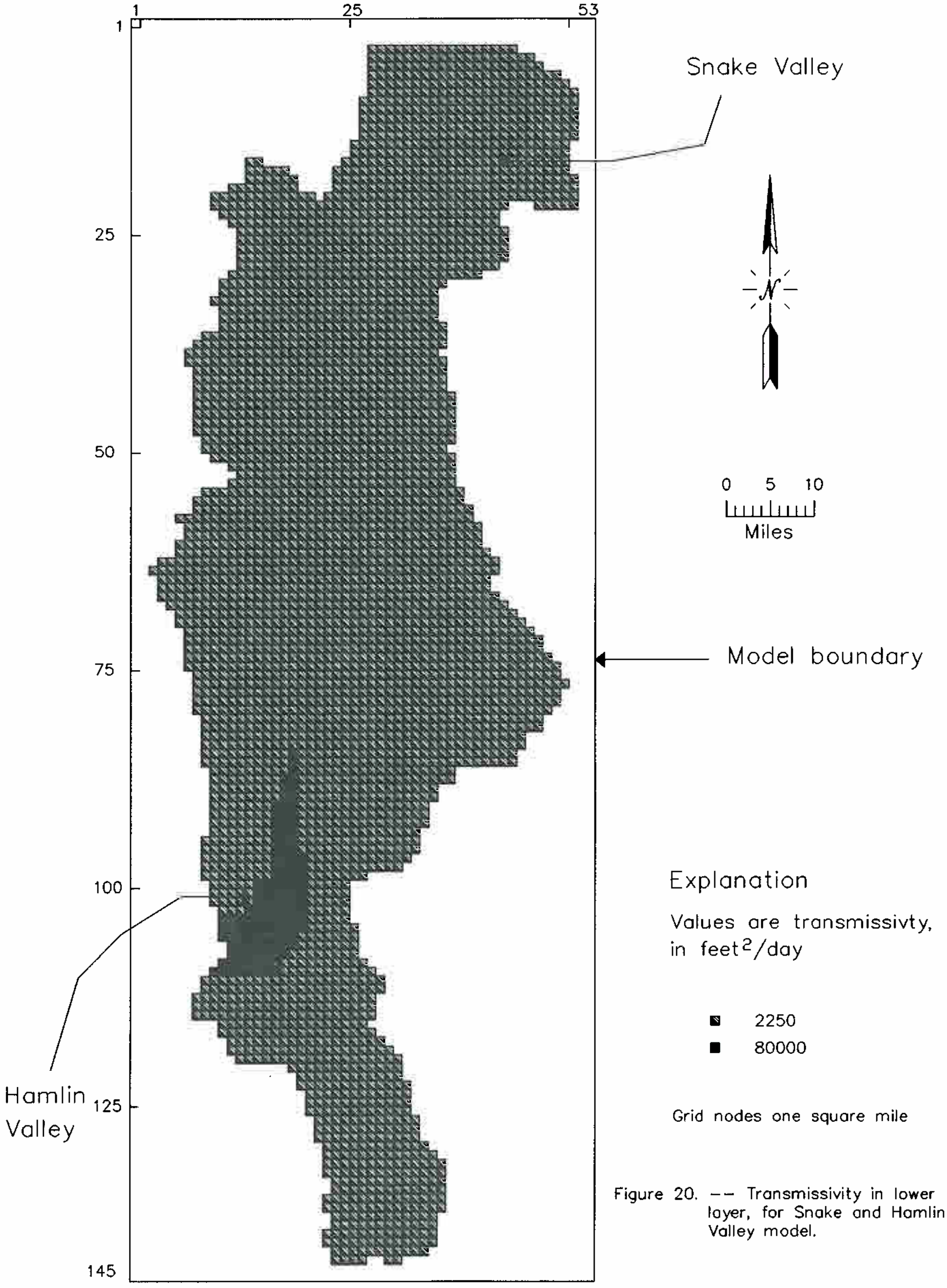


Figure 20. -- Transmissivity in lower layer, for Snake and Hamlin Valley model.

majority of the transmissivity units the vertical conductance remained generally around 1 to 3 X 10^{-5} ft per day. However, the initial value for the conductance between the high lower transmissivity zone and the upper zone was around 1 X 10^{-4} and was raised to 1 X 10^{-3} during calibration to allow for high conductance between the upper and lower zone in this area. Figure 21 shows the distribution of the vertical leakance numbers within the modelled area. The sensitivity of the vertical leakance values is discussed in more detail in the section titled "Steady State Simulation".

Steady State Simulation

The potentiometric surfaces for the upper and lower layers resulting from the steady state simulation for Snake and Hamlin Valleys are shown in Figures 22 and 23 with the actual water levels imposed for the upper layer. There are no water level measurements in the bedrock or lower layer.

Upper Layer

Table 8 shows the 94 wells used for calibration and the differences between the actual and simulated water levels for the Snake and Hamlin Valleys model. These measurements are a subset from the complete water levels included in Table 1, with the same ID numbers. The ten water levels deleted from the calibration were from flowing wells or wells that were representative of a localized or perched system.

Figure 24 graphically illustrates the difference between the actual water levels and the model simulated levels for wells located from north to south in Snake and Hamlin Valleys. Of the 94 calibration points 89% are within 100 feet of the actual measurements with 69% being within 50 feet of the actual measurements. Also the distribution of positive and negative residuals is about even.

Three wells located in T14N, R69E, Sec.24 (well ID numbers 7,8, and 9) show the greatest differences between actual and simulated values. This area of the model (row 67 col.14 and row 66 col.13) is in an area of alluvial deposits surrounded by tertiary basin-fill and tertiary granitic rocks, as shown in Figure 13. The alluvial deposits in this area are probably shallow and the actual transmissivities are probably lower than the model values, therefore resulting in the lower simulated water levels. This also applies to well Nos. 3 and 6, located in T14N, R70E, Sec. 31 and Sec. 8.

Overall the match of the simulated values with the actual values is thought to be reasonable as well as the match with the USGS budget. Therefore, the steady state model provides a reasonable simulation of the potentiometric surface.

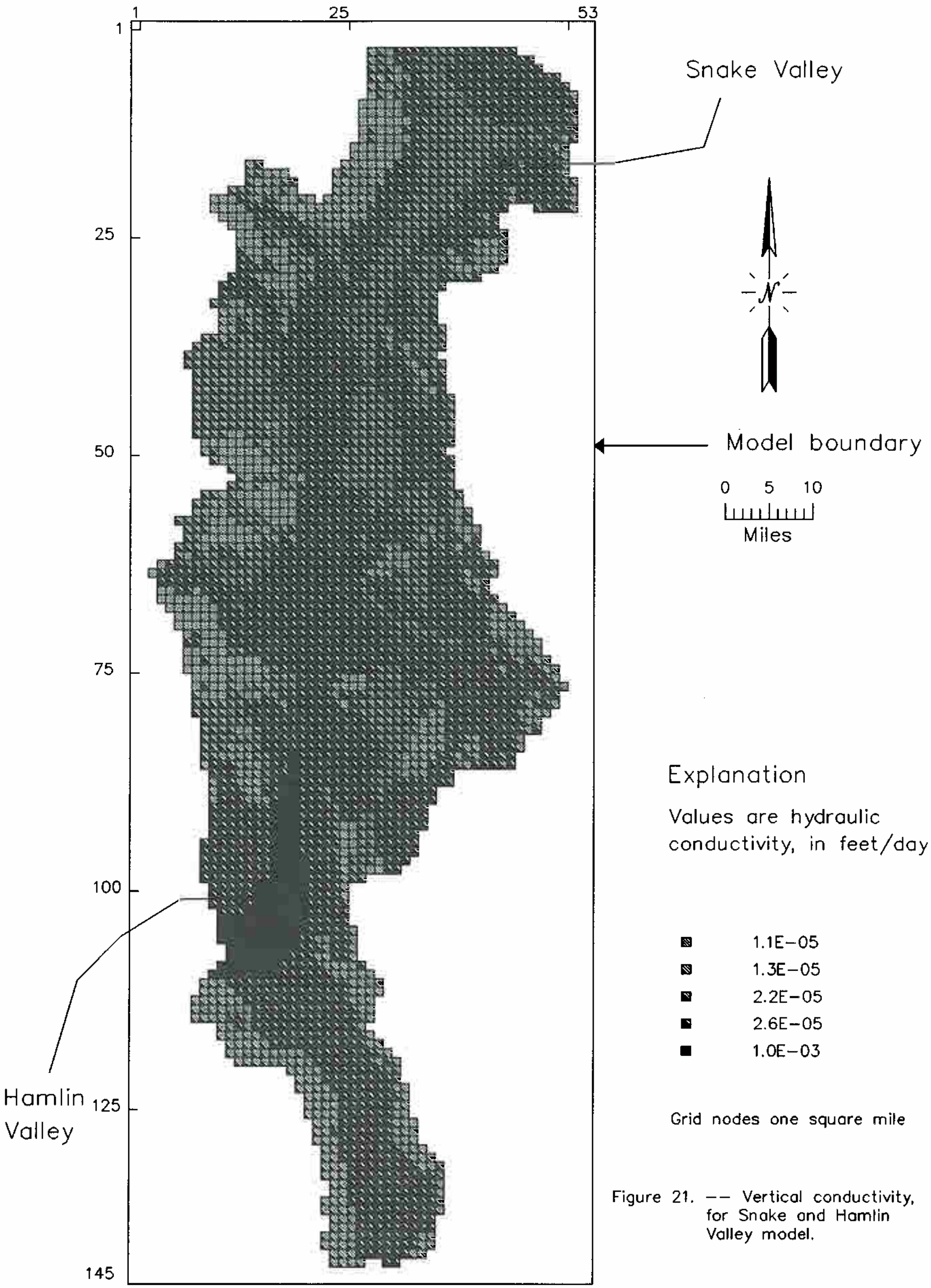


Figure 21. -- Vertical conductivity, for Snake and Hamlin Valley model.

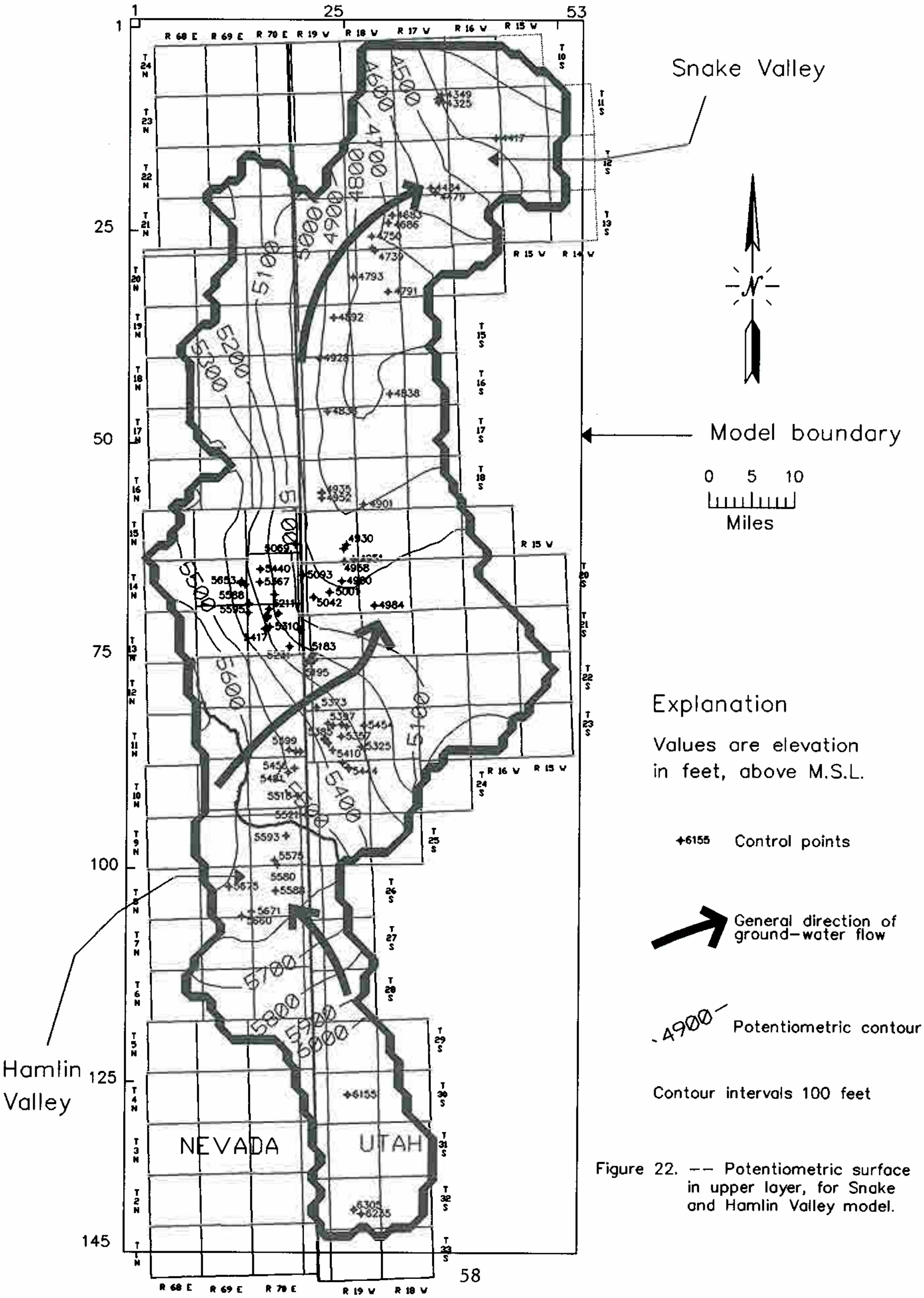


Figure 22. -- Potentiometric surface in upper layer, for Snake and Hamlin Valley model.

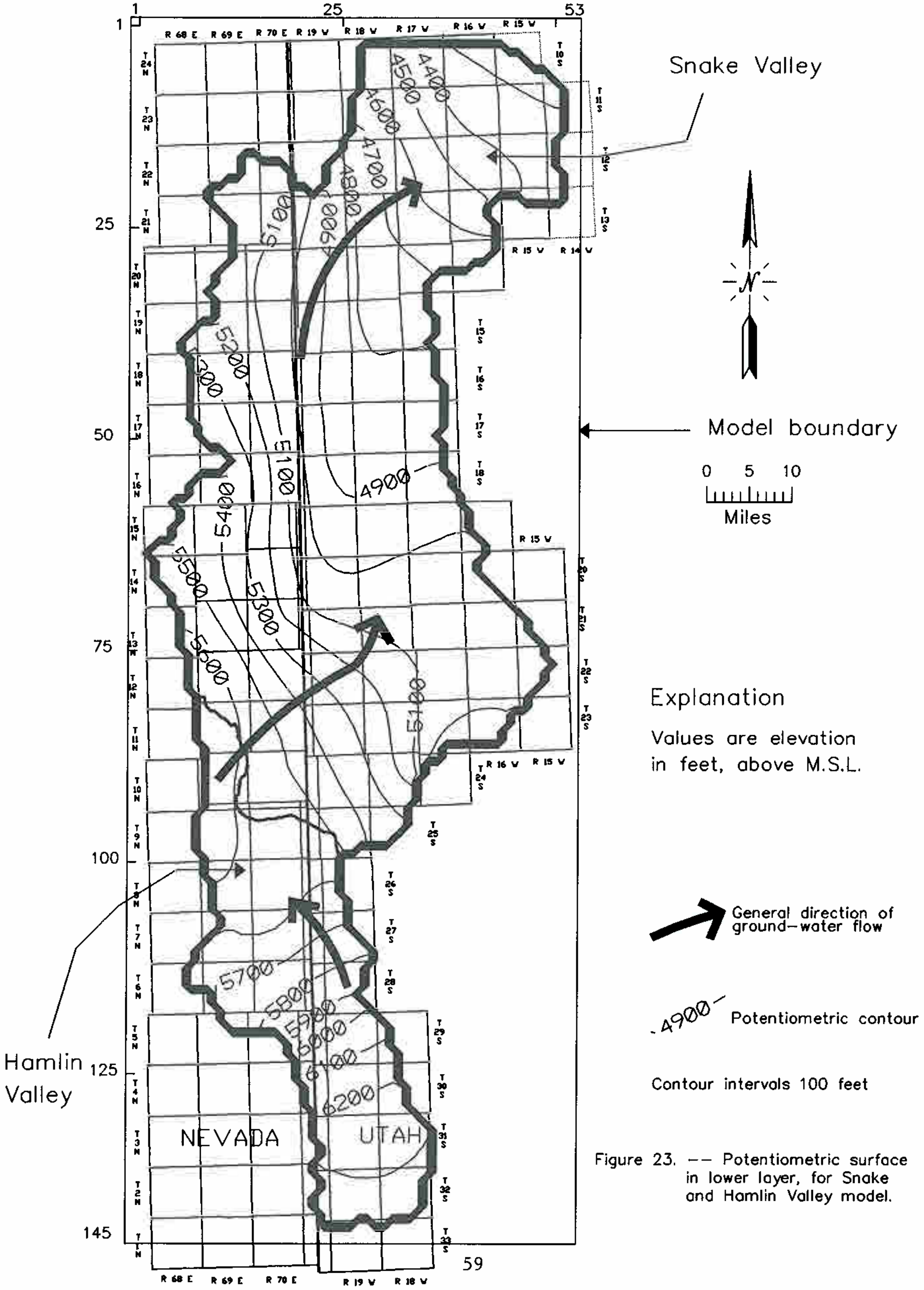


Figure 23. -- Potentiometric surface in lower layer, for Snake and Hamlin Valley model.

Table 8.--Comparison of actual vs. simulated water levels for wells used in calibration.

Well ID No.	Location	Row	Column	Water Level (feet above sea level)		Residual
				Actual	Simulated	Δ
2	15N/70E-25DD	62	20	5069	5066	3
3	14N/70E-31C	69	14	5595	5350	245
4	14N/70E-27C	68	17	5211	5224	-13
5	14N/70E-20	65	16	5367	5245	122
6	14N/70E-8DC	67	16	5440	5258	182
7	14N/69E-24DAB	67	14	5588	5331	257
8	14N/69E-24BDD	66	13	5618	5361	257
9	14N/69E-24A	66	13	5653	5361	292
10	13N/71E-19B	72	20	5139	5147	-8
11	13N/70E-35A	74	19	5231	5247	-16
12	13N/70E-16DB	72	17	5310	5273	37
13	13N/70E-16CC	72	16	5417	5314	103
14	13N/70E-16C	72	16	5396	5314	82
17	13N/70E-10ABA	70	18	5049	5183	-134
19	13N/70E-9CA	71	16	5272	5296	-24
20	13N/70E-9C	70	16	5314	5281	33
21	13N/70E-9BDD	70	16	5284	5281	3
22	13N/70E-9B	70	16	5332	5281	51
23	13N/70E-4CDC	70	14	5272	5362	-90
24	13N/70E-4D	69	17	5270	5225	45
28	11N/70E-36BD	86	20	5453	5472	-19
29	11N/70E-35BA	86	19	5539	5495	44
30	11N/70E-35AD	86	20	5526	5472	54
31	10N/70E-25D	91	20	5518	5490	28
32	10N/70E-12B	88	20	5456	5476	-20
33	10N/70E-11D	89	19	5481	5489	-8
34	9.5N/70E-33AB	99	17	5575	5570	5
35	9N/71E-6A	94	21	5521	5516	5
36	9N/70E-34DCD	100	18	5580	5574	6
37	9N/70E-14CAB	96	19	5593	5552	41
38	8N/70E-21AAD	103	17	5588	5586	2
39	8N/70E-6ABA	103	17	5582	5586	-4
40	8N/69E-36AAA	105	15	5671	5593	78
41	8N/69E-36A	105	15	5618	5593	25
42	8N/69E-35DC2	106	14	5660	5595	65
44	8N/69E-15BBD	102	12	5675	5602	73
45	(C-11-16)36DCB	14	43	4417	4365	52
46	(C-11-17)1BDC	9	36	4349	4402	-53
47	(C-11-17)11AAA	9	36	4335	4402	-67
48	(C-11-17)12ACC	10	37	4325	4381	-56
49	(C-11-17)12CBB	10	36	4336	4414	-78
50	(C-12-17)34AAC	20	35	4484	4575	-91
51	(C-12-17)35CAC	20	36	4479	4541	-62
52	(C-13-18)13CAC	23	31	4683	4684	-1
53	(C-13-18)23AAB	24	30	4686	4710	-24
54	(C-13-18)28DAB	26	28	4750	4766	-16

Table 8.--Comparison of actual vs. simulated water levels for wells used in calibration (cont'd).

Well ID No.	Location	Row	Column	Water Level (feet above sea level)		Residual
				Actual	Simulated	Δ
55	(C-13-18)33DDC	27	28	4750	4769	-19
56	(C-13-18)34CCC	27	29	4739	4726	13
57	(C-14-18)18DCC	30	26	4793	4825	-32
58	(C-14-18)26DBC	32	30	4791	4754	37
59	(C-15-19)11BCC	35	24	4892	4885	7
60	(C-16-18)26CBA	44	31	4838	4807	31
61	(C-16-19)4BBA	40	22	4928	4929	-1
62	(C-17-19)4ADD	46	23	4838	4883	-45
63	(C-18-18)31ADB	57	28	4901	4893	8
64	(C-18-19)20DAD	56	23	4935	4932	3
65	(C-18-19)20DDD	56	23	4964	4932	32
66	(C-18-19)28BCC	56	23	4952	4932	20
67	(C-19-19)26ABA	62	26	4930	4933	-3
68	(C-19-19)26BDD	62	25	4929	4932	-3
69	(C-19-19)35CDD	64	25	4966	4958	8
70	(C-19-19)35DCD	64	25	4958	4958	0
71	(C-19-19)36CDA	64	26	4951	4959	-8
72	(C-20-19)14BBC	66	25	4980	4981	-1
73	(C-20-19)19DCD	68	22	5042	5039	3
74	(C-20-19)21ACC	67	24	5001	5003	-2
75	(C-20-20)12ACC	65	20	5093	5094	-1
76	(C-21-18)32ABD	69	29	4984	5026	-42
77	(C-21-19)31CCA	75	22	5183	5189	-6
78	(C-22-19)6BCA	75	22	5176	5189	-13
79	(C-22-19)6BAC	75	22	5211	5189	22
80	(C-22-19)6BCC	76	22	5209	5223	-14
81	(C-22-19)31CB	81	22	5373	5356	17
82	(C-22-20)1AAC	75	21	5210	5217	-7
83	(C-22-20)1AAD	76	22	5207	5223	-16
84	(C-22-20)1ABA	75	21	5209	5217	-8
85	(C-22-20)1DAA	76	21	5195	5251	-56
86	(C-23-19)8D	83	24	5397	5346	51
87	(C-23-19)9CDB	83	24	5391	5346	45
88	(C-23-19)10CA	83	25	5416	5326	90
89	(C-23-19)10DD	83	26	5427	5308	119
90	(C-23-19)13AAB	83	28	5454	5276	178
91	(C-23-19)20BAC	85	23	5385	5391	-6
92	(C-23-19)20BDB	85	24	5392	5369	23
93	(C-23-19)20DBC	85	24	5399	5369	30
94	(C-23-19)22B	84	25	5357	5338	19
95	(C-23-19)24DCC	86	27	5325	5318	7
96	(C-23-19)28CB	86	24	5410	5380	30
97	(C-24-19)3CAD	88	26	5446	5356	90
98	(C-24-19)3DA	88	26	5444	5356	88
99	(C-24-19)4AA	87	25	5448	5368	80
100	(C-30-19)21CAB	126	26	6155	6144	11
103	(C-32-19)22DCB	140	27	6305	6315	-10
104	(C-32-19)27ACC	140	28	6235	6312	-77

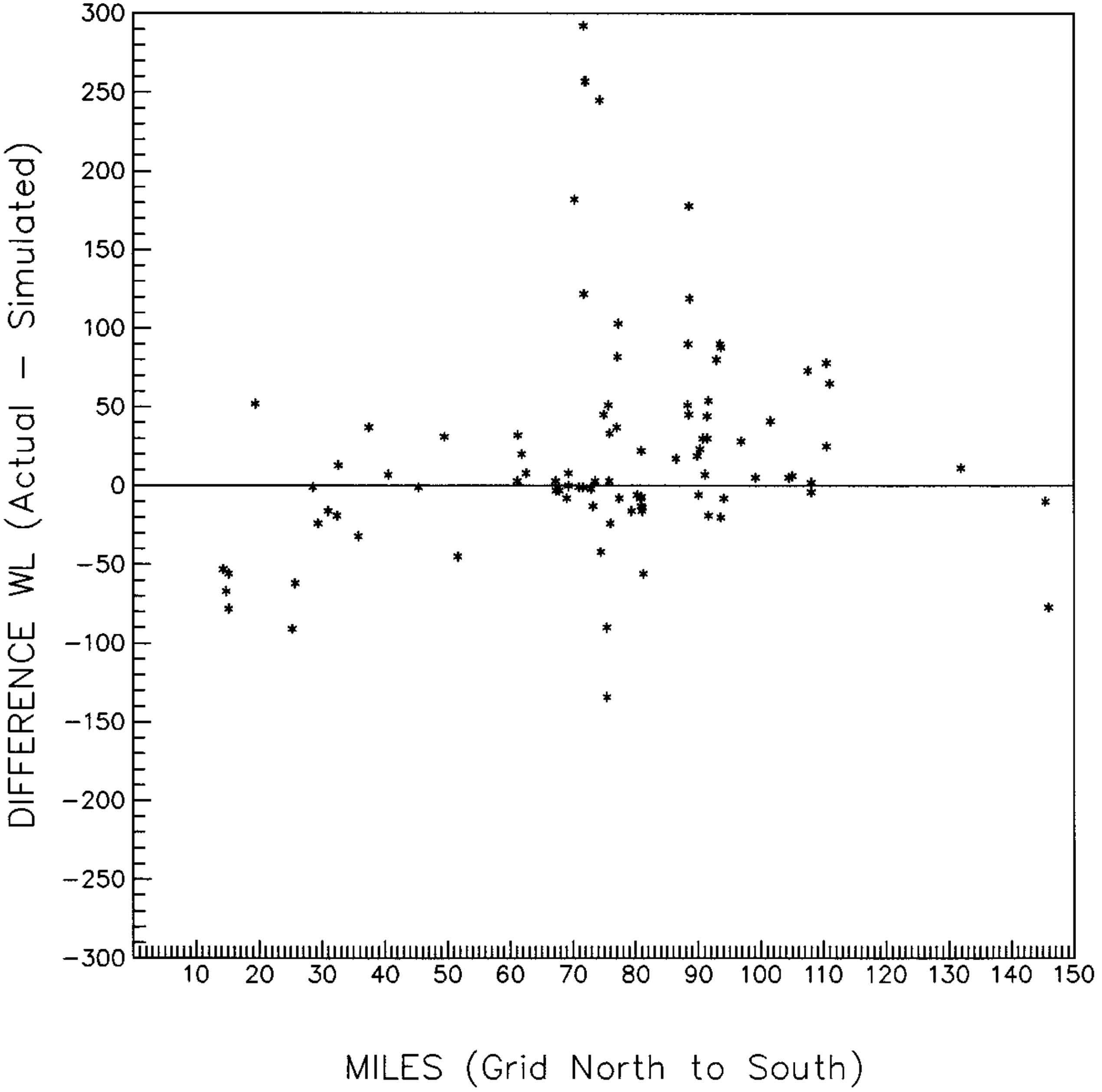


Figure 24. -- Difference between actual and simulated water levels.

Lower Layer

The potentiometric surface generated by the model for the lower layer is shown in Figure 23. There are no wells completed in the consolidated rock. As discussed in the section titled "Boundary Conditions" the general head boundaries are based on regional water levels found in Thomas et al. (1986). The contours indicating the potentiometric surface found in Thomas et al.(1986) for this area are dashed because there are no hard data to indicate the gradient in the consolidated rock aquifer, so values based on the upper heads were used. Only two transmissivity values were used for the lower layer as discussed above, with one area of relatively high transmissivitys to move water from northern Hamlin Valley to southern Snake Valley to the appropriate discharge areas while still matching the water levels in the alluvium. Outflow from Snake Valley is about 29,000 acre-feet per year with 14,000 acre-feet per year flowing through the alluvium and 15,000 acre-feet per year through the consolidated rock aquifer, compared to Harrill et al. (1988) estimation of 10,000 acre-feet per year flowing through the alluvium and 22,000 or 33,000 acre-feet per year flowing through the consolidated rock aquifer.

Based on the ground-water data and the uncertainties of the volume and flowpaths, the steady state model provides a reasonable match to existing water levels and the USGS ground-water budget. Table 9 compares the budget found in Hood and Rush (1965) with the model generated budget.

Table 9.--Comparison of Snake and Hamlin Valleys model budget with USGS (Hood and Rush, 1965, and Harrill et al., 1988) all values ac.ft./yr.

	USGS (Hood & Rush (1965)) (Harrill et al. (1988)	Steady State Model (rounded)
INFLOW:		
RECHARGE	103000	110000
From: Spring Valley	4000	4000
From: Pine and Wah Wah Valley	10000[a]	1000
Total:	117000	115000
OUTFLOW:		
ET	80000	87000[b]
To: Great Salt Desert (in alluvium)	10000	14000
Tule Valley (in consolidated rock)	22000 - 33000	15000
Total:	112000 - 123000	116000
SECONDARY RECHARGE[1]:	7000	6000

a) Based on the assumption that 1/2 flows (shown on HA694C) from Pine and Wah Wah Valleys combined enter Snake Valley.
b) Combination of springflow (drains) and evapotranspiration.
1) Not considered in model.

REFERENCES

Bunch R. L., and J. R. Harrill, 1984. Compilation of Selected Hydrologic Data from the MX Missile-Siting Investigation, East-Central Nevada and Western Utah, U.S. Geological Survey, Open-File Report 84-702.

Burbey, T.J., and D. E. Prudic, 1985. Simulation of Regional Ground-Water Flow in Carbonate-Rock Aquifers of the Great Basin in Nevada, Utah, and Adjacent States. (abs) Geological Society of America Abstracts, Vol. 17, p. 354.

Dettinger, M. D. , 1989. Distribution of Carbonate-Rock Aquifers in Southern Nevada and the Potential for their Development, U.S. Geological Survey.

Eakin, T.E., G.B. Maxey, T.W. Robinson, J.C. Fredericks, and O.J Loeltz, 1951. Contributions to the Hydrology of Eastern Nevada, Nevada Department of Conservation and Natural Resources, Water Resources Bullitin 12.

Ertec Western, 1981. MX Siting Investigations Water Resources Program Summary of Draft Environmental Impact Statement.

Fenneman, N. M., 1931. " Sierra Cascade Province,"Physiography of Western United States, Chapter IX, McGraw-Hill Book Co., Inc., New York, pp. 396-441.

Gates, J.S., 1963. Hydrogeology of Middle Canyon, Oquirrh Mountains, Tooele County, Utah, U.S. Geological Survey Water-Supply Paper 1619-K.

-----1965. Reevaluation of the Ground-Water Resources of Tooele Valley, Utah, Utah State Engineer Tech. Pub. 12.

Harrill, J. R., J. S. Gates, and J. M. Thomas, 1988. Major Groundwater Systems in the Great Basin Region of Nevada, Utah, and Adjacent States, U.S. Geological Survey Hydrologic Investigations Atlas HA-694-C.

Heath, R. C., 1984. Ground-water Regions of the United States, U.S. Geological Survey Water Supply Paper 2242.

Hintze, L.F., 1982. Geologic History of Utah, Brigham Young University Geology Studies, Vol. 20, Pt. 3.

Hood, J.W., and F.E. Rush, 1965, Water-Resources Appraisal of the Snake Valley Area, Utah and Nevada, State of Nevada, Department of Conservation and Natural Resources, Water Resources - Reconnaissance Series, Report 34.

Hose, R.K., and M.C. Blake, Jr., 1976, Geology and Mineral Resources of White Pine County, Nevada, Part I, Geology, Nevada Bureau of Mines and Geology, Bulletin 85.

Maxey, G.B. and T.E. Eakin, 1949. Groundwater in White River Valley, White Pine, Nye, and Lincoln Counties, Nevada, U.S. Geological Survey Water Resources Bulletin 8.

McDonald, Michael G. and A.W. Harbaugh, 1988. Techniques of Water-Resources Investigations of the United States Biological Survey, U.S. Geological Survey, Open-File Report 83-875, Chapter A1.

Mifflin, Martin D., 1968. Delineation of Ground-Water Flow Systems in Nevada, Water Resources Center, Publication No. 42004.

Nichols, William D., 1992. The Uncertainly of Water Budget Estimates in the Great Basin, Managing Water Resources During Global Change, America Water Resources Association, November 1992.

Plume, R.W., and S.M. Carlton, 1988. Hydrology of the Great Basin Nevada, Utah and Adjacent States: U.S. Geological Survey Hydrologic Investigation, Atlas HA 6594-A.

Quiring, R. F., 1965. Annual Precipitation Amount as a Function of Elevation in Nevada South of 38 1/2 Degrees Latitude: Las Vegas, Nevada, U.S. Weather Bureau Research Station.

Rush , Eugene F., and S.A. Kazmi, 1965. Water Resources Appraisal of Spring Valley, White Pine and Lincoln Counties, Nevada, Department of Conservation and Natural Resources, Water Resources-Reconnaissance Series Report 33, 36 p.

Scott, B. R., T. J. Smales, F. E. Rush, and A. S. Van Denburgh, 1971. Water for Nevada: Nevada Department of Conversation & Natural Resources, Water Planning Report No. 3.

Stewart J.H., 1980. Geology of Nevada: Nevada Bureau of Mines and Geology Special Publication #4, 136 p.

Stewart, John H., and John E. Carlson, 1978. Geologic map of Nevada, Reston, Va., U.S. Geological Survey, scale 1:500,000.

Thomas, J. M., J. L. Mason, and J. D. Crabtree, 1986. Groundwater Levels in the Great Basin Region of Nevada, Utah, and Adjacent States, U.S. Geological Survey, Hydrologic Investigations Atlas HA-694-B.

Tschanz, C.M., and E.H. Pampeyan, 1970. Geology and Mineral Deposits of Lincoln County, Nevada, Bulletin 73, Nevada Bureau of Mines.

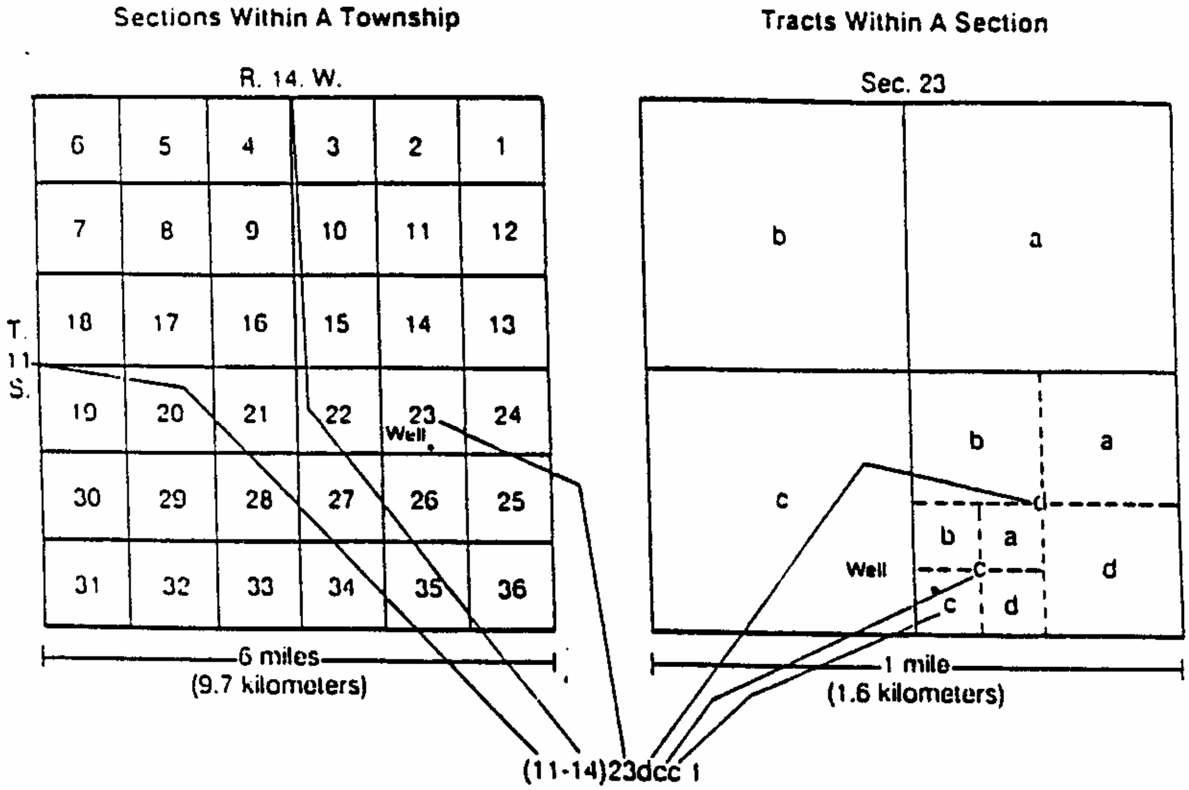
Turner, Robert M., and Walter J. Bawiec, 1992. Geology of Nevada: A Digital representation of the 1978 geologic map of Nevada, U.S. Geological Survey Digital Data Series DDS-2, 22 p.

Winograd, I.J., 1963. A Summary of the Groundwater Hydrology of the Area Between the Las Vegas Valley and the Amargosa Desert, Nevada, U.S. Geological Survey TEI-840

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

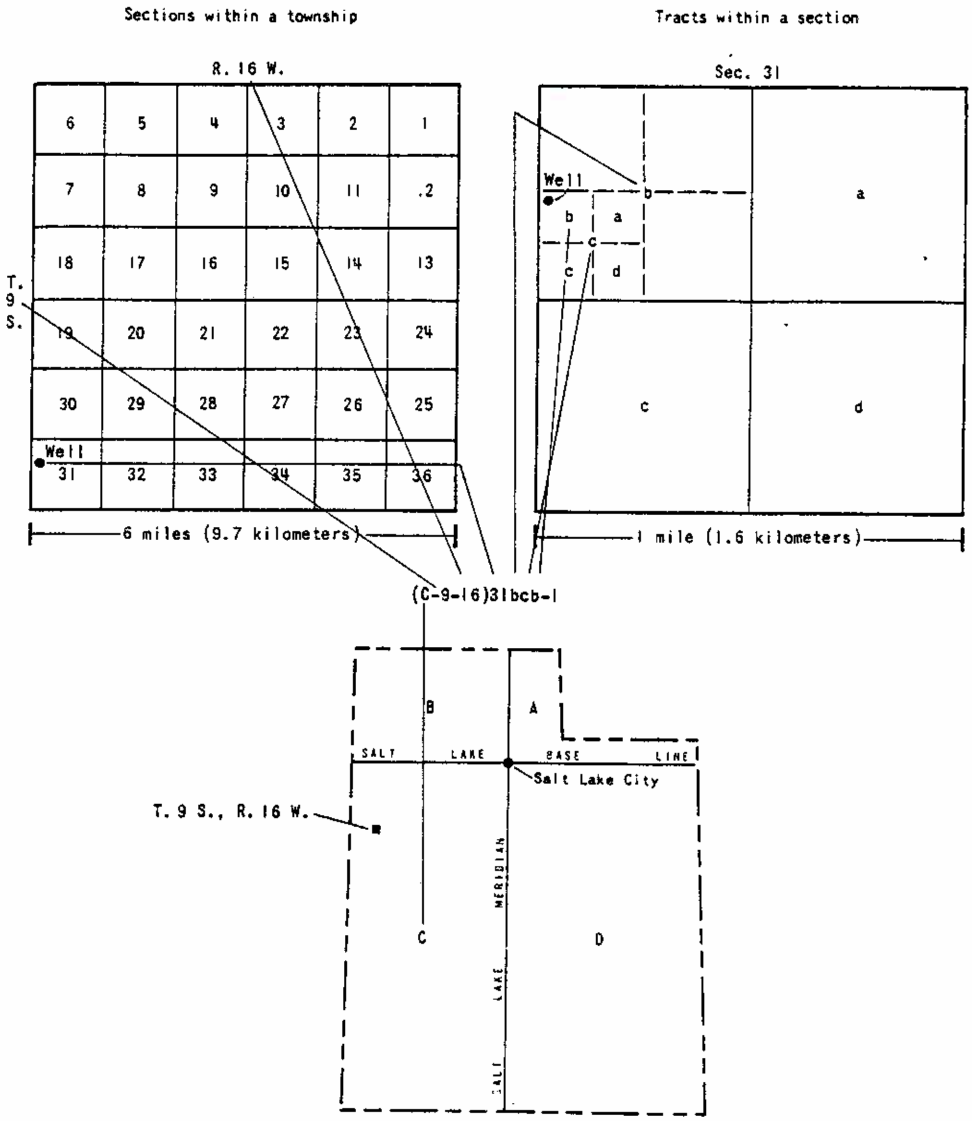
APPENDIX A

NEVADA LOCATION DESIGNATION



Well and spring locations are designated with respect to the Mount Diablo baseline and meridian as shown diagrammatically above. The first number within the parentheses represents the township south of the baseline and the second number represents the range east of the meridian. The section number follows along with the section 1/4, section 1/16th, and section 1/64th. The letter designations a, b, c, and d refer to the northeast, northwest, southwest, and southeast, respectively. If more than one well occurs within the same 1/64th section, a numerical identifier is added to the end of the designation. Thus (28-63) 27 abal represents the first well of record in the northeast quarter-section of the northwest quarter-section of the northeast quarter-section of Township 28 South, Range 63 East, Section 27.

UTAH LOCATION DESIGNATION



The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well or spring, describes its position in the land net. By the land-survey system, the State is divided into four quadrants by the Salt Lake base line and meridian, and these quadrants are designated by the uppercase letters A, B, C, and D, indicating the northeast, northwest, southwest, and southeast quadrants, respectively. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section, and is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section--generally 10 acres (4 hm^2);[1] the letters a, b, c, and d indicated, respectively the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the well or spring within the 10-acre (4-hm^2) tract; the letter "S" preceding the serial number denotes a spring.

APPENDIX B

WATER BASIN 195
SNAKE VALLEY
PERMITS AND APPLICATIONS

Application / Certificate		Point of Diversion				Diversion Rate	Consumption Allocated		Use	ACAD Block	Place of use	Notes
Permit/Proof	Date of Priority	1/4 1/4	Sec.	Township	Range		AcFt/Yr	Duty AcFt/Yr				
474 84	05/16/07	NW SE	14	14N	69E	1.4880	446.40	595.20	Irrigation, Stock, & Domestic	SURF PE	S1/2 SW S13, NE NW, NW NE, SW NE, SE NE S24 T14N R69E	
983 171	05/26/08	SW SE	2	14N	68E	1.0000	723.79	723.79	Power, Milling, & Domestic	SURF PE	NE SW S31 T14N R68E	Portion is non-consumptive
1024	01/01/86	SE SE	27	21N	69E	0.5000	0.00	0.00	Stockwater	SURF OTH	NE NE S29 T21N R69E	No stock count given. Permit 01024. "0" prefix not accepted by data base
1052 244	07/13/08	NE NW	23	13N	68E	0.2000	60.00	80.00	Irrigation, Stock, Domestic	SURF PE	NW NW S6 T13N R68E, E1/2 NE S1 T13N R67E	Permit 01052
1059 37	07/16/08	NE NE	24	14N	69E	0.6600	197.34	263.12	Irrigation	SURF PE	SW NW, N1/2 SW, SE SW S19 T14N R70E	
1064	01/01/82	SW SW	11	13N	69E	12.5000	0.00	0.00	Irrigation & Domestic	SURF PE	SW NE, NE NE, SE NE S11 NW NW, NE NW, SW NW, SW NE, SE NW, SE NE, NW SW, SW SW, E1/2 SW, W1/2 SE, SE SE, NE SE S12, NW NW, NE NW, NW NE, NE NE S13 T13N R69E	Permit 01064. Comingled with 01066
1065	01/01/90	SW SW	10	13N	69E	0.6250	22.50	30.00	Irrigation & Domestic	SURF PE	NE NW S15 T13N R68E	Permit 01065. Second POD at NE NW S15 T13N R69E
1066	01/01/68	NE SE	8	13N	70E	0.0000	7891.47	10521.96	Irrigation & Domestic	SURF PE	POR SECS 11-13 T13N R70E, POR SECS 3,4,9,10,11,14,15,16 T13N R70E	Permit 01066. Comingled with 01064, 2223, 3906
1131	01/01/78	NW SE	14	14N	69E	4.0000	135.66	180.88	Irrigation & Domestic	SURF PE	NE SE, SE SE S14, NE NE, NE SE, SE NW, NW NW S24 T14N R69E	Permit 01131
1147	01/31/02	SW SE	24	11N	69E	0.1000	0.00	0.00	Stockwater	SURF OTH	SW SE S24 T11N R69E	Permit 01147. No stock count given
1148	01/31/02	SW NE	25	11N	69E	0.3000	0.00	0.00	Stockwater	SURF OTH	SW NE S25 T11N R69E	Permit 01148. No stock count given
1209	01/01/77	SE NE	7	14N	70E	0.0000	0.00	0.00	Domestic & Stockwater	SURF OTH	NW NW S7, NE NW, SW NW S17 T14N R70E	Permit 01210. Div. rate given as 1000". No stock count given
1210	01/01/80	SE SE	7	14N	70E	0.0000	270.00	360.00	Irrigation & Stockwater	SURF PE	NW NW, SE SE, NW SE S17 T14N R70E	Permit 01210. Second POD at NW NW S17 T14N R70E. No div. rate given
1235	01/01/96	SE SE	32	14N	69E	0.0000	135.00	180.00	Irrigation	SURF PE	NW1/4 S33, NE NE S32 T14N R69E	Permit 01235. No div. rate given

WATER BASIN 195
SNAKE VALLEY
PERMITS AND APPLICATIONS

Application / Certificate		Point of Diversion				Diversion Rate	Consumption Allocated		Use	ACAD Block	Place of use	Notes
Permit/Proof	Date of Priority	1/4 1/4	Sec.	Township	Range		AcFt/Yr	Duty AcFt/Yr				
1311	02/02/89	NW SE	14	14N	69E	4.000	79.14	105.52	Irrigation & Domestic	SURF PE	NE SE, SE SE S14, NE NE, NE SE, SE NW, NW NW S24 T14N R69E	
1375 240	06/07/09	NW SE	11	13N	70E	1.3500	405.00	540.00	Irrigation, Stock, Domestic	SURF PE	S1/2 NW, N1/2 SW S12 T13N R70E	
1638 110	03/31/10	SW NE	3	20N	70E	0.1250	10.08	10.08	Stockwater & Domestic	SURF OTH	SW NE S3 SW SW S10, T20N R70E, NW SW S32 T20.5 R70E	Permit also includes Cert# 111 & 112. 2nd & 3rd POD at SW SW S10 T20N R70E, NW SW S32 T20N R70E
1650	01/01/98	NW NE	33	10N	70E	2.5000	0.00	0.00	Stockwater	SURF OTH	W1/2 SE, S1/2 NE, NE NE S15, E1/2 SE S10 T10N R70E, NW SW, S1/2 NW, NE NW S11, W1/2 SE, NE SE, SE NE S2 T10N R70E	Permit 01650. No stock count given
1651	01/01/84	NW NE	33	10N	70E	1.5500	482.40	643.20	Irrigation, Stock, Domestic	SURF PE	NE NW, NW NE S27, S1/2, E1/2 NE, NW NE, NE NW S22, NW NW S23 T10N R70E	Permit 01651
1652	01/01/87	NW NE	33	10N	70E	2.6000	231.00	308.00	Irrigation, Stock, Domestic	SURF PE	NW NE, SW NE, NE NE S33, SW SW S27 S1/2 SE S28, W1/2 NW S34 T10N R70E	Permit 01652
1710 203	06/08/10	SE SW	6	11N	70E	0.2400	72.00	96.00	Irrigation, Stock, Domestic	SURF PE	SE SW, SW SE S6, NW SW, NE SW S5 T11N R70E	
1717	01/01/00	NW SE	33	15N	68E	0.1000	0.00	0.00	Stockwater	SURF OTH	NW SE S33 T15N R68E	Permit 01717. No stock count given
1900 117	12/07/10	SW SE	2	17N	68E	0.0250	0.00	0.00	Stockwater & Domestic	SURF OTH	SW SE S2 T17N R68E	No stock count given
1930 87	01/14/11	SE NW	8	15N	70E	0.0250	0.00	0.00	Stockwater & Domestic	SURF OTH	SE NW S8 T15N R70E	No stock count given
1935	01/01/95	NE SE	27	21N	69E	0.0040	0.00	0.00	Stockwater	SURF OTH	NE SE S27 T21N R69E	Permit 01935. No stock count given.
2108 29	06/16/11					0.0250	0.00	0.00	Stockwater	SURF OTH	SEE NOTES	No stock count given
2119 1094	06/24/11	SE NW	19	14N	70E	0.6024	0.00	0.00	Irrigation	SURF PE	N1/2 SE, SE SE S19 T14N R70E	Comingled with 21174
2125	01/01/00	SE NE	3	9N	70E	0.0250	0.00	0.00	Stockwater	SURF OTH	SE NE S3 T9N R70E	Permit 02125. No stock count given
2200	01/01/00	NW NE	13	10N	70E	0.0250	0.00	0.00	Stockwater	SURF OTH	NW NE S13 T10N R70E	Permit 02200. No stock count given

WATER BASIN 195
SNAKE VALLEY
PERMITS AND APPLICATIONS

Application / Certificate		Point of Diversion				Diversion Rate	Consumption Allocated		Use	ACAD Block	Place of use	Notes
Permit/Proof	Date of Priority	1/4 1/4	Sec.	Township	Range		AcFt/Yr	Duty AcFt/Yr				
2223	10/02/11	NE SE	8	13N	70E	6.8000	0.00	0.00	Irrigation & Domestic	SURF PE	SE SE S4, SW SW S3, NE1/4, NE SW S9, NW1/4, E1/2 NE, N1/2 SW, N1/2 SE S10 T13N R70E	Comingled with 01066
2284 96	12/12/11	SW NE	22	20N	69E	0.0250	0.00	0.00	Stockwater & Domestic	WELL OTH	SW NE S22 T20N R69E	No stock count given
2507	09/12/12	SE SW	30	13N	70E	1.2000	0.00	0.00	Irrigation & Domestic	SURF PE	SE SW, W1/2 SE S30 T13N R70E	No acreage given. Unable to compute consumptive use
2519	01/01/74	SE NW	29	14N	69E	2.5000	330.00	440.00	Irrigation	SURF PE	S1/2 SE S9, NW NW, S1/W NW S15, N1/2 NE S16, T14N R69E	Permit 02519. Comingled with 26227
2520	01/31/02	UNK	24	14N	69E	1.0000	0.00	0.00	Irrigation & Stockwater	SURF PE	E1/2 SE S14, N1/2 NW, NE1/4, NE SE S24, S1/2 SW S13 T14N R69E	Permit 02520. Comingled with 474
2538	01/01/80	UNK	20	14N	70E	0.5000	0.00	0.00	Stockwater	SURF OTH	SEE NOTES	Permit 02538. POD, POU, Stock count not given
2654	01/01/96	NW SW	35	16N	70E	2.5000	649.72	866.29	Irrigation, Stock, Domestic	SURF PE	SW1/4, S1/2 NW, NE NW, W1/2 SE, W1/2, NE S21, N1/2 NW, NW NE S28 T18S R19W	Permit 02654
2710 259	05/12/43	SE SE		14N	68E	0.2000	144.76	144.76	Mining, Milling, & Domestic	SURF PE	NE NW S25 T14N R67E	POD given as "at S83005'E 13730 from N1/4 on Sec 26 T14N R67E
3442 860	06/16/15	NW NW	17	14N	70E	1.2819	288.43	384.57	Irrigation & Domestic	SURF PE	S1/2 NW, N1/2 SW, W1/2 SE S22 T14N R70E	
3723 1295	12/03/15	NW SE	3	11N	70E	0.0500	0.00	0.00	Stockwater	SURF OTH	NW SE S3 T11N R70E	No stock count given
3869 4349	04/06/16	NE SE	8	13N	70E	0.4950	171.00	228.00	Irrigation	SURF PE	SE NE S4, SW NW, NW NW S3 T13N R70E	
3906	09/01/11	SW SW	12	13N	6970	0.0000	0.00	0.00	Irrigation & Domestic	SURF PE	POR SECS 11,12,13 T13N R69E, POR SECS 2,3,4,9,10,11,14,15,16 T13N R70 E	Comingled with 01066. #1 of 2 pts. of diversion this permit
3906	09/09/11	SE SE	23	13N	69E	0.0000	0.00	0.00	Irrigation & Domestic	SURF PE	SEE BELOW	Comingled with 01066. #2 of 2 pts. of diversion this permit
3969	01/01/81	SW SW	30	13N	70E	1.0000	122.67	163.56	Irrigation & Stockwater	SURF PE	SE SW, SW SE S30, LOT1, NE NW S31 T13N R70E	Permit 03969
4100 825	06/10/15	SW NW	28	14N	70E	1.5862	475.86	634.48	Irrigation	SURF PE	LOT 1,2,5,6 OF THE NW1/4 S7 T20S R19W	
4568	01/31/70	NE NW	24	10N	70E	1.0000	0.00	0.00	Stockwater	WELL OTH	NE NW S24 T10N R70E	Permit 04568. No stock count given

WATER BASIN 195
SNAKE VALLEY
PERMITS AND APPLICATIONS

Application / Certificate		Point of Diversion				Diversion Rate	Consumption Allocated		Use	ACAD Block	Place of use	Notes
Permit/Proof	Date of Priority	1/4 1/4	Sec.	Township	Range		AcFt/Yr	Duty AcFt/Yr				
4596	01/01/80	SW NW	1	13N	69E	0.2007	45.00	60.00	Irrigation	SURF PE	SW NW S1 T13N R69E	Permit 04596. Source of water listed as 2 springs, 1 well
4597	01/01/80	SE NW	1	13N	69E	0.0223	0.44	0.44	Stockwater	SURF OTH	SE NW S1 T13N R69E	Permit 04597
4598	01/01/65	NW NW	1	13N	69E	0.0220	15.92	15.92	Domestic	SURF PE	NW NW S1 T13N R69E	Permit 04598
4854 4350	01/19/18	NE SE	8	13N	70E	0.6910	239.25	319.00	Irrigation	SURF PE	SE NW, S1/2 NE, NE SE S3, NW SW S2 T13N R20E	
5712 796	09/05/19	NE SE	29	20N	70E	0.0060	0.00	0.00	Stockwater	SURF OTH	NE SE S29 T20N R70E	No stock count given
5714 798	09/05/19	SW SW	13	18N	68E	0.0060	0.00	0.00	Stockwater	SURF OTH	SW SW S13 T18N R68E	No stock count given
6167 1772	06/11/20	NE NW	5	11N	70E	0.1850	33.54	44.72	Irrigation	SURF PE	NE NW, N1/2 NE S5, NW NW S4 T11N R70E	
6176 778	06/17/20	NE NW	35	14N	69E	0.0090	0.00	0.00	Stockwater	SURF OTH	NE NW S35 T14N R69E	No stock count given
6289 1301	10/04/20	NE NW	34	21N	69E	0.0125	0.00	0.00	Stockwater	SURF OTH	NE NW S34 T21N R69E	No stock count given
6644 1939	03/06/22	SE NE	2	18N	68E	0.0090	0.00	0.00	Stockwater	SURF OTH	SE NE S2 T18N R68E	No stock count given
6854 1354	01/24/23	NW SW	19	15N	70E	0.0125	0.00	0.00	Stockwater & Domestic	SURF OTH	NW SW S19 T15N R70E	No stock count given
6925 1540	06/29/73	NE NE	31	13N	70E	0.0031	0.00	0.00	Stockwater	SURF OTH	NW NW S32 T13N R70E	No stock count given
6935 1551	07/10/23	NE SW	17	20N	70E	0.0094	0.00	0.00	Stockwater	SURF OTH	NE SW S17 T20N R70E	No stock count given
7241 1384	10/30/24	NW NW	23	19N	69E	0.0125	8.96	8.96	Stockwater	SURF OTH	NW NW S23 T19N R69E	
7245 1336	11/09/24	NE NE	19	13N	70E	0.0156	0.00	0.00	Stockwater	SURF OTH	NE NE S19 T13N R70E	No stock count given
7263 1300	12/01/24	NW SW	26	21N	69E	0.0125	8.96	8.96	Stockwater	SURF OTH	NW SW S26 T21N R69E	
7331 1473	03/27/25	NW NE	32	13N	70E	0.0062	0.00	0.00	Stockwater	SURF OTH	NW NE S32 T13N R70E	No stock count given
7342 1344	04/25/25	NE NE	5	12N	70E	0.0019	0.00	0.00	Stockwater	SURF OTH	NE NE S5 T21N R70E	No stock count given
7418 1328	06/28/25	SE NE	8	14N	68E	0.0062	0.00	0.00	Stockwater	SURF OTH	SE NE S8 T14N R68E	No stock count given
7572 1347	11/16/25	NE SE	34	21N	69E	0.0130	0.00	0.00	Stockwater	SURF OTH	NE SE S34 T21N R69E	No stock count given
7707 1513	04/11/26	SW SW	30	15N	71E	0.0125	0.00	0.00	Stockwater	SURF OTH	SW SW S30 T15N R71E	No stock count given
7959 2252	12/30/26	NW SW	14	16N	70E	0.0125	0.00	0.00	Stockwater	SURF OTH	NW SW S14 T16N R70E	No stock count given
8038 2040	03/16/27	NW SW	7	13N	70E	0.0130	0.00	0.00	Stockwater	SURF OTH	NW SW S7 T13N R70E	No stock count given

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Permit/Proof	Date of Priority	1/4 1/4	Sec.	Township	Range		AcFt/Yr	Duty AcFt/Yr				
8052 2852	03/25/27	NW NE	36	15N	68E	0.0030	0.00	0.00	Stockwater	SURF OTH	NW NE S36 T15N R68E	No stock count given
11022 3431	10/29/43	SE SW	15	19N	69E	0.0250	17.90	17.90	Stockwater	WELL OTH	SE SW S15 T19N R69E	No stock count given
11035 3377	12/06/43	NW SW	31	15N	69E	0.0030	0.00	0.00	Stockwater	SURF OTH	NW SW S31 T15N R69E	No stock count given
11036 8900	12/06/43	NW NW	34	15N	69E	0.0031	0.00	0.00	Stockwater	SURF OTH	SW NW S34 T15N R69E	No stock count given
12932 4221	05/27/49	SW SW	14	13N	70E	0.0454	49.80	66.40	Irrigation & Domestic	WELL PE	SW SW S14 T13N R70E	
13067 3538	09/28/49	SE NW	20	14N	69E	0.2000	6.00	8.00	Irrigation & Domestic	SURF PE	NE SW S16 T14N R69E	2 houses, 1 AC of lawn
13089 3862	10/11/49	SE NW	15	12N	70E	3.0000	0.00	0.00	Fish Rearing	SURF OTH	NE NW, NW NE S15 T12N R70E	Non-consumptive use
13090 3863	10/11/49	NE NW	15	12N	70E	5.0000	0.00	0.00	Fish Rearing	SURF OTH	NE NW, NW NE S15 T12N R70E	Non-consumptive use
13206 4629	12/27/49	NE NE	23	17N	70E	2.0000	478.29	637.72	Irrigation & Domestic	SURF PE	NW NW, NE NW, SW NW, SE NW, NW SW, S3 T17S R19W, SE NE, NE SE S4 T17S R19W	159.543 AC
13536 4314	11/13/50	SE SW	36	15N	69E	1.0000	43.20	57.60	Irrigation	SURF PE	LOT 3&5, S1 LOT 7 S6, T14N R69E	14.4 AC
13640 4504	02/19/51	NW SE	9	13N	70E	0.7100	181.13	241.50	Irrigation & Domestic	WELL PE	NW NE, SW NE, NW SE S9 T13N R70E	
15213 4635	07/20/53	SE SW	4	13N	70E	1.0000	511.34	681.87	Irrigation	WELL PE	NW SW, SW SW, NE SW, SE SW, NW SE, SW SE S4 T13N R70E	
15555 4479	03/15/54	NE NW	15	12N	70E	0.0223	8.05	8.05	Domestic	WELL PE	NE NW S15 T12N R70E	
16204 5309	03/21/55	NE SE	7	14N	70E	0.5600	304.20	405.60	Irrigation	SURF PE	SE SE S7, SW SW, NW NW, SW NW, SE NW, NE SW, NW SE, NE SE, SE SE, SW SE S17 T14N R70E	
17017 46731	02/02/17	NE NW	6	13N	68E	0.3182	72.75	97.00	Irrigation & Domestic	SURF PE	NE NW, NW NW, SW NW S6, NE NE, SW NE S1 T13N R67E	
19524 5948	02/01/61	NW SE	33	15N	68E	0.2000	17.40	23.20	Irrigation & Domestic	SURF PE	SW NW S34 T15N R68E	
19740 6473	04/10/61	NW NE	10	13N	70E	5.4000	1362.00	1816.00	Irrigation	WELL PE	NE SE, SW SW, SE SE S3, NW SW, SW SW, SE SW, SW SE S2, NW NE, NE NE S10, N1/2 S11 T13N R70E	
20063 5853	08/31/61	NW SE	35	14N	69E	0.1100	3.08	4.10	Irrigation & Domestic	SURF PE	S1/2 NE, SE1/4 S35 T14N R69E	
20064 5780	08/31/61	NE SE	35	14N	69E	0.0062	0.00	0.00	Stockwater	SURF OTH	NE SE S35 T14N R69E	No stock count given

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Permit/Proof	Date of Priority	1/4 1/4	Sec.	Township	Range		AcFt/Yr	Duty AcFt/Yr				
20096 5852	09/21/61	NE SW	18	15N	69E	0.4456	166.68	222.24	Irrigation & Domestic	SURF PE	NE SW, NW SE, SW SE S18, NW NE, NE NE, SE NE, NE SE S19 T15N R69E	
20794 7573	10/18/62	SW NE	9	13N	69E	0.1500	109.50	109.50	Domestic, Recreation, Fire	SURF PE	POR. OF S10 & 15 T13N R69E	
21174 7574	04/03/63	SW NW	19	14N	70E	0.7530	137.28	183.04	Irrigation & Domestic	SURF PE	NW SE, NE SE S19 T14N R70E (59.8 AC)	Comingled with 2119
23195 6417	06/20/66	NW NE	35	15N	69E	0.4500	79.76	106.35	Irrigation	SURF PE	SE NE, NE SE S35, NW SW, SE SW S36 T15N R69E	
23580 7955	01/03/67	SW NE	16	13N	70E	1.0000	22.80	30.40	Irrigation & Domestic	WELL PE	SW NE S16 T13N R70E (7.6 AC)	
24022 7837	08/01/67	SE NW	24	14N	69E	0.0220	0.75	1.50	Quasi-municipal	WELL PE	SE NW S24 T14N R69E	Svc. to motel, bar, cafe, & service station
24072 8260	08/18/67	SE SW	14	16N	70E	3.2000	66.39	88.52	Irrigation & Domestic	SURF PE	NW NE, NE NE S8 T18S R19W (22.13 AC.)	
24121 7280	09/15/67	NW SW	13	18N	68E	0.0078	0.00	0.00	Stockwater & Domestic	SURF OTH	NW SW S13 T18N R68E	No stock count given
24122 7281	09/15/67	SW NW	13	18N	68E	0.0078	0.00	0.00	Stockwater	SURF OTH	SW NW S13 T18N R68E	No stock count given
26227 9154	07/23/71	NE SW	16	14N	69E	2.700	0.00	0.00	Irrigation & Domestic	SURF PE	SW SE, SE SE S9, NW NE, NE NE S16, NW NW, SW NW, SE NW S15 T14N R69E (81.25 AC)	Comingled with 02519
26735 9480	05/22/72	NW SW	25	10N	70E	1.0000	197.25	263.00	Irrigation & Domestic	WELL PE	NW SW, NE SW S25 T10N R70E	
27079 8614	10/17/72	NW SE	16	13N	70E	0.5000	41.40	55.20	Irrigation	WELL PE	NW SE, NE SE S16 T13N R70E	
33141	02/02/78	SW SE	35	10N	70E	2.7000	480.00	640.00	Irrigation & Domestic	WELL DLE	SE1/4 S35 T10N R70E	
33142	02/02/78	SW SW	36	10N	70E	2.7000	480.00	640.00	Irrigation & Domestic	WELL DLE	SW1/4 S36 T10N R70E	
33143	02/02/78	SW NE	35	10N	70E	2.7000	480.00	640.00	Irrigation & Domestic	WELL DLE	NE1/4 S35 T10N R70E	
33146	02/02/78	SW NW	36	10N	70E	2.7000	480.00	640.00	Irrigation & Domestic	WELL DLE	NW1/4 S36 T10N R70E	

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Permit/Proof	Date of Priority	1/4 1/4	Sec.	Township	Range		AcFt/Yr	Duty AcFt/Yr				
33148	02/02/78	SE NE	23	10N	70E	2.7000	480.00	640.00	Irrigation & Domestic	WELL DLE	NE1/4 S23 T10N R70E	
33149	02/02/78	NW NW	24	10N	70E	2.7000	480.00	640.00	Irrigation & Domestic	WELL DLE	N1/2 NW, NW NE S24, SW SW S13 T10N R70E	
33150	02/02/78	SW SE	23	10N	70E	2.7000	480.00	640.00	Irrigation & Domestic	WELL DLE	SE1/4 S23 T10N R70E	
33151	02/12/78	SW SW	13	10N	70E	2.7000	480.00	640.00	Irrigation & Domestic	WELL DLE	SW1/4 S13 T10N R70E	
41208 10254	08/12/80	NW SE	30	13N	70E	0.0017	0.00	0.00	Stockwater & Domestic	SURF OTH	W1/2, SE1/4, SE NE S30 T13N R70E	No stock count given
41209 10255	08/12/80	SE SW	30	13N	70E	0.0017	0.00	0.00	Stockwater & Domestic	SURF OTH	SW1/4, N1/2 SE, SW SE, SE NE S30 T13N R70E	No stock count given
42067	10/29/80	LOT 4	1	12N	70E	5.6000	960.00	1280.00	Irrigation	WELL DLE	SECTION 1	
42069	02/23/81	SE SW	36	13N	70E	5.6000	960.00	1280.00	Irrigation	WELL DLE	W1/2 S36 T13N R70E	
42096	01/16/81	NW NE	23	13N	70E	5.6000	960.00	1280.00	Irrigation	WELL DLE	N1/2 S23 T13N R70E	
42097	01/16/81	NE NW	24	13N	70E	5.6000	960.00	1280.00	Irrigation	WELL DLE	N1/2 S14 T13N R70E	
42393	10/29/80	LOT1	6	13N	71E	5.6000	960.00	1280.00	Irrigation	WELL DLE	SW NE, SE NE S1, N1/2 S6 T13N R70E, LOT 1&2	
42395	05/22/81	SW SE	36	13N	70E	6.0000	960.00	1280.00	Irrigation	WELL DLE	E1/2 S36 T13N R70E	
42397	05/01/81	SW NW	33	14N	70E	5.6000	960.00	1280.00	Irrigation	WELL DLE	W1/2 S33 T14N R70E	
42810	05/13/81	NW NE	27	14N	70E	7.4000	960.00	1280.00	Irrigation	WELL DLE	E1/2 S27 T14N R70E	
42812	11/10/80	NW NE	28	14N	70E	7.4000	960.00	1280.00	Irrigation	WELL DLE	E1/2 S28 T14N R70E	See Ruling 3711
43431	06/01/81	NW SE	36	14N	70E	6.0000	960.00	1280.00	Irrigation	WELL DLE	S1/2 S36 T14N R70E	
45501	04/05/82	NW SW	15	13N	70E	6.0000	0.00	0.00	Irrigation & Domestic	WELL PE	SW1/4 S15, E1/2 SE S16, W1/2 NW S22, S1/2 NE, SE1/4, E1/2 SW, SW SW S12 T13N R70E, SEC7 T13N R71E	Total flow NTE 3.0 AC.FT/AC. annually. Comingled with 45501
45502	04/05/82	SE NE	4	13N	70E	6.0000	2070.00	2760.00	Irrigation & Domestic	WELL PE	W1/2 NW S3, NE1/4, E1/2 NW S4, S1/2 NE, SE1/4, E1/2 SW, SW SW S12 T13N R70E, ALL SEC 7 T13N R71 E	Total flow NTE 3.0 AC.FT/AC. annually. Comingled with 45501

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Permit/Proof	Date of Priority	1/4 1/4	Sec.	Township	Range		AcFt/Yr	Duty AcFt/Yr				
45503	04/05/82	NW NW	22	14N	70E	5.4000	720.00	960.00	Irrigation & Domestic	WELL PE	NW1/4, W1/2 NE, W1/2 SE S22 T14N R70E	Total flow NTE 3.0 AC.FT/AC. annually
45518	08/12/82	SW SW	11	13N	69E	4.5000	0.00	0.00	Hydroelectric	SURF OTH	SE1/4 S9 T13N R70E	Non-consumptive use
45519	08/12/82	SW SW	7	13N	70E	10.0000	0.00	0.00	Hydroelectric	SURF OTH	SE1/4 S9 T13N R70E	Non-consumptive use
45974	08/12/82	SW SW	11	13N	69E	3.0000	0.00	0.00	Hydroelectric	SURF OTH	SE1/4 S9 T13N R70E	Non-consumptive use
47113	08/02/83	NW SE	35	15N	68E	2.0000	4.28	4.28	Mining, Milling & Domestic	WELL PE	SE SW, S1/2 SE S34, SW SW, SE SW, SW SE, NW SE S35 T15N R68E	
47277	09/29/83	SE NW	34	15N	68E	3.0000	264.38	264.38	Mining & Milling	WELL PE	S1/2 S32, S1/2 S33, ALL S34 T15N R68E, SECS 2,3 N1/2 S4, NW1/4 S10 T14N R68E	
47278	09/29/83	SE NW	10	14N	68E	3.0000	0.00	0.00	Mining & Milling	WELL PE	S1/2, S32, S1/2 S33, ALL S34 T15N R68E, SECS 2, 3, N1/2 S4, NW1/4 S10 T14N R68E	Comingled with 47277
48167	09/27/84	SW NW	36	10N	70E	5.4000	960.00	1280.00	Irrigation & Domestic	WELL DLE	NW1/4, W1/2 NE, LOTS 5&6, S36 T10N R70E	
48255	07/30/84	NE SE	7	14N	69E	2.5000	0.00	0.00	Mining, Milling & Domestic	WELL PE	LOT 1, SE NE, SW NE S1, SE NW, S1/2 NE S12 T14N R68E, LOT 4, SE SW S31 T15N R69E, LOT 1&2, S6, SW1/4 S5, LOT 1,2,3, (CONTINUED IN NOTES)	E1/2 NW, NE SW, N1/2 SE, NE1/4 S7, NW1/4, N1/2 SW, SW NE, LOT 2&3, NW SE S8 T14N R69E. Non-consumptive use
49819	07/01/77	NW NE	25	10N	70E	5.4000	0.00	0.00	Irrigation & Domestic	WELL PE	E1/2 NW, W1/2 NE, LOT 4,5,6,7 S25 T10N R70E	Comingled with 49820
49820	07/01/77	LOT 5	25	10N	70E	5.4000	720.00	960.00	Irrigation & Domestic	WELL PE	E1/2 NW, W1/2 NE, LOT 4,5,6,7 S25 T10N R70E	Total consumptive use for 49819 & 49820 NTE 960 AC.FT./YR., or 3.0 AC.FT./AC.
51446	10/21/87	SE SW	9	13N	70E	1.0000	14.00	28.00	Quasi-municipal	WELL PP	BAKER TOWNSITE (SE SW S9 T13N R70E)	25 Space Trailer Park
52067	10/29/80		1	12N	70E	5.6000	960.00	1280.00	Irrigation	WELL DLE	SECTION 1	
52382	08/05/88	NE SE	16	13N	70E	1.0000	31.27	62.54	Quasi-municipal	WELL PE	E1/2 S16 T13N R70E	
52488	09/09/88	NW SE	9	13N	70E	0.1000	0.92	0.92	Commercial	WELL PE	NW SE S9 T13N R70E	
54022	10/17/89	NE NE	8	13N	70E	0.0000		12.00	Municipal & Domestic	WELL LVP		

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Permit/Proof	Date of Priority	1/4 1/4	Sec.	Township	Range		AcFt/Yr	Duty AcFt/Yr				
54023	10/17/89	NW SE	36	13N	70E	0.0000		12.00	Municipal & Domestic	WELL LVP		
54024	10/17/89	LOT 7	13	11N	70E	0.0000		12.00	Municipal & Demestic	WELL LVP		
54025	10/17/89	SE SE	27	10N	70E	0.0000		12.00	Municipal	WELL LVP		
54026	10/17/89	SE NE	26	14N	69E	0.0000		20.00	Municipal & Demestic	WELL LVP		
54027	10/17/89	NE NW	30	13N	70E	0.0000		20.00	Municipal & Domestic	WELL LVP		
54028	10/17/89	SE SE	22	12N	70E	0.0000		20.00	Municipal & Domestic	WELL LVP		
54029	10/17/89	SW NE	20	11N	70E	0.0000		20.00	Municipal & Domestic	WELL LVP		
54030	10/17/89	NW SE	4	10N	70E	0.0000		12.00	Municipal & Domestic	WELL LVP		
Total***							36758.09	48742.22				

APPENDIX C

APPENDIX C

STEADY STATE MODEL SENSITIVITY

A steady state simulation is a simulation in which recharge and pumping rates are held constant with no change in ground-water storage, so that model-predicted ground-water levels are representative of long-term stabilized ground-water conditions in the natural environment. Therefore, the steady-state simulation will agree with historic measured water levels if appropriate hydraulic parameters are used in the simulation model. Model hydraulic parameters are adjusted until the steady-state simulation closely approximates the historical ground-water levels. The adjusted parameters must be reasonable. Both the number of differing and discernable values and the range of these values must be consistent with the occurrence of strata which possess these properties and the estimated range, or variabilities of these properties, based on field observations and testing of these properties of the strata.

The primary purpose of the steady-state simulations is to calibrate the model. Transmissivity can be calibrated if sufficient water level elevations are known. This was done as a part of the present study. Calibration of Snake and Hamlin Valleys ground-water model was accomplished using several constraints that were identified in the "Model Development" section of this report.

The calibration of the model was carried out so that the total quantity of ground-water flow was matched, as closely as possible, the estimates made in Hood and Rush (1965) and Harrill et al. (1988). The calculation of the recharge to the Snake and Hamlin model resulted in a value about seven percent greater than that calculated by Hood and Rush (1965) even though the same method (Eakin et al., 1951) was used. The difference could be attributed to the slightly different areas used for each elevation range, since the model area is based on grid nodes or the sum of square mile areas. The transmissivities of the modelled units, the leakance between these units, and the conductances used in the general head boundary conditions that connect the modelled area to adjacent hydrographic basins were constrained with the intent to replicate the quantities of water reported in Hood and Rush (1965) and Harrill et al. (1988), while at the same time matching the actual water levels. However, the model was not able to simulate the amount of inflow to Snake Valley from either Pine or Wah Wah Valleys with ground-water elevations based on Thomas et al. (1986). Harrill et al. (1988) indicate a question in the flowpath, postulating that this water could possibly enter Tule Valley directly from Wah Wah Valley, not entering Snake Valley.

As stated above, the calibration of the model was also carried out so that observed ground-water levels and the gradient or changes between these levels within the modelled area were matched as well as possible with little subjective changes in the model parameters. Ninety-four wells were used in Snake and Hamlin Valleys for model calibration. With the number of wells and the areal coverage, matching the actual water levels, while generally preserving the overall budget volumes became the most significant constraint.

The ground-water levels in the wells shown in Table 8 of the report were used during the calibration. The ground-water levels, resulting from the calibration are shown in Figures 22 and 23, together with the observed ground-water levels.

Model Parameter Sensitivities

Sensitivity simulations were done to determine the effects of each parameter on the ground-water levels and flows and are reported in the attached Table 1. These parameters are the transmissivities (L1T1, L2T1, etc.) and leakances (TK1, TK2). The sensitivities were performed about the calibrated values of the model and represent the linearized change in water level elevation that would occur with a change in the specific parameter value. The model rows and columns for the observation wells are listed in the attached Table 1 as well as designated in Table 8 in the report with each individual well for correlation. The sensitivities represent the estimated change in ground-water level at the wells with a 100 percent increase in the calibrated values that have been previously reported in the "Model Development" section of this report. The results of these sensitivity simulations are discussed briefly.

Analyses of the sensitivity simulations resulted in several general observations regarding the estimated model properties. All of the wells located in Snake and Hamlin Valleys are in the alluvium. The transmissivities of the alluvial, valley-fill aquifer and the lower carbonate aquifer produced the most significant changes in ground-water levels and flows over the modelled area. The transmissivity of the alluvial aquifer in Snake and Hamlin Valleys fell within the lower range of transmissivities resulting from aquifer tests preformed as part of the Air Force MX siting activities but was necessary to best match the actual water levels. The high lower layer carbonate aquifer transmissivities were necessary to move the water from the recharge areas to discharge (ET and drains) areas and match existing water levels. Changes in the upper layer volcanic and clastic aquifers and upper layer carbonate aquifer transmissivities and the leakances between the layers did not produce significant changes in the majority of the ground-water levels.

Table 1.--Wells used in calibration.

Well ID No.	Location	Row	Col	Actual	Simulated	▲	RESULTS OF SENSITIVITY RUNS T1L1 1250	T2L1 500	T3L1 250	T4L1 400	T1L2 2250	T2L2 80000	TK1 2.6-10^{5}	TK2 2.2-10^{5}	TK3 1.1-10^{5}	TK4 1.3-10^{5}	TK5 1.0-10^{5}
2	15N/70E-25DD	62	20	5069	5066	3	16	-1	0	1	17	0	2	1	0	0	0
3	14N/70E-31C	69	14	5595	5350	245	51	2	0	4	80	0	5	1	0	0	1
4	14N/70E-27C	68	17	5211	5224	-13	26	0	0	2	37	-1	4	0	0	0	0
5	14N/70E-20	65	16	5367	5245	122	43	-3	1	4	61	0	5	1	0	0	0
6	14N/70E-8DC	67	16	5440	5258	182	37	-1	0	3	55	-1	5	0	0	0	0
7	14N/69E-24DAB	67	14	5588	5331	257	49	1	1	4	83	0	5	0	0	0	0
8	14N/69E-24BDD	66	13	5618	5361	257	52	4	1	5	99	-1	6	0	0	0	0
9	14N/69E-24A	66	13	5653	5361	292	52	4	1	5	99	-1	6	0	0	0	0
10	13N/71E-19B	72	20	5139	5147	-8	0	0	0	0	2	0	-1	0	0	0	0
11	13N/70E-35A	74	19	5231	5247	-16	22	-2	-1	0	19	-1	1	0	0	0	0
12	13N/70E-16DB	72	17	5310	5273	37	29	1	-1	1	34	0	2	0	0	0	0
13	13N/70E-16CC	72	16	5417	5314	103	40	1	-2	1	50	-1	3	0	-1	0	0
14	13N/70E-16C	72	16	5396	5314	82	40	1	-2	1	50	-1	3	0	-1	0	0
17	13N/70E-10ABA	70	18	5049	5183	-134	3	0	0	0	6	0	0	0	0	0	0
19	13N/70E-9CA	71	16	5272	5296	-24	35	1	-1	1	47	-1	3	0	0	0	0
20	13N/70E-9C	70	16	5314	5281	33	32	1	0	2	47	0	4	1	0	0	1
21	13N/70E-9BDD	70	16	5284	5281	3	32	1	0	2	47	0	4	1	0	0	1
22	13N/70E-9B	70	16	5332	5281	51	32	1	0	2	47	0	4	1	0	0	1
23	13N/70E-4CDC	70	14	5272	5362	-90	52	2	-1	3	79	-1	4	0	0	0	0
24	13N/70E-4D	69	17	5270	5225	45	19	0	0	1	29	0	2	0	0	0	0
28	11N/70E-36BD	86	20	5453	5472	-19	12	1	1	1	24	-6	0	0	0	0	3
29	11N/70E-35BA	86	19	5539	5495	44	12	0	1	0	27	-8	1	0	0	0	4
30	11N/70E-35AD	86	20	5526	5472	54	12	1	1	1	24	-6	0	0	0	0	3
31	10N/70E-25D	91	20	5518	5490	28	0	0	0	0	4	0	0	0	0	0	1
32	10N/70E-12B	88	20	5456	5476	-20	5	1	1	1	14	-3	-1	0	0	0	3
63	10N/70E-11D	89	19	5481	5489	-8	4	1	1	1	10	-3	1	1	0	0	-2

							RESULTS OF SENSITIVITY RUNS										
Well ID No.	Location	Row	Col	Actual	Simulated	▲	T1L1 1250	T2L1 500	T3L1 250	T4L1 400	T1L2 2250	T2L2 80000	TK1 $2.6\text{-}10^{5}$	TK2 $2.2\text{-}10^{5}$	TK3 $1.1\text{-}10^{5}$	TK4 $1.3\text{-}10^{5}$	TK5 $1.0\text{-}10^{3}$
34	9.5N/70E-33AB	99	17	5575	5570	5	6	0	0	1	15	23	0	0	0	0	3
35	9N/71E-6A	94	21	5521	5516	5	4	1	1	2	14	10	1	1	1	0	3
36	9N/70E-34DCD	100	18	5580	5574	6	6	0	0	1	15	25	0	0	0	0	3
37	9N/70E-14CAB	96	19	5593	5552	41	6	0	1	1	15	16	1	0	0	0	4
38	8N/70E-21AAD	103	17	5588	5586	2	6	0	1	1	15	31	1	0	0	0	3
39	8N/70E-6ABA	103	17	5582	5586	-4	6	0	1	1	15	31	1	0	0	0	3
40	8N/69E-36AAA	105	15	5671	5593	78	6	0	1	1	15	34	1	0	0	0	3
41	8N/69E-36A	105	15	5618	5593	25	6	0	1	1	15	34	1	0	0	0	3
42	8N/69E-35DC2	106	14	5660	5595	65	6	0	0	1	14	35	0	0	0	0	3
44	8N/69E-15BBD	102	12	5675	5602	73	8	1	1	1	14	29	1	0	0	0	3
45	(C-11-16)36DCB	14	43	4417	4365	52	-1	-1	0	0	-4	0	0	0	0	0	0
46	(C-11-17)1BDC	9	36	4349	4402	-53	0	2	0	0	1	0	1	0	0	0	0
47	(C-11-17)11AAA	9	36	4335	4402	-67	0	2	0	0	1	0	1	0	0	0	0
48	(C-11-17)12ACC	10	37	4325	4381	-56	1	-2	0	0	-1	0	1	-2	0	0	0
49	(C-11-17)12CBB	10	36	4336	4414	-78	0	2	-1	0	1	0	0	-1	0	0	0
50	(C-12-17)34AAC	20	35	4484	4575	-91	1	7	-1	0	7	0	1	2	0	0	0
51	(C-12-17)35CAC	20	36	4479	4541	-62	1	0	0	0	2	0	0	0	0	0	0
52	(C-13-18)13CAC	23	31	4683	4684	-1	0	10	-1	-1	16	0	0	2	0	0	0
53	(C-13-18)23AAB	24	30	4686	4710	-24	4	8	0	0	15	0	0	3	0	0	0
54	(C-13-18)28DAB	26	28	4750	4766	-16	9	5	0	-1	21	0	-1	3	0	0	0
55	(C-13-18)33DDC	27	28	4750	4769	-19	4	7	0	0	18	0	-1	2	0	0	0
56	(C-13-18)34CCC	27	29	4739	4726	13	1	1	0	0	8	0	0	0	0	0	0
57	(C-14-18)18DCC	30	26	4793	4825	-32	11	7	-2	-2	25	0	-1	3	-1	-1	.0
58	(C-14-18)26DBC	32	30	4791	4754	37	4	3	1	1	1	0	1	3	0	0	0
59	(C-15-19)11BCC	35	24	4892	4885	7	10	11	1	-1	32	0	2	4	0	0	0
60	(C-16-18)26CBA	44	31	4838	4807	31	0	2	0	0	-8	0	1	4	0	0	0

							RESULTS OF SENSITIVITY RUNS										
Well ID No.	Location	Row	Col	Actual	Simulated	▲	T1L1 1250	T2L1 500	T3L1 250	T4L1 400	T1L2 2250	T2L2 80000	TK1 $2.6\text{-}10^{5}$	TK2 $2.2\text{-}10^{5}$	TK3 $1.1\text{-}10^{5}$	TK4 $1.3\text{-}10^{5}$	TK5 $1.0\text{-}10^{5}$
61	(C-16-19)4BBA	40	22	4928	4929	-1	24	4	1	-1	36	0	3	3	0	0	0
62	(C-17-19)4ADD	46	23	4838	4883	-45	8	1	0	-1	10	0	-1	2	0	0	0
63	(C-18-18)31ADB	57	28	4901	4893	8	-2	4	0	0	-9	0	3	1	0	0	0
64	(C-18-19)20DAD	56	23	4935	4932	3	8	0	-1	0	3	0	0	1	0	0	0
65	(C-18-19)20DDD	56	23	4964	4932	32	8	0	-1	0	3	0	0	1	0	0	0
66	(C-18-19)28BCC	56	23	4952	4932	20	8	0	-1	0	3	0	0	1	0	0	0
67	(C-19-19)26ABA	62	26	4930	4933	-3	-3	0	0	0	-7	0	0	0	0	0	0
68	(C-19-19)26BDD	62	25	4929	4932	-3	-5	0	0	0	-6	0	-1	0	0	0	0
69	(C-19-19)35CDD	64	25	4966	4958	8	-3	0	0	0	-6	0	0	0	0	0	0
70	(C-19-19)35DCD	64	25	4958	4958	0	-3	0	0	0	-6	0	0	0	0	0	0
71	(C-19-19)36CDA	64	26	4951	4959	-8	-1	0	0	0	-7	0	1	1	0	0	0
72	(C-20-19)14BBC	66	25	4980	4981	-1	-4	0	0	0	-6	0	0	0	0	0	0
73	(C-20-19)19DCD	68	22	5042	5039	3	-5	0	0	0	-3	0	-1	0	0	0	0
74	(C-20-19)21ACC	67	24	5001	5003	-2	-3	0	0	0	-5	0	0	0	0	0	0
75	(C-20-20)12ACC	65	20	5093	5094	-1	15	0	1	1	14	0	4	1	0	0	0
76	(C-21-18)32ABD	69	29	4984	5026	-42	-4	0	0	0	-4	0	1	0	0	0	0
77	(C-21-19)31CCA	75	22	5183	5189	-6	1	0	0	1	5	0	0	0	0	0	1
78	(C-22-19)6BCA	75	22	5176	5189	-13	1	0	0	1	5	0	0	0	0	0	1
79	(C-22-19)6BAC	75	22	5211	5189	22	1	0	0	1	5	0	0	0	0	0	1
80	(C-22-19)6BCC	76	22	5209	5223	-14	4	0	0	1	9	-1	1	0	0	0	0
81	(C-22-19)31CB	81	22	5373	5356	17	9	1	1	3	28	-2	3	0	0	0	2
82	(C-22-20)1AAC	75	21	5210	5217	-7	8	-1	0	0	8	-1	0	0	0	0	0
83	(C-22-20)1AAD	76	22	5207	5223	-16	4	0	0	1	9	-1	1	0	0	0	0
84	(C-22-20)1ABA	75	21	5209	5217	-8	8	-1	0	0	8	-1	0	0	0	0	0
85	(C-22-20)1DAA	76	21	5195	5251	-56	13	-1	1	1	16	-1	2	0	0	0	1
86	(C-23-19)8D	83	24	5397	5346	51	3	1	2	5	21	-1	3	1	0	0	2

Well ID No.	Location	Row	Col	Actual	Simulated	▲	T1L1 1250	T2L1 500	T3L1 250	T4L1 400	T1L2 2250	T2L2 80000	TK1 2.6-10^{5}	TK2 2.2-10^{5}	TK3 1.1-10^{5}	TK4 1.3-10^{5}	TK5 1.0-10^{3}
							RESULTS OF SENSITIVITY RUNS										
87	(C-23-19)9CDB	83	24	5391	5346	45	3	1	2	5	21	-1	3	1	0	0	2
88	(C-23-19)10CA	83	25	5416	5326	90	-1	1	1	5	18	-1	3	0	0	0	2
89	(C-23-19)10DD	83	26	5427	5308	119	-4	1	1	7	17	0	3	1	0	0	2
90	(C-23-19)13AAB	83	28	5454	5276	178	-12	0	1	10	12	0	4	1	0	0	1
91	(C-23-19)20BAC	85	23	5385	5391	-6	6	0	1	3	20	-2	1	0	0	0	2
92	(C-23-19)20BDB	85	24	5392	5369	23	3	0	0	3	17	-2	1	0	0	0	2
93	(C-23-19)20DBC	85	24	5399	5369	30	3	0	0	3	17	-2	1	0	0	0	2
94	(C-23-19)22B	84	25	5357	5338	19	0	1	1	5	18	-1	3	1	0	0	2
95	(C-23-19)24DCC	86	27	5325	5318	7	-5	0	0	5	10	0	3	0	0	0	2
96	(C-23-19)28CB	86	24	5410	5380	30	5	1	1	3	16	-1	2	1	0	0	3
97	(C-24-19)3CAD	88	26	5446	5356	90	2	0	0	2	8	1	1	0	0	0	2
98	(C-24-19)3DA	88	26	5444	5356	88	2	0	0	2	8	1	1	0	0	0	2
99	(C-24-19)4AA	87	25	5448	5368	80	3	1	1	3	12	0	2	0	0	0	2
100	(C-30-19)21CAB	126	26	6155	6144	11	99	1	15	5	230	33	2	0	0	0	3
103	(C-32-19)22DCB	140	27	6305	6315	-10	129	1	19	5	296	32	1	1	0	1	3
104	(C-32-19)27ACC	140	28	6235	6312	-77	128	0	18	4	295	32	1	0	0	0	2