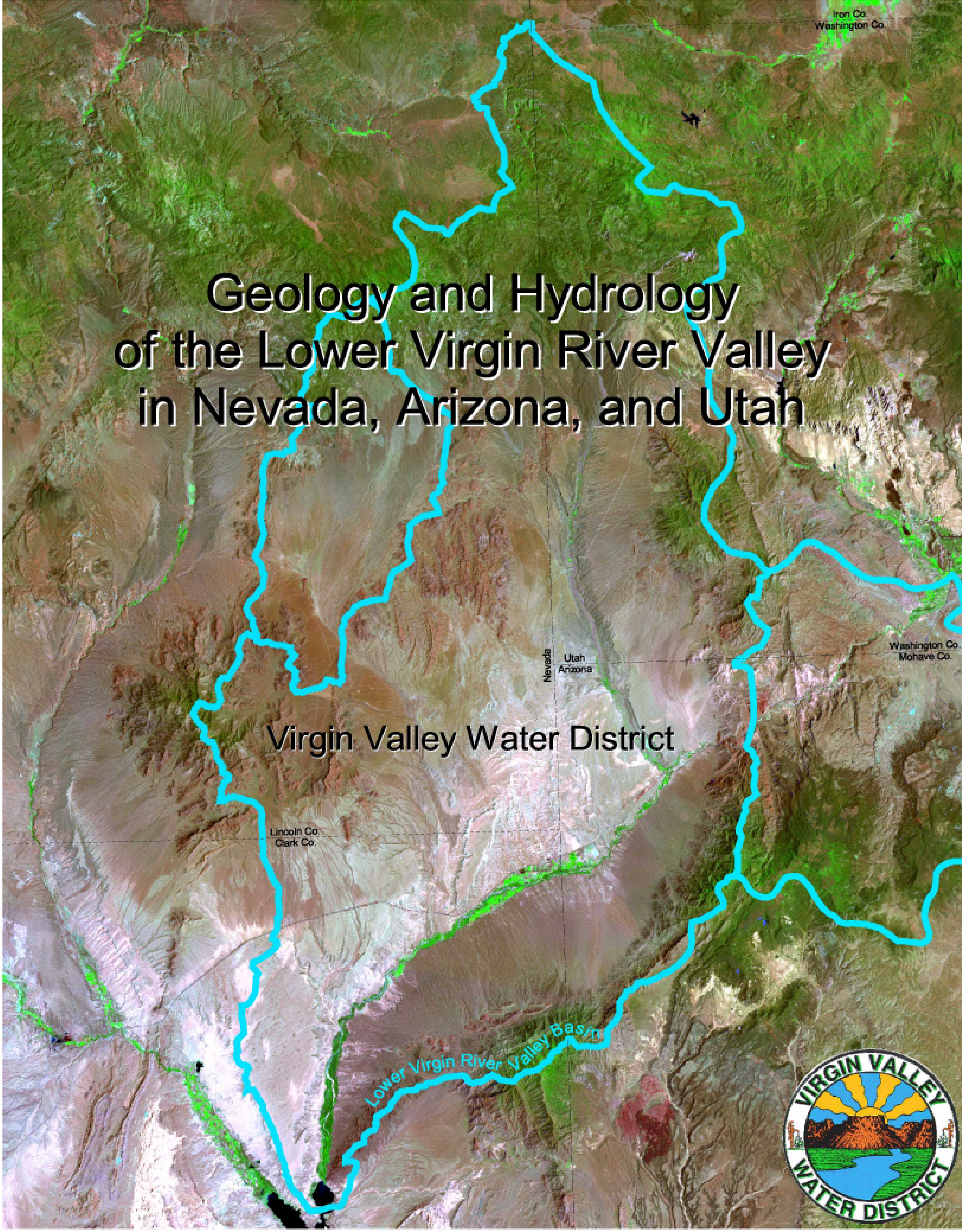
Geology and Hydrology of the Lower Virgin River Valley in Nevada, Arizona, and Utah



expression of many of these fault/fracture zones is a wash, such as Toquop, Abbot, and Town, to name a few. Undoubtedly ground water exits the basin in a similar fashion, through fault/fracture zones of high permeability underlying the Virgin River and extending downward to the carbonate rocks. The most significant of these faults is the Piedmont fault zone (Plate 1), a major west-trending fault zone that transects the upper piedmont adjacent to the Virgin Mountains and exits into the next basin to the southwest. This fault/fracture zone probably acts as a conduit system for ground water exiting the basin. Other south-trending fault/fracture zones within the Virgin Mountains potentially intercept ground-water recharges and convey that water to the south, out of the basin and to discharge points that are yet to be defined.

The ground-water contours in the Toquop Wash area (Plate 3) have been drawn to show that the wash is a line source for ground-water recharge inferring ground-water movement from the wash to the ground-water system. This reflects the surface-water runoff that ultimately reaches the ground-water table. There are no ground-water data to support this, but in the Mountain-Front Runoff section of this report, we show considerable surface-flow losses to the ground-water system. This analysis was not made on the other ephemeral washes.

Ground-Water Recharge

Ground-water recharge was calculated from techniques described in the Precipitation Section, using the altitude-area-precipitation-recharge table (Table 4). In this table, 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, as used by the USGS for the state-wide Reconnaissance and Bulletin series to estimate ground-water recharge, is listed in Table 5 along with the respective precipitation and recharge efficiencies used for this study. Glancy and Van

Denburgh (1969, Table 9, p. 38) also modified this table slightly for their recharge calculations for the Virgin River basin.

Table 4. Estimate of ground-water recharge for the lower Virgin River Valley.

Location of drainage area	Altitude zone, in feet	Area, in acres	Precipitation, in inches/feet[1]	Total precipitation, in acre-feet	Recharge efficiency factor	Total recharge, in afy, rounded
Lake Mead (Hoover Dam) Spillway altitude at mouth of Virgin River to Littlefield gage	1,000-2,000	144,757	6.6/0.55	79,486	0	0
	2,000-3,000	247,102	9.12/0.76	187,089	0	0
	3,000-4000	167,619	11.6/0.97	162,590	0.045	7,320
	4,000-5,000	70,818	14.2/1.17	82,857	0.078	6,460
	5,000-6000	30,080	16.6/1.38	41,510	0.122	5,060
	6,000-7000	10,621	19.1/1.59	16,887	0.179	3,020
	7,000-8,000	1,563	21.6/1.8	2,813	0.25	700
	8,000-9,000	1	24.1/2.01	2	0.25	< 1
	Sub-Total (rounded)	672,600		573,200		22,600
	Sub-Total > 3,000 (rounded)	280,700		306,700		22,600
Littlefield gage to Narrows gage	1,000-2,000	5,909	6.6/0.55	3,250	0	0
	2,000-3,000	61,084	9.12/0.76	46,424	0.023	0
	3,000-4000	123,032	11.6/0.97	119,341	0.045	5,370
	4,000-5,000	123,320	14.2/1.17	144,284	0.078	11,250
	5,000-6000	85,705	16.6/1.38	118,273	0.122	14,430
	6,000-7000	40,648	19.1/1.59	64,630	0.179	11,570
	7,000-8,000	1,519	21.6/1.8	2,734	0.25	680
	Sub-Total (rounded)	441,200		498,900		43,300
	Sub-Total > 3,000 (rounded)	374,200		449,300		43,300
	TOTAL > 3,000	**654,900**		**756,000**		**65,900**
	TOTAL	**1,113,800**		**1,072,100**		**65,900**

Data provided by D. Donovan (SNWA, written commun., 1999)
[1] Precipitation values are for mid-altitude ranges.

Table 5. Standard format and values for altitude-precipitation-recharge efficiency compared to values used for this study.

Altitude, in feet	Precipitation, in inches		Recharge efficiency (percent)	
	Hardman map	Virgin River Valley (in this study)	Maxey-Eakin	This Study
> 8,000	> 20	> 23	25	25
7,000 – 8,000	15 - 20	20 – 23	15	25
6,000 – 7,000	12 – 15	18 – 20	7	17.9
5,000 – 6,000	8 – 12	15 – 18	3	12.2
< 5,000	< 8	-	0	-
4,000 – 5,000	NA	13 – 15	NA	7.8
3,000 – 4,000	NA	10 -13	NA	4.5
< 3,000	NA	< 10	NA	0

As stated previously, any natural recharge estimate based on precipitation is composed of two parts: (1) Precipitation or "effective precipitation" is estimated, and (2) each precipitation interval is assigned a recharge efficiency. The natural recharge amount is the precipitation amount multiplied by the efficiency rate. The standard efficiency rates are those of Maxey and Eakin (1949), listed in Table 5, and are normally used in conjunction with the "Hardman" map. The recharge efficiency, however, is a function of the precipitation rate. Thus, the Maxey-Eakin efficiencies, which are non-unique, can be used with other precipitation maps. Donovan and Katzer (2000) working in the Las Vegas Valley, modified the form of the Maxey-Eakin precipitation-efficiency relationship. This "stepped" relationship (one rate per ~ 4 inch precipitation interval), was modified into an equation where each value of precipitation used has a calculated efficiency rate. The available precipitation records were used to create linear altitude-precipitation relationships. The equation listed previously for that relationship follows, and was used to calculate the average precipitation for a given altitude interval:

$$P= 0.000208033 (A) + 0.237049365$$

The recharge efficiency is calculated using the recharge efficiency curve equation, also developed by Donovan and Katzer in the Las Vegas Valley (2000). The recharge efficiency equation $R = 0.05\ (P)^{2.75}$ is for the interval between 8 and 20 inches of precipitation, < 8 inches R = 0, > 20 inches R = 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.

The altitude-area-precipitation values listed in Table 4, used to estimate ground-water recharge, were created using a GIS database derived from 7.5 minute quadrangle Digital Elevation Models (DEM), (D. Donovan, SNWA, written commun., 1999). From this we calculate the recharge to the lower Virgin River Valley to be 65,900 afy. According to Cole and Katzer (SNWA, written commun., 1999) the ground-water recharge from the Narrows gage upstream to the Bloomington gage, an area that is tributary to the lower Virgin River Valley, provides an additional 19,000 afy of recharge. This brings the total ground-water recharge to the lower Virgin River Valley to about 85,000 afy. The drainage area from the Narrows gage to the Bloomington gage (most of which is shown on Plate 5), was not included in Glancy and Van Denburgh's (1969) work.

According to D. Donovan (SNWA, written commun., 1999) ….three other general estimators of natural recharge verses "effective" precipitation exist. Harrill and Prudic (1998) developed a log-log equation: $\log Q = -1.74 + 1.10 \log P_{P>8}$ by regressing the natural recharge estimates throughout the Great Basin, where Q is ground-water recharge in afy and P is precipitation in inches. This equation was developed following the example of Anderson (1985) for valleys in southern Arizona. Anderson's (1985) equation is: $\log Q = -1.40 + 0.98 \log P_{P>8.}$ In the range of interest, 300,000 to 1,000,000 afy of "effective" precipitation, the Harrill and Prudic (1998) equation estimates that about 7 percent "effective" precipitation becomes recharge and the Anderson (1985) equation predicts about 3 percent. For the central and western part of the Virgin River basin on the Colorado Plateau, Cordova and others (1972) estimated about 4 percent of the "effective precipitation" becomes natural recharge.

Glancy and Van Denburgh (1969) assigned the 8-inch precipitation contour to the 4,000-foot altitude contour and used a 2,000-foot interval for the zone between 8 and 12 inches of precipitation. These assumptions yield significantly less precipitation than other methods and a relatively small percentage of natural recharge because of the significant acreage between 4,000 and 6,000 feet. These assumptions are consistent with the then available precipitation data and also the later 1972 version of the "Hardman" map (Nevada Division of Water Resources, 1972). The precipitation data used by Glancy and Van Denburgh (1969, Table 3, p. 20-21) were sparse and included areas far from the Virgin River basin (Desert Game Range, Pioche, and Pierce Ferry). The total precipitation greater than 8 inches, as used by Glancy and Van Denburgh (1969) is 303,000 afy, about 30 percent of some other estimates. The amount of estimated natural recharge is about 12,000 afy, or about 4.0 percent of the total precipitation. Thus, the published recharge estimate of Glancy and Van Denburgh (1969) is at the lower range of other evaluations. This analysis assumes there is no recharge where the precipitation is less than 10 inches, and this occurs at an altitude of about 3,000 feet. However, in the Mountain-Front Runoff Section of this report, we develop a counter argument to this assumption.

Additionally, low-altitude recharge has recently been investigated by Pohlman and others (1998). They used both stable and radioactive isotopes of spring water in the Lake Mead area to determine that a significant source of recharge appears to be coming from relatively low mountain block altitudes ($< 5{,}500$ feet, and generally $< 3{,}000$ feet). The investigators came to this conclusion because of the relatively heavy stable isotopic signatures of the ground water. This indicates ground-water recharge may be occurring at much lower altitudes than was previously thought.

One of the difficulties in estimating recharge for the lower Virgin River basin is that it is nearly impossible to accurately estimate discharge from the basin. The evapotranspiration (ET) can be estimated fairly close, and the river out-flow can also be measured/estimated, but the great unknown is the amount of water leaving the basin in the subsurface. The river flow budget listed in Table 6 is useful for defining part of the ground-water recharge component.

Table 6. Virgin River flow and ground- and surface-water inflow from Bloomington, Utah to Littlefield, Arizona.

Virgin River Flows[1]	Long-Term Average, in af
Near Bloomington, Utah	142,000
Santa Clara return flow	1,000
Discharge from the St. George Regional Water Reclamation Facility	7,000
Ephemeral inflow between Bloomington and Littlefield	2,000
Beaver Dam streamflow, tributary to the Virgin River upstream of Littlefield gage	1,000
Evapotranspiration between Bloomington and Littlefield gages	(3,000)
Subtotal	150,000
Littlefield gage, long-term average plus 3,000 afy of bypasses in the Littlefield Ditch and Petrified Springs	180,000
Difference, a gain of:	30,000

1. Cole and Katzer (2000)

The gain of 30,000 afy at the Littlefield gage is real, and the source of the gain is from ground-water recharge that occurs in the river drainage area upstream of the Littlefield gage to the Bloomington gage. We assume that the ground-water inflow at the Bloomington gage basin boundary is negligible because the gage is located in a bedrock constriction with bedrock nearly at the surface of the channel bed. Based on Table 4, the total amount of recharge upstream from the Littlefield gage to the Narrows gage, including Beaver Dam Wash is about 43,000 afy. This is fairly consistent with the work of Holmes and others (1997, Table 5, p. 39) who indicated total recharge to the Muddy Creek Formation is about 44,000 afy. The sources of the total recharge are from stream infiltration along Beaver Dam Wash, from consolidated rocks, and infiltration of runoff at the mountain front. They discounted significant recharge from precipitation that falls directly on the Muddy Creek Formation. They have included in their study (Holmes and others, 1997, fig. 6, p. 18) all of Beaver Dam Wash drainage area plus the drainage to the river from Sand Hollow Wash, a tributary to the river downstream from the Littlefield gage. Additive to this is the 19,000 afy as defined by Cole and Katzer (SNWA, written commun., 1999) that is recharged between the Narrows and Bloomington gages for a grand total of 62,000 afy. About half of this amount is accounted for in the gain in river flow as measured at the Littlefield gage. This leaves about 32,000 afy of ground water that bypasses the Littlefield gage as it moves through the surrounding sediments and underlying carbonate rocks.

We believe ground-water recharge occurs downstream of the Littlefield gage, (about 5,800 feet to 3,000 feet altitude) and have estimated it to be an additional 23,000 afy (Table 4). This study estimates the total ground-water recharge to the lower Virgin River basin to be about 85,000 afy.

The source of water used for Municipal and Industrial (M&I) purposes in the St. George and Bloomington area is mostly a combination of surface and ground water upstream from the Bloomington gage. However, some of the water returns to the river from the St. George Regional Water Reclamation Facility (SGRWRF), downstream from the Bloomington gage. This flow has averaged about 7,000 afy since 1992 (SGRWRF, written commun., 1999). Thus, this volume is in the Virgin River flow as measured at the Littlefield gage. The average flow of the river at the Littlefield gage through 1989 is about 174,000 afy. This is the average flow rate prior to the start of wastewater discharge. The additional 3,000 afy (174,000 versus 177,000, period of record through 1998) is well within the accuracy of the river gage. Also Quail Creek reservoir, an off channel Virgin River storage reservoir constructed upstream from St. George in 1985, has a storage capacity of about 40,000 af. Quail Creek Reservoir dike failed on January 1, 1989 (Carlson and Meyer, 1995) and has since been rebuilt. It is difficult to see the impact of this reservoir on the flow of the river, but there is a slight deflection in the double-mass plot shown on Figure 8 starting in about 1990, indicating less flow. Undoubtedly, the drought years of the early 1990's contributes to this impact. Reservoir storage is used for agriculture and M&I, some of which returns to the river via wastewater discharge. There is probably some amount of return flow to the river from agriculture, however, much of it is lost through ET. And finally there is a diversion from the Santa Clara River that diverts water upstream from the junction above the Santa Clara and the Virgin Rivers and bypasses the Bloomington gage. This water is currently used to irrigate a golf course (previously used by agriculture) and the return flow to the Virgin River may average 1,000 afy (Cole and Katzer, 2000).

Discharge

Discharge from the basin, during both current conditions and prior to development is by: (1) river outflow, (2) ground-water outflow, (3) springflow, including direct ground-water discharge to the river, and (4) ET (water returned to the atmosphere by evaporation from surface-water bodies, bare soil, and water transpired by vegetation back to the atmosphere). ET, outside of the mountain blocks, is restricted to the riparian vegetation along Beaver Dam Wash and the Virgin River. Additionally, pumpage mainly in Nevada and Arizona is an additional discharge process. Although minor in comparison to the other processes, pumpage is becoming a significant factor.