SURFACE-WATER RESOURCES AND BASIN WATER BUDGET FOR SPRING VALLEY, WHITE PINE AND LINCOLN COUNTIES, NEVADA

For
THE LAS VEGAS VALLEY WATER DISTRICT, LAS VEGAS, NEVADA

2003

By

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Cordilleran Hydrology, Inc., Reno, Nevada
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TABLE OF CONTENTS

TABLES

FIGURES

ABSTRACT

The water resources of Spring Valley have two components, surface-water runoff from the mountain front, commonly called *mountain-front runoff* and secondly, *ground-water recharge.* This report estimates the total basin resource of Spring Valley is between 123,000 and 126,000 acre-feet per year and if water use by phreatophytes is captured, plus evaporation from surface water areas, perennial yield is about 110,000 acre-feet per year. The basin-resource estimates are all larger than previous estimates. This report emphasizes mountain-front runoff, ground-water recharge, evapotranspiration, and the relationship between these processes.

Although Spring Valley is "typical" of the basin and range, the hydrologic and geologic setting and hence the hydrogeologic setting is complex and many aspects must be estimated due to scarcity of information. The geology is further complicated by the presence of two metamorphic core complexes and extensive folding and faulting. The presence of large amounts of Cretaceous and Tertiary igneous and volcanic rocks, and pre-Cambrian metamorphic rocks, in addition to the major rock type of Paleozoic carbonate rocks, also add to the complexity. Pleistocene glacial features are found in the higher altitudes; shorelines and playas deposits are at low altitudes. The basin-fill, although voluminous, is poorly defined due to limited drill-hole data and geophysical analysis. The hydrogeologic properties of the various rocks and alluvium are largely unknown, because of a lack of aquifer test data.

Due to the wide variety of rock types in the ranges and surficial closure of the valley, perennial streams and standing water are significant hydrologic features of Spring Valley. Because mountain-front runoff and natural recharge are related to precipitation, which easily varies by 100 percent annually, both processes were difficult to estimate without good spatial and temporal information. It was also observed that perennial streams are in drainages with large amounts of non-carbonate rocks. Data indicate drainages and ranges with large amounts of carbonate rocks tend to have little runoff, but a large amount of natural recharge. These data apply to Spring Valley in particular and the Great Basin in general.

This report benefits from earlier research, 7 years (1996 to 2002) of miscellaneous streamflow measurements on the significant perennial streams in the valley, collected by the Las Vegas Valley Water District and the Southern Nevada Water Authority and 15 years (1984 to 1999) of high altitude precipitation information collected by the U. S. Geological Survey. Because of the abundance of hydrologic information on Spring Valley, the minimal amount of human alteration of the hydrologic system and complex geology, Spring Valley is a good location to assess the relationship between mountain-front runoff and the standard technique (Maxey-Eakin) of estimating natural recharge.

The Maxey-Eakin technique, although successful in application and utility, is empirical and its greatest strength is in applying the technique over large regions. Paradoxically the technique's greatest weakness is that it does not incorporate most of the physical processes that control recharge. Conversely mountain-front runoff estimation techniques were developed by Moore (1968) after the Maxey-Eakin technique. These two estimating techniques were used in many of the same reports, but never combined together in a total basin budget. This report proposes one method of combining the surface-water runoff and ground-water recharge by using geologic controls.

INTRODUCTION

In October 1989, the Las Vegas Valley Water District (LVVWD) filed numerous applications for ground-water rights in Spring Valley. In support of those applications LVVWD published the "Hydrology and Steady State Ground-Water Model of Spring Valley, Lincoln and White Pine Counties, Nevada" by Brothers and others (1994); that report presents the hydrologic knowledge base for Spring Valley and represents the understanding at that time in a steady-state ground-water model. Since 1994 there has been significant new data collection and interpretation by the LVVWD / SNWA and the U.S. Geological Survey (USGS) that increases the understanding of the various hydrogeologic processes in Spring Valley and redefines the water-resource budget for the valley.

PURPOSE AND SCOPE

The purpose of this report is first, to present the results of recent data collection/interpretation activities used to estimate mountain-front runoff by the LVVWD / SNWA during 1996-2002. Second, ground-water recharge was estimated and a new water-resource budget developed. This new budget draws heavily on the results of a cooperative regional evapotranspiration (ET) investigation between the LVVWD, USGS, and the Nevada Department of Conservation and Natural Resources conducted by the USGS in eastern Nevada.

The scope is to revisit the water-resource budget components for Spring Valley, originally developed by Rush and Kazmi (1965), modified later by Brothers and others (1994) and Nichols (2000), and to revise those budgets based on new data and interpretations.

LOCATION

Spring Valley is located on the eastern edge of the state, about 20 miles east of Ely, 200 miles north of Las Vegas and about 300 miles east of Reno. The location of the valley and the general physiographic setting are shown on Figure 1. Spring Valley is a typical Basin and Range valley (Fenneman, 1931, and Fenneman and Johnson, 1946) orientated north-south between nearly parallel mountain ranges, Schell Creek Range on the west and the Snake Range on the east. Other smaller mountain blocks bound the valley such as the Antelope Range on the north, the Kern Mountains on the northeast, the Limestone Hills on the southeast, the Wilson Creek Range on the extreme south, and finally the Fortification Range on the southwest. Much of the valley is in White Pine County with the southern end located in northern Lincoln County.

Access to the valley from east or west is by U.S. Highway 50 and north to south by Nevada State Route 893 north of U.S. Highway 50 and by U.S. Highway 93 south of U.S. Highway 50. The valley has never been accessible by rail, but always by mule.

The mountain ranges bordering the valley are predominantly carbonate rocks and thus Spring Valley is considered within the Carbonate Rock Province as defined by Plume (1996). The valley's ground-water system flows generally east toward Snake Valley, which places the valley in the Great Salt Lake Desert System of Harrill and others (1988).

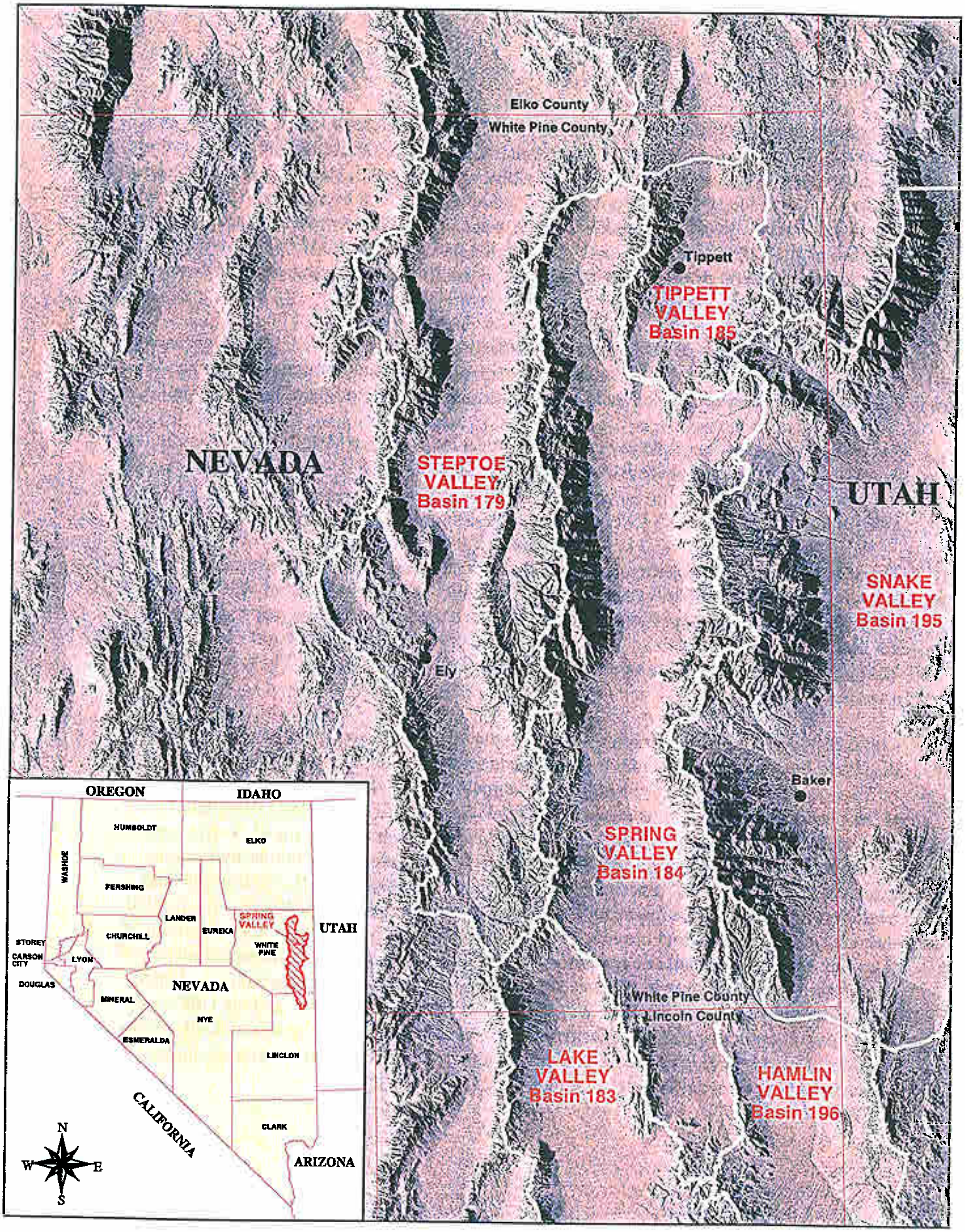

Figure 1.-- Location map showing Spring Valley and adjacent valleys.

ACKNOWLEDGEMENTS

Numerous LVVWD / SNWA personnel, both past and present, in addition to the authors, participated in field data collection and they are listed in alphabetical order: Alan Bernholtz, Kay Brothers, Andrew Burns, Erin Cole, Greg Febbo, Holly Johnson, Jeff Johnson, Michael Johnson, Gavin Kistinger, Joe Leising, Tom Maher, Zane Marshall, Janet Monaco, and Michael Wallen. The Virgin Valley Water District, Mesquite Nevada, currently employs Michael Johnson and LVVWD appreciates their cooperation through the participation of Mr. Johnson in the hydrologic fieldwork. Cartography by Michael Wallen and Judy Brandt also enhanced the report.

The authors acknowledge the significant contributions to this study by USGS scientist William "David" Nichols who died in 2002. Science has lost a most important member of Nevada's water-resource community and his contributions to the understanding of hydrology are notable.

Also we greatly appreciate the review of this report by Dr. Steve Mizell, Desert Research Institute, University of Nevada System, Las Vegas, Nevada.

PREVIOUS INVESTIGATIONS

There have been numerous investigators who have reported on some aspects of the geology of the valley: Simpson (1876), Spurr (1903, p. 44-47), Misch (1960), Drewes (1960 and 1964), Young (1960), and Langenheim (1960). Most notably are the geologic maps prepared by Tschanz and Pampeyan (1961), Whitebred and others (1962), and Hose and Blake (1976). Other investigators have delineated bedrock stratigraphy such as Bissell (1962 and 1964) and Misch and Hazzard (1962).

The first hydrologic work of note was done in the valley by Snyder and Langbein (1962) who discussed the ancestral lakes in relation to past and present climates, as did Mifflin and Wheat (1979). Rush and Kazmi (1965) defined, on a reconnaissance level, the water resources of the valley. This work stood alone until the early 1980's when Ertec Western (1981) evaluated numerous valleys in Nevada, including Spring Valley, for suitable sites for the U. S. Air Force MX missile facilities. Leeds, Hill, and Jewett, Inc., (1983) followed with another hydrologic evaluation for the siting of a power plant. These last two studies added to the hydrologic data base by well drilling and limited aquifer tests. In the early 1990's the LVVWD began a limited data collection program and published its findings along with a steady state ground-water model (Brothers and others 1994). Broadbent and others (1995) investigated the mountain-front runoff and ground-water recharge in three valleys in central eastern Nevada, one of which was Spring Valley. At the same time the LVVWD cooperated with the State of Nevada and the USGS to investigate evapotranspiration (ET) rates. That study has resulted in a series of publications by Nichols (1992a and b, 1993, 1994, 2000a, b, and c), which revised ground-water budgets for 16 contiguous valleys in eastern Nevada, including Spring Valley.

WATER RESOURCES

The water resources of Spring Valley originate from precipitation that falls on the drainage area. The water yield of the basin is considerably less than the total precipitation and is difficult to estimate because the interrelationship between surface and ground water and ET is complex.

Water that falls as rain or forms from melting snow is surface water for a brief period in the hydrologic cycle. Some of it remains as surface water and runs off the mountain block as streamflow. Some of this streamflow infiltrates to the ground-water system and some is lost to the atmosphere through ET. Some portion of the water that does not become streamflow infiltrates through the soil mantle and percolates down to bedrock and thus becomes ground water. This water moves down gradient until it is either intercepted by a stream channel and becomes streamflow or if the bedrock is fractured sufficiently for water to infiltrate directly it does so and moves down gradient as ground water. The ground water can either reappear as surface water in a perennial stream or ultimately reach the ground-water system in the valley.

The primary physical parameters that govern these processes are: antecedent conditions, precipitation, storm tracts, the amount and type of precipitation, aspect of the mountain block, solar radiation, temperature, wind, humidity, lithology of the surface and underlying bedrock, degree of permeability of the surface sediments and bedrock, earth structures, thickness of the deposits, vegetation type and density; and land surface gradient. Because of the wide variability in the values representing these parameters between mountain ranges and drainages within the same mountain range, precipitation, recharge, runoff, and ET are difficult to estimate.

There are only two ways for water to exit Spring Valley, through ground-water outflow and ET. ET is by far the largest component of discharge in the water-resource budget.

SURFACE-WATER RESOURCES

Surface-water resources (mountain-front runoff) are a vital part of the basin's total resource. The numerous perennial streams discharge thousands of acre-feet per year into the basin, mostly from the Schell Creek Range with lessor amounts from the Snake Range. Much of this water results from melting snow with minor amounts from winter and summer rains. A large number of springs and spring seeps contribute some portion to streamflow. Nearly every perennial stream is used for irrigation of alfalfa, native hay, or meadowlands. There are no surface storage facilities on any of the streams so the winter / spring runoff is largely unused by agricultural interests. The unused water provides some amount of ground-water recharge, but much of it returns back to the atmosphere through the ET process.

Mountain-Front Runoff

Mountain-front runoff is that part of the surface-water runoff that exits the mountain block and is defined as the volume of surface water that crosses the contact between the consolidated rocks of the mountain block and the unconsolidated sediments of the alluvial basin. It is caused when water from melting snow or rain literally runs off of the mountain block. This occurs when the volume of available water exceeds not only the infiltration capacity of soil and rock, but also the volume of water consumed by ET.

Precipitation or surface water that infiltrates through the soil mantel, escapes ET, and moves down-gradient as ground water is often intersected by a drainage channel or fractures in the bedrock and brought back to the surface as springflow. Changes in permeability caused by lithologic differences and earth structures can also force ground water to the surface. Thus ground water, which started as surface water, reappears through specific springflow orifices or as diffuse springflow and is considered once again to be surface water. This surface water is subject to ET during its transient time to the valley and also, depending on other hydrogeologic parameters, may reinfiltrate the channel bed to the ground-water system. Springflow that does not reach a channel in sufficient volume to create runoff is, in part, probably lost to ET with some portion reinfiltrating to the ground-water system once more becoming ground-water recharge. So, depending on the individual drainage, surface-water runoff probably always has a component of ground water in it when it reaches the mountain front.

Mountain-front runoff in Spring Valley is a major component of the water-resource budget and represents a significant contribution to the available water resources. Moore, in Rush and Kazmi (1965, p. 12), first estimated the amount of water that discharges from the mountain block into Spring Valley by applying a technique developed by Moore in Eakin and others, (1965, p. 21). This technique is based on the assumption that precipitation rates increase with altitude and the more precipitation the greater the resulting runoff. By using available stream gaging records Moore developed a set of runoff factors to apply to drainage areas within 1,000 feet (ft) altitude zones in any given mountain block anywhere in the state. These mountain-front runoff regions for Nevada are shown in Figure 2. This technique was in the development stage when Moore was working in Spring Valley and the runoff factors he used are not shown, however Table 1 list Moore's (1968) final published factors.

Table 1.– Runoff values by altitude zones for different regions in Nevada.

Altitude zones, in feet	**Runoff in each region, in inches per acre per year**					
	Regions					
	A	B	C	D	E	F
5,000 - 6,000	0	0	0.5	0.5	1.6	0.3
6,000 - 7,000	0	0	1.2	3.5	5.5	0.7
7,000 - 8,000	0.4	0.5	3	7	10	1.5
8,000 - 9,000	2.5	3.2	5.5	11.5	15.5	2.8
9,000 - 10,000	5.6	7	9.5	16.2	21	4.5
10,000 - 11,000	9.4	12	14	21	26	-
11,000 - 12,000	16	18	-	-	-	-

After Moore (1968), all regions are shown in Figure 2; table excludes two zones in Lake Tahoe, NV area

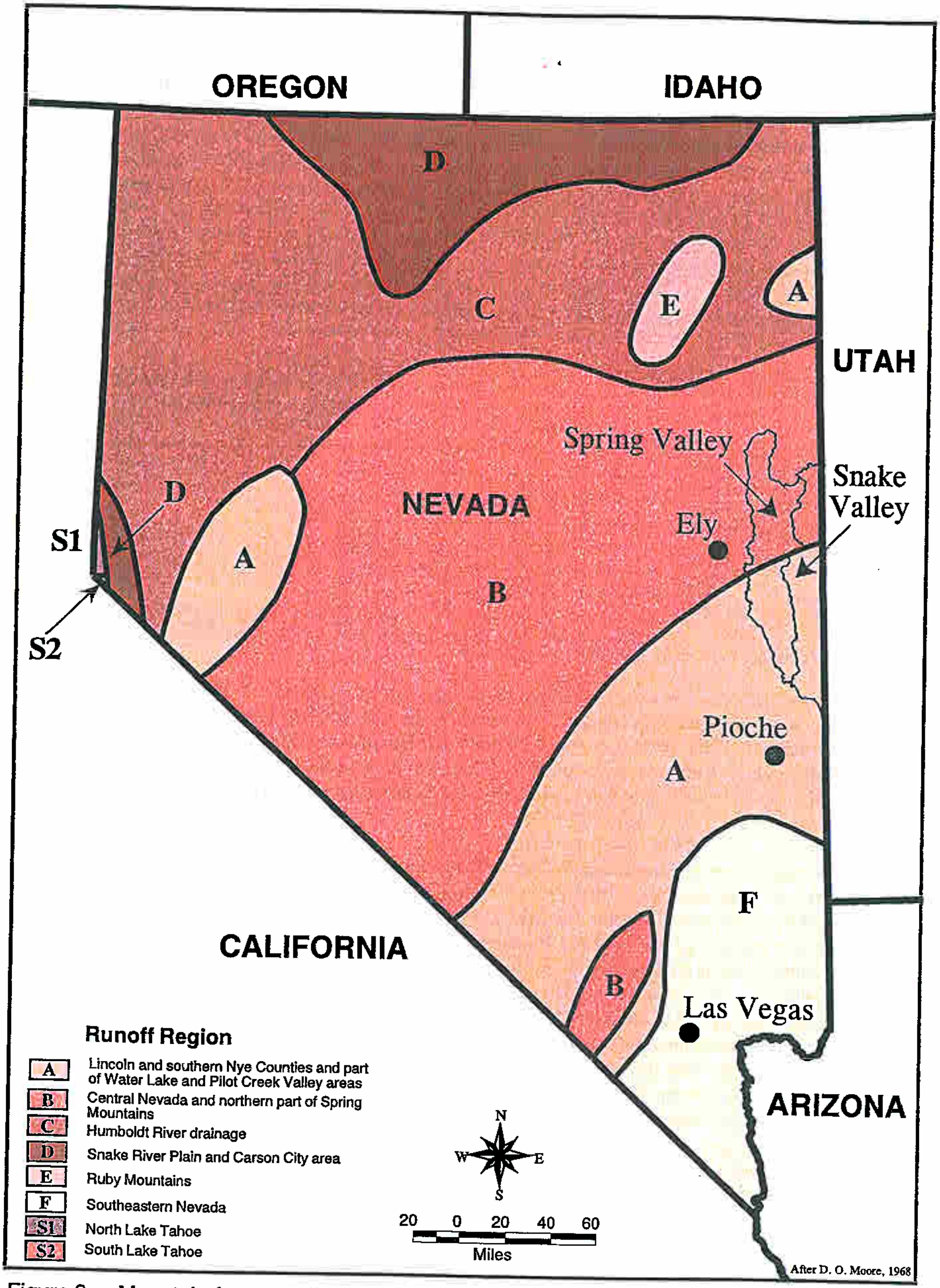

Figure 2. -- Mountain-front runoff regions in Nevada

Spring Valley is in two regions, A and B; A is significantly dryer than B, particularly at the higher altitudes above 8,000 ft. This technique is similar to the well known Maxey-Eakin technique for estimating primary ground-water recharge (see Avon and Durbin, 1994) except it should be more accurate, because the technique uses measured stream discharge to calculate the runoff factors in comparison to estimated ground-water discharge used to estimate ground-water recharge. Table 2 is a comparison of applying the runoff factors to Cleve Creek with the actual gaged record and the difference is large. Using Runoff Region B factors gives a flow of about 9,300 acre-feet/year (afy) compared to the 6,270 afy as defined by the gaged record available at the time to Moore. However, today's calculations are based on additional flow data and on the 1:24,000 scale maps, which were not available at the time to Moore.

Table 2.– A comparison of Cleve Creek annual flow calculated by runoff factors and actual record.

Altitude zones, in feet	Cleve area, in acres	Factor B, in feet	Total, in acre-feet	Average recorded flow, in acre-feet/year[1]
5,000 - 6,000	0	0	—	
6,000 - 7,000	1,408	0	—	
7,000 - 8,000	4,261	0.04	170	
8,000 - 9,000	5,349	0.27	1,444	
9,000 - 10,000	5,340	0.58	3,097	
10,000 - 11,000	3,420	1	3,420	
11,000 - 12,000	771	1.5	1,157	
Total	**22,766**		**9,288**	**7,500**

1. Period of record water years 1914-2000, not continuous.

There are major differences between mountain ranges and between drainages in the same mountain block, which Moore recognized. For instance, the flow in Cleve Creek originates mostly from that part of the basin dominated by relatively low permeability metamorphic/clastic rocks. It is difficult to compare today's work with Moore's because he was in the process of developing the runoff technique and did not publish the runoff efficiencies used for Spring Valley.

Moore estimated the average mountain-front runoff into Spring Valley to be 90,000 afy. This runoff seems high even though the runoff relationship used by Moore in 1964 was in part based on the annual flow of Cleve Creek for the eight years of available record. The Cleve Creek runoff, if used by Moore, is low by about 16 percent compared to the period of record through water year 2000. Thus if the total mountain-front runoff for Spring Valley as estimated by Moore is low by that same percentage then adjusting it to the long-term flow of Cleve Creek by that percent equals a runoff of 105,000 afy. This is a simplistic assumption and is probably not true. This study has estimated the runoff from nearly all of the perennial streams in the valley to equal about 50,000 afy. The few remaining perennial streams not measured contribute about 3,000 afy for a total mountain-front runoff from perennial streams of 53,000 afy, and this estimate is used in the water-resource budget discussed later. It seems unreasonable to assume the ephemeral drainages could contribute nearly an equal amount, as implied by Moore's total of 90,000 afy. Most of the ephemeral drainages in Spring Valley drain from predominantly carbonate rock areas, which, as will be discussed later, have minimal surface-water runoff. An example is Cooper Canyon, the second largest drainage area in the Valley (27.6 square miles), an ephemeral drainage with an estimated annual runoff of only 500 afy.

Available Streamflow Records

Cleve Creek is the only stream in the Valley that has a recording gage. The period of record, in water years (October 1-September 30) has not been continuous and is as follows: June 1914-December 1916, October 1959-September 1967, October 1976-September 1981, December 1982-September 1987, and March 1990 through the 2000 water year (currently in operation, 2003). The total monthly and annual flows for the above period of record are listed in Table 3 (29 complete water years). The mean daily flow is 10.4 cubic feet/second (cfs) which equals 7,520 afy (Allander and others, 2000, p. 109). This contrasts with the mean annual flow of 6,270 afy used by Moore (Rush and Kazmi, Table 3, p. 13, 1965). The hydrograph of annual flows for Cleve Creek is shown in Figure 3.

Table 3.– Monthly and annual flow values for Cleve Creek, in acre-feet.

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Total
1915	539	534	446	498	447	510	793	1200	1230	618	442	363	7620
1916	442	436	396	297	359	912	1100	1490	1020	504	419	374	7749
1960	287	283	289	249	254	324	377	528	372	305	245	223	3736
1961	281	304	263	251	253	286	389	631	510	318	297	257	4040
1962	290	269	284	274	313	367	1450	1110	885	505	362	315	6424
1963	356	360	328	316	428	358	374	895	1620	610	426	403	6474
1964	392	388	395	400	360	387	461	1320	877	498	439	384	6301
1965	338	354	393	377	325	378	605	1130	1200	572	502	499	6673
1966	445	423	396	387	352	428	684	650	436	339	309	320	5169
1967	315	328	385	381	334	370	373	1610	3460	1090	590	529	9765
1977	447	374	370	327	284	318	371	506	855	388	391	329	4960
1978	360	342	320	331	321	586	908	2330	2250	684	524	426	9382
1979	437	502	467	381	479	553	823	1810	1040	502	459	403	7856
1980	435	426	423	402	407	508	761	2380	2200	972	637	628	10179
1981	579	540	454	425	362	395	534	978	784	440	398	395	6284
1984	980	847	766	708	676	946	1800	4360	2020	1140	978	906	16127
1985	1030	908	795	631	554	746	1380	1230	829	692	516	516	9827
1986	531	499	489	491	481	946	1370	1740	1100	710	570	560	9487
1987	640	586	579	542	479	543	907	1020	686	655	533	386	7556
1991	301	301	278	330	268	281	310	523	1490	436	402	326	5246
1992	336	326	335	310	307	381	459	519	335	283	262	248	4101
1993	279	285	280	289	275	656	600	1740	962	542	428	395	6731
1994	390	357	336	336	293	367	449	678	460	357	335	308	4666
1995	340	337	325	360	395	637	667	1840	3980	1530	746	565	11722
1996	501	460	441	450	403	575	642	988	634	467	416	390	6367
1997	378	417	451	413	360	515	641	1120	849	626	576	506	6850
1998	495	467	340	337	413	623	757	1710	3100	1500	772	633	11140
1999	594	534	542	589	531	544	586	1270	1880	918	603	532	9120
2000	502	480	551	555	474	529	632	780	653	491	428	398	6473
Mean	**457**	**437**	**418**	**401**	**386**	**516**	**731**	**1313**	**1301**	**645**	**483**	**432**	**7520**

Note: Mean annual flow of Cleve Creek, in cfs, for Period of record through: 1996 = 10.18; 1998 = 10.35; and 1996 = 10.38. These flow values were used to estimate long-term discharge of the perennial streams.

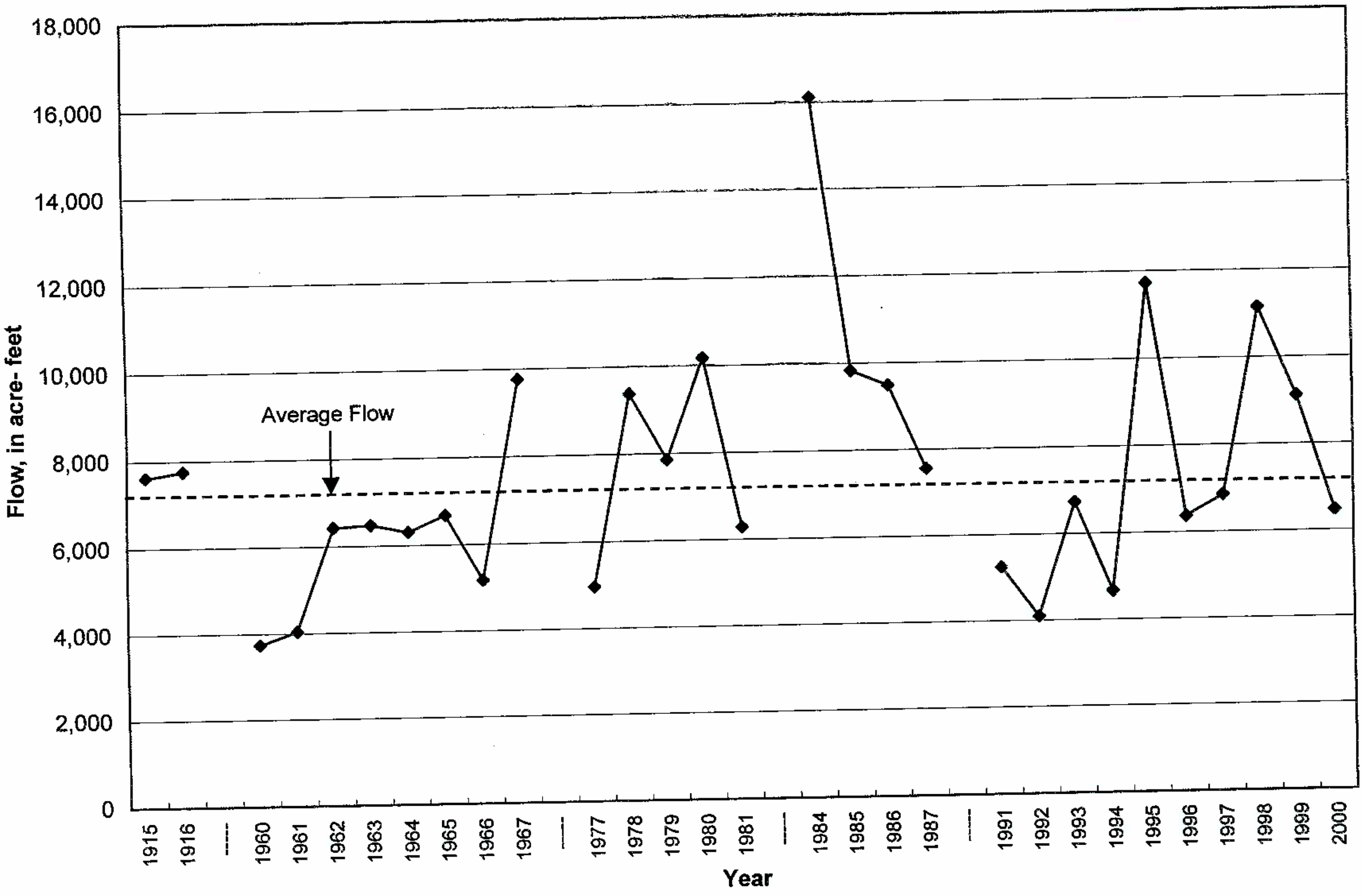

Figure 3. -- Hydrograph of Cleve Creek showing annual and long-term average stream flow.

Miscellaneous measurement sites used in this study along with other pertinent data calculated by LVVWD are listed in Table 4. This data includes the few miscellaneous measurements made by LVVWD in 1993. The individual drainages listed in Table 4 are also identified by site numbers and are shown on Figure 4 along with major basin subdivision boundaries (Table 29).

Table 4.-- Miscellaneous streamflow measuring sites in Spring Valley.

Site number and Name	Latitude N[1]	Longitude W[1]	Period of record[2], / water year	No. of measure-ments	Drainage Area[3], mi^2	Altitude at point of meas[4]., in feet	Data source[5]
1. Cooper	39°06' 07"	114°35' 09"	1991/2001	30[a]	27.63	6,529	A & B
2. Bastian	39°09' 21"	114°33' 21"	1998/2002	6	2.77	6,398	B
3. Cleve	39°12' 58"	114°31' 44"	b.	c.	32.11	6,140	A
4. Stephens	39°16' 40"	114°29' 50"	2000	2	2.99	7,973	B
5. Taft	39°20' 29"	114°31' 42"	1991/2001	28	4.38	6,955	A & B
6. McCoy	39°22' 25"	114°31' 44"	1991/2002	32	6.36	6,594	A & B
7. Odgers	39°24' 09"	114°31' 45"	1972/2001	41	3.96	6,479	A & B
8. Little Negro	39°25' 15"	114°31' 47"	1995/2001	7	3.02	6,365	B
9. Bassett	39°26' 29"	114°31' 57"	1968/2002	95	6.48	6,266	A & B
10. Garden	39°27' 42"	114°32' 18"	1999/2001	3	2.93	6,266	B
11. Piermont	39°29' 13"	114°32' 44"	1972/2002	41	7.71	6,397	A & B
12. Kalamazoo	39°33' 48"	114°33' 12"	1982/2002	39	14.67	6,200	A & B
13. Muncy	39°36' 03"	114°33' 12"	1964/2001	8	14.29	6,200	A & B
14. Frenchman	39°39'14"	114°33' 55"	1996/2001	6	4.87	6,529	B
15. North	39°40' 52"	114°35' 21"	1996/2002	12	3.21	6,972	B
16. Silver	39° 42' 11"	114°35' 04"	1999/2001	d.	2.42	7165	B
17. Siegel	39° 43' 53"	114°34' 15"	1996/2002	7	5.95	6,643	B
18. Stage	39°48' 47"	114°36' 32"	1998/2001	4	5.22	6,857	B
19. Eight Mile	39°23' 32"	114°19' 08"	1997/2001	7	3.25	6,562	B
20. Negro	39°15' 15"	114°20' 34"	1998/2002	8	27.55	6,230	B
21. Willard	39°01' 45"	114°22' 36"	1964/1998	26	4.23	7,380	A
22. Swallow	39°50' 29"	114°21' 02"	1993/2002	11	3.74	6,398	B

a. Thirty observations of no flow; peak flow in Spring 1999 ~ 40-50 cfs.
b. 6/1914-12/1916, 10/1959-9/1967, 10/1976-9/1981, 12/1982-9/1987, 3/1990-current year (2002).
c. Recording gage.
d. Three observation of 'no flow'.
1. Latitude and longitude determined by LVVWD using Global Positioning System.
2. Period of record is not necessarily inclusive, generally 3-4 measurements per year by the USGS as indicated; not shown are measurements made by LVVWD during July, 1996 and 1997 at all USGS stations; and seepage measurements made in 1997 and 1998 on Cleve, Kalamazoo, McCoy, and Piermont Creeks, seepage measurements made in 2000 on Basset and Bastian Creeks, and seepage measurements made in 2001 on Negro Creek. Measurements made in 1964 are by Rush and Kazmi (1965, Table 4, p. 15).
3. Determined by LVVWD using appropriate DEMs.
4. Altitude determined by LVVWD from 1:24000 scale maps.
5. A = U. S. Geological Survey; B = Las Vegas Valley Water District.

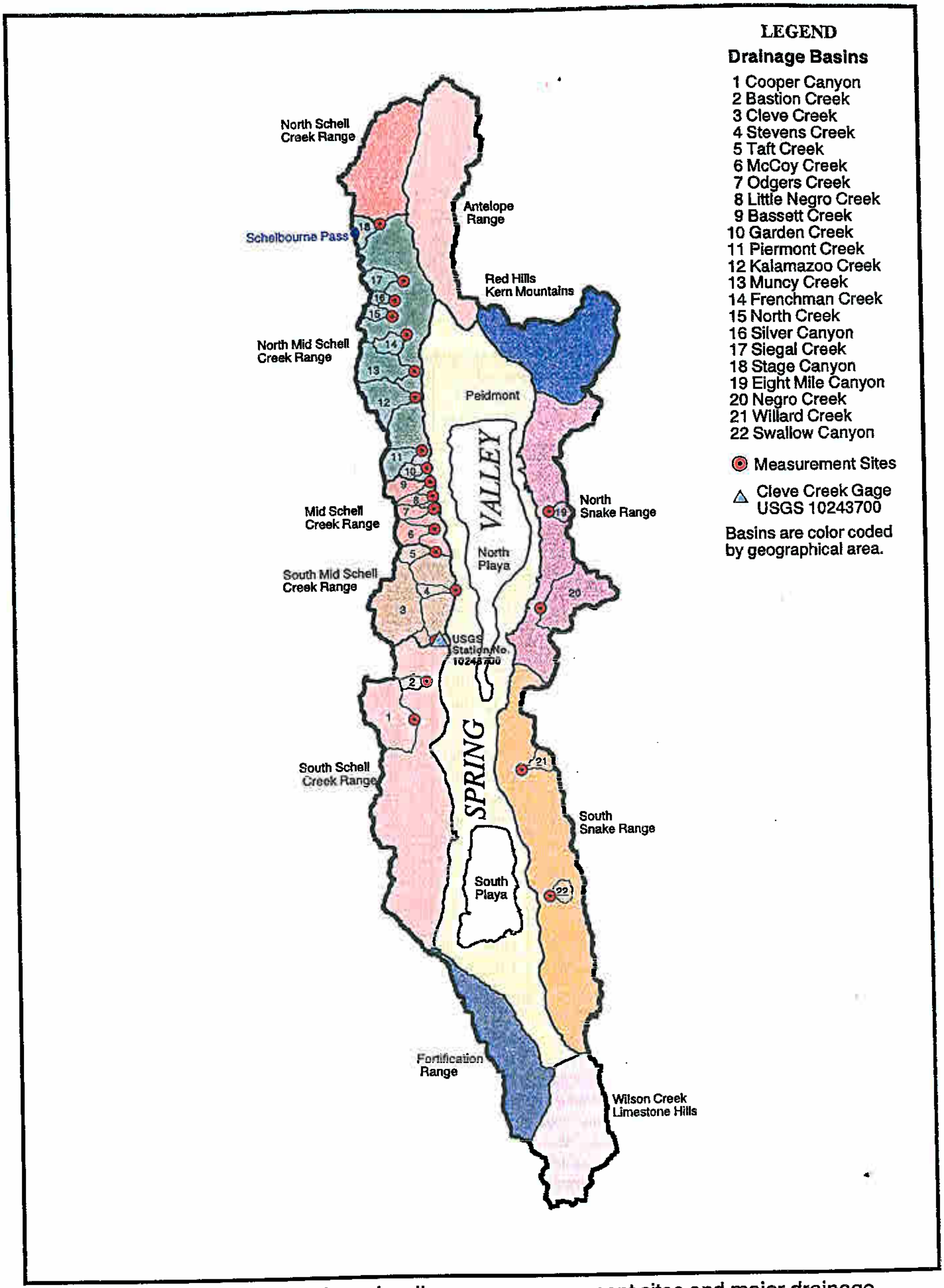

Figure 4. -- Location map showing miscellaneous measurement sites and major drainage basin subdivisions in Spring Valley.

Perennial Streamflow

Perennial streamflow is caused by surface-water runoff and continuous ground-water discharge to a drainage channel. The main factors that control streamflow are: variations in precipitation, temperature, drainage area, area distribution by altitude, aspect, vegetation, type and cover, channel and land-surface gradients, and geologic control imposed by lithology and structure. Lithology and structure are discussed at length later in this report.

Perennial streamflow is not uniformly divided between the Schell Creek and the Snake Ranges, nor is it uniform between drainages in either range. Figure 4 shows the location of the mountain ranges and stream drainages. The total mountain-front runoff is far greater from the Schell Creek Range than the Snake Range with most of the perennial runoff occurring from Bastian Creek in the south to Siegle Creek in the north. Moore, in Rush and Kazmi (Table 5, p.16, 1965), shows slightly over 80 percent of the total runoff into Spring Valley originating in the Schell Creek Range with most of the flow from the central part of the range. This study shows about 80 percent of just the perennial flow comes from the Schell Creek Range.

The perennial monthly streamflow runoff distribution is characterized on Figure 5 by the hydrograph of Cleve Creek, which shows the monthly mean flow for the period of record. Peak flow generally starts in April-May with base flow in late summer-fall. Low flows are generally during the winter months. Cleve Creek is the largest perennial stream in the valley with a mean annual flow of 10.4 cfs (7,500 afy, rounded).

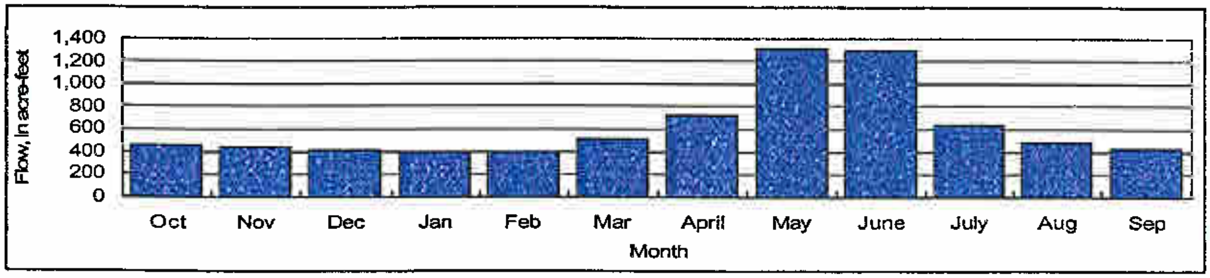

Figure 5. -- Hydrograph of Cleve Creek showing monthly mean discharge, in acre-feet.

The USGS gaging station on Cleve Creek is located just down-gradient from the mountain-front-alluvial contact, which is generally the point on all streams that will have the maximum amount of flow. The premise for this is streamflow, as indicated previously, has two components, direct surface-water runoff from precipitation events and ground-water discharge. This ground water, considered by many investigators as rejected recharge, generally continues to add to the streamflow in a down-stream direction to the edge of the mountain block. Once the stream exits the mountain block water will begin to infiltrate through the channel bed to the underlying ground-water system. This is somewhat dependent on the depth to ground water because if the water table is near land surface the stream may continue to act as a drain if the channel is incised to any extent. Nevertheless, the bedrock-alluvial contact is generally the dividing line between a gaining and a losing stream reach. There are exceptions to this rule caused by geologic controls.

Ephemeral Streamflow

Ephemeral streamflow occurs in the northern and southern parts of Schell Creek Range; mostly north of Siegel Creek (and in particular north of Schellbourne Pass) and south of Bastian Creek. For some of the drainages the ephemeral nature of their runoff is directly related to lack of high altitude drainage area and the geology, which is mostly limestone. Lack of runoff, even minor amounts, probably indicates most of the available water (excess to ET requirements on the mountain block) infiltrates into the permeable limestone and becomes ground-water recharge. Cooper Canyon, a major ephemeral drainage just south of Bastian Creek, is totally within carbonate rocks and is a prime example of this. Cooper Canyon, as indicated previously, is the second largest drainage in the valley and the largest ephemeral drainage. It has nearly 60 percent of its 27.63 mi^2 drainage area between an altitude of 7,000 and 8,000 feet and has no observed perennial reaches. For these reasons Cooper Canyon is included in this analysis with the perennial streams.

In the Snake Range most of the drainages are ephemeral and their size is smaller than the drainages in Schell Creek Range, but there are some notable exceptions such as Negro Creek (not to be confused with Little Negro Creek in the Schell Creek Range). This creek has the second largest perennial drainage area in the valley. However, the southern branch of Negro Creek is ephemeral. The northern perennial branch probably accounts for at least half the surface flow as measured at the Negro Creek Ranch located at the mountain front with the remaining flow coming from springs in the immediate vicinity of the ranch.

Moore first postulated (in Rush and Kazmi, 1965, p. 14) that the low runoff of the Snake Range compared to the Schell Creek Range was due to lack of precipitation and the fact that the prevailing dip of the limestone beds is east toward Snake Valley. The relatively impermeable metamorphic/clastic rocks cause most of the runoff from the Schell Creek Range. There is very little runoff from limestone rocks in either range.

Estimation of Annual Mean Runoff

The estimation of annual runoff in Spring Valley began in earnest in water year 1996 with the measurement of nearly all of the perennial streams in the valley. The measurements were correlated with the average flow of Cleve Creek and were made in July, because the daily mean flow of Cleve Creek at this time is nearest to the mean annual flow. Occasionally the high springflow continues into July, which shifts the 'average' conditions to August. During some years the absence of high springflow shifts the 'average' to June and sometimes May. The daily mean flow in Cleve Creek during the time of miscellaneous measurements for July 1996 (considered the start of LVVWD's data collection) varied from about 72 to 79 percent of the long-term average flow and the total flow for the year was about 14 percent lower than the long-term average. Most of the perennial streamflow was estimated based on 1996 and earlier data, although later in the study other streams were estimated based on subsequent years (1998 and 2000) and are so noted. During water year 1997 the runoff in Cleve Creek was about 10 percent lower than average and only one stream, other than Cleve Creek, was measured. The measurements made in 1998 varied from 176 to 235 percent and total runoff was 150 percent of average with flow in Cleve Creek totaling 11,140 af. Runoff in Cleve Creek for 1999 was about

20 percent greater than average and for water-year 2000 about 15 percent below average. Thus, the 1996 water year appeared to be closest to the long-term mean for Cleve Creek during the period of investigation. The miscellaneous measurement method theoretically accounts for this variability of flow as defined by the ratio, nevertheless, only the 1996 estimations were used with some exceptions as additional streams were included.

Comparing the 1996 measurements with the 1998, 1999, 2000, and 2001 measurements shows quite different results for most streams. In general, the flows during the 1998 and 1999 were higher than measured in 1996, 2000, and 2001. As a comparison the mean annual flow for several of the streams was calculated based on the 1998 measurements, and averaged if more than one measurement was made, and then compared to the 1996 estimates of mean annual flow. Because the 1996 estimates of flow were closer to average flow conditions for Cleve Creek, the results of the 1996 miscellaneous measurements were not changed to reflect the increases or decreases as indicated by measurements made in 1998, 1999, 2000, and 2001. In retrospect, if the analysis was made now the correlations would use the 2001 flow data, because that year is closest to the long-term annual mean than the other four years of record during the investigation.

The miscellaneous measurements and corresponding flow of Cleve Creek made by LVVWD in 1996 and 1998 are listed in Tables 5 and 6 respectively. All streamflow measurements were made as near as possible to the bedrock-alluvial contact and upstream from all diversions. Price Standard AA and Pygmy Current Meters were used as appropriate for depths and velocities measured. Data collection will probably continue into the foreseeable future.

Synthesization of Streamflow

Synthesizing streamflow was done by four techniques. First, miscellaneous measurements made by the LVVWD during July 1996 were correlated with the daily mean and long-term gaged flow of Cleve Creek. Second, a linear regression analysis was made on selected streams using historic measurements of streamflow by the USGS. Third, a geomorphic technique was used that correlates certain channel geometry with average streamflow. And fourth, a simplistic graphical approach was used to crudely estimate average streamflow.

Miscellaneous Measurements

Instantaneous discharge measurements, termed miscellaneous measurements, were made on most of the perennial streams in the valley in 1996 and are listed in Table 5. The daily mean flows of Cleve Creek used throughout this report are from published values in the Nevada Water-Resources data books by the USGS. The technique used first is explained by Moore (1968, p. 5) and involves solving the equation: $Q_M / Q_m = Q_b / Q_a$; where:

Q_M = long-term mean annual gaged flow of Cleve Creek,
Q_m = unknown long-term mean annual flow of the miscellaneous site,
Q_b = daily mean streamflow of Cleve Creek on the day the miscellaneous site is measured, and
Q_a = measured flow at the miscellaneous site.

Table 5.-- Miscellaneous measurements made by the LVVWD in Spring Valley, July, 1996.

Creek or Canyon	**Date**	**Q, in cubic feet/second**	**Cleve Creek, daily mean Q, in cubic feet/second**	**Miscellaneous site, mean annual flow, in acre-feet**
Taff	18	2.08	7.3	2,110
McCoy	17	5.81	7.5	5,720
Odgers	18	2.17	7.3	2,200
Little Negro	17	0.94	7.5	930
Bassett	18	5.26	7.3	5,320
Piermont	16	1.29	8.0	1,190
Kalamazoo	15	4.75	7.6	4,620
Frenchman	17	0.66	7.5	650
North	17	1.76	7.5	1,730
Siegel	16	1.49	8.0	1,380
Eight Mile [1]	19	1[e]	7.3	1,110
Swallow [1]	19	2[e]	7.3	2,020

1. Measurements included in the table are from July 19, 1997, due to the limited data collection in 1997.

e. Estimated by measuring width/depth and estimating velocity.

Table 6.– Miscellaneous measurements made by the LVVWD in Spring Valley, July 1998.

Creek or Canyon	July Date	Time	Q, in cubic feet/second[1]
Cleve at gage: instantaneous flow/*daily mean flow*	12	–	24
	13	–	22
	14	–	21
	15	–	19
	16	–	18
	17	–	18
	18	–	18
Cooper[2]	18	–	0
Bastian	15	1345	10.5
	17	0930	6.52
Silver[2]	17	–	0
Taft	15	1130	10.7
	16	1615	8.43
McCoy	15	1230	15.4
	15	1520	14.9
	17	1055	10.8
Odgers	15	1355	6.39
	17	1245	6.34
Little Negro	15	1540	2.48
	17	1440	1.80
Bassett	17	1555	11.5
Garden	14	1230	1.12
Piermont	14	1430	5.94
	15	0925	6.47
	17	1405	4.96
Kalamazoo	12	1415	9.31
	14	0945	9.96
Muncy	16	0830	5.17
	17	1235	5.14
Frenchman	14	1130	0.9
	17	1100	0.86
North	14	0930	3.11
	17	0900	2.74
Siegel	13	1700	2.65
Stage	13	1400	0.15
Eight Mile	14	1550	2.17
	16	1300	2.02
Negro	14	1420	4.44
	16	1115	6.69
Swallow	13	1330	52.4
	14	1010	21.5
	16	1210	35.4
	18	1055	32.3

1. Daily mean flow for Cleve Creek, instantaneous flow for all other creeks.
2. These drainages are ephemeral and are included for continuity of coverage.

The miscellaneous measurements made in 1999 are listed in Table 7. The daily flow at Cleve Creek in July 1999 is much lower than when the measurements were made in 1998 (Table 6) and significantly higher than the measurements made in 1996 (Table 5). The flow of Swallow Canyon has wide variability and is very prone to high runoff rates during periods of snow melt as evidenced by the above measurements. Additionally, a flow of 44 cfs was measured in Swallow Canyon during the spring runoff in May 1993 (see Appendix) at a road crossing nearly a half-mile west of the mountain front, presumably the flow at the canyon mouth was higher.

Table 7.-- Miscellaneous measurements made by the LVVWD in Spring Valley, July 1999.

Creek or Canyon	**July Date**	**Time**	**Q, in cubic feet/second**[1]
Cleve at gage: instantaneous flow/*daily mean flow*	12	1530	13.7/*16*
	13	1515	14.2/*18*
	14	0830	12.8/*17*
	15	0745	13.7/*15*
	16	1000	13.6/*14*
Cooper	13	1530	0
Bastian	13	1445	5.91
Taft	13	1415	4.32
McCoy[1]	15	0930	8.61
Odgers	15	1030	4.35
Little Negro	13	1230	1.26
Bassett	13	1330	5.96
Garden	13	1030	0.93
Piermont[2]	14	1045	2.9
Kalamazoo	13	1430	7.26
Muncy	13	1400	5.04
Frenchman	12	1300	1.04
North	12	1415	2.40
Siegel	12	1545	2.66
Stage	12	1645	0.09
Eight Mile	13	1030	1.67
Negro	13	1215	5.80
Swallow	14	1200	7.74
	16	1015	6.87

1. Seepage run made 10 additional measurements.
2. Seepage run made 11 additional measurements.

In general, the flows measured during July 2000 are some of the lowest observed for several years in many of the creeks as shown in Table 8. Lower flows were measured on some creeks the following year, listed in Table 9, but they were made in August when flows should be lower.

Table 8.-- Miscellaneous measurements made by the LVVWD in Spring Valley, July 2000.

Creek or Canyon	July Date	Time	Q, in cubic feet/second
Cleve at gage: instantaneous flow[1]/*daily mean flow*	24	1030	7.33/*7.2*
	25	1700	7.14/*7.2*
	26	1430	6.85/*7.0*
	27	1015	8.05/6.9
	27	1130	7.37/*6.9*
	27	1245	7.48/*6.9*
	27	1345	7.44/*6.9*
Cooper	28	-	0
Bastian	25	1130	0.78
Stephens	25	1330	0.69
	27	1130	0.76
Taft	24	0845	1.24
	27	1015	1.27
McCoy	24	1100	4.31
	27	1000	3.54
Odgers	24	1315	2.00
Little Negro	24	1430	0.45
	27	1100	0.48
Bassett [1]	24	0945	4.13
	26	0945	4.34
Garden	25	-	0
Piermont	24	1300	0.92
	27	1200	0.68
Kalamazoo	24	1615	3.27
	27	0900	3.51
Muncy	24	1515	1.06
	27	1545	0.75
Frenchman	25	0930	0.07
North	24	1715	0.60
	25	1130	0.66
	25	1230	0.55
	25	1300	0.61
	25	1345	0.57
Silver	24	-	0
Siegel	24	1500	0.25
	27	0915	0.47
Stage	24	-	0
Eight Mile	24	1500	0.48
	26	1130	0.56
Negro	24	1330	1.17
	26	1300	1.08
Swallow	23	1500	0.97
	25	1530	0.75
	27	1300	0.79

1. See Table 20 for additional measurements.

Table 9.– Miscellaneous measurements made by the LVVWD in Spring Valley, August 2001.

Creek or Canyon	August Date	Time	Q, in cubic feet/second
Cleve at gage: instantaneous flow/*daily mean flow*	6	1100	6.09/*6.1*
	7	1315	6.20/*6.1*
	8	1000	6.26/*6.3*
	9	1415	6.57/*6.3*
Cooper	9	-	0
Bastian	7	1515	1.27
Taft	7	1500	1.21
McCoy	8	1115	4.38
Odgers	7	1130	1.34
Little Negro	8	1215	0.44
Bassett	8	1400	1.93
Garden	7	0945	0.10
Piermont	8	1500	0.51
Kalamazoo	9	1145	3.77
Muncy	7	0930	0.80
Frenchman	7	1030	0.10
North	6	1715	0.37
Silver	6	-	0
Siegel	6	1600	0.12
Stage	6	-	0
Eight Mile	7	1515	0.52
Negro[1]	8	1530	1.35
Swallow	7	1145	1.13

1. See Table 22 for additional measurements.

The 2002 data collection was scaled back to less than half the usual number of surface-water measurements. These data were not used in the analyses for this study and are listed in Table 10 for completeness and to present the up-to-date surface-water data collected by LVVWD in Spring Valley.

Table 10.-- Miscellaneous measurements made by the LVVWD in Spring Valley, July 2002.

Creek or Canyon	July Date	Time	Q, in cubic feet/second
Cleve at gage: instantaneous flow	16	0930	6.01
	17	1300	5.61
Bastian	16	0830	0.36
McCoy	16	1045	4.55
Bassett	16	1215	2.60
Piermont	16	1500	3.10
Kalamazoo	16	1145	3.77
North	16	1400	0.68
Siegel	16	1715	0.21
Negro[1]	17	1100	0.54
Swallow	17	1545	2.31

1. Measurement location ¼ mile down stream from ranch.

Linear Regression

The second technique used to estimate the long-term average for the miscellaneous streamflow sites was linear regression where all of the miscellaneous measurements made by the USGS were regressed with the daily mean Q of record for Cleve Creek in Excel Version 5.0. The miscellaneous sites, regression factors, and long term mean annual streamflow for select perennial streams are listed in Table 11.

Table 11.-- Summary of linear regression results for select streams in Spring Valley.

Site	No. of data points[1]	Slope	Intercept	Correlation coefficient	Mean annual runoff	
					cfs	acre-feet
Taff	18	0.315	-0.922	0.96	2.14	1660
McCoy	19	0.582	-0.286	0.98	5.65	4090
Odgers	31	0.137	0.448	0.90	1.85	1340
Bassett	29	0.496	-1.25	0.96	3.81	2760
Piermont	12	0.322	-1.04	0.97	2.24	1620
Kalamazoo	26	0.487	0.897	0.91	5.86	4250
Willard	18	0.105	-0.316	0.98	0.76	550

1. Miscellaneous measurements made by USGS; source from USGS Water-Resource Data for Nevada.

Geomorphology

The third method used to estimate the average annual runoff is described by Hedman and Osterkamp (1982). The technique is based on certain channel characteristics that are formed by the discharge of water and sediment in a natural channel. The magnitude, duration, and frequency of flows dictate stream-channel geometry with additional control imposed by the distribution and size of sediment on the channel bed and banks. The channel characteristic measured in the Spring Valley streams was the active channel width and the equations governing its use are found in Hedman and Osterkamp (1982, Table 2, p. 13). The results of channel geometry measurements are listed in Table 12 and all sites are perennial except for Silver and Cooper Canyons, which are ephemeral.

Table 12.-- Summary of channel geomorphology measurements in Spring Valley.

Site	Active channel width, in feet	Mean annual runoff, in acre-feet	Channel sediment characteristics for bed and bank
Cooper	3	500	Coarse sand and gravel
Cleve	12	6840	Gravel/cobbles
Taft	8	3190	Cobbles
McCoy	7	2480	Gravel/cobble, brush
Odgers	6	1860	Gravel/cobble, brush
Little Negro	4	870	Cobbles and heavy brush
Bassett	8	3190	Gravel/cobbles and coarse sand
Piermont	8	3190	Gravel, cobbles, and boulders
Kalamazoo	8	3190	Coarse sand, gravel, and cobbles
Frenchman	4	870	Cemented gravel
North Canyon	4.5	1080	Cobbles and brush
Silver	< 3	400	Coarse sand and gravel
Siegle	6	1860	Coarse sand and gravel
Stage	3	500	Coarse sand and gravel
Eight Mile	6	1860	Bedrock and cobbles
Swallow Canyon	11	5810	Cobbles and small boulders

Graphical

The fourth method to estimate runoff is termed the graphical method wherein the miscellaneous measurements are plotted on the daily/monthly hydrograph of a continuous recording station, in this case Cleve Creek, and the average annual flow is picked off of the graph. This value is either increased or decreased according to the ratio of the particular year to the long-term flow of Cleve Creek. Admittedly, this method is somewhat primitive and does share a commonality with the miscellaneous measurement method, but it does require a quantitative approach and provides an additional reality check with the other methods. These values are listed in Table 13 along with the results of the other estimating techniques.

Summary of Results

The results of the various methods are listed in Table 13 and define the long-term average mountain-front runoff for select drainages evaluated in this report. Not all techniques could be applied to each drainage for a variety of reasons; two of the sites are ephemeral so miscellaneous measurements were not made; linear regression used only USGS flow data, which was lacking on many streams; some stream channels were not suitable for the channel geometry method, because of thick brush and small size; and the graphical method requires a large number of streamflow data.

Table 13.-- Estimates of annual mean flow with various techniques for select drainages in Spring Valley, in acre-feet.

Site	Miscellaneous Measurement	Linear Regression	Channel Geometry	Graphical	Selected value[1]
Cooper	NA[2]	NA	500	NA	**500**
Bastian[3]	3400	NA	NA	NA	**3,400**
Cleve	NA	NA	6,840	NA	**7,500[a]**
Stephens[4]	720	NA	NA	NA	**720**
Taff	2,110	1,660	3,190	1,900	**2,170**
McCoy	5,720	4,090	2,480	4,600	**4,470**
Odgers	2,200	1,340	1,860	1,800	**1,830**
Little Negro	930	NA	870	NA	**910**
Bassett	5,320	2,760	3,190	3,100	**3,900**
Garden[3]	430	NA	NA	NA	**400**
Piermont	1,190	1,620	3,190	1,700	**1,770**
Kalamazoo	4,620	4,250	3,190	4,200	**4,180**
Muncy[3]	3,700	NA	NA	NA	**3,700**
Frenchman	650	NA	870	NA	**720**
North	1,730	NA	1,080	NA	**1,510**
Silver	NA	NA	400	NA	**400**
Siegle	1,380	NA	1,860	NA	**1,540**
Stage[5]	70	NA	500	NA	**210**
Eight Mile	800	NA	1,860	NA	**1,150**
Negro[3]	2,200	NA	NA	NA	**2,200**
Willard	300	550	NA	NA	**410**
Swallow[5]	2,020	NA	5,850	NA	**6,000**
			Subtotal		**49,590**
Remaining (3-5) unmeasured perennial streams estimate					**3,000**
			Total (rounded)		**53,000**

1. Value calculated by weighted average: Miscellaneous measurement factor is '4' regression factor is '3' geomorphology factor is '2', and; graphical method factor is '1'.
2. NA means not available, the measurement technique could not be used for a variety of reasons.
3. Based on July 1998 measurement and daily/annual mean for Cleve Creek.
4. Based on July 2000 measurement and daily/annual mean for Cleve Creek.
5. A comparison of the miscellaneous measurements made in 1996 and 1998 indicate the stream has great variability and thus the channel geometry method may be more reliable.

a. Gaged record used.

Because of the differences in reliability of the various techniques, the representative mean annual flow was determined by a weighted average technique. In this calculation, more weight is given to a technique by using a multiplication factor. A multiplication factor of 4 was used for the miscellaneous measurement method, because it uses actual measurements it is considered the most accurate method. The regression method is considered next most accurate with a multiplication factor of 3. The multiplication factor of 2 used for the geomorphology method is probably low because where the technique has been used elsewhere in Nevada and Utah, on perennial rivers/streams, at gaging stations the results are generally within 10-15 percent of the gaged average flow (Katzer and others, 1999, Cole and Katzer, 2000, and Dixon and Katzer, 2002). Hedman and Osterkamp (1982) state the method has a standard error of 26 percent for perennial streams and an unknown standard error for ephemeral streams. The graphical method is considered the least accurate of the four techniques and is given a factor value of 1.

An example of the calculation for Kalamazoo Creek is shown in the following tabulation.

Type of Measurement	Value in acre-feet		Weighting Factor	Product
Miscellaneous Measurement	4,620	x	4	18,480
Regression Estimate	4,250	x	3	12,750
Geomorphology Estimate	3,190	x	2	6,380
Graphical Estimate	4,200	x	1	4,200
Total			10	41,810
Rounded weighted average value			**1/10**	**4,180**

The total, 41,810, is divided by 10 (sum of the factors), and the weighted average is 4,180 afy (rounded). For those sites where less than four of the techniques could be applied, due to lack of data, the appropriate factor sums were used.

The rationale for assigning factors to the various techniques is to weight the selected value to, what we consider, the most accurate technique and at the same time allow for the influence of the other techniques. Clearly using the same miscellaneous measurements in the first and fourth technique insures a commonality between them; however the measurements represent actual streamflow at the contact between the mountain front and the alluvial fan. The miscellaneous measurements by the USGS for the regression analysis were not used in the other estimating methods. The channel geometry method is independent of the other three methods.

There were a few small perennial streams not measured because access was restricted and in some cases the flow was just a seep at the mountain front. Also there are two streams, Williams Canyon and Shingle Creek, that flow off the west side of the Snake Range between Swallow Canyon and Willard Creek that are in aqueducts from the mountain front to the valley floor. No attempt was made to measure these two streams. The runoff from these few unmeasured streams is estimated to be 3,000 afy, which increases the total average annual runoff into Spring Valley to 53,000 afy. No attempt was made to adjust the ground-water recharge estimate for these streams because the values are minor.

Unit Runoff

The factors that control unit runoff, as mentioned previously, are: variations in precipitation, temperature, drainage area, area distribution by altitude, aspect, vegetation type and cover, channel and land-surface gradients, and geologic control imposed by lithology and structure. Part of this investigation was to examine the impact of geologic structure and lithology on mountain-front runoff and ground-water recharge. The unit runoff for each of the streams studied is listed in Table 14. In some geologic terrain, drainage area and unit runoff correlate, but this is not true for the streams in Spring Valley. Geologic structure and lithology are examined here as potential causes for this apparent discontinuity.

Table 14.-- Estimated annual and unit runoff values for select drainages in Spring Valley.

Name	Mean annual runoff, in acre-feet	Drainage area, in acres	Drainage area, in mi^2	Unit runoff[1]	
				cfs/mi^2	af / a
SCHELL CREEK RANGE, south to north					
Cooper	500	17,681	27.63	0.02	0.03
Bastian	3,400	1,770	2.77	1.69	1.92
Cleve	7,500	20,548	32.11	0.32	0.36
Stevens	720	1,914	2.99	0.33	0.38
Taft	2,170	2,801	4.38	0.68	0.77
McCoy	4,470	4,070	6.36	0.97	1.10
Odgers	1,830	2,534	3.96	0.64	0.72
Little Negro	910	1,930	3.02	0.42	0.47
Bassett	3,900	4,149	6.48	0.83	0.94
Garden	400	1,873	2.93	0.19	0.21
Piermont	1,770	4,933	7.71	0.32	0.36
Kalamazoo	4,180	9,389	14.67	0.39	0.44
Muncy	3,700	9146	14.29	0.36	0.40
Frenchman	720	3,118	4.87	0.20	0.23
North	1,510	2,057	3.21	0.65	0.73
Silver	400	1,549	2.42	0.23	0.26
Siegel	1540	3,808	5.95	0.36	0.40
Stage	210	3,339	5.22	0.056	0.06
SNAKE RANGE, south to north					
Swallow	6,000	2,394	3.74	2.21	2.51
Willard	410	2,710	4.23	0.13	0.15
Negro	2,200	17,629	27.55	0.11	0.12
Eight Mile	1,150	2,077	3.25	0.49	0.55

1. cfs/mi^2 is cubic feet per second per square mile, af/a is acre-feet per acre

Geologic and Lithologic Control

Figure 6a is an accompanying geologic legend for Figure 6b, a geologic map of the basin with the drainage area of the streams listed in Table 14 superimposed. There are some general similarities in unit runoff that may be related to geologic controls. The distribution of unit-runoff values indicates generally larger unit runoff from the metamorphic/clastic rocks compared to the carbonate rocks. A notable exception is North Canyon, which is 50 percent carbonate rock, yet the drainage has a high unit runoff. Other exceptions are Bastian Creek and Swallow Canyon, which are discussed later. There is a change in unit runoff in the Schell Creek Range north and south of Piermont Creek. The geology of the drainages from, and including, the Piermont Creek drainage south to the north fork of Cleve Creek is composed of predominantly metamorphic rocks. Kalamazoo Creek is anomalous because of the volcanic rocks in the upper altitudes.

GEOLOGIC LEGEND

CENOZOIC

Quaternary

▨ Qal	Younger alluvium
▨ Ql	Younger lake beds
▨ Qol	Older alluvium
▨ Qp	Recent playa deposits
▨ Qs	Sedimentary rocks

Quaternary/Tertiary

▨ QTg	Older gravels
▨ QTl	Intermediate lake beds

Tertiary

▨ Tys	Younger sedimentary and volcanic rocks
▨ Ts	Younger volcanic rocks, intravolcanic sedimentary rocks
▨ Tvd	Younger volcanic rocks, biotite dacite
▨ Tvt	Younger volcanic rocks, tuffs and tuffaceous sediments
▨ Tvy	Younger volcanic rocks, undivided
▨ Tov	Older volcanic rocks
▨ Tot	Older ash-flow tuffs
▨ Ti	Intrusives; monzonite, quartz monzonite
▨ Tsp	Sheep Pass Formation

MESOZOIC/CENOZOIC

Tertiary/Cretaceous

▨ TKi	Intrusive rocks (eastern group)
▨ TKvu	Volcanic rocks, undifferentiated

MESOZOIC

Cretaceous

▨ Kb	Thrust breccia
▨ Ki	Intrusive rocks (intermediate group)

Jurassic

▨ Ji	Intrusives (eastern group); quartz monzonite to granodiorite

Triassic

▨ TRs	Lower Triassic sedimentary rocks

PALEOZOIC

Permian

▨ Pa	Arcturus Formation
▨ Par	Arcturus Formation and Rib Hill Sandstone
▨ Pc	Carbon Ridge Formation
▨ Pl	Permian limestone, w/fossilif. Pennsylvanian beds
▨ Pp	Park City Group; Kaibab/Gerster Limestone, Plympton Formation
▨ Pr	Rib Hill Sandstone

Pennsylvanian/Permian

▨ PPP	Riepe Spring Limestone of Steele (1960), Ely Limestone
▨ PPPl	Permian and Pennsylvanian limestone and sandstone

Pennsylvanian

▨ PPl	Pennsylvanian limestone, w/very Late Mississippian fauna
▨ PPs	Pennsylvanian limestone, w/very Late Mississippian fauna

Mississippian

▨ Mc	Clastic rocks, Chainman Shale
▨ Ml	Joana, Mercury, and Bristol Pass Limestones
▨ Msc	Upper Mississippian clastic rocks, undivided
▨ Msw	Clastic rocks, Scotty Wash Quartzite

Mississippian/Devonian

▨ MD	Chainman Shale, Joana Limestone, Pilot Shale
▨ MDp	Pilot Shale

PALEOZOIC

Paleozoic Undivided

▨ Pzj	Paleozoic carbonate rocks, jasperoid alteration

Devonian

▨ Dg	Guilmette Formation; metamorphic rocks
▨ Ds	Simonson/Sevy Dolomites; metamorphic rocks
▨ Dse	Sevy Dolomite
▨ Dsl	Simonson Dolomite
▨ Du	Guilmette Limestone, Simonson/Sevy Dolomites, undivided

Devonian/Silurian

▨ DSu	Devonian and Silurian dolomite, undifferentiated

Silurian

▨ Sl	Laketown Dolomite

Silurian/Ordovician

▨ SOu	Silurian-Odrovician, upper part; dolomites

Ordovician

▨ Oe	Eureka Quartzite
▨ Oes	Ely Springs Dolomite
▨ Ol	Ordovician, lower part; Pogonip Group, Eureka Quartzite
▨ Op	Pogonip Group

Devonian/Cambrian

▨ DCu	Devonian to Cambrian limestone and dolomite, undifferentiated

Ordovician/Cambrian

▨ OC	Pogonip Group, quartzite, shale, Cambrian limestone

Cambrian

▨ Cl	Cambrian, lower part; quartzite, shale, metamorphic rocks
▨ Cld	Limestone and dolomite, and Dunderberg Shale, undifferentiated
▨ Cm	Cambrian, middle part; limestone, shale
▨ Cp	Pioche Shale
▨ Cpc	Pole Canyon Limestone
▨ Cpm	Prospect Mountain Quartzite
▨ Cs	Patterson Pass Shale of Kellogg (1959)
▨ Cu	Cambrian, upper part; shale, limestone

PROTEROZOIC

pre-Cambrian

▨ pC	McCoy Creek Group; Metamorphic rocks

This legend reflects geologic units as depicted on the White Pine and Lincoln Counties Geologic maps and is to be used in conjunction with figure 6.

Figure 6a. -- Legend for units on geologic map (Figure 6b).

The metamorphic rocks are principally quartzite with extremely low primary permeabilities causing the unit runoff to be high. Ground-water recharge is undoubtedly low throughout this area and the runoff at the mountain front probably represents most of the water yield from this part of the Schell Creek Range. The unit runoff is generally 2-3 times greater in the metamorphic rocks than drainage areas in carbonate rock. However, the unit runoff from Little Negro Creek is somewhat anomalously low. One explanation is there may be unmapped structure present that provides a conduit for downward flow, or it may be the lack of sufficient high-altitude drainage, above 8,000 ft, compared with other creeks.

Swallow Canyon, a relatively small drainage area on the west side of the southern part of the Snake Range, is also anomalously high with the second largest estimated mean annual discharge in the valley and the highest unit runoff (Table 14). The flow from this canyon emanates from a spring orifice near the mountain front and the main drainage channel just upstream from the orifice is ephemeral. The flow is quite variable ranging from a low of 2 cfs in the late summer to over 40 cfs in the spring. This indicates a high degree of secondary permeability in the carbonate rocks and short transient times from recharge areas to the orifice. Carbonate rocks dominate the geology with minor quartzite in the upper elevations of the basin.

There are several metamorphic core complexes in the Schell and Snake Ranges and one of these is located just north of Swallow Canyon (Maldonado and others, 1988) and probably has extremely low permeability. This core complex may be forcing ground water into north-south fault structures that act as conduits allowing ground water to flow to Swallow Canyon, thus in effect increasing the size of the drainage area by some unknown amount. This helps explain why the estimated discharge from Swallow Canyon is nearly twice the estimated precipitation on its drainage area. Murphy Wash, an ephemeral drainage located immediately to the east of the Swallow Canyon drainage, bisects the western edge of the southern part of the Snake Range and extends in a northerly direction from several miles south of Swallow Canyon to about a mile north of the canyon. The ephemeral nature of the wash is an indicator of lack of, not only runoff, but also ground-water discharge to the wash. This may indicate that ground-water recharge to the wash is being intercepted and diverted by fault structure to Swallow Canyon.

In an effort to understand the impact of geologic structure on streamflow, numerous flow measurements were made on Cleve Creek at two sites; at the current USGS gaging station and about 2 miles west on the upstream side of a series of north trending faults that cross the stream. These measurements, listed in Table 15, were made over three days and the stage was recorded intermittently. Only the measurements for July 14, 1997, are listed because they best define the potential loss, which may be at least one cfs, but includes some water use by native vegetation along the stream that is mostly offset by a minor amount of springflow into the creek. One factor that may contribute to the difference between the flow measurements is that upstream measurements were made when the flow was steady or rising and down-stream measurements were made during a falling stage. The stage changes were on the order of 0.01 to 0.02 ft, and because the snow pack was gone, local ET along the stream is undoubtedly the cause for the stage change. The consistencies of the measurements tend to mitigate measurement error.

Table 15.-- Results of flow measurements at two sites on Cleve Creek, July 14, 1997.

Time	Flow at sites, in cubic feet/second		
	Sites		
	No. 1[a]	No. 2[b]	Rising, Falling, or Steady Stage
1030	9.28		S
1120		7.11	F
1125	9.09		S
1250	8.79		R
1330		8.27	F
1340	8.81		F
1430	8.55		S
1500		7.61	F
1530	8.64		R
1630		7.43	F

a. Site is just below junction of north and south forks, about 1.7 miles west of USGS gaging station.
b. Site is 100 ft upstream of USGS gaging station at canyon mouth.

This stream-loss relationship was briefly re-examined on July 27, 2000, with a single measurement at the upstream site (7.74 cfs) and several measurements at the gage (Table 8). Allowing for travel time of about two hours shows a slight loss between the sites, but the differences are also within measurement error. Nevertheless, the loss from the stream channel is fairly consistent and averages a little less than 1 cfs.

The results of the same type of fault structure evaluation made on Kalamazoo Creek are listed in Table 16 and are quite different. A geologic map with the measurement sites is shown on Figure 7. The creek gains 3-4 cfs in less than 1,000 feet and continues to gain over 1cfs to the mountain front. The fault zone where most of the gain occurs is about 500 feet wide and is totally in carbonate rocks. The fault zone is north trending and has a lower permeability than the carbonate rocks it cuts and therefore acts as a dam bringing ground water to the surface. Conversely the fault zone may have a greater vertical permeability than the down-gradient rocks and acts as a conduit with the same end result of bringing ground water to the surface. This gain is from ground water that was recharged at higher elevations and was moving to the valley's ground-water system. The higher elevations are the source area for the most of the ground-water recharge. Volcanic rocks commonly have low permeability and the runoff is expected to be large, however, the runoff is small suggesting that the older volcanic rocks are well fractured with a permeability approaching that of carbonate rocks. East of the fault zone, down gradient, the geology of the contributing drainage area is all quartzite with low permeability. One cfs gain over a distance of about 2.5 miles is probably low, which may indicate that some ground-water recharge is taking place.

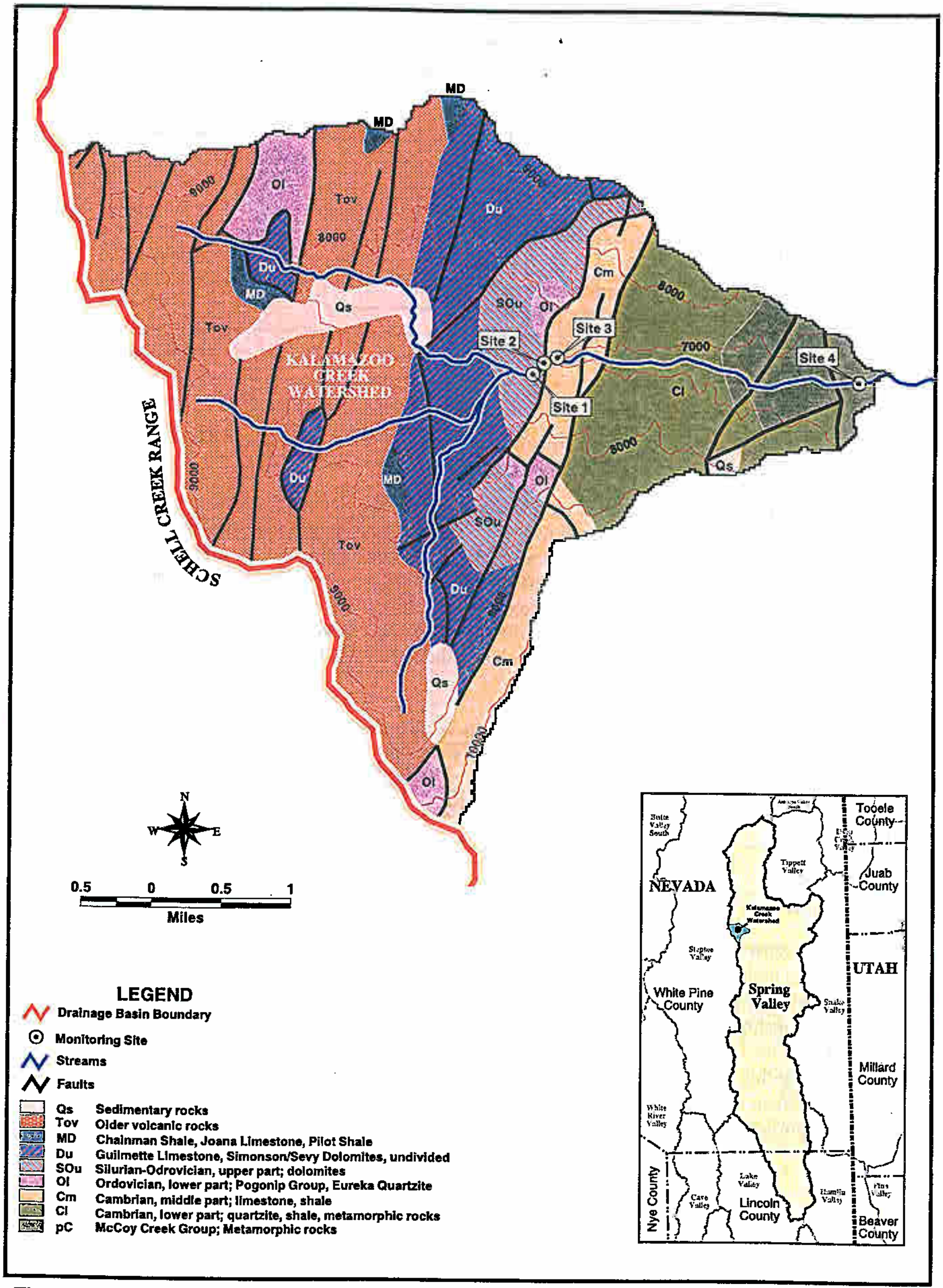

Figure 7. -- Geologic map of Kalamazoo drainage showing location of miscellaneous measurement sites.

Table 16.-- Results of flow measurements at four sites on Kalamazoo Creek, July 17, 1997.

Time	Flow at sites, in cubic feet/second				
	Sites[1]				
	No. 1	No. 2	No. 3	No. 4	Rising, Falling, or Steady Stage
800	1.09				S
830		0.88		5.75	S
900			4.59		S
1000	1			5.98	S
1100		0.82			S
1130	1.02				S
1200			3.74	5.79	S
1230		0.74			S
1300		0.82	4.76		S
1330				5.83	S
1600	0.94			5.74	S
1630		0.88			S

1. Locations shown on Figure 7. Listed in table in down-stream order; fault zone is located between sites 2 and 3. Site No. 4 is at the mountain front about 200 ft up stream of first diversion.

In July of2000 (Table 17), the loss and gain relationship for Kalamazoo Creek was reevaluated and found essentially the same as defined in 1997. The results of this limited seepage investigation show the hydrologic impacts caused by faults and fault zones are quite variable and that the total amount of water measured at the mountain front, such as at Cleve Creek, may not represent all the water yield from a basin. However, the flow at the mountain front for Kalamazoo Creek probably represents most of the yield for that drainage, but there is undoubtedly some amount of ground-water recharge that infiltrates into the bedrock and moves directly to the alluvial ground-water system.

Table 17.-- Results of flow measurements at three sites on Kalamazoo Creek, July 27, 2000.

Time	Flow at sites , in cubic feet/second				
	Sites[1]				
	No. 1	No. 2	No. 3	No. 4	Rising, Falling, or Steady Stage
1400	0.36	-			S
1500		-	2.9		S
0900		-		3.51	S

1. Sites correspond to seepage run sites listed in Table 16. No measurement at site No. 2.

During the August 2001 field investigation SNWA personnel Gavin Kistinger and Zane Marshall discovered the major spring orifice along the fault zone between measurement sites 2 and 3 (Tables 16 and 17) just south of the creek about 20 yards; the spring was flowing 2.62 cfs. Immediately upstream of the confluence of the springflow and the creek the flow in the creek measured 0.16 cfs (corresponds nearly to site No. 2, Table 15). The flow at site No. 1 (Table 15 and 16) during this same time period measured 0.31 cfs. Thus, the loss/gain relationships for Kalamazoo Creek appear to be constant and of such a magnitude that potential measurement error is insignificant.

The results of this seepage loss/gain investigation of streamflow for McCoy and Piermont Creeks are listed in Tables 18 and 19.

Table 18.-- Results of flow measurements at two sites on McCoy Creek July 15, 1999.

Time	Flow at sites, in cubic feet/second		
	Sites		
	No. 1[a]	No. 2[b]	Rising, Falling, or Steady Stage
0930		8.47	S
1000		8.33	S
1015	6.85		S
1115	6.62		S
1145		8.52	S
1245		8.60	S
1330	6.40		S
1345		8.70	S
1430	6.45		S
1445		6.84	S
1545		7.98	S

1. Site is 1.8 miles upstream from mountain front site.
2. Site is at mountain front (normal measurement site).

Based on the limited measurements it appears there is a constant gain in flow in a down-stream direction of about 2 cfs and there is no noticeable impact from the fault zones. The gain is to be expected because low permeable metamorphic/clastic rocks dominate the geology and McCoy Creek has a very high unit runoff. This is in contrast to the apparent loss in streamflow in Piermont Creek that is probably caused by a combination of the fault zones shown on Figure 6b and the permeable carbonate rocks in the upper elevation of the basin that allow ground-water recharge to take place. The runoff at the mountain front from Piermont Creek does not equal the entire water yield of the drainage basin. This loss in streamflow is considered ground-water recharge and if this loss is fairly constant with time then the amount of ground-water recharge might equal at least 500 afy. However, as discussed later, only 100 afy of recharge was estimated for Piermont Creek based on the percent of sedimentary rocks in the basin.

Table 19.-- Results of flow measurements at two sites on Piermont Creek July 14, 1999.

Time	Flow at sites, in cubic feet/second		
	Sites		
	No. 1ª	No. 2ᵇ	**R**ising, **F**alling, or **S**teady Stage
0915		2.91	S
1015	3.51		S
1045		2.90	S
1100	3.52		S
1145		2.87	S
1200	3.53		S
1245		2.74	S
1300	3.44		S
1345		2.83	S
1400		2.74	S
1415	3.45		S
1500		2.81	S

1. Site is 1.8 miles up stream from mountain front site.
2. Site is at mountain front (normal measurement site).

During water year 2000 two additional streams were evaluated for loss/gain relationship, Bassett and Bastian Creeks and these measurements are listed in Tables 20 and 21 respectively.

Table 20.-- Results of flow measurements at two sites on Bassett Creek July 26, 2000.

Time	Flow at sites, in cubic feet/second		
	Sites		
	No. 1ª	No. 2ᵇ	**R**ising, **F**alling, or **S**teady Stage
0930		4.34	F
1015		3.54	S
1115		4.51	S
1215		3.28	R
1245	4.38		R
1315		3.58	S
1345	3.68		S
1415		3.49	S

1. About 1.5 miles up stream of mountain front measurement site.
2. At mountain front, annual measurement site.

Table 21.-- Results of flow measurements at two sites on Bastian Creek July 25, - 27, 2000.

Date/Time	Flow at sites, in cubic feet/second Sites		
	No. 1ª	No. 2ᵇ	**R**ising, **F**alling, or **S**teady Stage
25/1130		0.78	S
26/1515	3.89		S
27/1300		0.79	S

1. Site is about 1 mile up stream of mountain front site.
2. Mountain-front annual measurement site.

These few measurements on Bassett Creek suggest a loss of flow within the mountain block that is difficult to quantify, but probably not more than 1,000 afy for Basset Creek. The flow in Bastian Creek comes mostly from springs at the mountain front and the unit runoff is very high (similar to Swallow Canyon), which indicates there is probably some capture of ground-water recharge from adjacent drainages. The loss of over 3 cfs between sites cannot be explained without additional field investigations.

During the August 2001 field investigation the streamflow loss/gain relationship for Negro Creek in the Snake Range was evaluated. Numerous streamflow measurements were made at three sites along the creek and these are listed in Table 22. This drainage is the third largest of all the drainages evaluated and of the perennial streams is second in drainage area size to Cleve Creek in the Schell Creek Range (see Table 4).

Table 22.-- Streamflow measurements on Negro Creek, August 9, 2001.

Time	Flow at sites, in cubic feet/second			
	Sites			
	No. 1[a]	No.2[b]	No. 3[c]	Rising, Falling, or Steady Stage
1100			1.51	S
1200			1.61	S
1230	1.57			S
1300			1.67	S
1315	1.31			S
1330		1.37		S
1400	1.39		1.67	S
1430		1.32		S
1500	1.36		1.62	S
1530		1.35		S

a. Site 1 is located just up stream of the junction of Salt Marsh Canyon and Negro Creek, about 3 miles up stream from site 2.
b. Site 2 is located at the mountain front in the meadow down stream from the ranch buildings and the main spring complex.
c. Site 3 is located 600 feet down stream from Site 2 and is on a north trending fault (Michael Johnson, Virgin Valley Water District, oral commun., 2001).

In Table 22, only Site 2 is shown on the location map (Figure 4). The streamflow at Site 1 is nearly the same as Site 2. This is somewhat surprising because the only way this can happen is if the ET along the stream is balanced by the inflow from ground water. This relationship is complicated by the diurnal variation at the two sites, which was not defined. The increase in streamflow between Sites 2 and 3 is undoubtedly caused by a decrease in permeability across the fault zone causing ground water to rise to the level of the incised stream channel.

Rarely in water-resource studies is there the opportunity to determine the surface- and ground-water relationship. Often empirical factors are applied to estimate ground-water recharge and mountain-front runoff with sparse data. In Spring Valley the data set, although still somewhat limited, does allow relatively accurate estimates of these two parameters, particularly the mountain-front runoff. The estimates of surface-water flow at the mountain front appear reasonable and the loss/gain relationship for some individual drainages is fairly constant over time. The difference in unit runoff between drainages is easily explained by a combination of lithology and structure. In general metamorphic/clastic rocks have lower permeabilities and higher unit runoff values than carbonate rocks. This has ramifications for ground-water recharge and is discussed in the next section.

GROUND-WATER FLOW SYSTEM

Movement

The ground-water flow system for Spring Valley starts in the source areas, which are the surrounding mountain blocks and alluvial fans, and as ground-water recharge, moves down gradient to discharge areas in the valley lowlands. Most of the ground-water discharge from Spring Valley is through ET with minor amounts exiting the basin to the north and southeast as ground-water outflow. There is also a minor amount of ground-water inflow to Spring Valley from Tippett Valley (Nichols, 2000, p. C22, Figure C-5).

There are numerous granitic plutons in the area and their impact on ground-water movement is unknown. The primary permeability of plutons is undoubtedly low, but secondary fractures may have developed from cooling and tectonic movement resulting in increased permeability. An example of the impact of the plutons on ground-water movement is probably expressed in the ground-water discharge from Swallow Canyon where the estimated discharge from the basin far exceeds the estimated precipitation on the basin. The large pluton in the Mt. Washington area north of the Swallow Canyon may be responsible for this increase by forcing ground water to move to the south.

Precipitation

Although interbasin flow into Spring Valley probably occurs, precipitation is the largest source of water. The fate of precipitation that falls on the Spring Valley drainage is shown on Figure 8.

Melting snow is the single largest source of precipitation on the valley drainage area, however rainstorms (winter and summer) undoubtedly also contribute significant amounts to the total water resource. Visual inspection of the USGS high-altitude precipitation gage records suggests winter precipitation is usually larger than summer. Estimation of the temporal and spatial variability of precipitation in any area must incorporate a set of assumptions, because of a general lack of precipitation data and complicating local effects such as topography and storm tracts.

Orographic Effect and Historical Precipitation Estimates

Estimation of precipitation in Nevada must emphasize the orographic effect (increased rates of precipitation with increasing altitude) because of general physiography of the valleys. The fact that most of the highland parts of every mountain range in Nevada are tree covered, whereas desert shrubs cover most of the valley floors is an obvious result of the orographic effect.

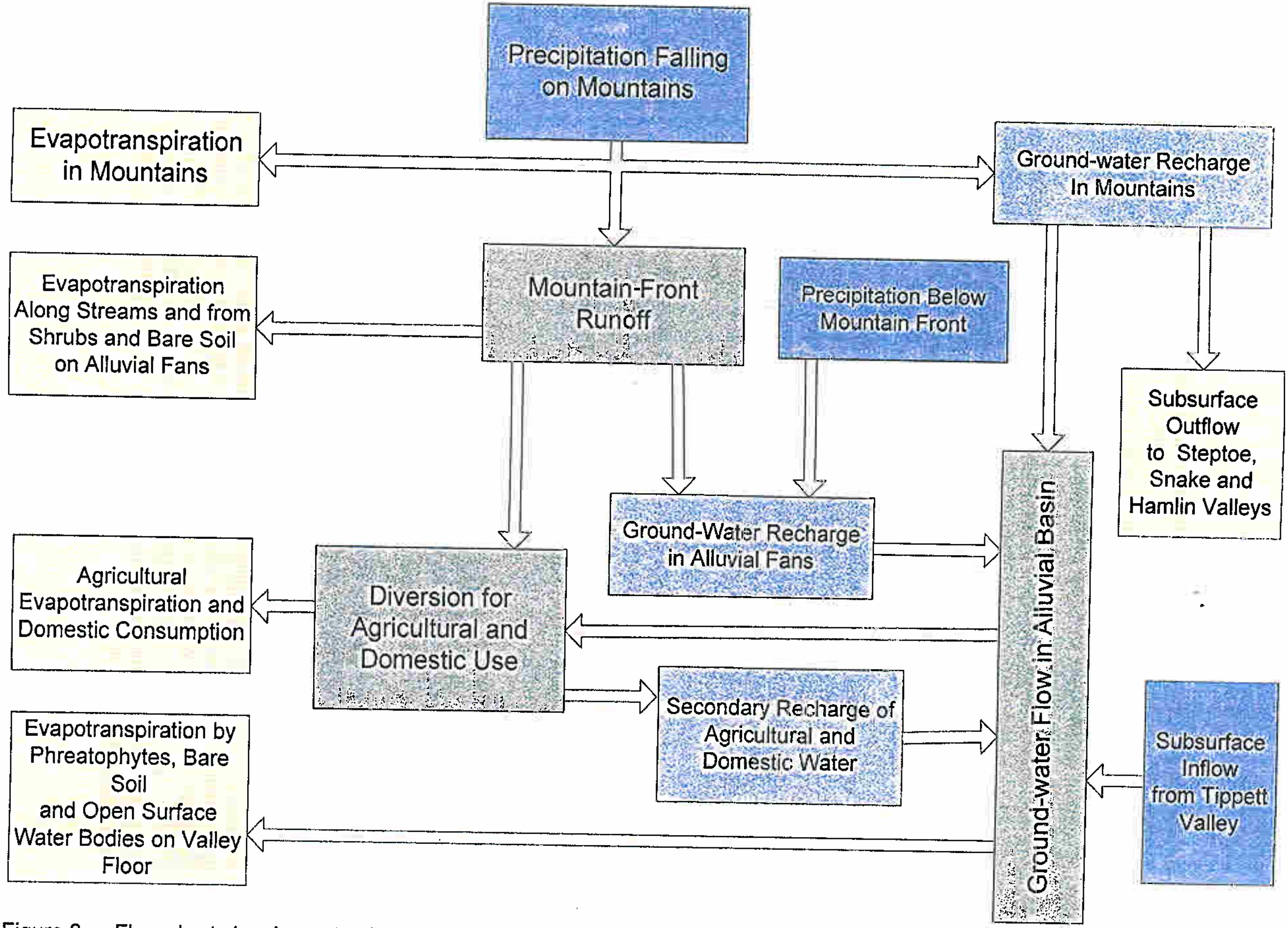

Figure 8. -- Flow chart showing potential fate of precipitation in Spring Valley.

Because of the inherent assumptions (such as importance of slope direction, use of vegetation patterns as surrogates for precipitation records, importance of storm tracts, etc…) all precipitation maps vary, even maps that are based on the same precipitation data. Some of the differences are also introduced by the approximation method used to convert point data to regions, some of which do not honor the actual point data.

Although the existence of the orographic effect is easily documented, the actual rate of increase in precipitation with altitude is subject to interpretation. Within Nevada, and generally the Great Basin, the early hydrology reports of the various valleys used the Maxey-Eakin technique (Maxey and Eakin, 1949) to estimate precipitation. Rush and Kazmi (1965) used the standard version of this technique in Spring Valley, which assumes a specific altitude precipitation relationship for the entire valley.

The Maxey-Eakin technique used by Rush and Kazmi (1965) is simple, and was the most appropriate technique at the time due to the general scarcity of precipitation information. The technique used in this study is closely related to the Maxey-Eakin technique. Newer estimates of precipitation are more complicated approaches and the relationship between attitude and precipitation varies spatially within any given valley. These newer precipitation estimates, although more complicated, are not necessarily "better" due to scarcity of data, specifically at high altitude.

The history of precipitation maps for Nevada is both short and primarily based on the work of one individual, George Hardman of the University of Nevada, Reno. The first regional estimate of precipitation was made by Bixby and Hardman (1928). Hardman's later work was developed on the observations reported in the 1928 paper and he made the first statewide map of precipitation in 1936. Hardman distributed the 1936 map in Hardman and Mason (1949) and Hardman updated the 1936 map in 1965.

The Nevada Division of Water Resources (NDWR) made minor revisions to the Hardman (1965) map (B. Scott, formerly with NDWR, oral communication, 2000) and published it in the State Water Plan of 1972 as Plate S3. The NDWR (1972) map was used in this analysis because it is newer and more amenable to GIS techniques, being a simple line drawing.

During the period (late 1940's to late 1970's) when the USGS and NDWR first developed basin budgets in Nevada, the early reports used the 1936 and the later reports used the 1965 Hardman precipitation maps. The Hardman maps were the only maps available and were used extensively with the Maxey and Eakin (1949) method of estimating hydrologic basin budgets.

Since the middle 1990's, advances in computer technology have increased the availability of other precipitation maps. The best-known maps are produced from the Parameter Regression on Independent Slopes Model (PRISM) of the Oregon State Climatic Service (Daly and others, 1994, 1997). The Utah State Climatologist (Don Jenson, electronic communication January 18, 1996) developed the other precipitation map used in this analysis, which is principally a map of Utah but overlaps onto the adjacent states.

In summary, the previously available estimates of precipitation are: the Hardman maps (1936 and 1965); the basin report of Rush and Kazmi (1965); NDWR (1972); Utah State (1996); and PRISM (1997) maps.

Development of Local Altitude-Precipitation Relationships

The available precipitation stations are shown on Figure 9 and the site-specific characteristics are listed in Table 23. This table lists 25 precipitation stations in either Spring or adjacent valleys, of which 20 were used for the analysis. These data are from three sources, the Western Regional Climate Center (WRCC) (http://www.wrcc.dri.edu/), unpublished files of NDWR, and USGS data published in their annual data reports for Nevada. These particular stations were defined as "local" because they are either within Spring or adjacent valleys, therefore eligible for the local altitude-precipitation analysis.

The five stations (Figure 9, Table 23) not used to develop the altitude-precipitation relationship are so designated and described as follows: the Currie station is missing over half of the period of time it was in operation and therefore the long term average is unreliable; the Geyser Ranch, in Lake Valley, was not used because nearly 60 percent of the record is missing; Lake Valley at Steward Ranch appears to be anomalously high even though it is off set by the Cherry Creek station, which is anomalously low, neither station was used; the Robinson Pass station is located on the western edge of the Steptoe Valley drainage and was not used because it is low in precipitation compared to other mountain passes, which are in the Spring Valley drainage.

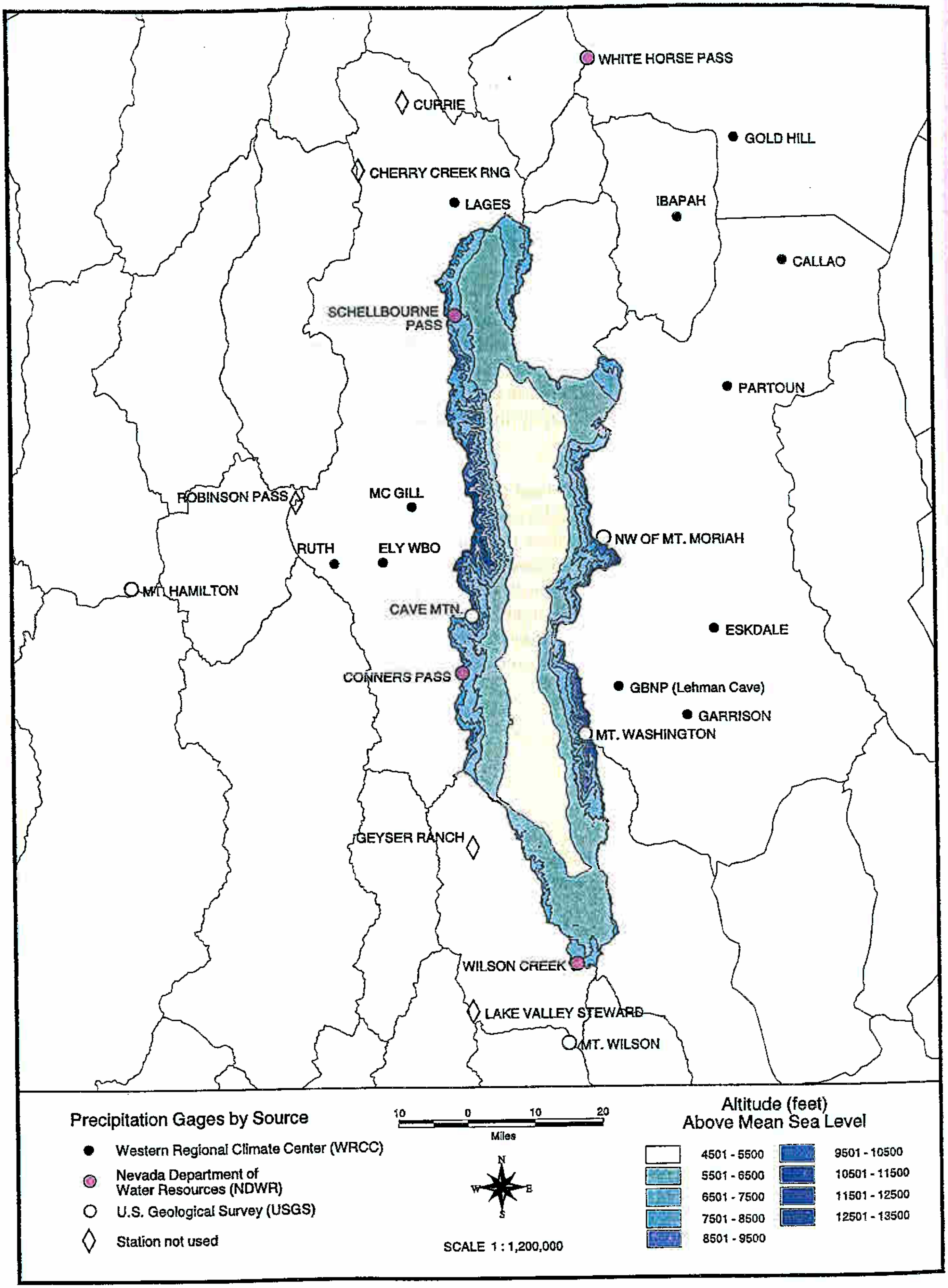

Figure 9. -- Precipitation stations in the study area.

Table 23.-- Characteristics of precipitation stations used in this analysis for Spring Valley.

Site Name	ST	Source	Period	Latitude	Longitude	Altitude	Mean Annual Precipitation	
				DMS[3]	DMS[3]	in feet	in feet	in inches
CALLAO	UT	WRCC	1948-2001	39 54 00	113 43 00	4330	0.48	5.8
PARTOUN	UT	WRCC	1950-2001	39 38 00	113 53 00	4780	0.56	6.8
ESKDALE	UT	WRCC	1966-2001	39 07 00	113 57 00	4980	0.54	6.5
GOLD HILL	UT	WRCC	1966-1990	40 10 00	113 50 00	5250	0.93	11.1
GARRISON	UT	WRCC	1951-1990	38 56 00	114 02 00	5260	0.63	7.6
IBAPAH	UT	WRCC	1948-2001	40 00 00	114 00 00	5280	0.80	9.7
CURRIE[2]	NV	WRCC	1961-1991	40 16 00	114 45 00	5820	0.60	7.2
LAGES	NV	WRCC	1984-2001	40 03 00	114 37 00	5,960	0.70	8.4
GEYSER RANCH[2]	NV	WRCC	1948-2001	38 40 00	114 38 00	6,020	0.73	8.7
ELY WBO	NV	WRCC	1939-2001[1]	39 17 00	114 51 00	6,250	0.80	9.7
MC GILL	NV	WRCC	1914-2001	39 24 00	114 46 00	6,300	0.74	8.9
LAKE VALLEY STEWARD[2]	NV	WRCC	1971-1998	38 19 00	114 39 00	6,350	1.31	15.7
GBNP (Lehman Caves)	NV	WRCC	1948-2001	39 00 00	114 13 00	6,830	1.09	13.1
RUTH	NV	WRCC	1958-2001	39 17 00	114 59 00	6,840	1.02	12.2
WHITE HORSE PASS	NV	NDWR	1954-1998	40 21 00	114 13 45	6,000	0.77	9.2
SCHELLBOURNE PASS	NV	NDWR	1954-1998	39 48 30	114 37 45	7,100	1.11	13.3
WILSON CREEK	NV	NDWR	1954-1998	38 24 45	114 21 45	7,200	1.37	16.5
CONNERS PASS	NV	NDWR	1954-1998	39 02 30	114 38 45	7,732	1.17	14.0
ROBINSON PASS[2]	NV	NDWR	1954-1998	39 25 00	115 05 00	7,800	1.06	12.7
MT. WILSON	NV	USGS	1984-1999	38 14 38	114 23 33	9,200	1.87	22.5
NW OF MT. MORIAH	NV	USGS	1984-1999	39 19 13	114 14 31	9,300	1.52	18.3
CHERRY CREEK RNG[2]	NV	USGS	1984-1999	40 07 26	114 52 47	9,700	1.23	14.7
MT. WASHINGTON	NV	USGS	1984-1999	38 54 09	114 18 54	10,440	2.15	25.8
MT. HAMILTON	NV	USGS	1984-1999	39 14 36	115 32 39	10,600	1.82	21.8
CAVE MTN.	NV	USGS	1984-1999	39 09 46	114 36 49	10,650	1.78	21.4

1. Also 1897-1904.
2. Not used to develop altitude precipitation relationship.
3. DMS – Degrees Minutes Seconds.

The lower part of the altitude-precipitation relationship is defined by the six low altitude stations in Utah located on the east side of the Snake Range. Although most of the low altitude data are from adjacent valleys, most of the high altitude (USGS) data are in Spring Valley. The relationship between altitude and precipitation for each of the stations listed in Table 23 is shown on Figure 10. The regression equation, shown on the figure, represents the altitude-precipitation relationship and is:

$$P = 0.00023709 (A) - 0.5701628,$$ where:

P is precipitation in feet; and A is altitude in feet above mean sea level. The adjusted r^2 of the regression of these data is 0.91 implying that 91 percent of the variability of these data are explained by this regression. The adjusted r^2 is a measure of the goodness of fit between the regression line and the precipitation data. The adjusted r^2 differs from the "normal" r^2 because it is smaller and incorporates a compensation for the limited number of data points.

Comparison of Precipitation Estimates

The comparison between the precipitation gage data and the altitude-precipitation relationship developed for this analysis is shown in Figure 10, which predicts precipitation estimates. The curve labeled "This Study" is the altitude-precipitation relationship described above. The Rush and Kazmi (1965 Table 6, p. 21) curve is directly from their report. The three precipitation maps [NDWR (1972), Utah State (January, 1996), and PRISM (May, 1997)] were processed using Geographic Information System (GIS) to determine the weighted precipitation means of the 1,000 foot intervals for plotting the altitude-precipitation curves.

This weighted mean technique allows precipitation maps, which usually do not have a direct correspondence between altitude and estimated precipitation rate, to be compared to the standard altitude intervals commonly used in the basin reports, such as Rush and Kazmi (1965). This weighted mean technique was found to be more reproducible and more representative than a visual method used in a similar hydrologic investigation for Las Vegas Valley (Donovan and Katzer, 2000).

In comparing the various precipitation estimates on Figure 10, the PRISM (Daly and others 1994, 1997) curve plots above the measured precipitation data presented in this study indicating PRISM over-estimates the precipitation. The regression equation developed for this analysis, the Utah State and PRISM altitude-precipitation curves all estimate similar (8.8, 8.6 and 8.9 inches respectively) precipitation at an altitude of 5,500 feet. This similarity probably arises from the fact that the long-term low altitude stations, in Utah, heavily influence all of these estimates. Compared to this study and PRISM, the Utah State map, despite starting at a very similar value, is conservative and appears to under-estimate the precipitation.

The standard Maxey-Eakin curve used by Rush and Kazmi (1965) and the NDWR (1972) curve are similar to each other (6.0 and 7.1 inches of precipitation respectively, at an altitude of 5,500 feet) but lower than the other three curves. There is also general agreement between these same two estimates (both Hardman based) below 7,500 feet of altitude, because of the similar origin discussed previously and the low to mid altitude range of data. Above 7,500 feet these two estimates deviate from each other and the NDWR (1972) curve (being more conservative) fits poorly with the high altitude data of the USGS in Spring Valley.

These differences in the altitude-precipitation curves on Figure 10 explain most of the variation in volume between the precipitation estimates used in this analysis. The PRISM (May, 1997) map estimates the largest volume followed in decreasing order by this study, Rush and Kazmi (1965), NDWR (1972), and the Utah State (January, 1996) map. The different areas and amounts of precipitation are listed in Table 24, in chronological order for comparison.

Nichols (2000C, p. C51) published an estimate of the total amount of precipitation, based on the PRISM map, of 1,141,444 afy, which is listed in Table 24. In his report, Nichols (2000C, p. C19) indicated that his estimate came from a PRISM map with a specific download date (May 1997), other PRISM maps were available previously and subsequently, which are significantly different.

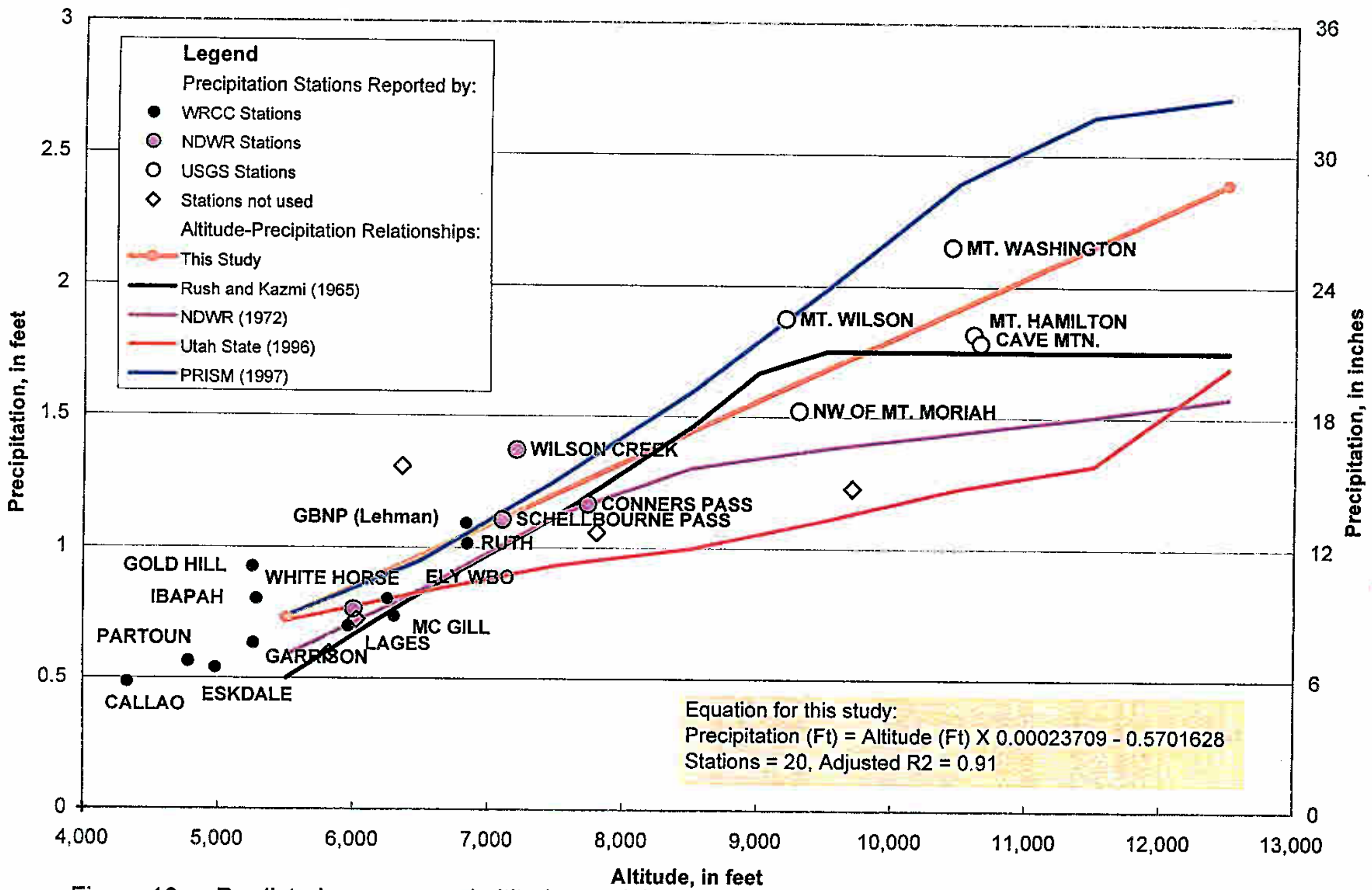

Figure 10. -- Predicted vs measured altitude-precipitation relationships for Spring Valley.

Table 24.-- Comparison of areas and precipitation amounts for Spring Valley using various estimates.

Investigator(s) or data set	Year	Area, in acres	Precipitation, in acre-feet/year[2]	Precipitation > 8 inches, in acre-feet/year
Rush and Kazmi	1965	1,085,000	960,000	789,000
NDWR	1972	1,066,556[1]	938,393	753,000
Utah State	1996	1,066,556[1]	902,592	902,592
PRISM[3]	1997	1,067,010	1,141,444	1,102,000
This study	**2000**	**1,066,556[1]**	**1,089,709**	**1,089,709[4]**

1. Areas calculated are the same because of common map scale 1:24,000, Rush and Kazmi (1965) used a map scale of 1:250,000.
2. Each investigator used a different altitude-precipitation relationship.
3. Nichols (2000C).
4. The altitude-precipitation relationship developed for this report suggests that no part of Spring Valley receives, on average, less than 8 inches of precipitation per year.

The areas in the above table for all except Rush and Kazmi (1965) and Nichols (2000C) are the same because the base maps were produced at the same scale. However, there are significant differences in the precipitation amounts, which is to be expected using different precipitation data sets.

For this study, the total amount of precipitation was estimated to be 1,089,709 afy (or rounded 1,090,000 afy). This was determined by multiplying the precipitation rate for each 1,000 foot interval determined from the altitude-precipitation relationship equation described above and shown on Figure 10, by the acreage of the area determined by GIS, then all volumes were summed.

Ground Water

Recharge

Any natural recharge estimate based on precipitation is composed of two parts, precipitation and recharge efficiency. Precipitation or "effective precipitation" is estimated and then each precipitation interval is assigned a recharge efficiency coefficient, which is multiplied by the estimated precipitation volume. In this study, ground-water recharge was estimated from the altitude-precipitation relationship described in the Precipitation Section, using altitude-area-precipitation-recharge tables. In these tables, the area of each precipitation interval was determined and a recharge efficiency factor applied to each value of precipitation. The recharge efficiency factor is the percentage of precipitation for any given altitude zone that becomes ground water through the recharge process. An example of the standard altitude-precipitation-recharge efficiency tables, as used by the USGS (Eakin, 1966 p. p. 260-262) for the state-wide Reconnaissance and Bulletin series to estimate ground-water recharge, is listed in Table 25 which also compares with the respective precipitation and recharge efficiencies used in this study.

Table 25. --Standard format and values for altitude-area-precipitation-recharge efficiency compared to values used for this study.

Altitude, in feet	Area, in acres, rounded[1]	Precipitation, in inches per year		Recharge efficiency, in percent	
		Hardman map[2]	This Study[3]	Maxey-Eakin[4]	This Study
>9,000 9,000 – 13,000[a]	62,000	> 20 (21)	21.3	25	25
8,000 – 9,000	92,500	15 – 20 (17.5)	17.3	15	14
7,000 – 8,000	181,000	12 - 15 (13.5)	14.5	7	8
6,000 – 7,000	382,000	8 – 12 (10)	11.6	3	5
5,000 – 6,000[b]	349,000	< 8 (6)	8.8	0	2

1. Areas differ from Rush and Kazmi (1965) due to map scale and rounding; total acreage listed in Table 24 is more precise and was used for calculation.
2. Rush and Kazmi (1965, Table 6, p. 21; based on Hardman, 1936). Mean precipitation rate for altitude-precipitation interval in parenthesis.
3. Mean precipitation rate for the altitude interval.
4. Efficiency coefficients as reported in: Maxey and Eakin (1949); Rush and Kazmi (1965); and Eakin (1966).

a. This interval commonly reported as a single interval (> 9,000 ft, abmsl).
b. Minimum altitude in basin is ~ 5,550 ft abmsl. Mean altitude below 6,000 ft used to estimate recharge is ~ 5,800 ft, which equals a precipitation rate 9.7 inches and a recharge efficiency of 3 percent. Interval is reported in Rush and Kazmi (1965) as; < 6,000 ft abmsl.

The standard efficiency factors are those of Maxey and Eakin (1949), listed in Table 25 and are normally used in conjunction with the "Hardman map". The recharge efficiency however is a function of the precipitation rate (Eakin, 1966 p. p. 260-262) and thus the Maxey-Eakin efficiencies, which are non-unique, can be used with other precipitation maps. Donovan and Katzer (2000) working in Las Vegas Valley modified the form of the Maxey-Eakin precipitation-efficiency relationship, which is a "stepped" relationship (one rate per ~ 4 inch precipitation interval), into an equation wherein each value of precipitation used has a calculated efficiency rate.

The recharge efficiency is calculated using the recharge efficiency curve equation described in Donovan and Katzer (2000) for Las Vegas Valley. The equation was developed to minimize manual calculation errors and the calculated recharge efficiency is the same, for each of the standard Maxey-Eakin precipitation intervals. The recharge efficiency equation, $\mathbf{R_e = 0.05 (P)^{2.75}}$, is for the interval between 8 and 20 inches of precipitation, < 8 inches $R_e = 0$, > 20 inches $R_e = 0.25$, where P is precipitation in feet. When this equation is used with a specific precipitation map each interval of precipitation is calculated. When used with the altitude-area-precipitation tables the recharge for each altitude interval is calculated. A minor variant of this equation is to assume recharge occurs in areas where the precipitation rate is less than 8 inches, which commonly occurs below 6,000 ft, but not in Spring Valley. The smallest precipitation rate considered "effective" (ie. a percentage becomes recharge) in Spring Valley is 9.6 inches per year at an altitude of 5,775 ft above mean sea level.

The Maxey and Eakin (1949) recharge efficiencies (0, 3, 7, 15 and 25 percent) listed in Table 25 are for irregular precipitation intervals (contours of 8, 12, 15 and 20 inches) of precipitation as defined on the Hardman maps (1936, and 1965). The contours of more recent precipitation maps are usually regular (i.e. 1 inch, 2 inch or 4 inch intervals).

Nichols (2000C, Table C19) lists the recharge efficiency factors used in conjunction with a GIS modified version (J. LaRue Smith, USGS oral communication, 2001) of the May 1997 PRISM precipitation map and that part of the table for Spring Valley is listed in Table 26.

Table 26.-- Precipitation areas and volumes for selected precipitation zones and estimated recharge for Spring Valley using PRISM map and Nichols' recharge efficiency factors.

Precipitation range, in inches per year	Weighted average of precipitation, in feet per year	Areas, in zone acres	Precipitation in zone, in acre-feet per year	Recharge efficiency factor	Estimated recharge, in acre-feet per year
8-11	0.806	536,370	432,094	0.008	3,457
12-15	1.089	311,781	339,613	0.130	44,150
16-19	1.429	122,768	175,490	0.144	25,271
20-32	2.022	96,091	194,247	0.158	30,691
	Total	**1,067,010**	**1,141,444**		**103,569**

The altitude area distribution for select drainages in Spring Valley is listed in Table 27. These drainages are the focus of numerous miscellaneous surface-water measurements and other estimating techniques to estimate the annual runoff from the mountain block.

Table 27.-- Altitude-area distribution for select drainages in Spring Valley, in acres

Drainage	**Altitude Zones, in feet above mean sea level, areas in acres**							**Totals**
	5000-6000	**6000-7000**	**7000-8000**	**8000-9000**	**9000-10000**	**10000-11000**	**11000-12000**	
Cooper	0	2,012	10,133	4,500	716	321	0	17,681
Bastian	0	322	559	488	319	0	0	1,770
Cleve	0	1408	4261	5349	5340	3420	771	20,548
Stevens	0	177	361	518	398	398	61	1,914
Taft	0	7	220	510	780	935	348	2,801
McCoy	0	105	541	926	1,139	965	395	4,070
Odgers	0	134	366	664	718	485	166	2,534
Little Negro	0	191	484	582	422	182	68	1,930
Bassett	0	174	511	781	1,278	1,191	213	4,149
Garden	0	203	519	570	486	96	0	1,873
Piermont	0	188	831	1,607	1,768	537	1	4,933
Kalamazoo	0	525	2,980	4,449	1,361	74	0	9,389
Muncy	0	585	2,370	4,917	1,274	0	0	9,146
Frenchman	0	215	2,126	777	0	0	0	3,118
North	0	28	377	1,130	458	65	0	2,057
Silver	0	0	237	579	669	66	0	1,549
Siegel	0	318	1,617	1,085	772	16	0	3,808
Stage	0	136	2,455	744	4	0	0	3,339
Eight Mile	0	172	767	941	197	0	0	2,077
Negro	0	2,495	5,472	5,193	3,737	560	172	17,629
Willard	0	68	622	926	934	158	3	2,710
Swallow	0	215	674	784	560	161	0	2,394
							TOTAL	**121,419**

The estimated precipitation, recharge, and runoff for the study area streams are listed in Table 28 and for the entire Spring Valley drainage in Table 29.

Table 28.-- Estimated precipitation, recharge, runoff for selected drainages in Spring Valley, in acre-feet/year.

Drainage	Total area, in acres[1]	Total precipitation[2]	Ground-water recharge[3]	Mountain-front runoff[4]
Cooper	17,681	22,516	2,469	500
Bastian	1,770	2,387	342	3400[a]
Cleve	20,548	31,453	5,862	7500
Stevens	1,914	2,923	539	720
Taft	2,801	4,868	1,089	2170
McCoy	4,070	6,713	1,399	4470
Odgers	2,534	4,029	799	1830
Little Negro	1,930	2,818	475	910
Bassett	4,149	6,812	1,439	3900
Garden	1,873	2,648	425	400
Piermont	4,933	7,517	1,414	1770
Kalamazoo	9,389	12,970	1,819	4180
Muncy	9146	12,679	1,780	3700
Frenchman	3,118	3,900	380	720
North	2,057	3,009	488	1510
Silver	1,549	2,373	452	400
Siegel	3,808	5,159	726	1540
Stage	3,339	4,179	405	210
Eight Mile	2,077	2,785	356	1,150
Negro	17,629	24,271	3,634	2200
Willard	2,710	4,035	720	410
Swallow	2,394	3,407	547	6000[a]
TOTALS	**121,419**	**173,451**	**27,559**	**49,4950[b]**

1. Table 27, GIS data base created using 7.5 minute quadrangle Digital Elevation Models (DEMs).
2. Figure 10, altitude/precipitation relationship.
3. Table 25, Donovan and Katzer (2000) factors in equation form.
4. Table 13.

a. Recharge and runoff equal more than the precipitation which indicates some percentage of the runoff captured from other drainages as ground-water recharge and transferred to the drainage along either fault/fracture zones or bedding plains.

b. As indicated in Table 13 there is an additional 3,000 afy of runoff from the few unmeasured perennial streams for a grand total of mountain-front runoff that equals 53,000 afy (rounded).

There appears to be a problem with the relationship between ground-water recharge and mountain-front runoff in Table 28. In nearly all cases the mountain-front runoff is much greater than ground-water recharge, particularly in the clastic rock drainages. There is no doubt that double accounting of the water budget occurs if the amount of ground-water recharge (Table 28) is added to the amount of mountain-front runoff (Table 28) to obtain the total water resource. Part of the rationale for the Maxey-Eakin technique is in the words of Eakin (1966, p. 260) .... *"The distribution of water runoff from the mountains also permits some inferences to the distribution and manner of recharge to the ground-water system. For mountainous areas of otherwise similar characteristics, proportionally large runoff suggests little recharge by deep infiltration in the bedrock in the mountains and small runoff suggests proportionally large* *recharge by deep infiltration in the bedrock. Also, substantial runoff from the mountains suggests that recharge by infiltration from streamflow on the valley fill may be significant.*"

This statement infers uncertainty in the distribution of recharge and does not define the relationship between recharge and runoff, particularly when runoff greatly exceeds recharge.

The clastic rocks in Spring Valley provide a unique example of the potential recharge, regardless where recharge occurs, for given drainages and a rough check on the applicability of the Maxey-Eakin recharge technique. The total amount of runoff from the clastic rock drainages greatly exceeds the estimated recharge for those drainages. This means the extra water, as runoff, is unaccounted for because the Maxey-Eakin method underestimates the recharge considerably. Likewise potential recharge in carbonate rocks is also underestimated because for any given altitude/area the amount of precipitation on carbonate rock drainages is equal to the amount of precipitation on clastic rock drainages yet the runoff is absent. This is because the potential runoff from the carbonate rock drainages is recharged in the mountain block due to greater permeability than clastic rock.

Another way of examining this process is to compare two drainages, a carbonate rock and clastic rock, of equal altitude-area distribution, precipitation and ET. Both drainages have the same estimated ground-water recharge, but the clastic rock has a large runoff value. This runoff is not present in the carbonate drainage even though it received the same amount of precipitation, but because the carbonate rock is more permeable than the clastic rock the component of runoff is recharged. However, in general, the clastic drainages in Spring Valley have larger areas at higher altitudes than the carbonate rocks, which accounts for additional water. Therefore, we are reluctant and lack data to increase the recharge accordingly in the carbonate rocks. While the Maxey-Eakin technique may be reasonable for a reconnaissance evaluation it appears it is very conservative, at least in Spring Valley.

Thus, basins dominated by clastic rocks in comparison to carbonate rocks have an insignificant amount of ground-water recharge in the mountain block, but a significant amount of mountain-front runoff, some of which may ultimately recharge the ground-water system depending on a multitude of factors. The distribution of recharge is not critical, but still not all the runoff can be accounted for by assuming runoff recharges the ground-water system at lower altitude. Recharge from these perennial streams under predevelopment conditions must have occurred between the mountain front and the valley lowlands. However, numerous streamflow measurements were made on several of the streams between the mountain front and the valley lowland and a consistent loss could not be detected that was significantly greater than measurement error. These measurements were made on the recession of the spring peak, which may indicate infiltration from the channel bed may only take place during short periods of high-energy flow when the channel-bed sediments are undergoing scour. The reason why virtually all perennial streams in Spring Valley, at least from the clastic rock drainages, have been diverted from natural channels and are in aqueducts may have more to do with sediment transport and the attenant problem rather than streamflow loss.

It matters little where recharge occurs, but it matters greatly that runoff is much greater than recharge for individual perennial streams because it shows the volume of water is much greater for potential recharge. It appears the Maxey-Eakin method under- estimates potential recharge in Spring Valley by as much as 10-20 thousand afy.

As indicated previously, the recharge for the entire drainage of Spring Valley is listed in Table 29, which includes the drainages listed in Table 28 above, but does not include an adjustment based on geology and mountain-front runoff.

Table 29.-- Area, precipitation and ground-water recharge by mountain blocks including perennial drainages listed in Table 28.

Mountain Range	Area, in acres	Precipitation, in acre-feet	Ground-water recharge, in acre-feet
North Schell Creek Range	38,060	43,252	3,609
Antelope Range	70,189	77,339	5,626
North Mid Schell Creek Range	93,994	116,107	13,243
Red Hills/Kern Mountains	53,790	56,013	3,492
North Snake Range	79,161	94,482	9,723
Mid Schell Creek Range	20,617	29,200	4,859
South Mid Schell Creek Range	39,952	57,792	9,840
South Schell Creek Range	116,953	130,731	10,652
South Snake Range	108,080	131,911	15,181
Fortification Range	44,427	44,518	2,329
Wilson Creek/Limestone Hills	51,506	52,309	2,862
Piedmont, N & S (between 5,775 and 6,000 ft)[2]	242,397	195,120	5,372
Sub Total	960,125	1,028,773	86,787
North Playa (between 5,550 and 5,575 ft)[1]	71,856	53,795	0
South Playa (between 5,750 and 5,775)	34,575	27,524	0
Playa Sub Total	106,431	81,319	0
Grand Total (rounded nearest 1000)	**1,067,000**	**1,110,000**	**87,000**

1. Lower altitude, 5,575 ft abmsl corresponds to lowest altitude Pleistocene lake beach bar.
2. Permeabilities are estimated to be sufficient to allow ground-water recharge to occur. Remaining north and south playa considered discharge areas.

Adjusted Ground-Water Recharge

There are two processes of concern: 1) there is a degree of double accounting for water yield in clastic rocks if the amount of ground-water recharge is added to the mountain-front runoff without adjustment for the carbonate rocks in the drainage area, and 2) ground-water recharge is under-estimated in the carbonate rocks.

Ground-water recharge for the perennial drainages in Table 28 and included in Table 29 is probably not entirely correct, because the amount of surface-water runoff or mountain-front runoff represents a significant amount of the water yield of the individual perennial drainages. Undoubtedly some amount of ground-water recharge does occur, but probably not the magnitudes estimated in Table 28. This analysis, based on field investigations and stated previously, has shown mountain-front runoff from carbonate rocks is virtually non-existent and runoff from drainages that have a significant amount of metamorphic/clastic rocks is large. Therefore, ground-water recharge in carbonate rocks is greater than in metamorphic/clastic rocks. The estimated ground-water recharge amount was modified based on the percentage of carbonate and metamorphic/clastic rocks in any given drainage. For instance, the carbonate rocks in Cleve Creek make up about 40 percent of the drainage area and the estimated ground-water recharge is 5,862 afy and the runoff is 7,500 afy; this results in a total yield of 12,800 afy, which we believe is incorrect. To adjust this total multiply the percent of sedimentary rock (40) by the estimated ground-water recharge (5,862 afy) equals the adjusted ground-water recharge (2,300 afy) plus the runoff (7,500 afy) equals an adjusted yield of 9,800 afy. The adjusted ground-water recharge calculations are listed in Table 30 for the majority of the perennial streams in Spring Valley. It is assumed these values are conservative because undoubtedly some amount of ground-water recharge does take place through the metamorphic/clastic rocks or certainly at least at the soil-rock interface as water moves down gradient to the alluvial ground-water system.

Table 30.-- Adjusted ground-water recharge based on surficial lithology.

Drainage Basin	**1** Percent of sedimentary rock in basin	**2** Estimated ground-water recharge, in acre-feet/year (Table 28)	**3** **1 x 2 = 3** Adjusted ground-water recharge[1] in acre-feet/year
Cooper	100	2,469	2500
Bastian	30	342	100
Cleve	40	5,862	2300
Stevens	0	539	0
Taft	20	1,089	200
McCoy	<10	1,399	100
Odgers	<10	799	100
Little Negro	0	475	0
Bassett	0	1,439	0
Garden	0	425	0
Piermont	11	1,414	200
Kalamazoo	42	1,819	800
Muncy	52	1,780	900
Frenchman	52	380	200
North Canyon	50	488	200
Silver	50	452	200
Siegel	50	726	400
Stage	50	405	200
Eight Mile	28	356	100
Negro	75	3,634	2700
Willard	66	720	500
Swallow	100	547	500
	TOTALS	**27,559**	**12,200**

1. Rounded to nearest 100 afy.

No attempt was made to recalculate the altitude-precipitation-area relationship based on geology, but rather a straight percentage of the total carbonate rock area in any given drainage was used. This introduces some errors into the estimate, but the errors are minimal and tend to cancel out because of unequal distribution of carbonate rocks with altitude in any given drainage.

Applying the ground-water recharge technique to the entire area equals a valley-wide recharge of 87,000 afy (Table 29). Subtracted from this amount, to eliminate double accounting, is the total calculated ground-water recharge for the perennial streams of 27,559 afy (Table 28) which equals ground-water recharge of 59,441 afy for the remainder of the drainage basin. The adjusted ground-water recharge for the perennial streams is added back in, 12,200 afy (Table 30) for a valley-wide ground-water recharge of **71,641 afy**. These numerical adjustments are summarized in Table 31. Even though double accounting for ground-water recharge/mountain-front runoff is hopefully eliminated, a significant amount of recharge remains unaccounted for. By incorporating the surface-water runoff from the clastic rocks into the water-resource budget we have moved closer to the actual water yield of the entire area, but we are unable at this time to define the actual ground-water recharge from the carbonate rocks, which may be several thousand afy more than estimated. If this is true then the discharge from the valley is low and the imbalance between inflow and outflow is greater.

Table 31.-- Summary of adjusted water-resource inflow from precipitation to Spring Valley, in acre-feet/year

Element		Amount	**Total (rounded)**
Ground-water recharge:			
Valley wide	(Table 29)	87,000	
Perennial streams	(Table 28)	- 28,000	
Adjusted, perennial streams	(Table 30)	+12,000	**71,000**
Mountain-front runoff			
Measured perennial streams	(Table 13)	50,000	
Unmeasured perennial streams	(Table 13)	+ 3,000	**53,000**
		TOTAL	**124,000**

There is one other adjustment to ground-water recharge that deviates from the standard way of estimating recharge that occurs on part of the playa area. Typically playa areas are considered ground-water discharge areas because they are the lowest areas in any given valley and generally discharge ground water during at least part of the year. The sediments that make up playas are finer-grained silts and clays that are relatively impermeable so these areas are generally not conducive to ground-water recharge.

In Spring Valley there are two separate playas. The northern playa has a series of beach bars located in the northern end of the playa. The lowest altitude of the beach bars is just about equal to 5,575 ft and the playa area north of this bar is considered a recharge area (Table 29) because it not only receives nearly 10 inches of precipitation, but the sediments are mostly fine to coarse grained sand and are conducive to infiltration. The southern playa, which is about 200 ft higher than the northern playa, is considered a discharging area, because it is generally wet. Because both of the playas are considered discharge rather than recharge areas the potential recharge was excluded from Table 29. Thus, the total water resource from precipitation for Spring Valley is estimated to be **124,000 afy.**

Discharge

Discharge from Spring Valley occurs through two processes: 1) ET, the largest amount of water exiting the valley of the two processes and this amount is subdivided into ET from the mountain block and from the valley floor, and 2) ground-water outflow to Steptoe, Hamlin, and Snake Valleys and this outflow is estimated using a form of the Darcy flow equation.

Ground water also discharges as springflow at many springs and seeps throughout the valley and in the mountain block. In general these springs contribute to perennial streamflow, some springs are used to irrigate agricultural lands, and the flow from some is consumed by non-phreatophytic vegetation through ET on the mountain block and by phreatophytes through ET on the valley floor. When springflow starts at the mountain block (such as Bastian Creek, Swallow Canyon, and Negro Creek) an unknown percentage of the flow ends up re-infiltrating to the ground-water system.

Spring Valley is a closed topographic basin and no surface-water discharges from the basin.

Evapotranspiration

mountain block

The average ET rate for all the mountain block perennial drainages (includes one ephemeral, Cooper Canyon and two nearly perennial drainages, Silver and Garden) is about 0.9 afy/a. This is based on a total annual precipitation volume of about 173,000 af, adjusted ground-water recharge of about 12,000 afy, and mountain front runoff of 50,000 afy. Subtracting the recharge and runoff from the precipitation equals about 111,000 afy of water that is returned to the atmosphere. Dividing that amount of ET by the area of about 121,000 acres equals an average ET rate of 0.9 afy/a.

This compares reasonably well to other areas we have studied such as Las Vegas Valley, where the mountains surrounding the valley above an altitude of 3,000 ft have an annual ET rate of about 0.86 af/a based on the work of Donovan and Katzer (2000, Table 4, p. 1143). East of the Las Vegas Valley in the lower Virgin River Valley the Virgin, Beaver Dam, and Clover Mountains (altitude areas > 3,000ft) have an estimated ET rate of about 1.0 af/a (based on data presented in Dixon and Katzer, 2002, Table 4, p. 37).

The hydrogeologic processes in each valley controlling ET, creating ground-water recharge, and mountain-front runoff are the same, however, each valley has its own unique set of variables, as discussed previously. In examining the individual drainages listed in Table 32 (includes area, precipitation, recharge, runoff, unit runoff, and ET) there are definite relationships, shown on Figure 11, between ET and unit runoff. The drainages in the Schell Creek Range that are in predominantly metamorphic/clastic rocks generally have higher ET rates and higher unit runoff values than those drainages that are in predominantly carbonate rocks. The main reason for this is low permeability in the metamorphic/clastic rocks causes water to be retained longer in the thin soil mantel and more susceptible to ET and runoff than in carbonate rocks where the permeability is greater allowing a greater percentage of water to infiltrate and become ground-water recharge. The carbonate rock drainages in the Schell Creek Range are from south to north Cooper, Kalamazoo, Muncy, Frenchman, North Canyon, Siegel, and Stage. Negro and Eight Mile Creeks in the Snake Range plot with the carbonate drainages in the Schell Creek Range; Negro Creek is about 75 percent carbonate rock, but Eight Mile Creek with less than 30 percent carbonate rock is anomalous.

Figure 11 is a first approximation quantification of the influence of rock type and drainage area on the quantity of runoff. Factors that influence the scatter of these relationships are the variability of the numerous parameters and the accuracy of the estimating techniques. There is, however, one additional factor that was not taken into consideration and that is the distribution of the two major rock types with altitude. While the areas of the rock types are known the distribution with altitude was not determined. The perennial flow estimated for the carbonate drainages may be derived from mostly clastic rocks (or faulting) within the drainage and this may be responsible for the coincidental slope of the trend lines on Figure 11. Additional mapping and field work are required to improve these relationships.

Even though the Silver Creek drainage has approximately 50 percent carbonate rocks it does not fall on the carbonate trend line on Figure 11, but on the metamorphic/clastic trend line. The reason for this is unknown. This is the smallest drainage studied, has minimal runoff and recharge and is borderline between perennial and ephemeral. Bastian and Swallow Creeks were excluded because both discharge more water than the estimated precipitation on these drainages. These creeks are discussed in other sections of this report.

Mountain-block ET and unit runoff rates listed in Table 32 are the end result of a great many measurements and some estimates. The relatively high correlation coefficients (adjusted $r^2 =$ 0.95 and 0.98 respectively for metamorphic/clastic and carbonate) indicates the basic hydrogeologic assumptions and techniques used in this study are reasonable.

Table 32.-- Estimated precipitation, adjusted recharge, runoff, ET, and unit runoff for selected drainages in Spring Valley.

Drainage	1 Total area, in acres[1]	2 Total precipitation, in acre-feet/year[1]	3 Adjusted ground-water recharge[2], in acre-feet/year, rounded	4 Mountain-front runoff[1], in acre-feet/year[1]	5 5=2-(3+4) Mountain-block ET, acre-feet/year, Rounded	6 6=5/1 Mountain-block ET, in acre-feet/acre/year	7 7=4/1 Unit runoff[3], in acre-feet/acre/year
Cooper	17,681	22,516	2,500	500	19,500	1.10	0.03
Bastian	1,770	2,387	100	3,400	a	a	1.92
Cleve	20,548	31,453	2,300	7,500	21,700	1.05	0.36
Stevens	1,914	2,923	0	720	2,200	1.15	0.37
Taft	2,801	4,868	200	2,170	2,500	0.89	0.77
McCoy	4,070	6,713	100	4,470	2,100	0.53	1.10
Odgers	2,534	4,029	100	1,830	2,100	0.83	0.72
Little Negro	1,930	2,818	0	910	1,900	0.99	0.47
Bassett	4,149	6,812	0	3,900	2,900	0.70	0.94
Garden	1,873	2,648	0	400	2,200	1.20	0.21
Piermont	4,933	7,517	200	1,770	5,500	1.12	0.36
Kalamazoo	9,389	12,970	800	4,180	8,000	0.85	0.44
Muncy	9146	12,679	900	3,700	8,100	0.88	0.40
Frenchman	3,118	3,900	200	720	3,000	0.96	0.23
North	2,057	3,009	200	1,510	1,300	0.63	0.73
Silver	1,549	2,373	200	400	1,800	1.14	0.26
Siegel	3,808	5,159	400	1,540	3,200	0.84	0.40
Stage	3,339	4,179	200	210	3,800	1.13	0.06
Eight Mile	2,077	2,785	100	1,150	1,500	0.74	0.55
Negro	17,629	24,271	2,700	2,200	19,400	1.10	0.12
Willard	2,710	4,035	500	410	3,100	1.15	0.15
Swallow	2,394	3,407	500	6,000	a	a	2.51

1. From Table 27.
2. From Table 30.
3. From Table 14.

a. Recharge and runoff exceed precipitation volume, additional proof of capture of recharge from adjacent drainage basin.

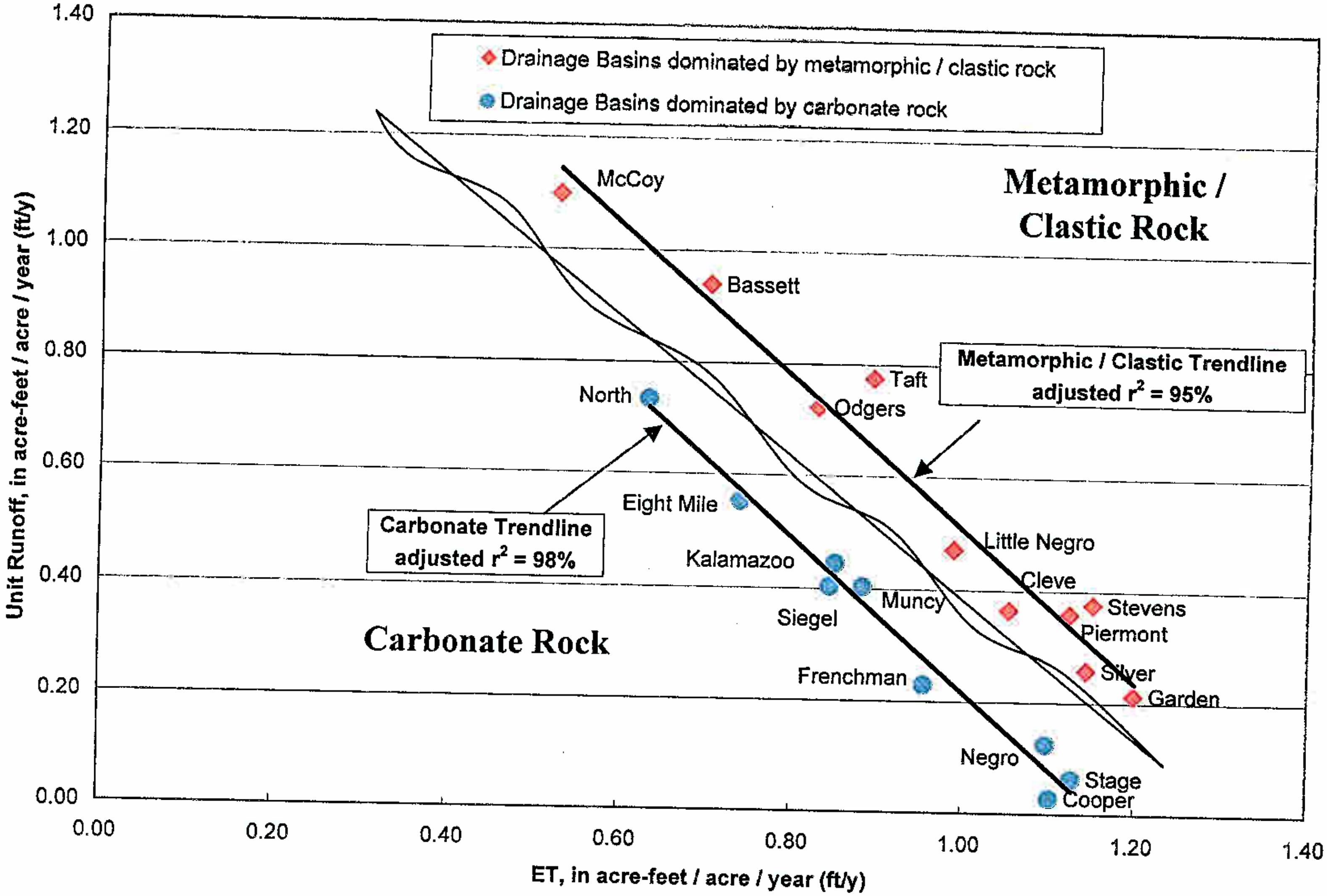

Figure 11. -- Relationship between ET and unit runoff for selected drainages in Spring Valley.

Other investigators have estimated ET from mountain block areas. For instance Leydecker and Melack (2000) using a model estimated evaporation from six alpine and sub-alpine basins in the southern and central Sierra Nevada in California and determined the evaporation was about 37 percent of the annual precipitation. Most of the water loss was from bare soil after the snow melt period was over, and the winter loss was minor. Kattelmann and Elder (1991), in an earlier study of one of the same basins (Emerald Lake watershed in the Sequoia National Park in the southern Sierra Nevada), determined through water balance and energy exchange that the total loss to the atmosphere from all sources was about 22 percent of the precipitation and the loss due to sublimation was about 17 percent of the precipitation amount. Marks and Dozier (1992) using the same techniques evaluated this same basin again and estimated the amount of water lost to the atmosphere from the snow pack surface was about 20 percent of the total precipitation (about 8 ft of water). The bedrock underlying these study basins was considered nearly impervious so ground-water outflow was estimated to be minor.

The above studies are cited to determine if the amount of ET estimated for the mountain block or individual drainages in this study is reasonable. There are major differences, however, between the southern Sierra Nevada and the Schell/Snake Ranges. The Sierra Nevada is wetter, greater humidity, less permeability in the dominantly granitic bedrock, which produces much more surface runoff. Another major difference is the distribution of the drainage area with altitude. In the sublimation studies mentioned above the basins are small, maximum surface area about 300 acres with maybe only a thousand feet of vertical relief. In this study of Spring Valley, the drainages are very large; Cleve Creek, for example, is the largest with slightly more than 32 mi^2 and the smallest of the perennial basins is Little Negro Creek with about 3 mi^2. In Spring Valley the altitude range from the mountain front to the highest peak is 3,000 to 5,000 ft so there is a scale difference of significant proportions. Nevertheless, if sublimation accounts for at least 20 percent based on the above studies, and probably more because of lower humidity of central-eastern Nevada, the residual ET (after subtracting runoff plus ground-water recharge from precipitation, Table 32) may be in the range of 0.5-0.7 af/a/y. This seems reasonable for bare soil evaporation plus transpiration by local vegetation and is significantly less, which is expected, than ET rates by phreatophytes in the valley (> 10 percent plant cover, Nichols, 2000, Table C17, p. C44) where water availability has minimal fluctuation.

valley lowlands

According to Rush and Kazmi (1965, Table 7, p 23) there are 186,000 acres of phreatophytes and bare soil in Spring Valley that use 70,000 acre-feet of water per year. Nichols (2000C, Table C17, p. C44) estimated the acreage of phreatophytes, at about 168,000 acres based on a vegetation index derived from LANDSAT data, which assumed agriculture displaced phreatophytes and included open water and bare soil evaporation. Based on a series of studies in the Great Basin (Nichols, 1992a, b, 1993, 1994, 2000, and Nichols and others, 2000), Nichols further estimated the amount of ET for two different time periods (1985 and 1989) and used an average of 90,000 afy for annual water use to represent the long-term average. This current study did not estimate a water use amount for ET by phreatophytes, but relies on Nichols' work with the exception that Nichols discounted significant evaporation of ground water from open water bodies ((D. Nichols, oral commun., 2002). Brothers and others (1994) estimated 15,000 afy of evaporation and this study estimates 19,000 afy of evaporation from open water areas (surface water runoff and spring discharge).

Ground-Water Outflow

Ground-water out flow probably takes place in at least three areas; from the north end of Spring Valley to Steptoe Valley, from the southeast end of Spring Valley to Hamlin Valley and then on to Snake Valley and from north-central Spring Valley directly east to Snake Valley. As stated previously, Spring, Hamlin and Snake Valleys were defined, as part of the Great Salt Lake Desert by Harrill and others (1988, p. A8). Solving the Darcy flow equation for the northern part first and using a section width of about 8 miles along the 6,100 ft. contour line equals a flow of about 2,000 afy ($I = 0.0125$, $T= 500$ ft^2/day). Outflow in the southern end of the valley, as first described by Rush and Kazmi (1965, p. 24), and using the potentiometric map by Brothers and others (1994, Figure 7, p. 27) with a width of about 5 miles along the 5,700 ft. contour line equals a ground-water flow of about 4,000 afy ($I = 0.01$, and the T in the lower layer of Brothers and others, model (1994, Figure 20, p. 60) equals 2,000 ft^2/day). Nichols (2000C, Table C14, p C28), in order to balance his water budget estimated there were about 10,000 afy of outflow to Hamlin Valley and about 4,000 afy exiting Spring Valley directly to Snake Valley in the area between the north end of the Snake Range and the Kern Mountains. Sparse water level data in this northern area presented by Brothers and others (1994, Figure 7, p. 27) does not support this assumption of ground-water flow directly to Snake Valley. However, Warm Springs in Snake Valley appears to be on a structural lineament that trends east to west connecting Spring and Snake Valleys. This lineament could be a conduit from the carbonate rocks underlying Spring Valley allowing some inter-basin flow to occur. Hood and Rush (1965, Table 8) report the temperature of Warm Springs to be approximately 27°C, with a flow rate of about 8 cfs (approximately 6,000 afy) (Hood and Rush, 1965, Table 9). The total ground-water outflow used in this study is 12,000 afy.

Springs

Spring Valley is aptly named undoubtedly because of the many springs in the valley. Carlson (1974, p. 221) indicates that Spring Valley is shown on Captain James H. Simpson's 1859 map that documents his explorations in the Great Basin.

Springs are classified on the basis of origin, discharge, and temperature. Bryan (1919) presented one of the first classifications that divided springs into those driven by gravitational pressure and those driven by other processes. Bryan further divided the gravitational springs into four groups: 1) depression springs which occur where the land surface intersects the water table; 2) contact springs that occur when a saturated permeable strata, underlain by a less permeable strata, intersects land surface; 3) artesian springs that occur when a permeable strata is overlain by a less permeable strata; and 4) springs that occur in impermeable rock from fractures, tubes, or solution openings.

Springs are also classified by their discharge according to Meinzer (1942, p. 424) as shown in Table 33.

Table 33.-- Classification of springs based on discharge.

Order of Magnitude	Discharge	
	Cubic feet per second	Gallons per minute
First	> 100	
Second	10-100	
Third	1 - 10	
Fourth		100 – 450
Fifth		10 – 100
Sixth		1 – 10
Seventh		0.125 – 1
Eight		< 0.125

Springs are found throughout Spring Valley, on alluvial fans on both sides of the valley, in the middle of the valley and in the surrounding mountain blocks. There are two main spring areas in Spring Valley: in the northern part of the valley most of the springs are on the west side, and in the southern part the springs are generally on the east side. The mountain blocks that provide the ground water for these larger concentrations of springs represent the high altitude areas where recharge is greatest so the geographical location of springs is not surprising. Most of the springs are classified as gravitational, but there are thermal waters in the southern part of the valley in the area called the Cedars. In this area there are several flowing wells that provide about 21° C water to ponds which are also the home of several endangered species of fish that were introduced into Spring Valley many years ago. Additionally, there is also thermal water reported by Rush and Kazmi (1965, Table 9) from two wells in the northwestern part of Spring Valley (near junction of Schellbourn Pass road and Nevada State Route 893). Historic spring characteristic data are scarce and Rush and Kazmi (1965, Table 8) report water quality for only one spring and virtually no flow data.

The magnitude of the springflow ranges from seeps and minor measurable amounts of a few gpm at the Shoshone Springs to Bastian Spring reported by Bunch and Harrill (1984, p. 104) to flow 1,700 gpm. The maximum discharge measurement made during this study for Bastian Creek down stream of the main orifices was 10.5 cfs (about 4,700 gpm) on July 7, 1998. There is another spring reported by Bunch and Harrill (1984, p. 104) named *Wallow* that reportedly was flowing *42,000* gpm in June 1980. It is highly probable the name and the discharge are typographical errors because the spring discharge for the same time is reported by Pupacko and others (1984, Table 1, p. 7) for Swallow Spring as 4,200 gpm. This spring is undoubtedly the same as Swallow Canyon reported in this study and the maximum measured and reported in this study is 19,800 gpm (44 cfs).

Other reported maximum springflow in the valley is no more than 300 to 400 gpm and most springflow is less than 100 gpm. Thus, the magnitude of the springs in the valley, based on discharge (Table 33), ranges from second to eighth order. Total springflow has never been determined but is probably on the order of several thousand afy.

Many of the springs, particularly those on the edges of the valley, are on obvious fault scarps, and some not so obvious except on LANDSAT imagery. These springs are all cold water, ranging from about 8 to 14^0C, and as such represent very recent ground-water recharge that is probably measured in transient times of months or a year or two depending on location. Ground water exits the mountain block over probably a very large depth interval, the top of which is likely very close to land surface. As this water moves toward the valley it is intersected by fault zones and brought to the surface. As there appears to be much more recharge than springflow it is apparent that the fault zones bring a small percentage of ground water to the surface.

WATER-RESOURCES BUDGET

WATER RESOURCES BUDGET EQUATION

The water budget equation for Spring Valley is different from a ground-water budget because it is an accounting of all the water entering and leaving the basin. The only way water enters the basin is from precipitation. There are no known surface or ground water sources entering the basin from outside its drainage area with the exception of a minor amount (about 2,000 afy) of ground-water inflow from Tippett Valley. Water leaves the basin, mostly as evapotranspiration from the mountain block and the valley areas, but there is also minor ground-water outflow. These components of the budget are shown in Figure 8 (quantified in Table 35). The inflow and outflow processes can be described mathematically by a simplistic steady-state water-budget equation in which over the long-term inflow equals outflow:

$$\mathbf{P + GW_I = ET_M + ET_V + GW_O} \qquad (1)$$

where:

P = precipitation, inflow into the total drainage area of Spring Valley, measured and estimated.
$\mathbf{GW_I}$ = ground-water inflow, estimated,
ET = evapotranspiration, mountain blocks ($\mathbf{ET_M}$) plus valley ($\mathbf{ET_V}$) , includes cropland, and phreatophytes, playa free-water surface, and playa/bare soil — all estimated and measured indirectly,
$\mathbf{GW_O}$ = ground-water outflow to adjoining basins, estimated by solving a form of the Darcy flow equation).

Water yield (**Wy**) is assumed to be the total amount of water available for development down-gradient from the mountain front and is a combination of ground-water recharge ($\mathbf{GW_R}$), surface-water runoff ($\mathbf{SW_R}$) and ground-water inflow from outside the valley. The fate of these three components of water yield are **ET** in the valley and ground-water outflow from the valley.

Rearranging the equation to ultimately arrive at water yield ($\mathbf{W_Y}$) requires the following steps:

$$\mathbf{P - ET_M = GW_R + SW_R}\text{, then it follows;} \qquad (2)$$

$$\mathbf{ET_V = GW_I + GW_R + SW_R, - GW_O}\text{, and from that equation;} \qquad (3)$$

$$\mathbf{W_Y = ET_V + GW_O} \qquad (4)$$

These components of the water-budget equation have been discussed previously and are mentioned briefly in the following sections to summarize and maintain continuity.

Inflow

There is one major source of water for Spring Valley and that is from precipitation on the mountains surrounding Spring Valley and on the valley floor. There is a minor amount of ground-water inflow estimated from Tippett Valley. There are no other adjacent valleys that contribute ground or surface water to Spring Valley.

Ground-Water

Ground-water inflow to Spring Valley was not recognized by Rush and Kazmi (1965), but later investigations by Rush and others (1971) and Harrill and others (1988) estimated about 2,000 afy of inflow from Tippett Valley. Brothers and others (1994, p. 28) indicate ..."*it is considered likely that a ground-water divide coincides with the topographic divide and there is only limited flow*"... For the purpose of this report it is assumed there is about 2,000 afy of ground-water flow from Tippett to Spring Valley.

Outflow

As indicated previously, inflow equals outflow and the majority of outflow is attributed to ET on the mountain block and the valley lowlands. ET from crops was estimated and measured, and estimated from phreatophytes, open water, and bare soil. Ground-water outflow is estimated by solving a form of the Darcy flow equation.

It is probable some amount of ground-water outflow from Spring Valley is tributary to Lake Valley through the carbonate rocks underlying Spring Valley and thus becomes part of the Meadow Valley Flow System and ultimately the White River Flow System. However, hydrogeologic data do not exist at this time to support this theory. The imbalance in the water budget suggests the entire ground-water outflow is not accounted for. This imbalance becomes more relevant if the ground-water recharge is significantly larger as suggested previously.

DISCUSSION OF PREVIOUS BUDGETS

Rush and Kazmi (1965, Figure 6, p. 25) were the first to develop a basin-wide water budget for Spring Valley. Their budget was based on estimating recharge (1965, Table 6, p. 21) into the basin using the Maxey-Eakin technique (Eakin at al., 1951, p. 79-81), which assumes that a percentage of precipitation, commonly termed recharge efficiency, reaches the ground-water system and the percentage increases with altitude.

Precipitation was estimated using Hardman's (1936) precipitation map of Nevada. Rush and Kazmi (1965, Table 6, p. 21) indicate the total recharge is 75,000 afy and 65,000 afy of that amount is "*..recharge from streams in the mountains and on the alluvial apron and underflow from the mountains to the alluvium ..*", the remaining 10,000 afy is "*..recharge from precipitation on the alluvial apron*". It is not explicitly clear where the recharge from the streams occurs. Streams that gain in flow from their headwaters to the mountain front are probably recharging a minimal amount until they exit the mountain block. However, several flow measurements made in 1996 on several creeks between the mountain front, across the alluvial apron, and at the bottom of the apron, did not define a loss nor a gain within measurement error (+ or – 5 percent). Intuitively, one would think the streams should be losing flow as they traverse the alluvial fans and maybe they do during high-energy flows and seal the channel bed with fine silt during the late-flow recession. There is a reason why many of the streams are now piped from the mountain front to the valley floor for irrigation and clearly it must be because the streams were losing a large percentage of their flow and/or the sediment loads were a problem in the irrigation system. Taff, McCoy, Odgers, Little Negro, Bassett, Piermont, Kalamazoo, Eight Mile, and Willard Creeks all have an aqueduct that transports most of the flow from the mountain front to the valley floor.

Complicating Rush and Kazmi's budget is Moore's estimate (in Rush and Kazmi, 1965, Table 5, p. 16) of 90,000 afy of mountain-front runoff. Rush and Kazmi (1965, Figure 6) show the fate of this runoff to be 65,000 afy of recharge, 8,000 afy for irrigation and the remainder 17,000 afy is considered rejected recharge and is lost through ET on the playas. The question immediately arises — how can the 65,000 afy of recharge take place in the mountain block when the 90,000 afy of mountain-front runoff is measured at the contact between the alluvial fan and the mountain block? It must be pointed out that Moore's estimate of runoff is complimentary to Rush and Kazmi's estimate of ground-water recharge, not addative. Undoubtedly Moore's runoff is dominated by rejected recharge. Yet Rush and Kazmi (1965, Table 6) show a typical Maxey-Eakin calculation for recharge of 75,000 afy. The actual ground-water recharge from the mountain block as stated by Rush and Kazmi (1965, p. 25) appears to be different from the subsurface inflow from the mountains, for which there is no estimate. The 90,000 afy of runoff defined by Moore (in Rush and Kazmi, 1965, Table 5, p. 16) was not verified by this study. The mountain-front runoff from the perennial streams is estimated by this study to be 53,000 afy; it is highly unlikely there is an additional 40,000 afy of ephemeral runoff. For this study the unmeasured ephemeral runoff is estimated as a percentage of ground-water recharge occurring below 6,000 ft altitude and equals about 5,000 afy(Table 29).

The discharge from the basin, principally from ET, was estimated by Rush and Kazmi (1965, Table 7, p. 23) based on use rates generally accepted at the time for phreatophytes in the Great Basin (Lee, 1912; White, 1932; Young and Blaney, 1942; and Houston, 1950). Ground-water outflow was estimated by Rush and Kazmi (1965, p. 24) solving a form of the Darcy flow equation for a section four miles in width between Spring and Hamlin Valleys, which showed about 4,000 afy leaving the basin and moving to Hamlin Valley. By comparison, Nichols (2000C) suggests there is about 10,000 afy of ground-water outflow in this area. As previously discussed and based on a potentiometric map by Brothers and others (1994, Figure 7, p.27) it is possible that subsurface outflow occurs in, not only the southern part of the valley, but also the extreme northern end of the valley. No other investigators have suggested ground-water outflow occurs in this northern area. However, Nichols (2000C) shows 4,000 afy of sub-surface outflow from Spring Valley to Snake Valley occurring between the north end of the Snake Range and the south end of the Kern Mountains. Sparse water-level data in this part of Spring Valley do not support this assumption (Brothers and others, 1994, Figure 7, p.27). However, Warm Springs (multiple orifices) is located due east of the low pass separating Spring Valley from Snake Valley just across the Stateline in Utah. Hood and Rush (1965, Table 9) estimated this springflow at 8 cfs on November 3, 1964, and the reported temperature is about 26^0C.

Rush and Kazmi (1965) did not identify ground-water inflow from Tippett Valley, however, later investigations by Rush and others, (1971) and Harrill and others (1988) estimated flow on the order of 2,000 afy. Brothers and others (1994, p. 28) indicates that based on published water-level data there appears to be a ground-water divide coincident with the topographic divide separating Tippett Valley from Spring Valley allowing for no more than 2,000 afy of ground-water inflow from Tippett Valley.

Rush and Kazmi's (1965, Table 6, p. 21; Table 7, p. 23; and Figure 6, p. 25a) recharge, discharge, and water budget calculations are compared with Nichols' (2000C, Table C19) more recent work listed in Table 34.

Table 34.-- USGS ground-water budgets for Spring Valley.

Ground-Water Budget Component	**Rush and Kazmi**[1]	**Nichols**[2]
INFLOW	Values in acre-feet/year, rounded	
Precipitation	(960,000)	(1,141,000)
Ground-water		
Recharge	75,000	104,000
Inflow	2000	0
Total (rounded)	**77,000**	**104,000**
OUTFLOW		
ET		
Phreatophytes	70,000	90,000
Crops	1,000	Included in phreatophyte estimate[3]
Ground-water flow to:		
Hamlin Valley	4,000	10,000
Snake Valley	Not determined	4,000
Total (rounded)	**75,000**	**104,000**

1. (1965, p. 22)
2. (2000C, Tables C11 and C14)
3. Nichols (oral commun., 2001)

Nichols method is similar to the Maxey-Eakin method except Nichols uses the new PRISM precipitation map where the mid-range average precipitation is higher than the Hardman (1936) map and a series of recharge factors that are much greater than those used by Maxey-Eakin. The area of recharge is also larger by about 324,000 acres (probably because the lower limit of 8 inches of precipitation includes a larger, lower altitude area than estimated by Rush and Kazmi). This difference results in about 30,000 acre-feet more ground-water recharge than defined by Rush and Kazmi (1965, Table 6, p. 21).

Brothers and others (1994, p. 39) developed a Water Resources Budget for Spring Valley based mostly on Rush and Kazmi (1965) that was not restricted to just the ground-water component and is shown in Table 35 along with the budget estimated by this study.

Table 35.-- Las Vegas Valley Water District water-resource budget for Spring Valley.

Water Resources Budget Component	Brothers and others[1]	This Study
INFLOW	Values in acre-feet/year, rounded	
Precipitation	(966,000)	(1,110,000)
Ground-water recharge	75,000	71,000[a]
Surface-water runoff	35,000	53,000[b]
Subsurface Inflow from Tippet Valley	2,000[c]	2,000[c]
Total (rounded)	**112,000**	**126,000**
OUTFLOW		
Evapotranspiration		
Phreatophytes	70,000	90,000[d]
Crops	21,000	e
Mining, domestic, and stock	2,000	2,000[f]
Surface-water evaporation	15,000	19,000[g]
Ground-water to: Hamlin Valley	4,000	4,000[h]
Steptoe Valley	Not determined	2,000[h]
Snake Valley	Not determined	6,000[i]
Total (rounded)	**112,000**	**123,000**
Imbalance	**0**	**3,000**

1. (1994, Table 7, p. 39)

a. Table 31.

b. Table 13.

c. Rush and others, (1971) and Harrill and others, (1988)

d. Nichols (2000C), includes bare soil evaporation from playas and transpiration from crops, however he lists only (Table C17, p. C44) ~ 18,200 acres. This study using recent LANDSAT coverage determined there were ~ 106,000 acres (Table 29) of playa area.

e. Brothers and others (1994, p. 45) list 6,900 acres under irrigation and according to Nichols (oral commun., 2000) agricultural lands are included in his estimation of ET for phreatophytes.

f. Brothers and others, (1994, Table 7, p. 29).

g. Nichols (2000C, p. C15) considers the area of permanent water to be insignificant for ground-water discharge, however he lists,~7,600 acres of open water from surface-water runoff and the evaporation rate used in this study is estimated at 2.5 af/a/y (Shevenell, 1996).

h. Darcy flow equation determination. Nichols (2000, Table C14, p. C28) estimates 10,000 afy of outflow.

i. Head data presented in Brothers and others (1994, Figure 7, p. 27) does not support ground-water discharge to Snake Valley. However, Nichols (2002C, C14, p. C 28) estimates 4,000 afy of ground water outflows to Snake Valley. For this study we assumed the discharge from hot springs in Snake Valley along an east-west geologic structure between the Snake Range and the Kern Mountains represents interbasin flow from Spring Valley.

The imbalance between inflow and outflow is minor, and equals about 2 percent of the inflow. This small percentage of closure certainly does not infer the estimating techniques are within this degree of accuracy. In just the ET estimates alone, the range of values for phreatophytes is 77,500 to 102,000 afy (Nichols, 2000C, Table C5, p. C15).

There is one other estimate of recharge for Spring Valley made by the USGS and that is the work of Dettinger (1989) who applied a chloride-balance technique. This method assumes a relationship exists between the concentration of chloride deposited in recharge areas and the resulting concentration in the basin's ground-water system. There is some commonality with the Maxey-Eakin method in that both methods use total precipitation on any given basin and for Spring Valley only the Hardman (1936, 1965) precipitation map was available. The total amount of natural ground-water recharge estimated for Spring Valley by Dettinger (1989, Table 2, p. 69) was 61,600 afy. This amount would increase if applied to the precipitation map used for this study. The recharge estimate is in question because of the vast amount of perennial streamflow that reaches the valley lowlands where most of the ground-water discharge occurs; a condition that adds uncertainty to the method.

WATER YIELD

The water yield in Spring Valley previously estimated from the water budget equation is:

$$\mathbf{W_Y = ET_V + GWo:} \qquad \mathbf{(4)}$$

where $\mathbf{W_Y}$ is water yield, **ETv** is ET in the valley, 109,000 afy, and **GWo is** ground-water outflow from the valley, 12,000 afy.

Substituting these values back into equation (4) gives; $\mathbf{W_Y = 109{,}000 + 12{,}000}$

$$\mathbf{W_Y = 121{,}000\ afy}$$

Thus the water yield is estimated to be 121,000 afy. Water yield does not necessarily mean the total amount can be captured for use. The capture of ground-water outflow is highly uncertain, but clearly a large percentage of water currently being consumed by phreatophytes can be salvaged with a reasonable lowering of the water table. In this study 110,000 afy is a reasonable estimate of perennial yield and is probably conservative. This is based on annual average phreatophye use and capture of surface-water evaporation.

Rush and Kazmi (1965, p. 26) estimated the perennial yield of Spring Valley to be equal to the total ET in the valley, 70,000 afy, plus one third of the 90,000 afy of mountain-front runoff or 30,000 afy for a total of 100,000 afy. The perennial yield concept as defined by Rush and Kazmi for Spring Valley (1965, p. 26) is .... *"The maximum amount of water of useable chemical quality that can be withdrawn and consumed economically each year for an indefinite period of time."* According to that definition there really is no limit on the amount of water available. The quality is very good and water demand is such that the water will always be economical However Rush and Kazmi (1965, p. 26) did put a constraint on the definition .... *"the perennial yield is limited to the amount of natural discharge that can be salvaged for beneficial use."* This definition was good 30 years ago when there was virtually no demand for water resources, but needs modification for this century because the regional value of water has increased over the years.

In Spring Valley Rush and Kazmi (1965, p. 27) indicate the amount of ground water stored in the upper 100 feet of saturated sediments is at least 4.2 million af. This is based on a specific yield of 10 percent, an alluvial area of 420,000 acres (1:250,000 scale map) where the saturated thickness is at least 100 feet. This study defines an alluvial area of about 350,000 acres (area less than 6,000 ft altitude) and using the same specific yield of 10 percent equals an estimate of 3.5 million af of ground-water storage in the upper 100 feet of saturated sediments. This means that to lower the ground-water level an average of 45 ft (assume average water table under all phreatophytes is about 15 ft), in order to capture the perennial yield, requires pumping approximately 1.6 million af of ground water.

Thus we believe the amount of storage should be considered when defining the available yield. Oftentimes when this aspect of perennial yield is discussed the reaction is… "The use of stored water is a one time use." This is not really true because lowering the ground-water level, particularly in alluvial ground-water systems, creates space in the aquifer to store additional runoff from above average water years and reduces loss by ET. Creating space in the aquifer is just as important as capturing ET, which has always been the essence of the perennial yield concept.

CONCLUSIONS

After several years of ground- and surface-water data collection and utilizing an extended precipitation data base with numerous high-altitude precipitation stations, the water-resources budget for Spring Valley is more accurate than the reconnaissance estimates by Rush and Kazmi (1965) that were made nearly 40 years ago.

Ground-water recharge was modified by reducing the estimate of recharge in proportion to the amount of carbonate rock in the drainage area. The amount of surface-water runoff, mostly the perennial streams, was measured and estimated by a variety of techniques and used in combination with the adjusted ground-water recharge to determine the amount of ET in the mountain block. The correlation between surface-water runoff and ET from individual perennial drainage basins showed ground-water recharge is greater in carbonate rocks and runoff is less when compared to the same processes in metamorphic/clastic rocks. This relationship is somewhat obvious with just a cursory inspection of the range fronts where the individual canyons are entirely in carbonate rocks perennial flow is lacking. Thus, ground-water recharge must be occurring in greater amounts than in drainage basins with less than 100 percent carbonate rocks.

This study has defined a somewhat larger water budget than both Rush and Kazmi (1965) and Nichols (2000C) and slightly greater than Brothers and others (1994). Nichols (2000C, Table C5, p. C15) estimated ET in Spring Valley for 1985 and 1989 was 102,000 and 77,500 af respectively. This is a wide range in ET, which indicates significant variability, and the maximum range is unknown.

The water-resources budget is composed of *Inflow* and *Outflow* components. The *inflow* is divided into the amount of ground-water recharge and the amount of surface-water runoff. These two components of recharge and runoff are the most important of the water-resources budget and together they equal 126,000 afy. This results in 3,000 afy more of *inflow* than *outflow* (see Table 35, p.61) and does not imply the budget numbers are within that degree of accuracy. Finally perennial yield is estimated at 110,000 afy.

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APPENDIX

Surface-water measurements were made in May and June 1993 on the creeks listed in Table 1A below. The sites listed were generally measured at the normal sites established at the mountain front that are listed in the numerous miscellaneous measurement tables in the text. The exception is Swallow Canyon where the measurement was made about ½ mile west of the mountain front at a road crossing. In addition to the six measurements listed below numerous measurements were made on diversions of some of the creeks in an effort to estimate the loss of streamflow to infiltration between the mountain front and the valley floor. However, most of the creeks have diversions that are in diversion structures, but some flow bypasses the diversion structures in natural channels and did show a slight loss, but within error of measurement. Thus, the analysis of ground-water recharge across alluvial fans is incomplete and requires additional data.

Table 1A.-- Miscellaneous measurements made by the LVVWD in Spring Valley, May and June 1993.

Creek or Canyon	Date	Q, in cubic feet/second
Cleve	May, 17	37.4
McCoy	May, 18	41.3
Odgers	June, 24	6.93
Bassett	June, 23	9.31
Kalamazoo	June, 23	9.64
Swallow	May, 19	44.4