Hydrologic Assessment of SNWA Water Right Applications for Delamar, Dry Lake, and Cave Valleys in the White River Flow System.

Timothy D. Mayer, Ph.D.
Hydrologist, Water Resources Branch
U.S. Fish and Wildlife Service

Expert Witness Testimony submitted on behalf of
the U.S Fish and Wildlife Service
for the Delamar, Dry Lake, and Cave Valley Protest Hearing
February 2008

EXHIBIT 501

Signature Timothy D. Mayer

Date November 14, 2007

In 1989, the Las Vegas Valley Water District (LVVWD) filed a number of water right applications to appropriate ground water in southern Nevada, including two in Delamar Valley, two in Dry Lake Valley, and two in Cave Valleys (see Exhibit 515). Of the two applications in each basin, one is for 6 cfs from the "underground basin" and one is for 10 cfs from the "underground rock aquifer." The combined duty of both applications is up to 11,000 afy from each basin, or a total of 33,000 afy for all three basins, although the applications do not state the annual volume of water sought. The U.S Fish and Wildlife Service protested all of the water right applications on the basis of water availability, injury to senior water rights, and public interest.

TESTIMONY

The White River Regional Flow System

The White River regional ground water flow system (WRFS) is one of several regional ground water flow systems in southern Nevada (Eakin 1966; Prudic et al. 1993). As originally defined by Eakin (1966), the WRFS encompasses thirteen topographic basins, extending over 250 miles along the presently dry White River drainage and terminating at the Muddy River Springs Area (Exhibit 514). The flow system consists of numerous local basin fill aquifers underlain by a large regional carbonate rock aquifer that transmits ground water from basin to basin, beneath topographic divides. Much of the flow in the regional carbonate rock aquifer occurs where rocks have been fractured or where openings have been enlarged by dissolution (Prudic et al. 1993; Dettinger et al. 1995).

Eakin (1966) identified the regional ground water flow system based on: 1) the hydrologic properties of the rocks in the area; 2) the movement of ground water inferred from hydraulic gradients; 3) the relative distribution and quantities of estimated recharge and discharge in the system; 4) the relative uniformity of the discharge of the principal springs; and 5) the chemical composition and warm temperature of the discharge from the principal springs.

The boundaries of the WRFS have been defined differently by some researchers since the original study. Kirk and Campana (1990) excluded Long Valley and included Lower Meadow Valley in the WRFS on the basis of potentiometric mapping. Prudic et al. (1993) included southern Jakes Valley but not Long Valley. These authors also extended the boundary of the WRFS to include Tikaboo Valley and the Pintwater and Desert Ranges to the west and southern Steptoe Valley, Lake Valley, Patterson Valley, Meadow Valley Wash, and western Escalante Desert to the east. LVVWD (2001) defined the flow system similar to Eakin (1966) except that they included four adjacent basins to the south: Hidden Valley, Garnet Valley, California Wash, and Black Mountains Area. The USGS BARCAS study did not specifically define the boundaries of the WRFS but they identified regional subsurface outflow from Steptoe Valley, Long Valley, Jakes Valley, and Cave Valley into White River Valley (Welch and Bright, 2007).

Ground water flow through the WRFS is generally from north to south, parallel to the White River drainage and across topographical divides. The White River drainage forms an axial topographic low between Garden and Coal Valleys to the west and Cave, Dry Lake, and Delamar to the east. The drainage is generally lower in elevation than the low parts of adjacent topographically closed basins. Ground water elevations in these basins follow the same topographic gradients.

Recharge for the WRFS is supplied almost entirely from precipitation in higher elevation areas. Outflow from the system is primarily to regional springs and evapotranspiration in three major discharge areas: White River Valley, Pahranagat Valley, and the Muddy River Springs Area. Eakin (1966) reports regional spring discharge of 37,000 afy in White River Valley, 25,000 afy in Pahranagat Valley, and 36,000 afy in the Muddy River Springs area. He regards the Muddy River Springs Area as the terminus of the flow system and Pahranagat Valley and White River Valley as intermediate discharge areas.

Water Budget Information for the WRFS

Eakin (1966) estimates total recharge to the WRFS as 109,000 afy and this is constrained to equal total discharge in his regional water budget. Total recharge as estimated by Kirk and Campana (1990) is similar to Eakin's estimate and ranged from 103,500 afy to 106,000 afy. Total recharge as estimated by Prudic et al. (1993) is 146,000 afy but their flow system boundary includes several additional basins, as described above.

Flint et al. (2004) use a recently developed physically-based water balance accounting model, the Basin Characterization Model, to estimate recharge in a number of hydrographic basins throughout the Southwest. They did not consider the WRFS explicitly but they did estimate recharge in the thirteen basins originally delineated by Eakin (1966). The total mean annual recharge estimate for these thirteen basins is 139,000 afy. However, the authors did not calibrate their method to discharge estimates. They caution that the estimates "are not relied on as accurate enough at this time to be used for assessment of water availability." (Exhibit 506, pg 160).

Total recharge by LVVWD (2001) in the same thirteen basins as originally delineated by Eakin (1966) is 199,000 afy, which is much larger than the other estimates (Exhibit 509). In their study, LVVWD applied Maxey-Eakin recharge coefficients to a different precipitation distribution, in what is termed a "modified Maxey-Eakin method." This is an incorrect application of the Maxey-Eakin method since the coefficients were calibrated with the Hardman precipitation map. Citing testimony from Keith Halford, the NPS's expert witness in the Kane Springs hearing, (Ruling 5712, pg 12, Exhibit 700), "...using the Maxey-Eakin recharge coefficients with any precipitation estimates other than the Hardman precipitation map is inappropriate. The Maxey-Eakin estimates are married to the Hardman map and cannot be used otherwise."

Eakin (1966) considers the WRFS to be a closed system, with the estimated ground water ET and regional spring discharge equal to the 109,000 afy of total recharge. Other researchers have had to specify additional subsurface outflow from the flow system to close the water budget or the mass balance for the regional flow system. Kirk and Campana (1990) required 3,700 to 4,400 afy of subsurface outflow west from Pahranagat Valley along the Pahranagat Shear Zone to calibrate their deuterium model. They noted that Winnograd and Friedman (1972) proposed that about 6,000 afy of the discharge at Ash Meadows originated in Pahranagat Valley, on the basis of deuterium concentrations.

Prudic et al. (1993) simulate about 19,000 afy more of ground water discharge at the Muddy River Springs area than the measured spring discharge (Exhibit 511, pg 71). This discrepancy is not fully explained in the study. They note that some or all of the extra discharge could be accounted for in the uncertainty of estimated evapotranspiration along the river, but that seems improbable based on results from a recent USGS ET study in the area (Guy Demeo, personal communication, November 7, 2007). They also acknowledge that the possibility of this much underflow through low-permeability rocks to Lake Mead seems unlikely, a point supported by other researchers (William Van Liew, personal communication, November 7, 2007).

The LVVWD (2001) water budget specifies 199,000 afy of total discharge (ground water ET, spring discharge, and subsurface outflow leaving the regional flow system) from the thirteen basins originally included in the WRFS (Exhibit 509, Table 4-9). Of the 199,000 afy total, 182,600 afy is ground water ET and regional spring discharge and 16,000 afy is subsurface outflow leaving the flow system through California Wash to Lower Moapa Valley. Note that it was the 16,000 afy of additional subsurface outflow that was identified as bypassing the Muddy River Springs and potentially available for capture by the existing permits in Coyote Spring Valley (Order 1169, p 5). The total discharge estimate in the LVVWD study is much greater than the other studies. The larger volume estimate is supported by the greater recharge estimates, as acknowledged in the report (Exhibit 509, pg 4-38). Since the recharge estimates may be erroneously large, the total discharge estimates may be too large as well.

Pahranagat National Wildlife Refuge

The Pahranagat National Wildlife Refuge (Refuge) is a 5,000 acre area of spring-fed wetlands, meadows, lakes and upland desert habitat. It is important for a variety of waterfowl, shorebirds, songbirds, raptors, and other wildlife. At least two species listed under the Endangered Species Act are found on the Refuge: the endangered southwest willow flycatcher (*Empidonax traillii extimis*) and the threatened bald eagle (*Haliaeetus leucocephalus*). The Refuge is located at the south end of the Pahranagat Valley (Basin 209) in south-central Nevada.

Pahranagat Valley is underlain by two ground water aquifers, a large regional carbonate aquifer and a local basin fill aquifer. The Pahranagat Shear Zone at the south end of the valley acts as a partial barrier for flow, based on the steep hydraulic gradient that exists across this feature (Eakin 1966). The hydrology of the valley is dominated by three regional springs aligned along the river drainage in the north central part of the valley. The three springs, from north to south, are: Hiko Spring, Crystal Spring, and Ash Spring. **The chemistry and warm temperature of the water as well as water budget considerations and the volume and consistency of flow are evidence that these are regional springs discharging from the carbonate aquifer** (Eakin, 1966). The three springs collectively discharge about 25,000 acre-feet/year (Eakin, 1966). Crystal Spring and Ash Spring, the two southernmost regional springs, are located about ten miles upgradient of the Refuge and are the principal water supply for the Refuge. Collectively, these two springs discharge about 26 cfs or 19,000 afy, based on recent USGS measurements. A number of other minor springs and seeps contribute water to the Refuge as well. These may discharge from either the carbonate aquifer or the basin fill aquifer.

Locally, recharge from precipitation in the Pahranagat Valley is considered small in relation to natural discharge and has been estimated by the Maxey-Eakin method to range between 1,500 to 2,000 acre-ft/year (Eakin, 1966). This is less than 8% of the 25,000 acre-feet of natural discharge from the regional springs in Pahranagat Valley. **The large discrepancy between recharge and discharge in Pahranagat Valley is evidence of regional flow and indicates that most of the ground water supporting the regional springs is derived from outside the hydrographic basin.**

Water Rights for Pahranagat NWR

The U.S. Fish and Wildlife (FWS) holds several water rights and permits for surface water and ground water on the Refuge. The total duty from five certified surface water rights on the Refuge is 5,044 afy. Priorities for these surface water rights range from 1880 to 1946. The ultimate source for most of this water is the regional spring discharge from Ash Springs and Crystal Springs. Some of the early priority water rights for the Refuge are associated with the Pahranagat Lake water rights decree, which adjudicated the entire flow of the springs in 1929. In Ruling 5560 (pg 3) (Exhibit 700), the State Engineer found that "said decree provides that the Hiko, Crystal, and Ash Springs are fully appropriated." The total duty from two certified water rights for ground water on the Refuge is 1,686 afy. Priorities for these ground water rights are 1970 and 1972. The total certified duty for the Refuge is 6,730 afy. All these certified water rights are senior to the 1989 LVVWD/SNWA applications. In addition, the FWS filed three new applications on 9/4/1996 for three minor springs on the Refuge. The perennial yield for Pahranagat Valley is given as 25,000 afy (information accessed on-line at **http://water.nv.gov/WaterPlanning/UGactive/index.cfm**). Current permitted water rights exceed this and total 34,600 afy (25,000 afy of spring water rights and 9,600 afy of supplementally adjusted ground water rights). The State Engineer has denied new ground water rights in Pahranagat Valley on the grounds that they would interfere with existing rights and be detrimental to the public interest (Rulings 3225, 5560) (Exhibit 700) .

Water Budget Information for Individual Hydrographic Basins

Estimates of water budgets for Pahranagat Valley from several studies are compiled by Burbey (1997) (see Exhibit 504). Eakin (1966), Welch and Thomas (1984), and Kirk and Campana (1990) estimate total recharge (subsurface inflow and local recharge) to be about 53,000 to 62,000 afy (only 1,500 to 2,000 afy of this is local recharge). Regional spring discharge and ground water ET within the valley is estimated to be 25,000 afy, which is the measured discharge of the regional springs. Subsurface outflow to Tikaboo and/or Coyote Spring Valley is estimated to be between 25,000 to 35,000 afy. The LVVWD (2001) estimates are slightly higher than these other studies, with 66,000 afy of total recharge (including 7,000 afy of local recharge), 38,000 afy of ground water ET and spring discharge, and 28,000 afy of subsurface outflow from Pahranagat to Coyote Spring Valley (Exhibit 509). Flint et al. (2004) estimates 7,000 afy of local recharge in Pahranagat Valley using their Basin Characteristic Model (Exhibit 506). These authors did not develop water budgets for basins, just recharge estimates.

Water budget estimates for Delamar Valley from Eakin (1966), Welch and Thomas (1984), and Kirk and Campana (1990) are compiled by Burbey (1997) as well (see Exhibit 504). Total recharge in Delamar Valley ranges from 6,000 to 9,000 afy (5,000 to 7,000 afy of subsurface inflow from Dry Lake Valley and 1,000 to 2,000 afy of local recharge). Total discharge ranges from 6,000 to 9,500 afy, with all of that being subsurface outflow. None of the three studies has any ground water ET or regional spring discharge in the basin. LVVWD (2001) estimates 17,000 afy of total recharge (12,000 afy of subsurface inflow from Dry Lake and 5,000 afy of recharge), 1,000 afy of ground water ET, and 16,000 afy of subsurface outflow (Exhibit 509). **The ground water ET estimate seems unrealistically high given depths to water of several hundred feet below the surface in the basin.** Flint et al. (2004) estimate recharge to be about 7,800 afy, in Delamar Valley using their Basin Characteristic Model (Exhibit 506). Recharge estimates from the LVVWD study (2001) and Flint et al. (2004) for Delamar Valley are generally much higher than the estimates from the other studies.

Most of the total recharge in Delamar Valley is subsurface inflow from Dry Lake Valley. Ground water appears to flow without restriction from one basin to the next since the two are separated by a low topographic divide in the basin fill (Burbey, 1997). Eakin (1966) estimates 5,000 afy of recharge in this basin, with all of it exiting the basin as subsurface outflow into Delamar Valley to the south. Kirk and Campana (1990) specify 5,250 to 7,500 afy of recharge in Dry Lake Valley, with a small percentage, 10% or less, entering Pahranagat Valley directly as subsurface outflow, and the other 90% or more going to Delamar Valley (Kirk and Campana, 1988) (see Exhibit 507 and 508). LVVWD (2001) estimates recharge in Dry Lake Valley of 13,000 afy, with 1,000 afy of local ground water ET and the remaining 12,000 afy entering Delamar as subsurface outflow. **The ground water ET estimate seems unrealistically high given depths to water of several hundred feet below the surface in the basin.** Flint et al. (2004) estimate 10,600 afy of recharge for Dry Lake Valley using their Basin Characteristic Model. The recharge estimate from LVVWD (2001) of 13,000 afy is the highest of any of the studies.

The water budget estimates can be related to perennial yield estimates in Delamar and Dry Lake Valleys. The State Engineer determines ground water availability in part based on the concept of perennial yield. As stated in Ruling 5645 (pg 43) (Exhibit 700), "for a ground water basin that has no evapotranspiration such as the basins under consideration here, the perennial yield has been established as one-half the volume of the basin discharge." The perennial yield estimate is 2,500 afy (one half the total recharge) for Dry Lake and 3,000 afy (one half the total discharge) for Delamar Valley (accessed on-line at **http://water.nv.gov/WaterPlanning/UGactive/index.cfm**). However, the perennial yield estimates for the two individual basins don't consider that most of the total recharge in Delamar consists of subsurface outflow from Dry Lake Valley. In the same ruling, the State Engineer notes that "if the water appropriated in an upstream basin is not deducted from the amount which discharges to the downstream basin or basins, it creates the potential for double counting and regional overappropriation." Using this approach, the perennial yield in Dry Lake is 2,500 afy and in Delamar is 500 afy for a combined perennial yield of 3,000 afy from both basins. As shown below though, the volume of perennial yield is moot since the total subsurface outflow from these two basins has been fully appropriated already.

The direction of subsurface outflow from Delamar Valley is not fully resolved in the literature. Eakin (1966) suggests that subsurface outflow from Delamar goes to Pahranagat Valley and supports regional spring discharge there. Welch and Thomas (1984) have subsurface outflow going to Coyote Spring Valley rather than Pahranagat Valley, on the basis of isotope chemistry, ultimately supporting regional spring discharge in the Muddy River. Kirk and Campana (1990) conclude, on the basis of an isotope-mixing model, that most of the discharge enters Coyote Spring Valley but a small portion enters Pahranagat Valley. LVVWD (2001) has subsurface outflow from Delamar Valley entering Coyote Spring Valley and the Muddy River. Johnson and Mifflin (2006) regard the Pahranagat Shear Zone at the south end of Pahranagat and Delamar Valleys as a no-flow barrier, suggesting that they believe subsurface outflow from Delamar Valley enters Pahranagat Valley rather than Coyote Spring Valley.

The direction of subsurface outflow from Delamar Valley may be relevant to potential injury of FWS water rights in Pahranagat Valley but it may not matter from a water availability perspective. What is most important is that all of the water in Dry Lake and Delamar Valleys becomes subsurface outflow, which unquestionably flows into the WRFS, either through Pahranagat Valley or Coyote Spring Valley. As discussed above and demonstrated below, both of these downgradient basins are fully appropriated and dependent on this subsurface outflow. The total combined subsurface outflow from both Pahranagat Valley and Delamar Valley into Coyote Spring Valley is given below, for the various studies:

Eakin (1966)	35,000 afy
Welch and Thomas (1984)	25,000 afy
Kirk and Campana (1988)	23,000 to 26,000 afy
Prudic et al. (1993)	24,000 afy
LVVWD (2001)	44,000 afy

The LVVWD (2001) study has the highest estimate of total subsurface outflow from the two basins of the five studies cited. As stated earlier, Pahranagat Valley is considered fully appropriated, based on the perennial yield, the decree, and recent rulings. Considering the water budget information and the volume of appropriated water rights in Coyote Spring Valley and adjacent basins, the total subsurface outflow from Delamar, Dry Lake, and Pahranagat basins has been fully appropriated in Coyote Spring Valley as well. Using the highest estimates of water availability, as given by the LVVWD (2001) study, the water budget for Coyote Spring Valley is indicated below:

Pahranagat Valley to Coyote Spring V:	28,000 afy
Delamar Valley to Coyote Spring V:	16,000 afy
Kane Springs to Coyote Spring V:	6,000 afy
Local recharge in Coyote Spring V:	4,000 afy
Total Inflow:	**54,000 afy**

Coyote Spring V outflow to Muddy River Springs:	37,000 afy
Coyote Spring V outflow to California Wash:	16,000 afy
Local ET in Coyote Spring V:	1,000 afy
Total Outflow:	**54,000 afy**

The permitted water rights for relevant ground water basins in the southern part of the WRFS are given below (along with the information source for the quantities):

Pahranagat V:	25,000 afy regional spring discharge (Pahranagat L decree) 9,600 afy ground water rights (supplementally adjusted) (**http://water.nv.gov/WaterPlanning/UGactive/index.cfm**)
Coyote Spring V:	16,300 afy (Order 1169, Exhibit 700)
Upper Moapa V:	37,000 afy regional spring discharge (Muddy River decree) 14,800 afy ground water rights (Order 1169, Exhibit 700)
California Wash:	3,000 afy ground water rights (Ruling 5115, Exhibit 700)
Hidden/Garnet V:	3,400 afy ground water rights (Order 1169, Exhibit 700)
Kane Springs V:	1,000 afy ground water rights (Ruling 5712, Exhibit 700)

The total volume of appropriated regional spring discharge is 62,000 afy and the total volume of appropriated ground water is 48,600 afy. All of these basins appear to be fully appropriated or over-appropriated, as discussed below.

The estimated 37,000 afy of subsurface outflow from Coyote Spring Valley to the Muddy River Springs area is considered to be completely appropriated as regional spring discharge and/or ground water rights in the Upper Moapa Valley. As stated on pg 5 of Order 1169 (Exhibit 700):

> "**Whereas**, testimony and evidence from the administrative hearing on the Las Vegas Valley Water District's applications indicates that a portion of the ground water outflow from Coyote Springs Valley is believed to discharge at a rate of approximately 37,000 acre-feet annually at the Muddy River Springs area and approximately 16,000 to 17,000 acre-feet annually flow to ground water basins further south. This 37,000 acre-feet is counted as part of the 53,000 acre-feet outflow from Coyote Springs Valley resulting in 16,000-17,000 acre-feet annual flow that by-passes the Muddy River Springs area."
>
> "**Whereas**, these referenced springs located near the central part of the Upper Moapa Valley, which that collectively discharge approximately 37,000 acre-feet annually of underground water, are fully appropriated pursuant to the Muddy River Decree."

The excess 16,000 afy of subsurface outflow from Coyote Spring Valley to California Wash is considered to be completely appropriated by existing ground water permits in Coyote Spring Valley alone. As stated on pg 6, Order 1169:

> "**Whereas**, if 16,000 to 17,000 acre-feet is believed to by-pass the Muddy River Springs area, the water right permits in Coyote Spring Valley alone equal the estimate of the amount of carbonate flow that by-passes the region and is not considered to be part of the flow discharged from the Muddy River Springs area."

The system appears to be over-appropriated when considering the 7,400 afy of additional ground water permits in Hidden, Garnet, and California Wash (Order 1169, p 5, Exhibit 700), even allowing for the 1,000 to 2,000 afy of estimated local recharge in these basins (LVVWD, 2001). This analysis is based on the highest estimates of water availability. The basins would be even more severely over-appropriated if the lower estimates from the other water budget studies were used instead.

The highest and most optimistic estimate of combined subsurface outflow from Pahranagat, Delamar, and Dry Lake Valleys is 54,000 afy, as given by LVVWD (2001) (Exhibit 509). This total quantity of subsurface outflow has already been accounted for and appropriated in downgradient basins: 37,000 afy as regional spring discharge through the Muddy River decree and 16,000 afy through existing permits in Coyote Spring Valley (see Order 1169). Since all water in Delamar Valley and Dry Lake Valley is subsurface outflow, there is no additional water available for appropriation in these two basins.

The question of perennial yield is moot in these basins, considering the information above. When the water budget estimates, the hydrologic connectivity of the flow system, and the volume of appropriated water rights in the area are taken into account, the entire subsurface outflow has already been appropriated in downgradient basins.

CONCLUSION/OPINION for Applications in Dry Lake and Delamar Valleys:

While the exact direction and magnitude of recharge and subsurface outflow from Delamar and Dry Lake is unresolved at this time, all of the water in these two basins is subsurface outflow and this outflow is completely appropriated in downgradient basins. Even considering the highest estimates of water availability (LVVWD, 2001), there is no additional ground water available in this part of the flow system. Existing appropriated water rights exceed even the most optimistic estimates of water availability and far exceed the estimates from other studies, when downgradient hydrographic areas and interbasin flows are considered. **New ground water appropriations in Dry Lake and Delamar Valleys threaten FWS water rights and resources in Pahranagat Valley and/or Coyote Spring Valley and the Muddy River Springs area.**

The State Engineer recognizes that he must consider the hydrologic connectivity of ground water basins in regional flow systems and that he is responsible for protection of senior water rights in downgradient basins. Most recently, this was demonstrated in the ruling to deny new water right applications by Nye County in basins upgradient of Ash Meadows and Devils Hole in the Armargosa Desert Hydrographic Basin (Ruling 5750). He has also considered interbasin flow, hydrologic connectivity, and protection of downgradient water rights in ruling in Coyote Spring Valley (Order 1169), Tikaboo/Three Lakes Valleys (Ruling 5465 and 5621), and Kane Springs Valley (Ruling 5712).

Water availability is difficult to measure, as demonstrated by the large range of estimates in the studies cited above. Furthermore, pumping will ultimately affect water resources, as explained by Theis (1940) and reiterated by Sophecleous (1997) and Bredehoeft (1997) (Exhibit 503 and 512). But the timing of these effects may be difficult to predict and difficult to reverse (see discussion on pp 35-36 in Ruling 5465, Exhibit 700). The propagation of climate and pumping impacts has been rapid and widespread in parts of this flow system, as documented by Mayer and Congdon (*in press*, Exhibit 510). There are a range of estimates for ground water recharge and discharge throughout the flow system and a cautious and conservative approach is warranted. **By any such measure, the system is completely appropriated and the State Engineer should deny all water right applications in Dry Lake and Delamar Valleys.**

White River Valley and Cave Valley

White River Valley is one of the intermediate discharge areas of the WRFS, with an estimated 37,000 afy of spring discharge and ground water ET (Eakin, 1966). This spring discharge and ET is supported by local recharge within the basin and subsurface outflow from adjacent basins. Several studies indicate that all or part of the subsurface outflow from Cave Valley goes to White River Valley (Eakin, 1962; Eakin, 1966; LVVWD, 2001; Welch and Bright, 2007). Kirk and Campana (1990) specified subsurface outflow from Cave Valley south to Pahroc Valley and Pahranagat Valley. The hydraulic gradient supports ground water flow in either direction. In any case, subsurface outflow from Cave Valley likely supports regional spring discharge in the White River Valley or ultimately Pahranagat Valley. Pahranagat Valley is fully appropriated, as discussed above. The State Engineer has ruled that White River Valley is considered fully appropriated as well (see Ruling 3640, Exhibit 700). The FWS holds no water rights in Cave Valley or White River Valley but there are a number of biological resources dependent on water that are of concern in both basins. (see FWS testimony and exhibits).

Recharge estimates for Cave Valley from various studies are given below:

Eakin (1966)	14,000 afy
Kirk and Campana (1990)	11,000 to 14,000 afy
LVVWD (2001)	20,000 afy
Flint et al. (2004)	10,300 afy
Welch and Bright (2007)	11,000 afy

The LVVWD (2001) estimates are much higher than the other studies. They are likely too high and in error for the reasons discussed previously.

Ground water ET estimates for Cave Valley from various studies are given below:

Eakin (1966)	several hundred afy
LVVWD (2001)	5,000 afy
Welch and Bright (2007)	1,600 afy

Subsurface outflow estimates from various studies are given below:

Eakin (1966)	14,000 afy
Kirk and Campana (1990)	11,000 to 14,000 afy
LVVWD (2001)	15,000 afy
Welch and Bright (2007)	7,000 afy

None of the studies estimate any subsurface inflow into Cave Valley from adjacent hydrographic basins. The 20,000 afy total discharge (5,000 afy of ground water ET and 15,000 afy subsurface outflow) from the LVVWD (2001) study is supported by their high recharge estimates for this basin, which may be in error as stated above. Additionally, it appears that the LVVWD (2001) estimate for ET in Cave Valley is higher than the other studies in part because they included ET discharge from a perched aquifer (pg 4-36). Whether or not this should counted as available water will depend on if this water can be salvaged through pumping.

The perennial yield is currently given as 2,000 afy for Cave Valley (information accessed on-line at **http://water.nv.gov/WaterPlanning/UGactive/index.cfm**) but this figure seems to have been based partly on economic considerations for pumping depths, which may not be valid today. There may be some ground water ET that is salvageable, however, the most reliable estimates are fairly low (up to 1,500 afy). In addition, there are biological resources that may be dependent on the vegetation and the springs resulting from this ground water discharge (see FWS testimony and exhibits).

The portion of subsurface outflow from Cave Valley available for ground water development will depend on the extent that water rights and resources in downgradient basins rely on this flow. Pahranagat Valley and White River Valley are considered completely appropriated and both basins are dependent on subsurface inflow from Cave Valley. Butterfield and Flag springs in White River Valley are just west and downgradient of the boundary separating White River and Cave Valleys. These springs support unique aquatic organisms and may be threatened by pumping upgradient in the southern part of White River Valley, where the SNWA applications are located. Appropriation and pumping of some or all of the subsurface outflow from Cave Valley potentially threatens spring discharge in both of these downgradient basins.

CONCLUSION/OPINION for Applications in Cave Valley:

The volume of recharge and ground water ET and the direction and magnitude of subsurface outflow from Cave Valley is unresolved in the literature. The large range of estimates is troubling and seems to demand caution in any assessment of water availability. It seems prudent to regard the recent BARCUS study (Welch and Bright, 2007, Exhibit 513) as the most reliable source of information, given the questions concerning the LVVWD estimates. Using the USGS estimates, there is only a small volume of ground water ET (up to 1,500 afy) that is potentially salvageable through ground water pumping. However, there may be biological resources that are dependent on this ground water. The portion of subsurface outflow from Cave Valley that could be captured through pumping is uncertain as well. There are biological resources and senior water rights in downgradient basins that are dependent on this outflow. Two of the basins, White River and Pahranagat Valleys, are fully appropriated. The State Engineer has typically considered half of the regional subsurface outflow in a basin to be available for development. Perhaps a judicious approach would be to appropriate half of the estimated 7,000 afy of the subsurface outflow, or 3,500 afy initially, with a commitment from the applicants to monitor water levels, springs, and biologic resources in Cave Valley and downgradient basins including White River Valley, Pahroc Valley, and Pahranagat Valley. Additional water could be allocated if the impacts from the initial pumping prove to be negligible.

Literature Cited

Bredehoeft, J.D. 1997. Safe yield and the water budget myth. *Ground Water* vol. 35, no. 6.

Burbey, T.J. 1997. Hydrogeology and potential for ground-water development, carbonate-rock aquifers, southern Nevada and southeastern California. U.S. Geological Survey Water-Resources Investigations 95-4168.

Dettinger, M.D., J.R. Harrill, and D.L. Schmidt. 1995. Distribution of carbonate-rock aquifers and the potential for their development, Southern Nevada and adjacent parts of California, Arizona, and Utah. U.S. Geological Survey Water-Resources Investigations Report 91-4146.

Eakin, T.E. 1962. Ground-water appraisal of Cave Valley in Lincoln and White Pine Counties, Nevada. Ground-water Resources Reconnaissance Series, Report 13.

Eakin, T.E. 1966. A regional interbasin ground water system in the White River Area, Southeastern Nevada. *Water Resources Research*, vol. 2: 251-271.

Flint, A.L., L.E. Flint, J.A. Hevesi, and J.B. Blainey. 2004. Fundamental concepts of recharge in the Desert Southwest: A regional modeling perspective. In: Groundwater Recharge in a Desert Environment: The Southwestern United States. J.F. Hogan, F.M. Phillips, and B.R. Scanlon, eds. Water Science Application 9, American Geophysical Union, Washington, D.C.

Johnson, C. and M. Mifflin. 2006. The AEM and regional carbonate aquifer modeling. *Ground Water* vol. 44, no. 1: 24-34.

Kirk, S.T. and M.E. Campana. 1988. Simulation of groundwater flow in a regional carbonate-alluvial system with sparse data: The White River Flow System, Southeastern Nevada. Water Resources center, Publication #41115, Desert Research Institute, University of Nevada System.

Kirk, S.T. and M.E. Campana. 1990. A deuterium-calibrated groundwater flow model of a regional carbonate-alluvial system. *Journal of Hydrology,* vol. 119: 357-388.

LVVWD. 2001. Water resources and ground-water modeling in the White River and Meadow Valley Flow Systems. Clark, Lincoln, Nye, and White Pine Counties. Prepared by Las Vegas Valley Water District. Submitted as Exhibit 54 for the Coyote Spring Protest Hearings, July 2001.

Mayer, T.D. and R.D. Congdon. (*in press*) Evaluating climate variability and pumping effects in statistical analyses. *Ground Water* doi: 10.1111/j.1745.6584.2007.00381.x

Prudic, D.E., J.R. Harrill, and T.J. Burbey. 1993. Conceptual Evaluation of Regional Ground-Water Flow in the Carbonate-Rock Province of the Great Basin, Nevada, Utah, and Adjacent States. U.S. Geological Survey Open-File Report 93-170.

Sophecleous, M. 1997. Managing water resources systems: Why "safe yield" is not sustainable. *Ground Water* vol. 35, no. 4.

Theis, C.V. 1940. The source of water derived from wells: Essential factors controlling the response of an aquifer to development. *Civil Engineer*, vol. 10, 277-280.

Welch, A.H. and J.M. Thomas. 1984. Aqueous geochemistry and isotope hydrology of the White River system, eastern Nevada (abs). *Geology Society of America Abstracts with Programs*, vol. 16, no. 6: 689.

Welch, A.H. and D.J. Bright, eds. 2007. Water resources of the Basin and Range carbonate- rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah – Draft Report: U.S. Geological Survey Open-File Report 2007-1156.

Winnograd, I.J. and I. Friedman. 1972. Deuterium as a tracer of regional ground-water flow, Southern Great Basin, Nevada and California. *Geologic Society of America Bulletin,* vol. 83: 3691-3708.

Orders/Rulings Cited

Ruling 3225. Pahranagat Valley. August 1985.

Ruling 3640. White River Valley. September 1989.

Order 1169. Coyote Spring Valley, Black Mountains Area, Garnet Valley, Hidden Valley, Muddy River Springs, Lower Moapa Valley. March 2002.

Ruling 5115, California Wash. April 2002.

Ruling 5465. Tikaboo Valleys and Three Lake Valleys. January 2005.

Ruling 5560. Pahranagat Valley. February 2006.

Ruling 5621. Tikaboo Valleys and Three Lake Valleys. June 2006.

Ruling 5712. Kane Springs Valley. February 2007.

Ruling 5750. Amargosa Desert Basin. July 2007.

Text Submitted as Exhibits to Support Testimony

Exhibit 503. Bredehoeft, J.D. 1997. Safe yield and the water budget myth. *Ground Water* vol. 35, no. 6.

Exhibit 504. Burbey, T.J. 1997. Hydrogeology and potential for ground-water development, carbonate-rock aquifers, southern Nevada and southeastern California. U.S. Geological Survey Water-Resources Investigations 95-4168. pp 7-19

Exhibit 505. Eakin, T.E. 1966. A regional interbasin ground water system in the White River Area, Southeastern Nevada. *Water Resources Research*, vol. 2: 251-271.

Exhibit 506. Flint, A.L., L.E. Flint, J.A. Hevesi, and J.B. Blainey. 2004. Fundamental concepts of recharge in the Desert Southwest: A regional modeling perspective. In: Groundwater Recharge in a Desert Environment: The Southwestern United States. J.F. Hogan, F.M. Phillips, and B.R. Scanlon, eds. Water Science Application 9, American Geophysical Union, Washington, D.C. pp 159-160 and Table 1.

Exhibit 507. Kirk, S.T. and M.E. Campana. 1988. Simulation of groundwater flow in a regional carbonate-alluvial system with sparse data: The White River Flow System, Southeastern Nevada. Water Resources center, Publication #41115, Desert Research Institute, University of Nevada System. Table 6-8. Figs 11-13.

Exhibit 508. Kirk, S.T. and M.E. Campana. 1990. A deuterium-calibrated groundwater flow model of a regional carbonate-alluvial system. *Journal of Hydrology,* vol. 119: 357-388.

Exhibit 509. LVVWD. 2001. Water resources and ground-water modeling in the White River and Meadow Valley Flow Systems. Clark, Lincoln, Nye, and White Pine Counties. Prepared by Las Vegas Valley Water District. Submitted as Exhibit 54 for the Coyote Spring Protest Hearings, July 2001. pp 4-23 to 4-30, 4-33 to 4-38, and 6-1 to 6-3. (see revised Fig 6-1)

Exhibit 510. Mayer, T.D. and R.D. Congdon. (*in press*) Evaluating climate variability and pumping effects in statistical analyses. *Ground Water* doi: 10.1111/j.1745.6584.2007.00381.x pp 1-16.

Exhibit 511. Prudic, D.E., J.R. Harrill, and T.J. Burbey. 1993. Conceptual Evaluation of Regional Ground-Water Flow in the Carbonate-Rock Province of the Great Basin, Nevada, Utah, and Adjacent States. U.S. Geological Survey Open-File Report 93-170. pp 69-72 and Fig 31 on p 67.

Exhibit 512. Sophecleous, M. 1997. Managing water resources systems: Why "safe yield" is not sustainable. *Ground Water* vol. 35, no. 4.

Exhibit 513. Welch, A.H. and D.J. Bright, eds. 2007. Water resources of the Basin and Range carbonate- rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah – Draft Report: U.S. Geological Survey Open-File Report 2007-1156. Plate 2

Exhibit 700. Selected pages from Nevada State Engineer Rulings and Orders:

Ruling 5712 (pp 11-12)
Ruling 5560 (pp 5-6)
Ruling 3225 (pp 1-3)
Ruling 5465 (pp 35-36, 43-44)
Ruling 5115 (pp15-16, 39-40)
Order 1169 (pp 5-6)
Ruling 3640 (pp 1-4)