Summary of Groundwater Withdrawal at Least Chub Population Sites

Draft Report

April 2014

Report by: USFWS, Utah Field Office

Statewide Trends in Groundwater Development

The Utah State Engineer (USE), through the Utah Division of Water Rights (UDWRi), is responsible for the administration of water rights, including the appropriation, distribution, and management of the State's surface and groundwater. This office has broad discretionary powers to implement the duties required by the office. The USE's Office was created in 1897, and the State Engineer is the chief water rights administrative officer. For groundwater management, Utah is divided into groundwater basins and policy is determined by basin (UDWRi, 2001). Based on the extent of groundwater development within each basin, they are either, open, closed or restricted to further appropriations. For basins that have significant overdraft, where discharge exceeds basin recharge, UDWRi has implemented groundwater management plans to return discharge to average recharge rates.

Since 1963, U.S. Geological Survey (USGS) and several State of Utah agencies have annually authored joint reports providing a description of groundwater conditions in the State of Utah. The authors developed these reports to enable interested parties to maintain awareness of changing groundwater conditions (Burden 2013, p. 1). Small volumes of groundwater can be obtained from wells throughout most of Utah, but large volumes that are of suitable chemical quality for irrigation, public supply, or industrial use generally can be obtained only in specific areas (Burden 2013, p. 1). The USGS reports on groundwater development within the latter areas, and further defines each as significant or less significant development areas based on the volume of groundwater withdrawal. The groundwater development areas described by USGS overlap with the UDWRi groundwater basins, but can span several basins and may not fully encompass the same spatial extent. Therefore, areas with significant development may be described for a USGS development area but these same trends may not be equally represented across all the UDWRi basins in which the development area spans.

Groundwater withdrawal numbers are estimations based on pumped and flowing wells, as well as data for public supply and industry provided by the State of Utah (Burden 2014, pers. comm.). The amount of water withdrawn from wells is related to demand and availability of water from other sources, which in turn are partly related to local climatic conditions (Burden 2013, p. 2); with statewide decreases during above-average precipitation, and statewide increases in pumping following drier than average years (Figure 1.1). While the reported amount of groundwater withdrawn within various basins has fluctuated since 1963, the total amount of groundwater withdrawn overall in the USGS studied basins has increased from 573,000 acre-feet per year (afy) in 1963 (Arnow 1964, p. 16) to 1,060,000 afy in 2012 (Burden et al. 2013, p. 6; Figure 1.2).

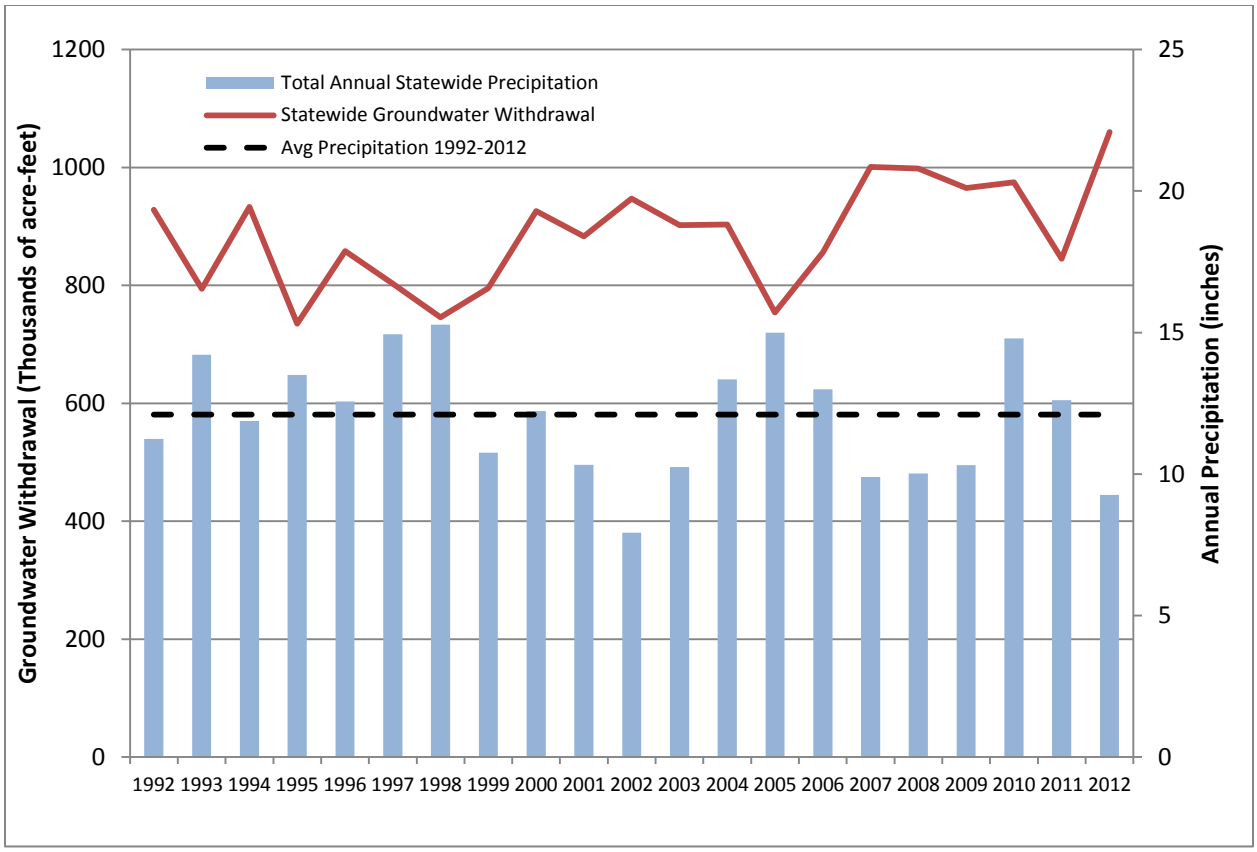


Figure 1.1. Groundwater withdrawals statewide and the corresponding precipitation by year (compiled from NOAA National Climatic Center and Burden et al. 2003-2013).

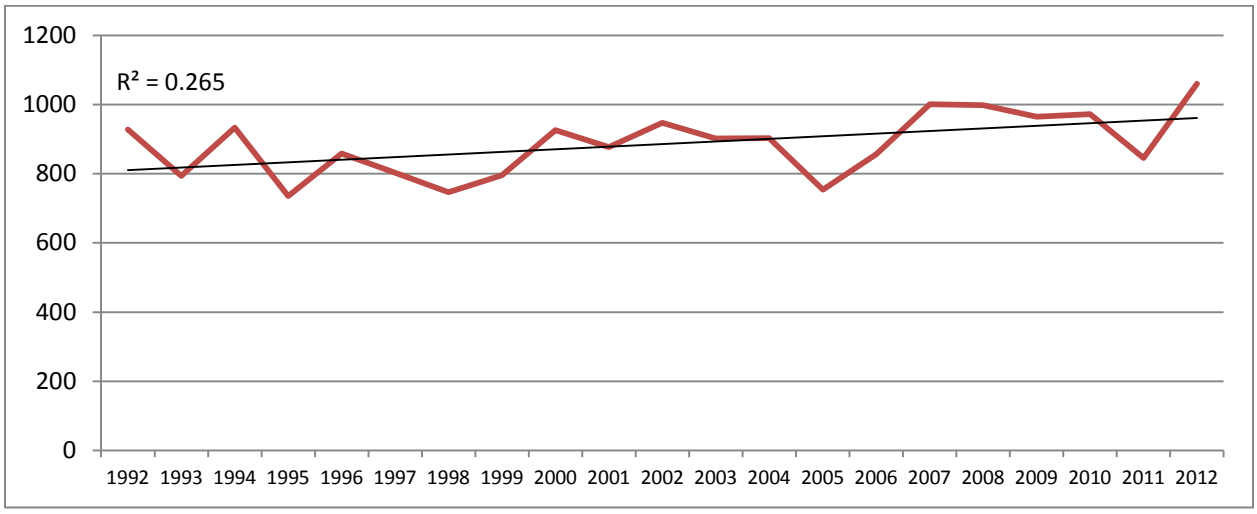


Figure 1.2. Statewide groundwater withdrawals from 1992-2012 (compiled from Burden et al. 2003-2013).

Although groundwater withdrawals have increased in recent years, the high clustered distribution of historic wells and the new wells are not located within areas where the wild least chub populations occur. The kernel density map (Figure 1.3) shows areas with a high density of historic wells in blue (greater than 5 wells within a square kilometer), and the density of new wells installed in 2012 (greater than 0.02 wells per square kilometer) in red concentric circles; however, the new wells are not necessarily for new appropriations, as they can often be replacement wells. The high density of historic wells and new wells overlap slightly with four least chub introduced populations, but not with wild sites, even when using a five mile buffer around each population (shown as an orange ring around the populations). Well density around the introduced sites is discussed in more detail under the Introduced Least Chub Sites Section.

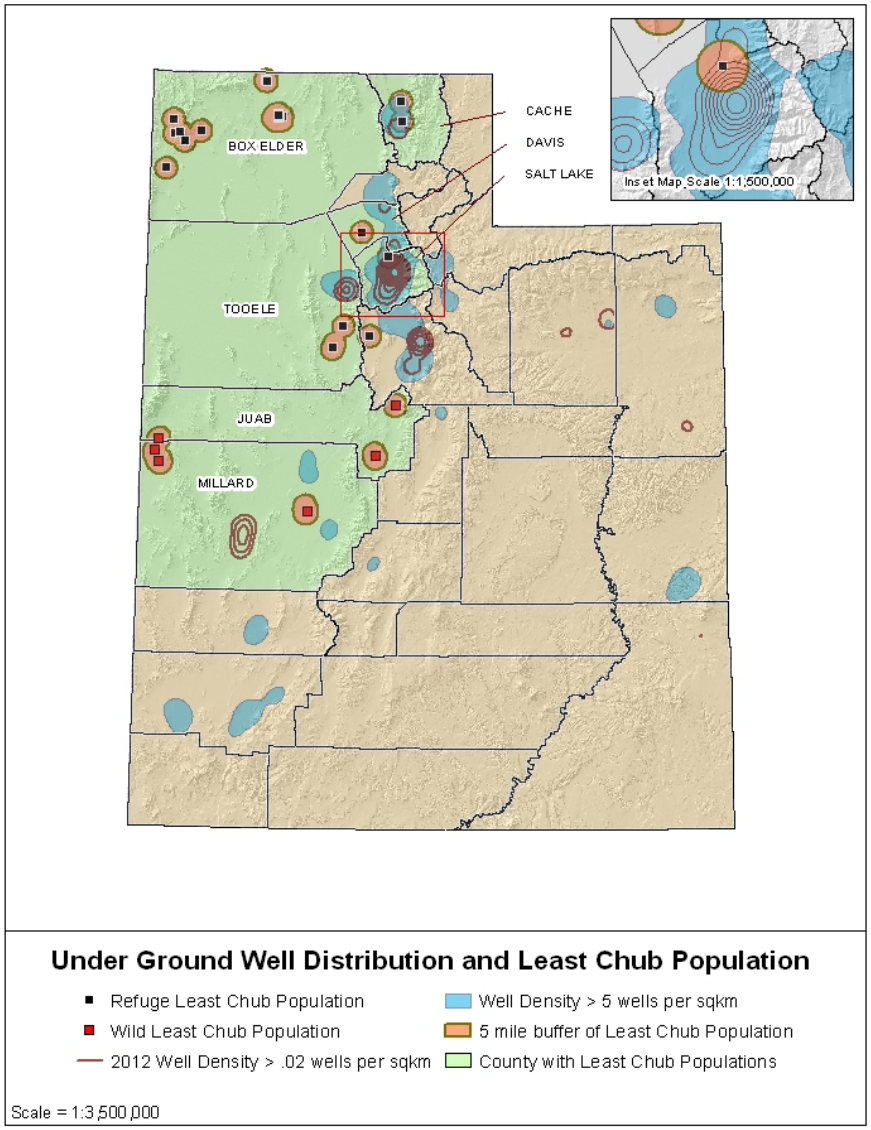


Figure 1.3. Well distribution across Utah, with increased well densities shown in green and new wells shown in brown concentric circles. Least chub sites are displayed as square icons with 5 mile buffers in light orange.

Regional Trends in Groundwater Development

With some exceptions, each of the locations occupied by least chub has a corresponding summary by groundwater basin, valley or hydrographic area for: (1) number of wells constructed on an annual basis; (2) estimated average annual withdrawal of groundwater from wells; (3) decade averages of those total annual withdrawals; (4) groundwater level monitoring results from several monitoring wells for varying periods of record (~20 to 75 years) (Burden 2013, entire); and (5) UDWRi groundwater basin policy (UDWRi, 2001; Figure 1.4). Although these summary areas were not specifically delineated to assess groundwater conditions in least chub habitat, they provide the best information available to discern general groundwater levels and pumping trends in areas where least chub populations are known. The predominant use of withdrawn groundwater in 2012 was for irrigation with remaining uses including industrial, public supply, domestic, and stock (Burden 2013, pp. 2, 89).

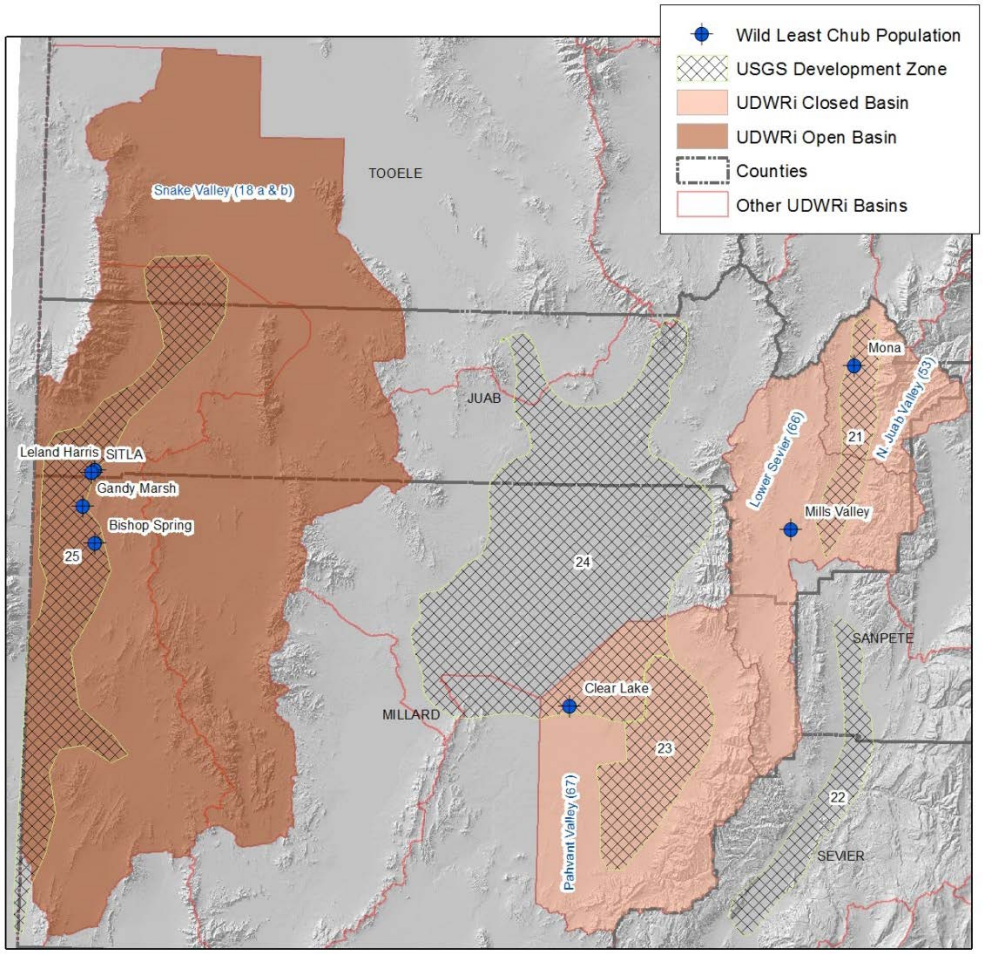


Figure 1.4. UDWRi groundwater policy basins (closed—light tan, open—brown) and USGS development areas (black hatchmark) corresponding to least chub wild population sites (blue dots).

Mona—Juab Valley (UDWRi Basin 53; USGS Zone 21)

The Mona Springs least chub site is located in the UDWRi Northern Juab Valley Basin and within the USGS Juab Valley area of groundwater development. In 1995, the Utah State Engineer re-evaluated the Northern Juab Valley and implemented the Northern Juab Valley Ground Water Policy, closing the basin to new appropriations (UDWRi 2013b, p. 1). All supplies of water are fully appropriated and no new applications have been approved since the implementation of the management plan in 1995 (UDWRi 2013b, p. 1). UDWRi allows existing groundwater rights change applications for points of diversion, purpose of use and place of use if there is no enlargement of the underlying rights (UDWRi 2013b, p. 1). However, any change applications must be publically noticed, allowing for public protests to proposed changes, therefore valid protests showing injury to existing water rights may preclude approval of the change application. New wells can be permitted through the change application process, and USGS reported four new wells constructed in 2012 within the Juab Valley area of groundwater development as shown in the UDWRi well drilling log database (Burden et al. 2013, p. 40; UDWRi 2013e; Figure 2.1). These new wells were changes in points of diversion, the majority for replacement of existing non-functioning wells, but none enlarged their existing rights, in spite of total groundwater withdrawal of 28,000 afy, an increase of 13,000 afy from 2011, and 5,000 afy increase from the 2002-2011 average annual withdrawal (Burden et al. 2013, p. 40; Figure 4). The total withdrawals in 2012 was 22,000 afy more than that withdrawn in 1983, when withdrawals were the lowest over the period of record (Seiler 1985, p.8). It is 3,000 afy less than that withdrawn in 1974 when withdrawals were at the highest over the period of record (Eychaner 1976, p.6). While levels of groundwater withdrawals have fluctuated over the period of record (Figure 2.2, 2.3, 2.4), the overall trend for groundwater withdrawals show increases during periods of below average precipitation and decreases with above average precipitation statewide (Figure 1.1). In the Juab Valley basin, UDWRi states that many water rights are surface water withdrawals that include supplemental groundwater wells, and during the periods of below average precipitation, the supplemental groundwater withdrawals are relied on more heavily than during periods of average or above average precipitation years (J. Greer, 2013, pers. comm), therefore displaying increases in groundwater withdrawal that appear to be an increase in appropriations, when in fact they are not new appropriations and are within the appropriated water rights.

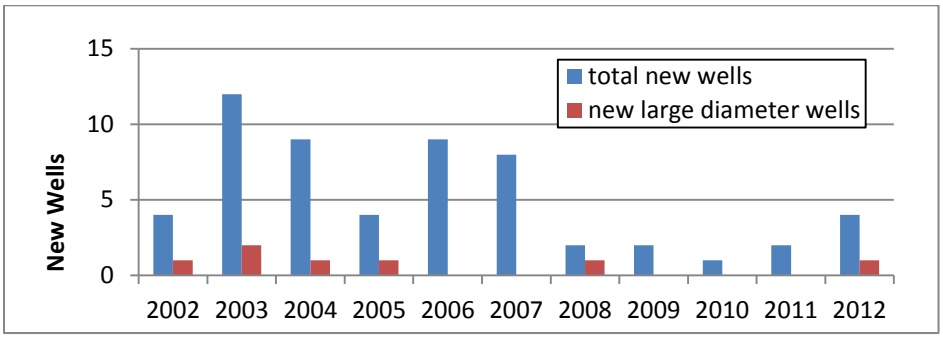


Figure 2.1. Number of new wells reported in Burden et al. (2013) for Juab Valley development area. They do not correspond to additional appropriations but are replacement wells or changes in points of diversion.

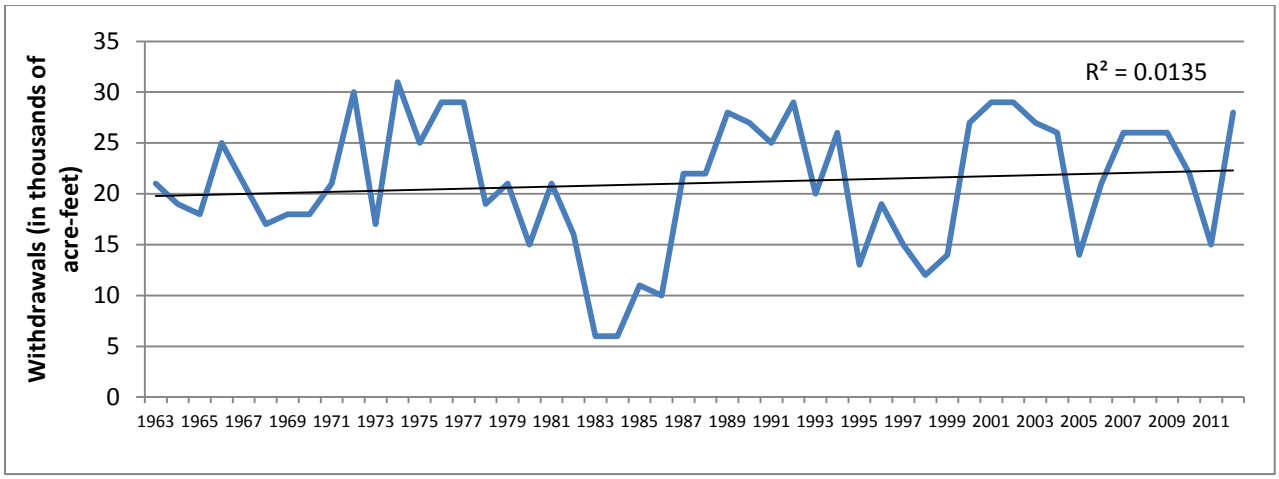


Figure 2.2. Total groundwater withdrawal in Juab Valley from 1992-2012 (Burden 1993-2013).

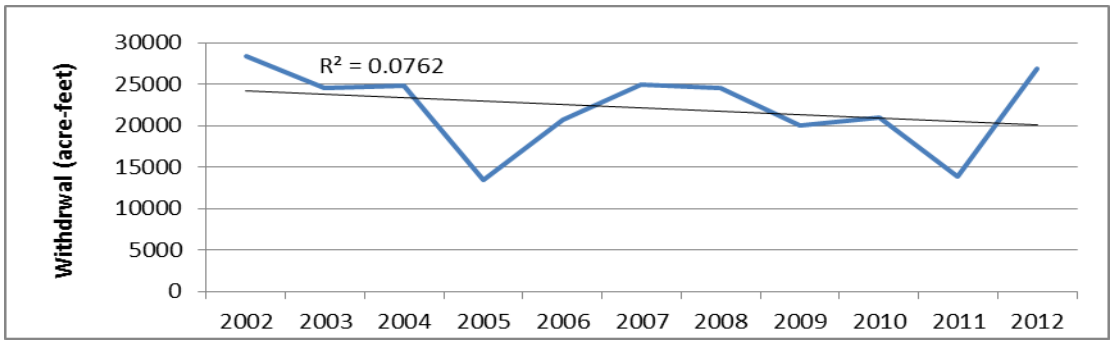


Figure 2.3. Irrigation groundwater withdrawal in Juab Valley from 1992-2012 (Burden 1993-2013).

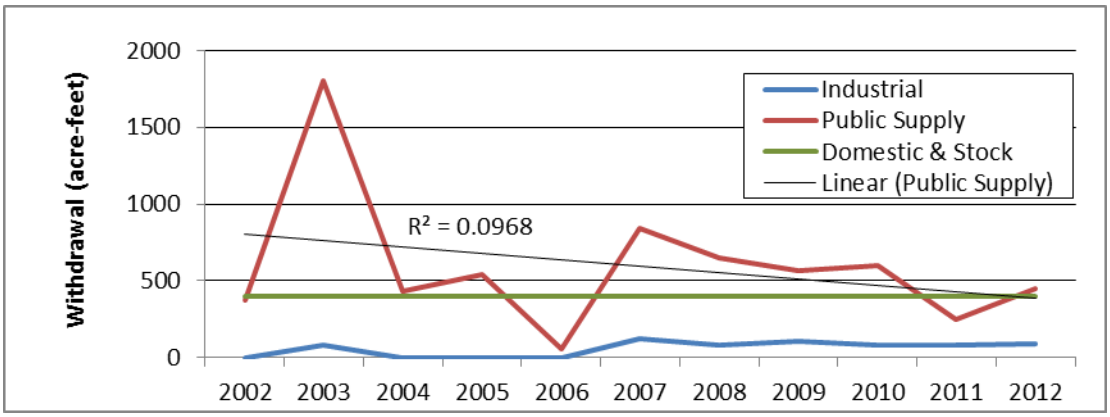


Figure 2.4. Groundwater withdrawal in Juab Valley for all uses other than irrigation (Burden 1993-2013).

Mills Valley (UDWRi Basin 66, no USGS Zone but near Central Sevier)

The Mills Valley least chub site is located in the UDWRi Lower Sevier Basin and is not within an area of groundwater development as defined and mapped by USGS (Burden et al. 2013, p. 3; Figure 3.1). However, the Central Sevier Valley groundwater development area is located upstream of the Mills Valley population site, within the Sevier River drainage. The 1937 Sevier River Decree apportioned most of the surface waters within the Sevier River Basin (which encompasses 7 UDWRi groundwater basins), and under a Governor's Proclamation in 1946, all surface waters were within this basin were closed to all new appropriations. In 1997, the Sevier River Basin was closed to all new groundwater appropriations and set forth the Sevier River Basin Groundwater Management Plan (UDWRi 2013f, p.1). Since the implementation of the basin management plan, no new appropriations have been approved in the Lower Sevier Basin in which the Mills Valley population resides (UDWRi 2013c, p. 3). UDWRi allows existing groundwater rights change applications for points of diversion, purpose of use and place of use if there is no enlargement of the underlying rights (UDWRi 2013c, p. 1). However, any change applications must be publically noticed, allowing for public protests to proposed changes, therefore valid protests showing injury to existing water rights may preclude approval of the change application. New wells can be permitted through the change application process, and USGS reported 19 new wells constructed in 2012 within the Central Sevier Valley groundwater development area, which is upstream of the Mills Valley population; as shown in the UDWRi well drilling log database (Burden et al. 2013, p. 52; UDWRi 2013e). These new wells were changes in points of diversion, the majority for replacement of existing non-functioning wells, but none enlarged their existing rights, in spite of total groundwater withdrawal of 28,000 afy. This is 7,000 afy more than the amount withdrawn in 1983, the initial year of data collection (for Central Valley specifically), and 17,000 afy more than the amount withdrawn in 2002 when withdrawals were at the lowest over the period of record (Burden 2013, p. 6). It is 3,000 afy less than that withdrawn in 2011 when withdrawals were at the highest over the period of record (Burden 2013, p. 6). Over the 10 year period between 2002 – 2011, groundwater withdrawals averaged 20,000 afy (Burden 2013, p. 6). While levels of groundwater withdrawal have fluctuated over the period of record, the overall trend for groundwater withdrawal is increasing, but withdrawals are within the appropriated water rights and not new appropriations.

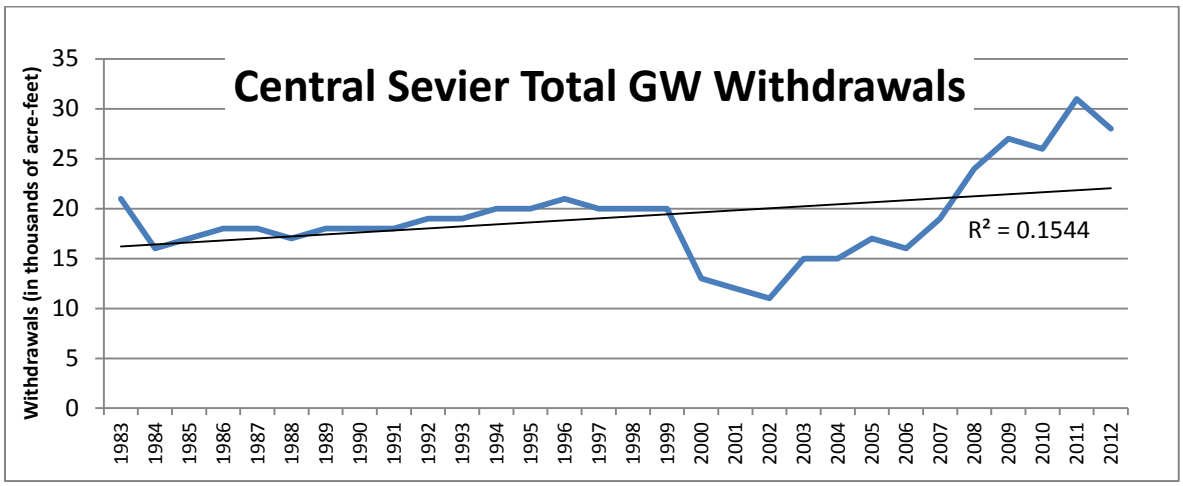


Figure 3.1. Groundwater withdrawal in Central Sevier from 1983-2012 (Burden 1984-2013).

Clear Lake –Pahvant (UDWRi Basin 67, USGS Zone Sevier Desert)

The Clear Lake least chub site is located within the UDWRi Pahvant Valley Basin and Sevier Desert groundwater development area, which has a period of record for groundwater withdrawals that extends back to 1963 when total groundwater withdrawal was 26,000 afy (Arnow 1964, p. 16). The 1937 Sevier River Decree apportioned most of the surface waters within the Sevier River Basin and under a Governor's Proclamation in 1946, all surface waters were within this basin were closed to all new appropriations. In 1997, the Sevier River Basin was closed to all new groundwater appropriations and set forth the Sevier River Basin Groundwater Management Plan, with exceptions for select areas of the Sevier Desert Basin for small domestic supply, limited to 1 afy (UDWRi 2013f, p.1). Since the implementation of the basin management plan, three new appropriations have been approved in the Sevier Desert Basin in which the Clear Lake population resides (UDWRi 2013c, p. 3). However, these appropriations are for non-consumptive uses; heat pump systems that do not remove nor deplete the groundwater. USGS reported that 24 new wells were constructed in the Sevier Desert groundwater development area in 2012 and total groundwater withdrawal was 24,000 afy (Burden 2011, p. 5; Figure 4.1). This is 2,000 afy less than the amount withdrawn in 1963 (Arnow 1964, p. 16), the initial year of data collection, and 16,000 afy more than that withdrawn in 1983 when withdrawals were at the lowest over the period of record (Seiler 1985, p. 8). It is 26,000 afy less than that withdrawn in 1977 when withdrawals were at the highest over the period of record (Burden 2013, p. 6). Over the ten year period between 2002 – 2011, total annual groundwater withdrawal averaged 34,000 afy, which is 10,000 afy higher than in 2012 (Burden 2013, p. 6, 45). While levels of groundwater withdrawal have fluctuated over the period of record (Figure 4.2), the overall trend for groundwater withdrawal is increasing and may correspond to annual precipitation.

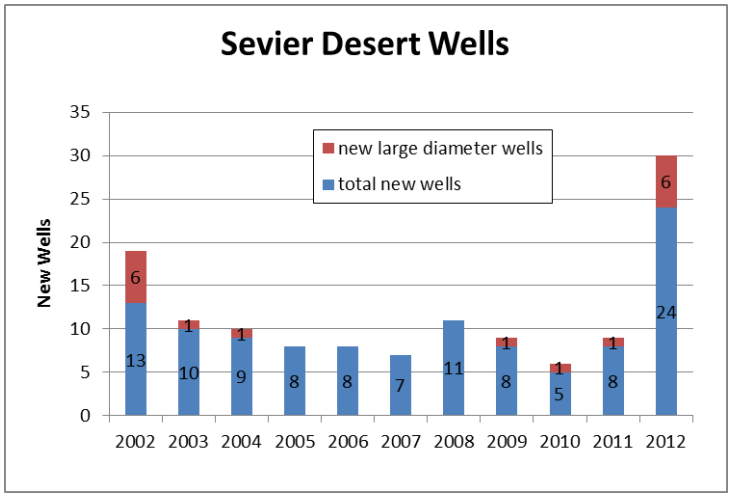


Figure 4.1. Number of new wells constructed between 2002 and 2012. New wells do not mean an increase in appropriations, and can include replacement wells and change applications for existing rights.

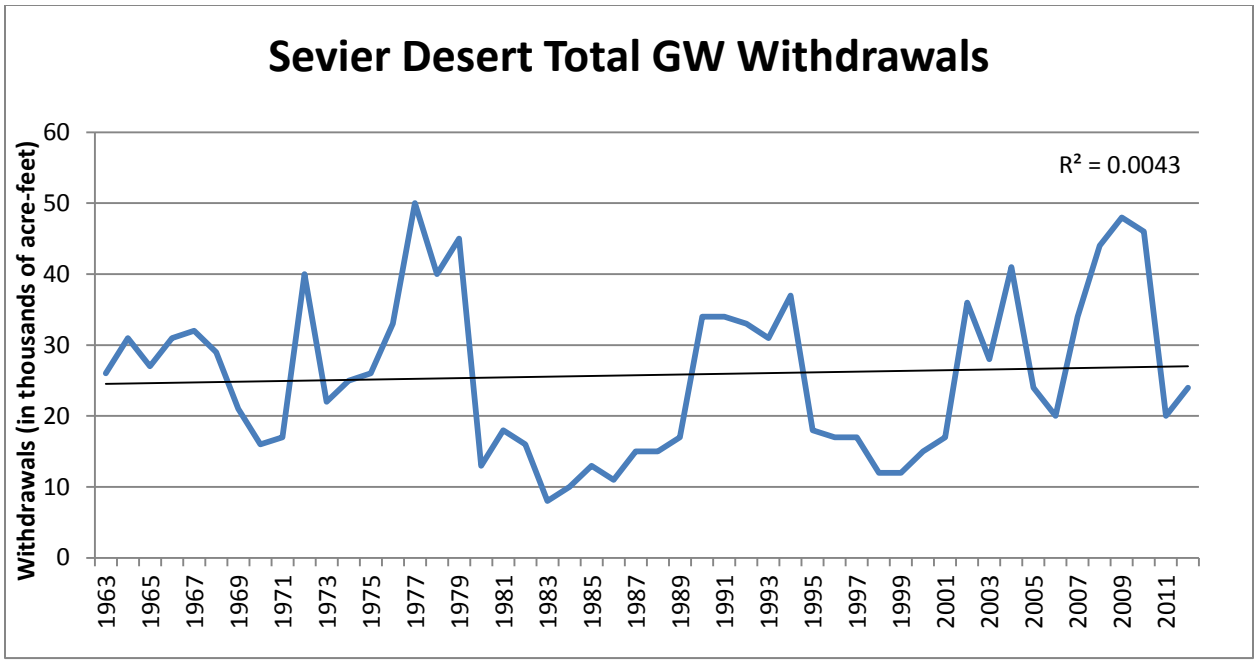


Figure 4.2. Groundwater withdrawals for the Sevier Desert groundwater development area during the period of record 1963-2012 (Burden 1964-2013).

The USGS and UDWRi authored the *Ground-Water Hydrology of Pahvant Valley and Adjacent Areas, Utah* Report in 1990 modeling the effects of groundwater withdrawals and changes in recharge on water levels from continued pumping for 20 years at 1977 levels (96,000 afy), the second highest on record at the time of the report (Holmes and Thiros 1990, p. 1, 61). Water level declines of more than 80 feet in some parts of Pahvant Valley were projected if groundwater withdrawals continued for 20 years at the 1977 rate, and rises of as much as 58 feet and declines of as much as 47 feet were projected with withdrawals of 48,000 afy per year for 20 years, depending on the locations of discharge and recharge (Holmes and Thiros 1990, p. 1, 61). The report shows Clear Lake Migratory Waterfowl Management Area in the digital model study area and the model appears to show that Clear Lake would not be affected by the high 1977 pumping rate impact areas (Holmes and Thiros 1990, p. 1, 54; Figure 4.3).

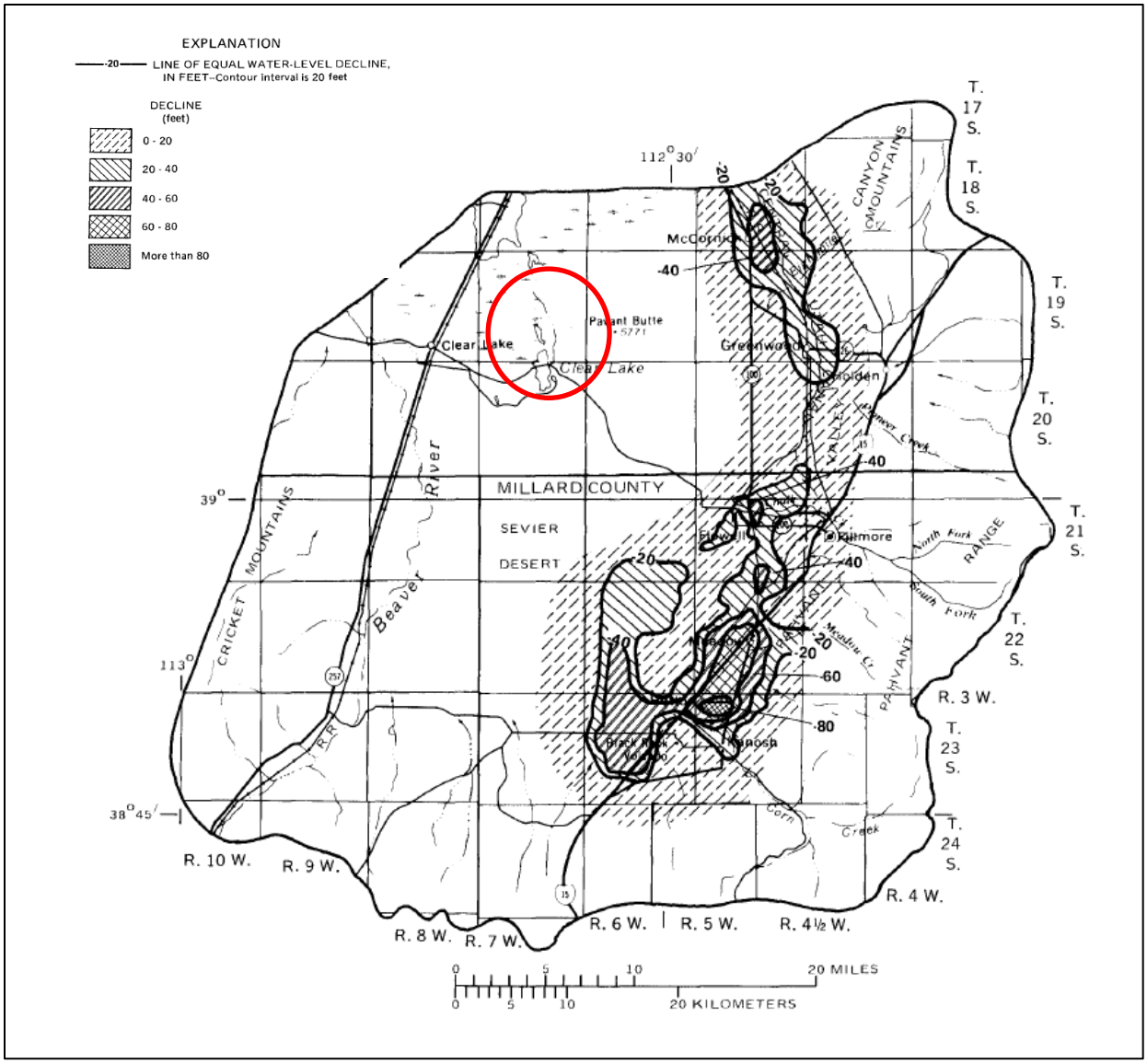


Figure 4.3. Projected water level declines assuming groundwater withdrawals remain at the 1977 rate for a period of 20 years, 1985-2005. Clear Lake highlighted by the red circle.

Regional Trends Summary

The following table provides a summary of the water rights ownerships across the basins and their basin status.

Table 4.1. Water rights ownership, basin number, status and closure date associated with the naturally occurring least chub populations.

Natural Site	Water Right Owner	Water Right Basin	Water Right Basin Status	Date Closed
Mona Springs	--	53	Closed	1995[1]
Mills Valley	--	66	Closed	1997[2]
Clear Lake WMA	UDWR	67	Closed	2003[3]
Leland Harris	--	18	Open	--
Gandy Marsh	BLM	18	Open	--
Bishop Springs	BLM & UDWR	18	Open	--

[1] Northern Juab Valley Ground Water Policy
[2] Water Rights Policy, Sevier River Basin
[3] Ground Water Management Plan for Pahvant Valley

Introduced Least Chub Sites

Least chub introduced populations are located primarily in the northern portion of the Bonneville Basin, spanning numerous UDWRi groundwater basins and USGS development zones (Figure 5.1, Table 5.1). All the sites have water rights and occur either within open, closed or restricted basins.

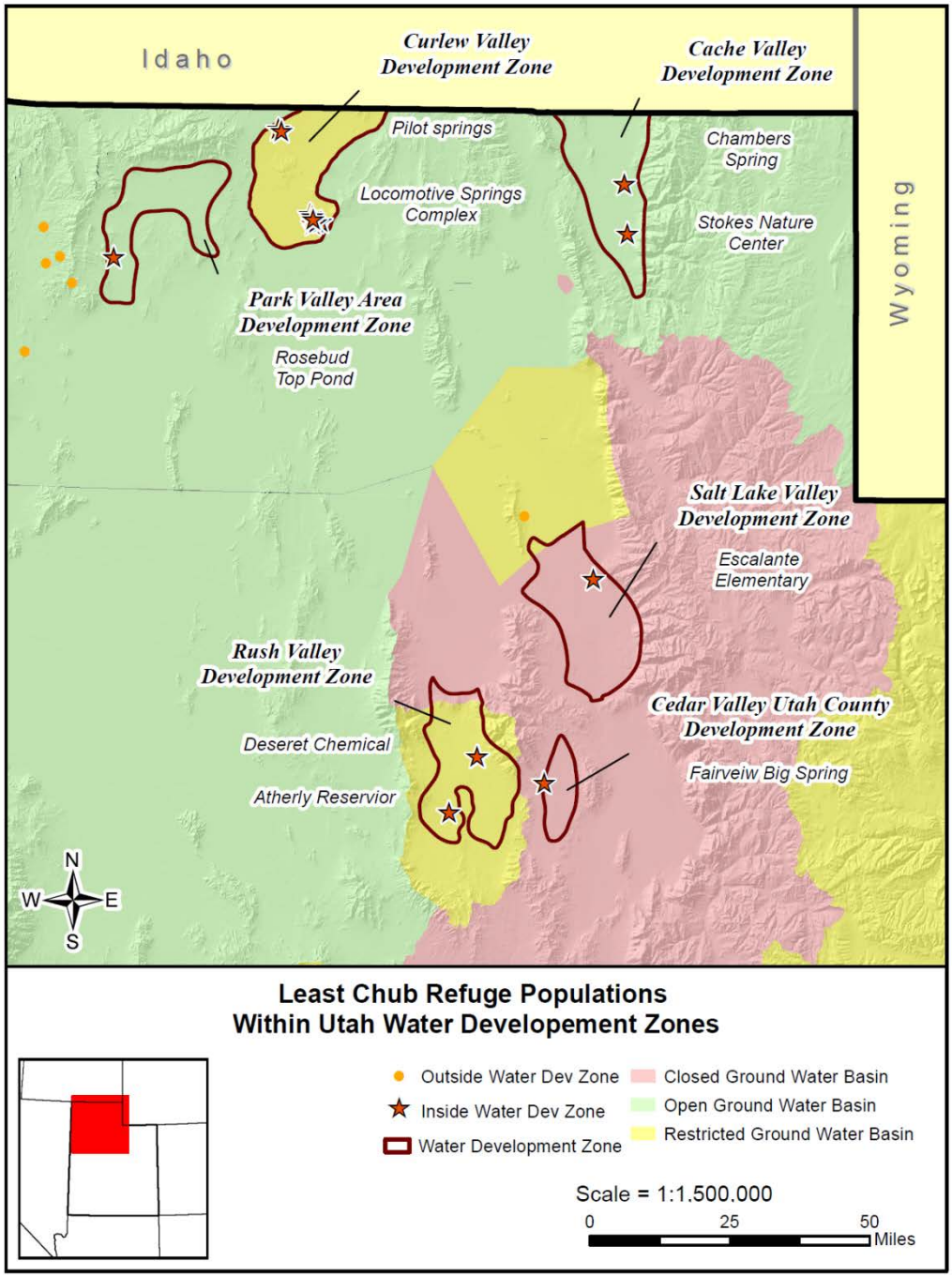


Figure 5.1. Least chub introduced sites and USGS development zones with corresponding UDWRi basin status.

Table 5.1. Water rights ownership, basin and status, and USGS Development Zone associated with introduced least chub sites.

Introduced Least Chub Site	Water Right Ownership	Water Right Basin	Water Right Basin Status	USGS Development Zone
Locomotive Springs-West Locomotive Spring	UDWR	13-0	Restricted	Curlew Valley
Locomotive Springs-Teal Spring	UDWR	13-0	Restricted	Curlew Valley
Locomotive Springs-Sparks Spring	UDWR	13-0	Restricted	Curlew Valley
Fitzgerald WMA/Atherly Reservoir	UDWR	15	Restricted	Rush Valley
Locomotive Springs-Off Spring	UDWR	13-0	Restricted	Curlew Valley
Locomotive Springs-Baker Spring	UDWR	13-0	Restricted	Curlew Valley
Locomotive Springs-Bar M Spring	UDWR	13-0	Restricted	Curlew Valley
Rosebud Top Pond	Private	13	Open	Park Valley
Cluster Springs	BLM	13	Open	--
Upper Garden Creek	Utah Parks	31	Open	--
Red Knolls Pond	BLM	13	Open	--
Keg Spring	BLM	13	Open	--
Pilot Spring	BLM	13-0	Restricted	Curlew Valley
Stokes Nature Center	Private	25	Open	Cache Valley
Chambers Spring	Private	25	Open	Cache Valley
Pilot Spring SE	BLM	13-0	Restricted	Curlew Valley
Lucin Pond	UDWR	13	Open	--
Escalante Elementary	Local Govt	59	Closed	Salt Lake Valley
Deseret Depot	DOD	15	Restricted	Rush Valley
Fairview	--	54	Closed	Cedar Valley

The Deseret Depot introduced population is located within UDWRi Basin 15, which has restrictions on water withdrawals. Surface waters are fully appropriated but groundwater is restricted to small appropriations up to 4.73 acre-feet in Rush Valley (UDWRi 2014a; Area 15, p. 1-2), where the introduced population is located. In 2008, the USE adopted a new policy to not approve any change applications moving a point of diversion into the eastern zone of the valley (where the population is located) (UDWRi 2014a, p. 1), thus heavily restricting water rights and change applications within the range of the populations.

Upper Garden Creek has an active water right, owned by Utah State Parks, and is located within UDWRi Basin 31, which has restrictions on water withdrawals. Surface waters are fully appropriated but groundwater is restricted to small appropriations up to 1.0 acre-foot in areas not served by a public supply system (UDWRi 2014b; Area 31, p. 1-2). There are two groundwater management plans in place for Area 31, which became effective in 1995, with the objective to guide future development, establish policy on new appropriations of water, protect the resource from over-utilization and preserve water quality.

The Fairview Big Springs introduced site is too new to meet the refuge criteria of two seasons of successful recruitment, but will likely meet the criteria in the coming year. The site is located in UDWR Basin 54, which is closed to all additional surface and groundwater appropriations (UDWRi 2014c; Area 54, p. 1-2).

The Escalante Elementary introduced population is located on the campus of an elementary school in Salt Lake County. It occurs in UDWRi Basin 59, which, like Basin 54 (for Fairview Big Spring), is closed to all additional surface and groundwater appropriations (UDWRi 2014 d; Area 59, p. 1-2). Additional groundwater withdrawal is limited to change applications only and has enhanced restrictions for such applications, and does not allow changes from surface to underground sources within the valley fill of the Basin.

The Stokes Nature Center and Chambers Spring introduced populations are located in UDWRi Basin 25 (UDWRi 2014e; Area 25, p. 1-2) and both sites have privately owned water rights. Neither site meets the introduction criteria, as they both are held under private ownership and lacks any formal agreements with the landowner. It is likely that land owners will participate in the Programmatic Candidate Conservation Agreement with Assurances, once completed. Thereby providing regulatory security for these populations and allowing them to be categorized as successful and secure introduced populations. The UDWRi Basin is open to appropriation of both surface and ground water, except in the Cache Valley. In 1999, the State Engineer issued the Interim Cache Valley Groundwater Management Plan which gives the conditions and limits under which further groundwater development may take place. Those filing an Application to Appropriate in Cache County are required to file a disclaimer form indicating their compliance of items in the Interim Cache Valley Groundwater Management Plan. The primary objective is to protect prior water rights while putting to beneficial use the greatest amount of available water. In addition, no filings are approved in canyon areas above fully appropriated springs and streams.

Eleven of the introduced populations are located in UDWRi Basin 13, of these, eight populations are within a restricted water rights designation (Table 5.1). All 11 populations have associated water rights. Basin 13 is open to appropriations, but surface waters are limited and generally considered to be fully appropriated. Groundwater is open in the valley locations, but canyon areas above full appropriated springs and streams are closed. However, there are some specific policies for certain areas: Curlew Valley—only filings for a single family domestic supply (up to 1.73 af/yr) will be considered where no other source of supply is available (Figure 5.2); Park Valley—applications are restricted to a single family domestic supply (Figure 5.3); Pilot Valley—applications larger than a single family domestic supply are being held unapproved until existing approved filings are perfected or lapse.

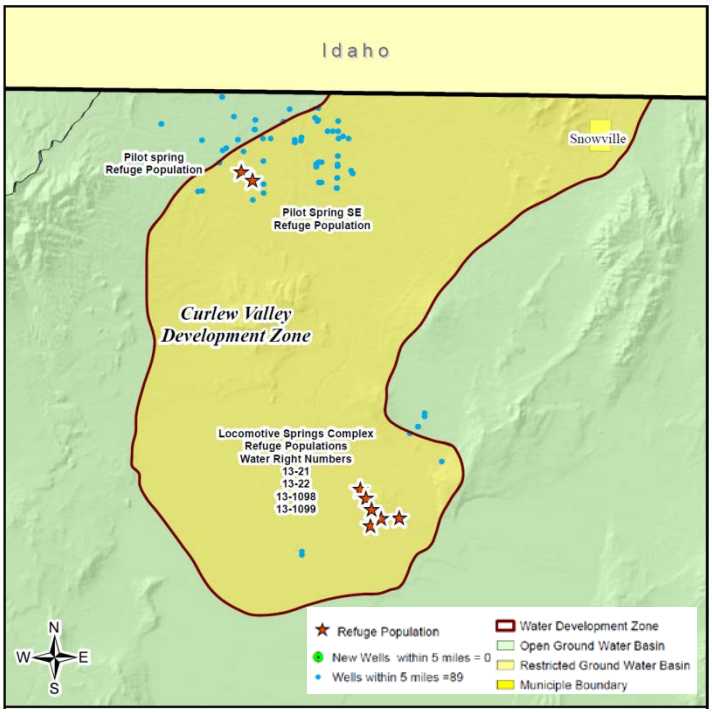


Figure 5.2. Location of least chub introduced sites in the Curlew Valley UDWRi Basin and USGS Development Zone. Location of historical and new wells within 5 miles of the sites are displayed.

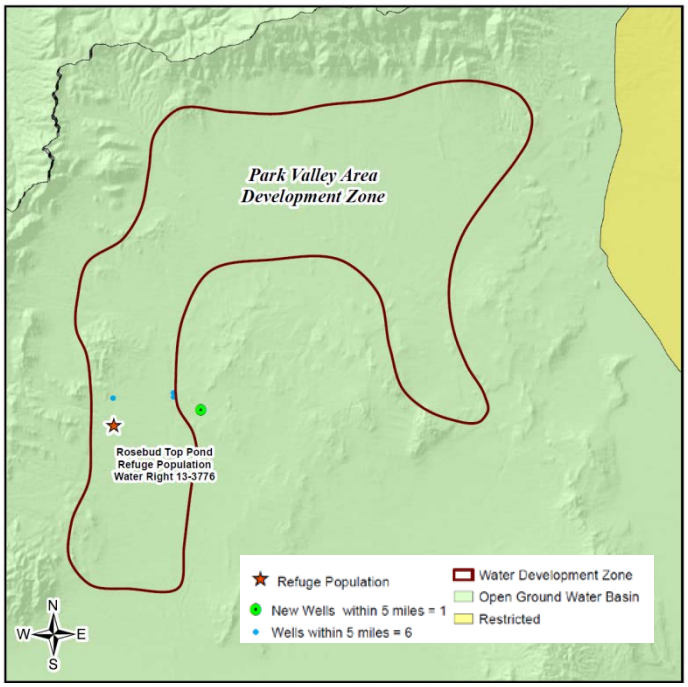


Figure 5.3. Location of least chub introduced sites in the Park Valley UDWRi Basin and USGS Development Zone. Location of historical and new wells within 5 miles of the sites are displayed.

Snake Valley

Snake Valley has harbored the most secure least chub populations over the past 50 years (Hickman 1989, p. 2; Hines et al**.** 2008, pp. 34-45), which include the Leland-Harris Spring Complex, Gandy Marsh, and Bishop Spring Complex populations (Figure 6.1). The Snake Valley, shared by western Utah and eastern Nevada, is one of several valleys located within the Great Salt Lake Desert regional groundwater flow system (Figure 6.2). The Snake Valley contains local shallow groundwater basin-fill aquifers, but is thought to be connected by deep groundwater flow through a shared carbonate-rock aquifer (Carlton, 1985 in DRAFT UGS, sec. 1.1, p. 1-2; Figures 6.3, 6.4). Recharge to the aquifer is mainly by infiltration of precipitation and snowmelt in the mountains bounding Snake and Spring Valleys, and the main discharge area is the western Great Salt Lake Desert (Harrill et al. (1988) in UGS Draft, sec. 1.4.4, p. 13).

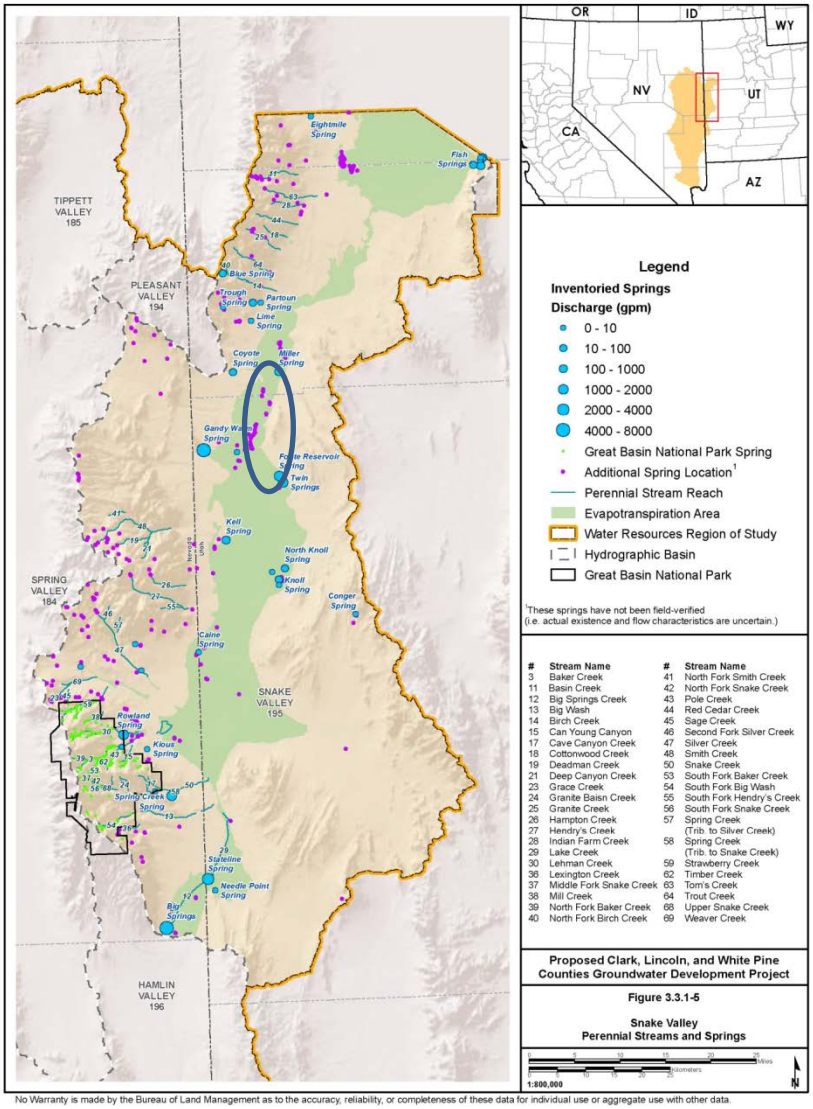


Figure 6.1. Snake Valley perennial streams and springs. Least chub populations highlighted by the blue oval. Source: BLM 2012a, p. 3.3-19.

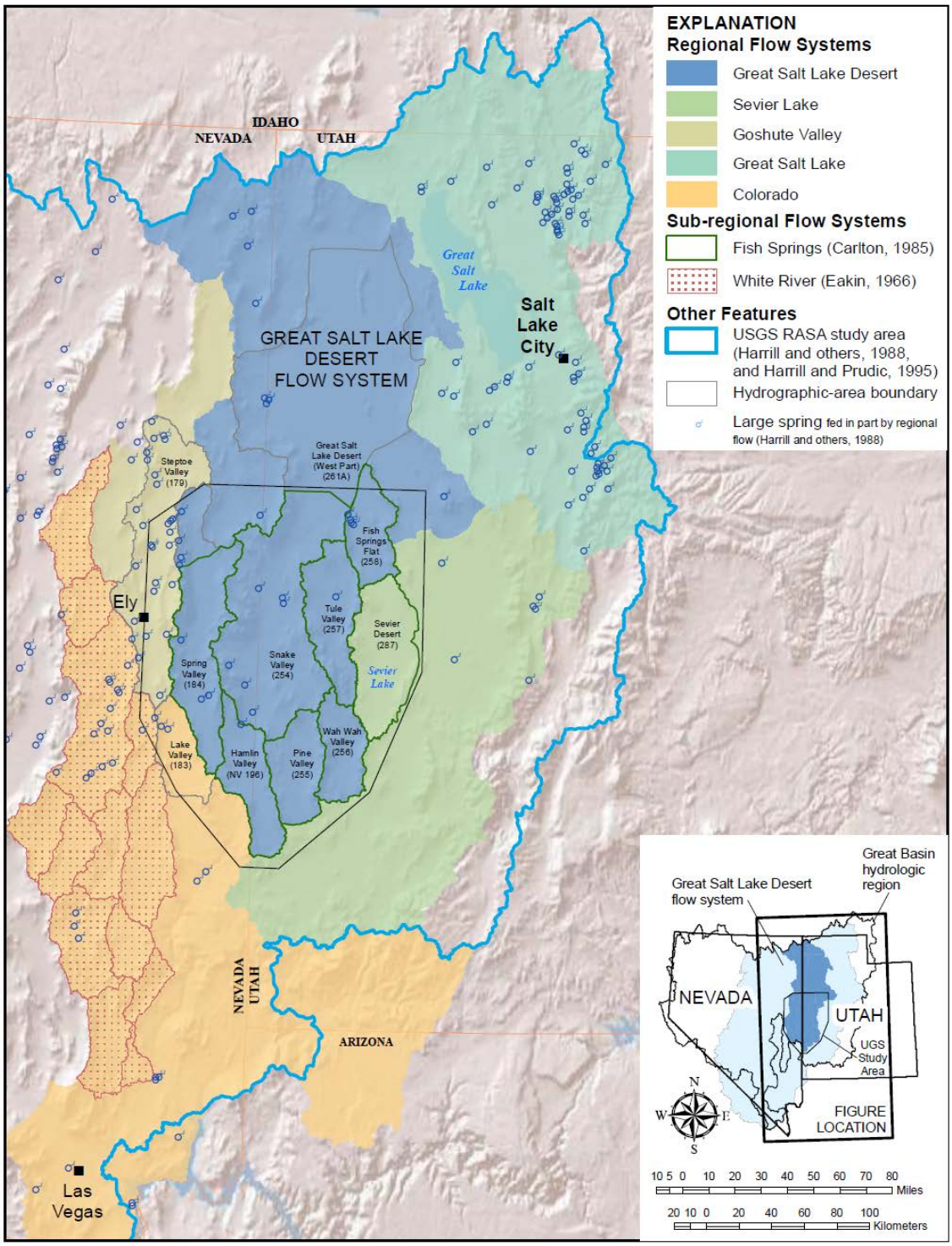


Figure 6.2. Regional flow systems of the eastern Great Basin. Source: UGS Draft Report, Figure 1.2, referenced sec. 1.4.4, p. 13).

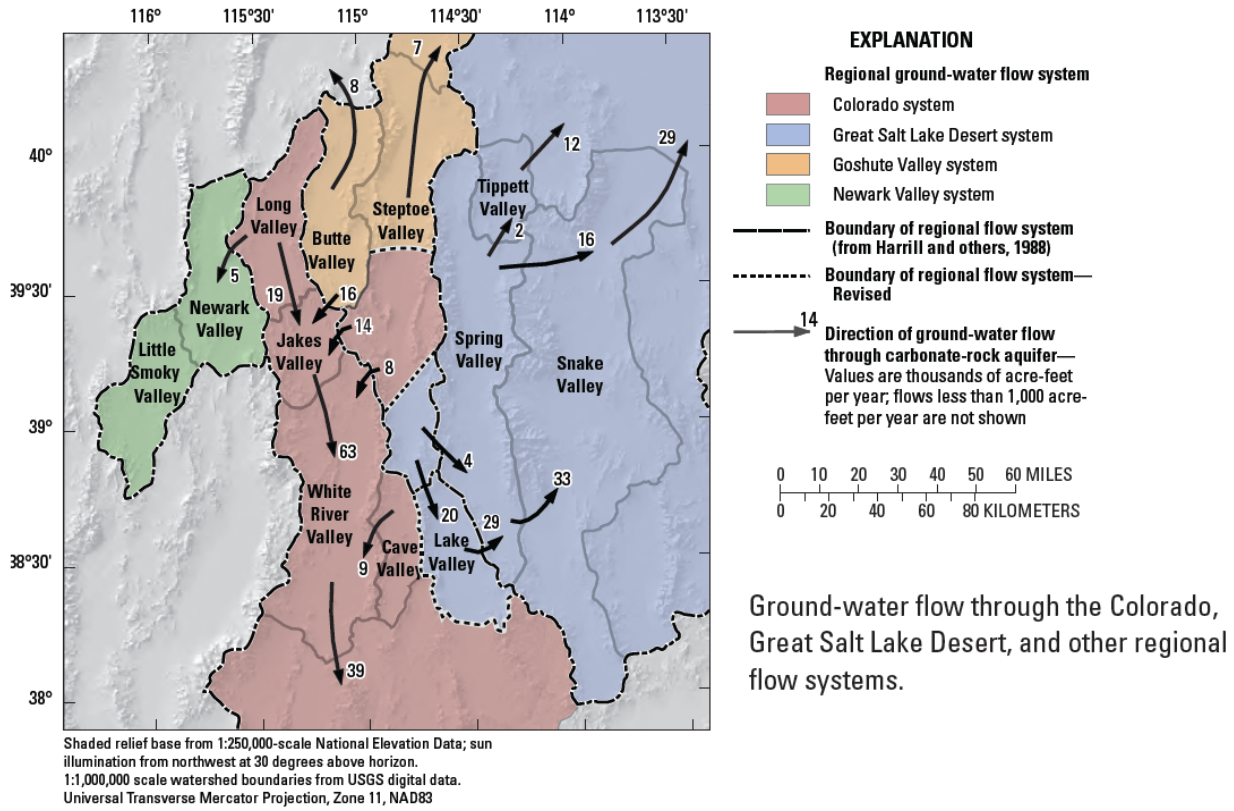


Figure 6.3. Regional groundwater flow among basins. Welsh et al. 2007, p. 5.

Spring Valley is adjacent and west of Snake Valley, and the two hydrographic basins are connected via groundwater flow along basin boundaries. USGS analysis of groundwater elevations of the carbonate-rock aquifer depicts an area of uncertain hydraulic connection along the northeast boundary of Spring Valley and a high likelihood for hydraulic connection along the southeastern boundary of Spring Valley (Heilweil and Brooks 2011, Plate 2; Figure 6.4, 6.5). The direction of groundwater flow through the carbonate-rock aquifer moves from Spring to Snake Valleys in both locations (USGS 2007 p. 5; Figure 6.3).

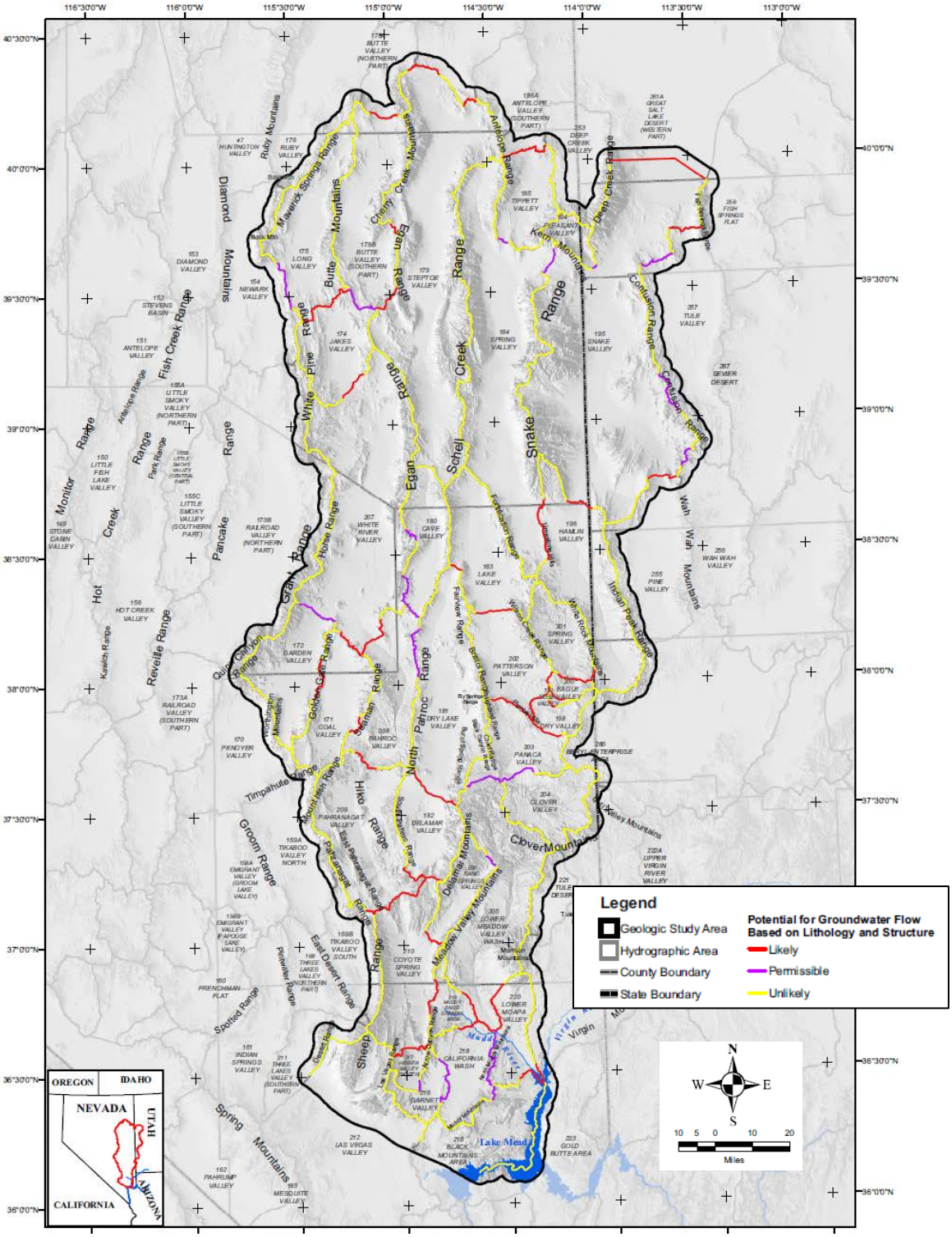


Figure 6.4. Potential for interbasin groundwater flow within the geologic study area. Source: SNWA 2008 Volume 1 Geology, p. 4-33.

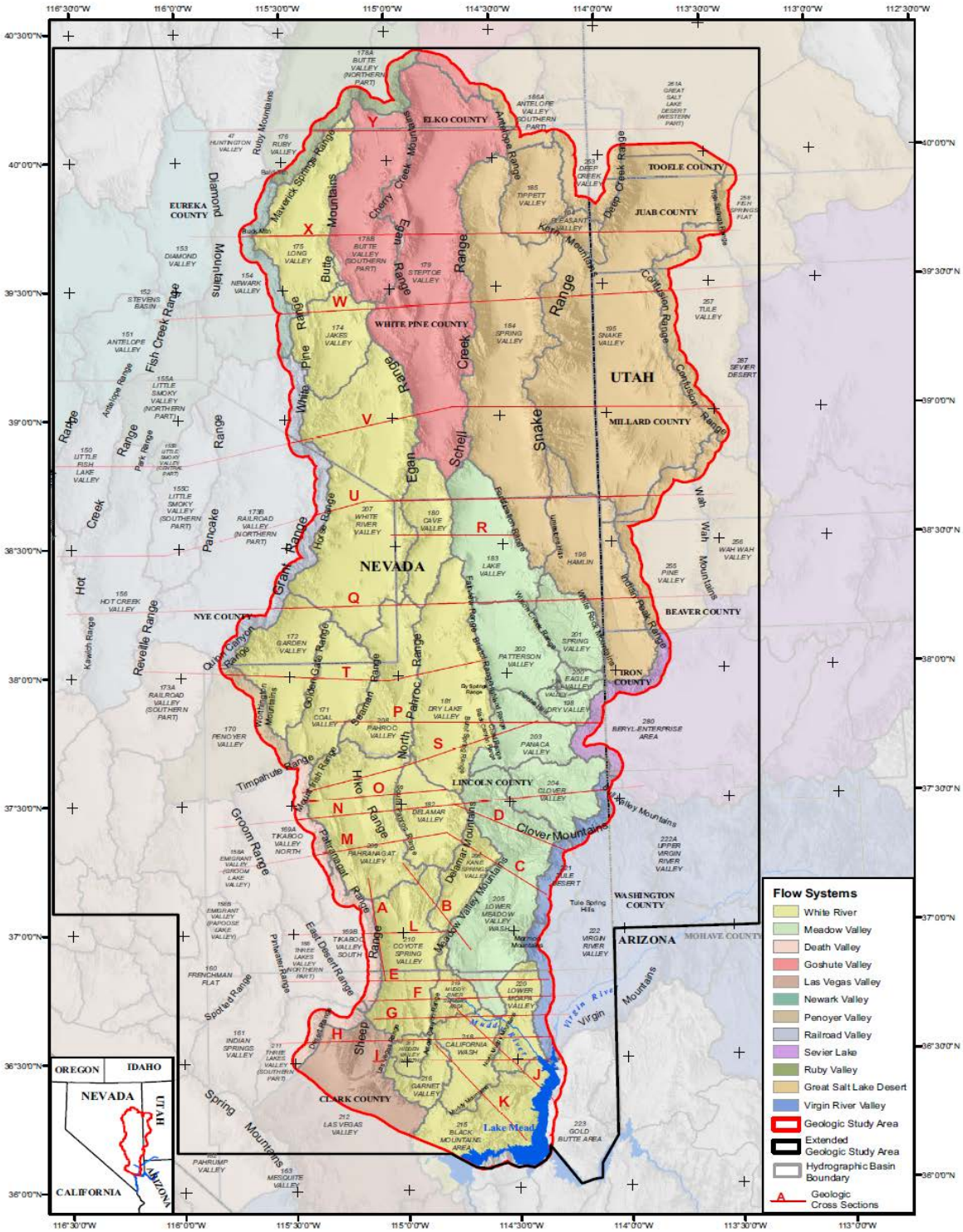


Figure 6.5. Hydrographic basins, ranges and flow systems within the geologic study area of the SNWA proposed project. Source: SNWA 2008-Geology, p. 2-2.

Snake Valley Hydrological Studies

Early reconnaissance studies of hydrographic areas in of eastern Nevada and western Utah (including Snake Valley) evaluated groundwater levels, groundwater storage, and developable groundwater volumes for the region (USGS reports in UGS Draft Rpt. 2013, sec. 1.4.3, p. 11). Additional studies delineating the regional- and local-scale groundwater-flow systems within this region and the development of a regional flow model were completed several decades later (Harrill et al. 1988, in UGS Draft Rpt, 2013, sec. 1.4.4, p. 13; Prudic and others, 1995, in UGS Draft Rpt, 2013, sec. 1.4.4, p. 13).

Proposed groundwater development within this region motivated further study of the aquifer flow system and the groundwater conditions in the region, and included USGS's Basin and Range Carbonate Aquifer System (BARCAS) study (Welch et al. 2007, entire), and conceptual and numerical groundwater-flow models by SNWA (2009a, 2009b, 2010a, 2010b), as well as many others (Durbin and Loy, 2010; Loy and Durbin, 2010; Halford and Plume, 2011; Heilweil and Brooks, 2011; all in UGS draft report, sec. 1.4.5.1, p. 15; Figure 6.6).

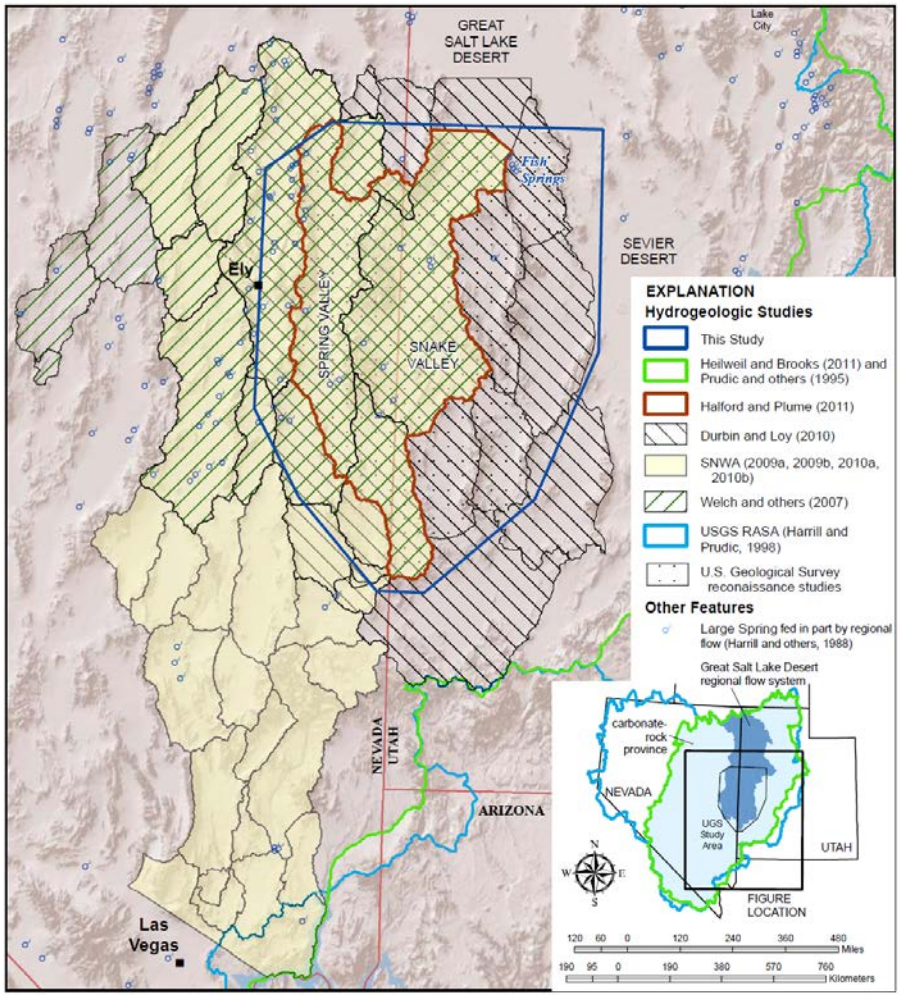


Figure 6.6. Locations of previous hydrological studies. Source: UGS Draft Report, Figure 1.4, referenced sec. 1.4.4, p. 13)

The Proposed groundwater development projects include a Southern Nevada Water Authority (SNWA) Groundwater Development (GWD) Project, appropriation of groundwater by the Central Iron County Water Conservancy District, and an increase of water development by the Confederated Tribes of the Goshute Reservation (Figure 6.7). The current groundwater rights (at the time of publication of the map) are shown in Tables 6.1 and 6.2 and Figure 6.8 and 6.9.

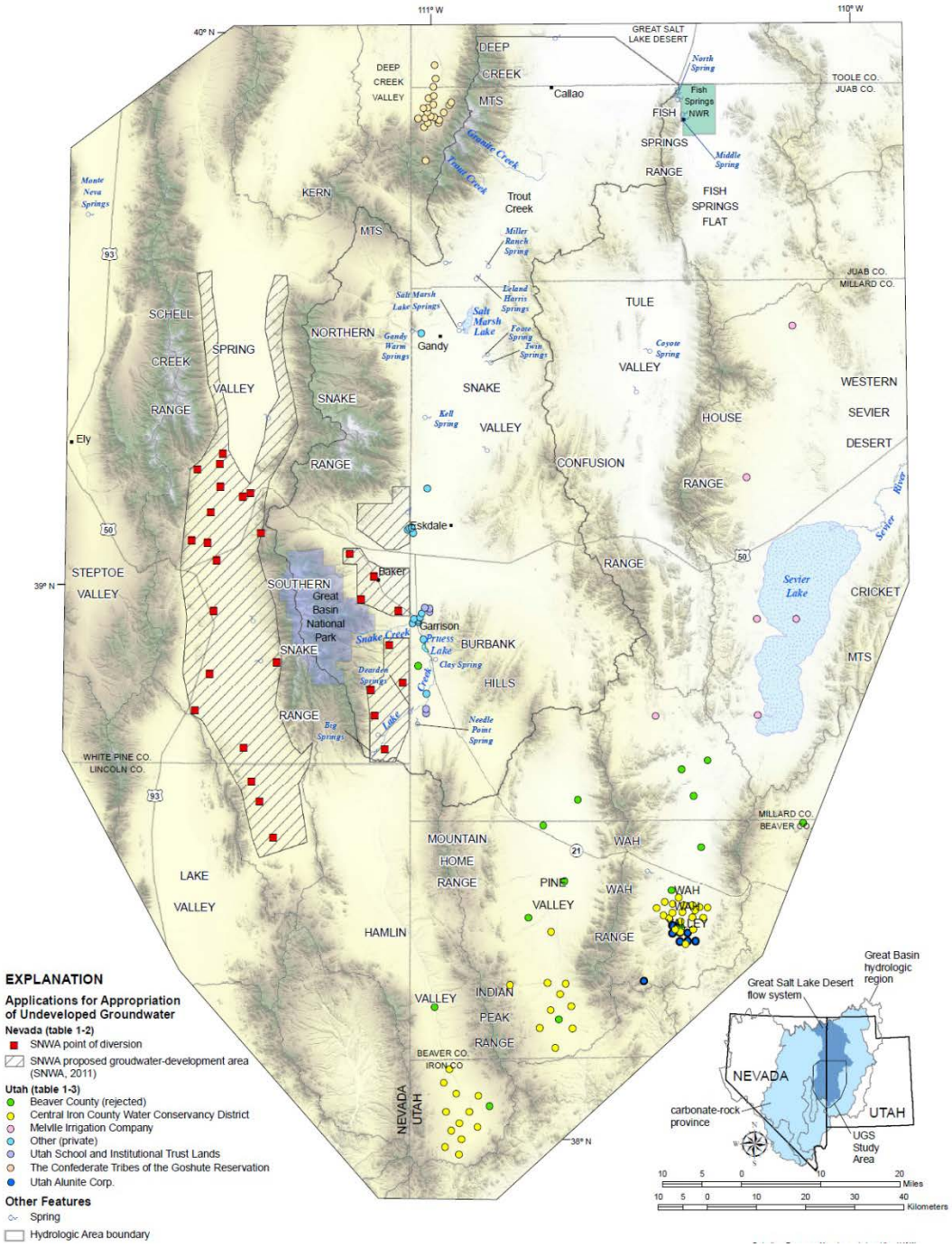


Figure 6.7. Points of diversion for proposed groundwater-development projects. Source: UGS Draft Report, Figure 1.3, referenced sec. 1.2, p. 4e.

Table 6.1. Preliminary estimates of active groundwater rights in Snake Valley (Nevada side). Source: SNWA 2008a, p. 7-7.

Manner of Use	Preliminary Total (afy)
Commercial	0.06
Domestic	1.63
Irrigation-Desert Land Entry	720
Irrigation	9,605.29
Quasi-municipal	55.58
Stockwatering	34.92
Total Underground	**10,417.49**

Source: Hydrographic Basin Summary by Manner of Use (Included on the CD-ROM) (NDWR, 2007c)

Table 6.2. Preliminary estimates of active groundwater rights in Snake Valley (Utah side). Source: SNWA 2008a, p. 7-8.

Manner of Use	Preliminary Total (afy)
Irrigation	37,941.69
Stock	824.22
Domestic	111.03
Municipal	0
Mining	0
Power	0
Other	1,563.24
Total Underground	**40,440.18**

Source: Clayton, 2007; (Included on the CD-ROM)

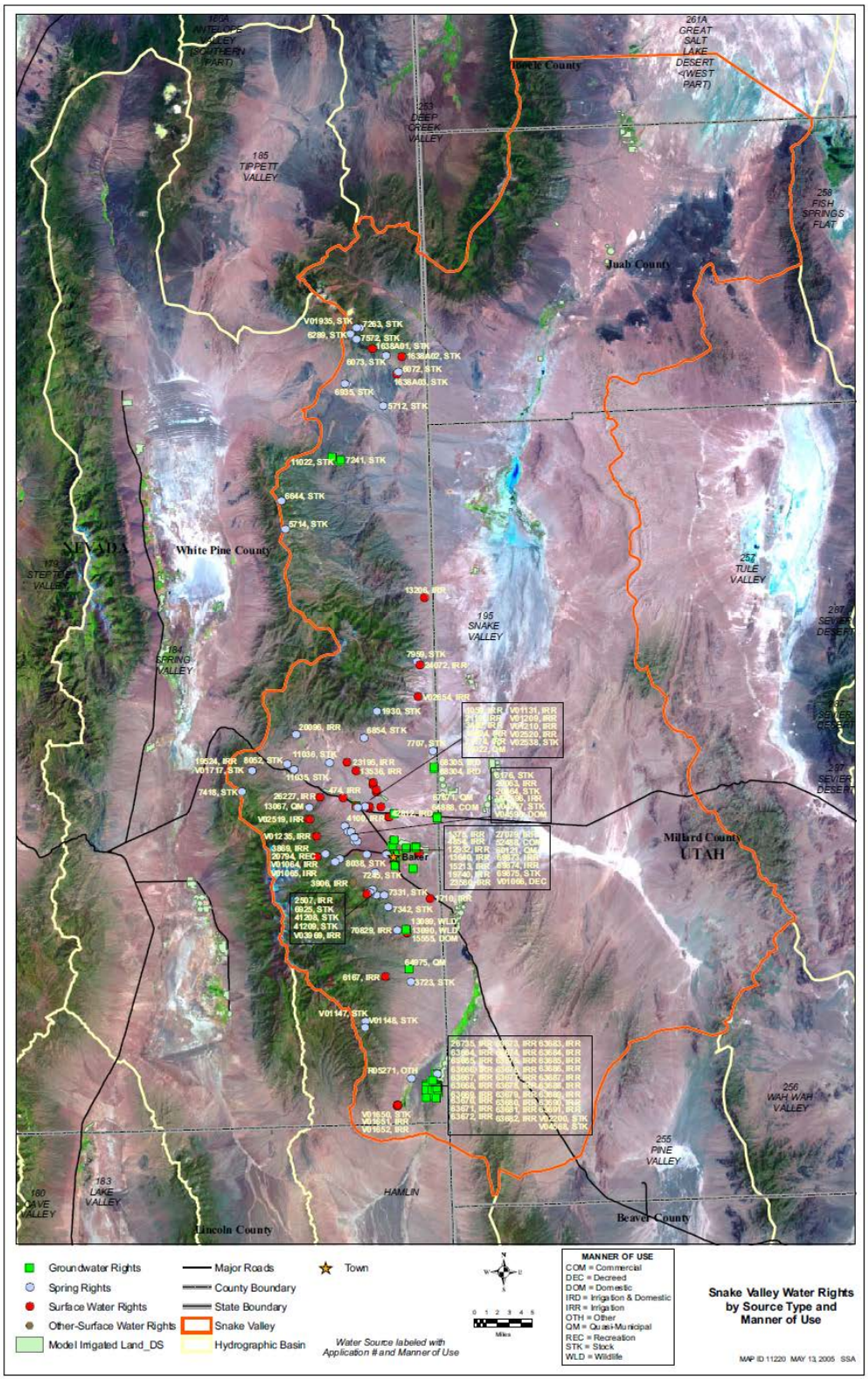


Figure 6.8. Snake Valley Water Rights in Nevada (as of 2005). Source: SNWA 2008a, p. 7-6.

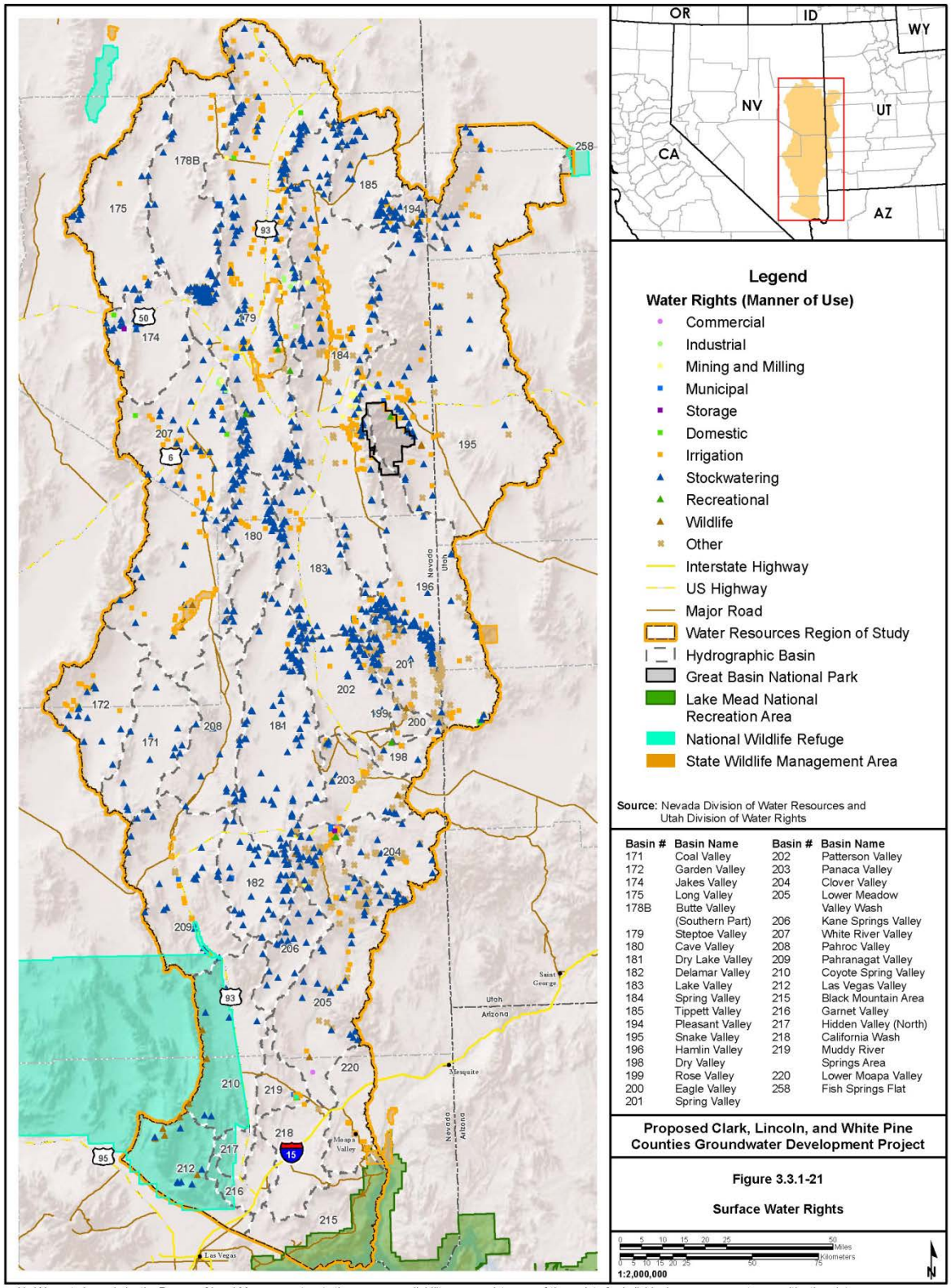


Figure 6.9. Surface water rights in SNWA study area. Source: BLM 2012a, p. 3.3-62.

Southern Nevada Water Authority Proposed Groundwater Development Project

In 1989, Las Vegas Valley Water District (LVVWD; whose interests are now under SNWA), applied for unappropriated water in eastern Nevada, specifically in: Cave Valley, Dry Lake, Delamar Valley and Spring Valley (7th District Court Decision 2013, p. 2; Figure 6.10). In March 2012, the Nevada State Engineer granted 22,861 afy in groundwater rights from Delamar, Dry Lake and Cave valleys and 61,127 afy from Spring Valley to SNWA (in April 2012, several parties filed petitions for judicial review of these rulings). The NSE orders required staged groundwater development for Spring Valley appropriations and include (see Orders and Court Ruling):

- Stage 1: Development of 38,000 afy for 8 years, data collected and modeled and reported to NSE annually;
- Stage 2: Development up to 50,000 (an additional 12,000 afy) for a minimum of 8 years with the data collection and modeling to be reported annually;
- Stage 3: Development of the entire amount may be granted depending on Stage 2 pumping; 61,127 afy.

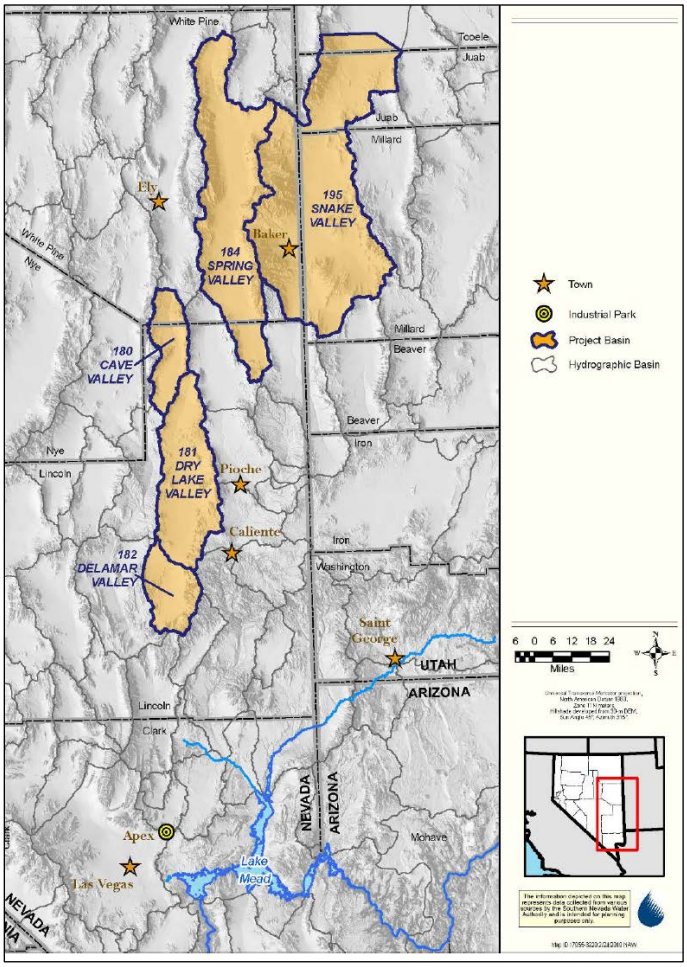


Figure 6.10. SNWA proposed groundwater development project hydrological basins. Source: SNWA 2011, p.1-6.

The Bureau of Land Management (BLM) published a Record of Decision (ROD) in December 2012 which authorizes the pipeline that will transport pumped groundwater from the four hydrological basins to Las Vegas, Nevada. The ROD authorizes the construction and operation of groundwater production, conveyance, and treatment facilities, and power conveyance facilities across public lands in these four hydrographic basins (SNWA 2011a, pp. 1-6). In the ROD, an Agency Preferred Alternative was selected, which was a modified version of Alternative F; the primary difference being the amount of water developed, 83,988 afy (Agency Preferred Alternative) compared to 114,129 afy (Alternative F). The modification decreased pumping, specifically in Spring and Cave valleys, and is therefore thought to reduce impacts to water resources (springs and streams) (BLM 2012b, p. 36; Table 6.3).

Table 6.3. Summary of the alternatives in the Final EIS Analysis. The Agency preferred alternative is not included but is a modified Alternative F, with lower groundwater withdrawals (83,988 afy) Source: BLM 2012b, p. 17.

Alternatives for Analysis	SNWA Groundwater Production[1]	Basins in Which SNWA Production Would Occur	Well Placement[2]	Assumed Full Build out
Proposed Action	Up to 176,655 afy	Spring, Snake, Delamar, Dry Lake, Cave	Distributed	Year 38
A	Up to 114,755 afy	Spring, Snake, Delamar, Dry Lake, Cave	Distributed	Year 38
B	Up to 176,655 afy	Spring, Snake, Delamar, Dry Lake, Cave	Points of Diversion	Year 38
C	12,000 to 114,755 afy (varies in response to drought)	Spring, Snake, Delamar, Dry Lake, Cave	Distributed	Year 38
D	Up to 78,755 afy	Spring (south), Delamar, Dry Lake, Cave	Distributed	Year 33
E	Up to 78,755 afy	Spring, Delamar, Dry Lake, Cave (no Snake)	Distributed	Year 33
F	Up to 114,129 afy	Spring, Delamar, Dry Lake, Cave (no Snake)	Distributed	Year 33
No Action	None	None	None	NA

In its ROD for the Clark, Lincoln, and White Pine counties Groundwater Development Project (2012b, entire), BLM authorizes the agency preferred alternative which encompasses construction of groundwater development and transportation facilities in the four Nevada valleys: Dry Lake, Delamar, Cave and Spring valleys. However, SNWA's proposed action described in the BLM FEIS (2012) includes groundwater pumping in Snake Valley, Nevada, where it has pending groundwater right applications for 50,679 afy. SNWA's intent to develop groundwater in Snake Valley is additionally described in SNWA's Conceptual Plan of Development referenced in the BLM FEIS (2012). Although the Nevada State Engineer has not yet acted upon SNWA's Snake Valley water rights applications or scheduled hearings, its unknown if it would be approved or when approval would occur. However, according to the Lincoln County Conservation, Recreation, and Development Act (LCCRDA) of 2004 (LCCRDA 2004, entire), the States of Utah and Nevada must reach an agreement on the division of Snake Valley groundwater prior to any trans-basin groundwater diversions. Therefore, an agreement between the states must be met before groundwater withdrawals from Snake Valley could be approved by the NSE. A draft of the agreement has existed since August 2009 (Styler and Biaggi 2009, entire) and as written, preserves and protects existing water rights, defines the

available groundwater supply in Snake Valley as 132,000 afy, apportions 41,000 afy of unallocated water to Utah and Nevada, and requires monitoring of groundwater withdrawal to identify and avoid adverse impacts (Kikuchi and Conrad 2009, p. 2). However, the agreement has yet to be signed.

Spring Valley Stipulated Agreement

Impacts from the proposed SNWA large-scale water withdrawal concerned several Department of Interior (DOI) agencies, including the U.S. Fish and Wildlife Service (Service). In 1990, the Service and other DOI agencies (BLM, National Park Service, and Bureau of Indian Affairs) protested water rights applications in Spring and Snake Valleys, based in part on potential impacts to water-dependent natural resources (Plenert 1990, p. 1; Nevada State Engineer (NSE) 2007, p. 11). In 2006, DOI agencies reached a Stipulated Agreement with SNWA for the Spring Valley water rights applications, withdrew their protests, and did not participate in the NSE's hearing (NSE 2007, p. 11). For groundwater pumping planned in Spring Valley, the Stipulated Agreement established a process for developing and implementing hydrological and biological monitoring, management, and mitigation for biological impacts (NSE 2007, p. 11). To date, implementation of the Spring Valley Stipulation has primarily involved development of monitoring plans, which while needed, are not in and of themselves fully protective of Federal trust resources. Additionally, while the Stipulated Agreement establishes a framework and process for working together to achieve common goals, it does not provide specific assurances regarding: unacceptable level(s) of impact, management responses, or mitigative measures. The term "Unreasonable Adverse Effect", for which the Stipulated Agreement was written to avoid, is not defined but instead will be the future product of a negotiation between the DOI Agencies and SNWA. Furthermore, methods to achieve avoidance are not specified. Additionally, the potential effectiveness of proposed mitigation actions (e.g. redistribution of pumping, curtailment, or cessation of pumping) to avoid or reduce impacts to federal resources has not been thoroughly evaluated in order to minimize the possibility of mitigation failure (USFWS 2011, p 12).

Seventh District Court Remand

On December 10, 2013 the Seventh District Court heard the petitions and remanded NSE orders 6164, 6165, 6166, 6167, which granted the water rights to SNWA in Delamar, Dry Lake, Cave and Spring valleys. The Court, through the remand, has required the following: recalculation of water available from the respective basins; additional hydrological study of Delamar, Dry Lake and Cave Valley; and establishment of standards for mitigation in the event of a conflict with existing water rights or unreasonable effects to the environment or the public interest (7th District Court Decision 2013, p.1,2). It is unclear how the requirements by the courts will operate in conjunction with the Stipulated Agreement and how the NSE will define standards, thresholds and triggers for mitigation. It spite of the uncertainties, it is likely that further evaluation is required which will augment the timeline for the SNWA groundwater development project, which for Spring Valley is currently set to begin for 2028 (SNWA, 2011a, p.4-15; Figure 6.11).

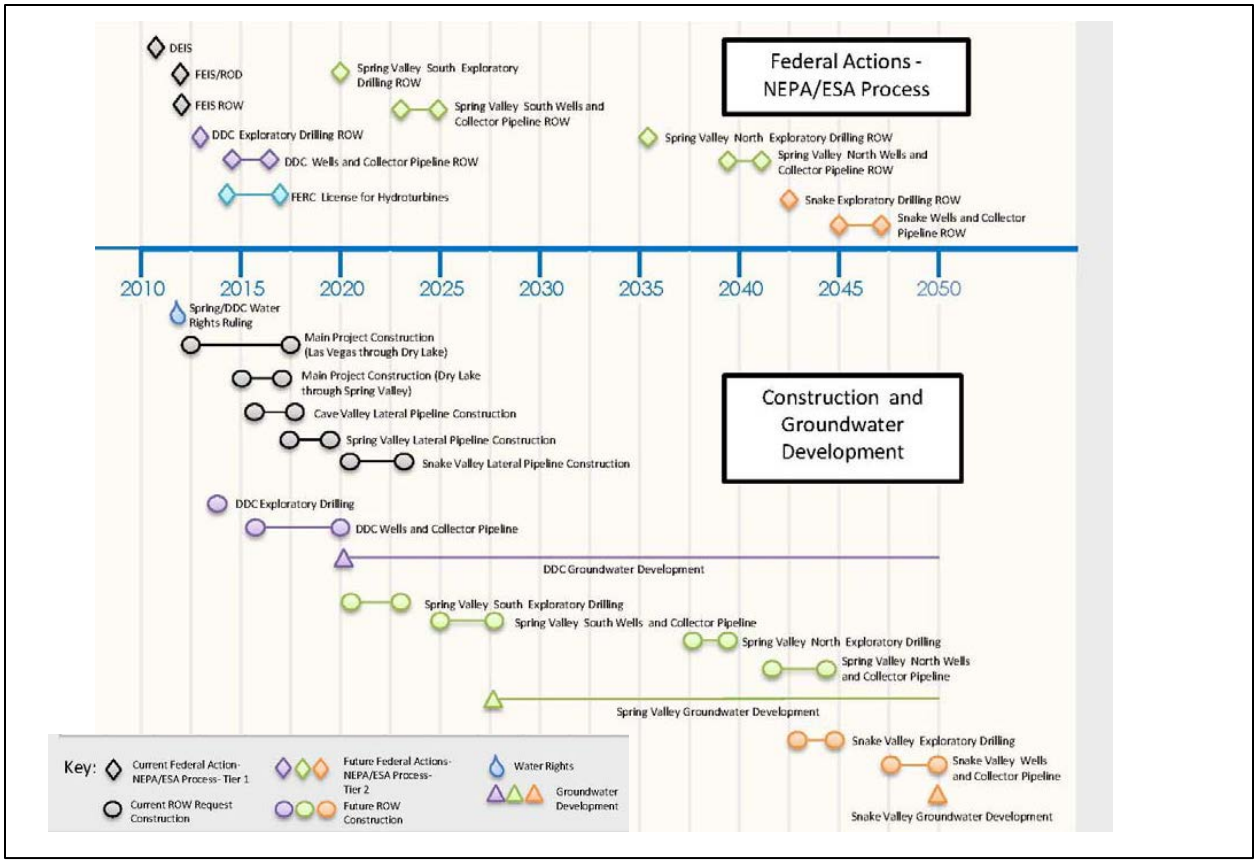


Figure 6.11. SNWA project timeline. Source: SNWA 2011, p. 4-15.

Hydrological Evaluation Used in the FEIS

To support the programmatic analysis of the SNWA project, a numerical groundwater flow model was developed to evaluate the probable long-term effects of groundwater withdrawal on a regional scale. The results of the model simulations were used in the analysis for both the Draft and Final EIS (BLM 2012b, p. 16). The model encompasses 35 hydrographic basins and covers more than 20,000 square miles of surface area (BLM 2012b, p. 16). The BLM established a technical review team of hydrology specialists, including scientists from the U.S. Geological Survey (USGS) and independent groundwater modeling experts (BLM 2012b, p. 16). The technical review team assisted the BLM by reviewing the model documentation reports and providing recommendations to the BLM for improvements to the model (BLM 2012b, p. 16).

The groundwater model was based on a generalized understanding of the nature and extent of surface and underground water and hydrogeologic conditions over the entire study area (BLM 2012b, p. 16). The model included a simplified hydrogeologic framework, representation of geological structures, recharge to the groundwater system, evapotranspiration (ET) from the system and spring flow. The model was used to simulate groundwater withdrawal for the eight alternatives for analysis (i.e., the Proposed Action, six action alternatives, and the No Action

Alternative) (BLM 2012b, p. 16). The selected alternative, the Agency Preferred Alternative, is a modified version of Alternative F (which is presented in the following Figures 6.12-6.14). It should be noted that Alternative F includes higher withdrawals than the Agency Preferred Alternative.

The model was also used to evaluate the combined effects associated with continuation of existing and historic pumping, project pumping, and reasonably foreseeable future pumping in the region over the same time period (BLM 2012b, p. 16). The assumed time frame for full build out of the conveyance system and associated groundwater development infrastructure under the Proposed Action is 38 years from the time the BLM issues a Notice to Proceed (BLM 2012b, p. 16). The modeling results were evaluated at three future time frames: full build out, full build out plus 75 years of subsequent groundwater production at the assumed quantities, and full build out plus 200 years of subsequent groundwater production at the assumed quantities (BLM 2012b, p. 16).

The model also has certain limitations, as do all models. In particular, this model does not offer the level of accuracy required to predict absolute values at specific points in time (BLM 2012b, p. 16). It does, however, provide valuable insight as to the general long-term drawdown patterns and relative trends likely to occur from the various pumping alternatives (BLM 2012b, p. 16). Thus, despite the inherent limitations and uncertainties associated with the hydrogeologic conditions over this broad region, the BLM has determined that the calibrated model is a reasonable tool for use in this programmatic analysis to estimate probable regional-scale drawdown patterns and trends over time related to the various pumping alternatives (BLM 2012b, p. 16, 17). Impacts have been evaluated in terms of the potential impacts to flows of seeps, springs and streams, potential impacts on water rights, and drawdown effects on subsurface water (BLM 2012b, p. 17).

The predicted change in groundwater levels attributable to groundwater development under the Alternative F at full build out, full build out plus 75 years, and full build out plus 200 years are provided in Figures 6.12, 6.13, and 6.14, respectively. These figures illustrate areas where the water levels are predicted to decrease in excess of 10 feet (3m) in comparison to the simulated No Action water levels (BLM 2012a, p. 3.3-179). Comparison of the simulation results for the three points in time indicates that the drawdown area continues to progressively expand as pumping continues into the future (BLM 2012a, p. 3.3-179). At full build out, the drawdown areas are localized in the vicinity of the pumping wells in central and southern Spring Valley, southern Cave Valley, and Dry Lake Valley, drawdown in excess of 10 feet does not occur at this time period in Snake Valley (BLM 2012a, p. 3.3-179).

At the full build out plus 75 years time-frame, there are two distinct drawdown areas (BLM 2012a, p. 3.3-184). The northern drawdown area encompasses most of valley floor in Spring Valley, and extends into northern Hamlin Valley and along the southwest margin of Snake Valley (BLM 2012a, p. 3.3-184). The southern drawdown area extends across the Delamar, Dry Lake, and Cave valleys in a north-south direction (BLM 2012a, p. 3.3-184). By the full build out plus 200 years time-frame, the 2 drawdown areas merge into one that extends approximately 190 miles in a north-south direction and up to 50 miles in an east-west direction (BLM 2012a, p. 3.3-184).

These groundwater drawdown estimates are may underrepresent because the model was developed for regional scale analysis and does not consider changes in groundwater elevation of less than 10 feet (BLM FEIS 2012, p. 3.3-87). Thus, the geographical extent of groundwater drawdown is likely greater than what it is presented in the analysis. The extent and timing of these effects will vary among springs, based on their distance from extraction sites and location relative to regional groundwater flow paths (Patten et al. 2007, pp. 398-399).

In spite of the regional model to simulate potential changes in groundwater flow as a result of large-scale pumping associated with the SNWA project, little is known about the extent of the aquifers, their hydraulic properties, and the distribution of water levels that would contribute to a reliable prediction of the amount or location of drawdown, or the rate of change in natural discharge, caused by pumping (Prudic 2006, p. 3).

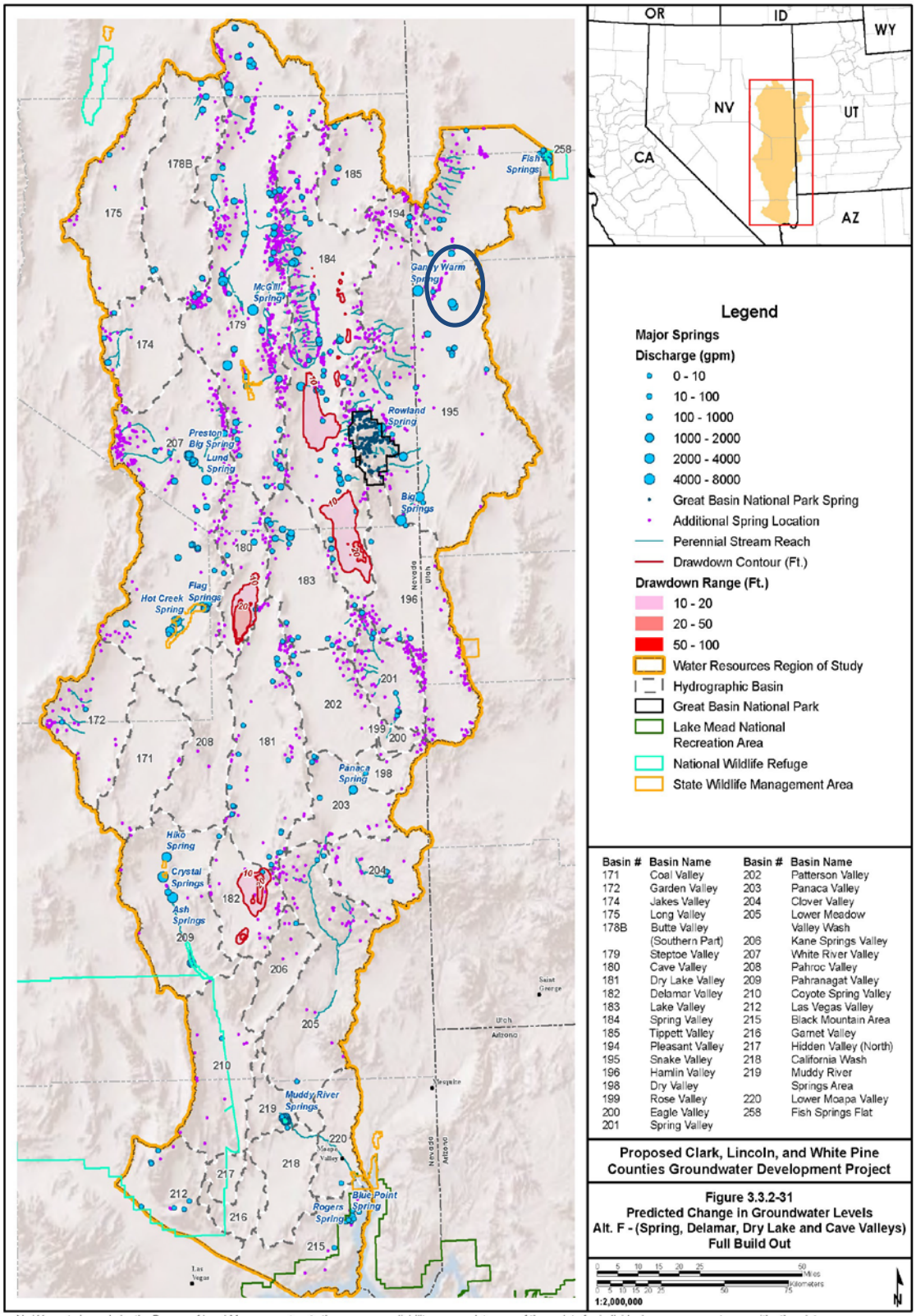
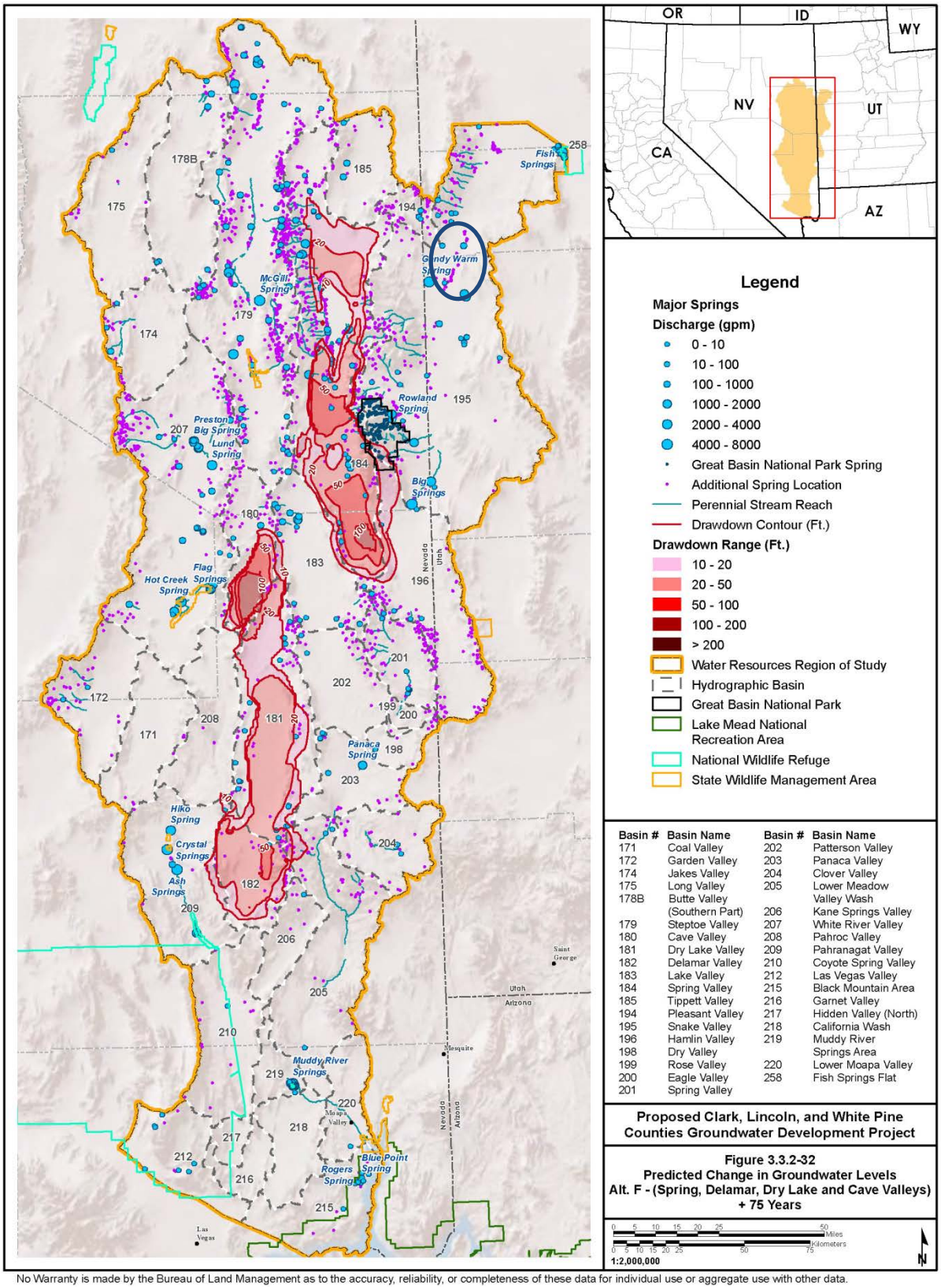


Figure 6.12. Groundwater drawdown range from pumping activities upon full build out, under Alternative F. Source: BLM 2012a, p. 3.3-181. The blue ring is the least chub population area.



No Warranty is made by the Bureau of Land Management as to the accuracy, reliability, or completeness of these data for individual use or aggregate use with other data.

Figure 6.13. Groundwater drawdown range from pumping activities 75 years after full build out, under Alternative F. Source: BLM 2012a, p. 3.3-182.

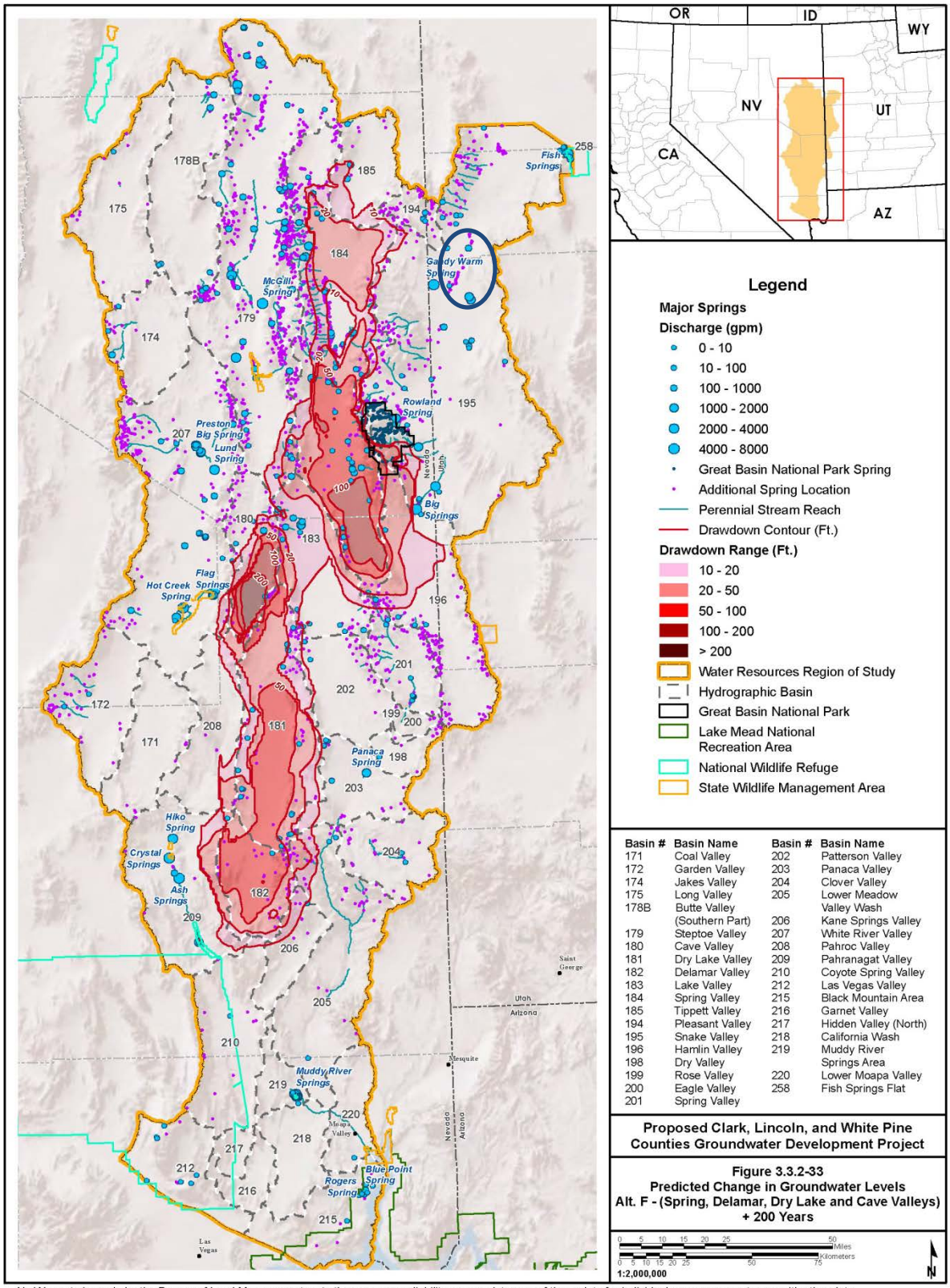


Figure 6.14. Groundwater drawdown range from pumping activities 200 years after full build out, under Alternative F. Source: BLM 2012a, p. 3.3-183.

Other Proposed Water Development Projects

In addition to SNWA, other municipalities are interested in developing water resources in near and likely hydrologically connected to the Snake Valley. On October 17, 2006, the Central Iron County (Utah) Water Conservancy District filed applications to appropriate underground water in Hamlin Valley, Pine Valley, and Wah Wah Valley in the amounts of 10,000, 15,000, and 12,000 afy, respectively (UDWRi 2009a, pp. 2, 12, 23). The principal use of this applied-for water is municipal, with minor amounts used for stock watering (UDWRi 2009a, entire). To date, the USE has not acted upon these applications. Similarly, Beaver County, Utah, purchased water right applications in 2007 originally filed on October 6, 1981, for Wah Wah, Pine, and Hamlin Valleys (UDWRi 2009b, pp. 2, 5, 8). A hearing was held on December 10, 2008, on these Beaver County (successor-in-interest) applications, and on September 14, 2009, these water rights were rejected by the USE (UDWRi 2009b, pp. 3, 6, 9). Lastly, the State of Utah School and Institutional Trust Lands Administration (SITLA) filed applications for up to 9,600 afy from underground water wells in the Snake Valley (UDWRi 2009c, entire). These water rights all occur in areas that are hydrologically connected to Snake Valley.

The Confederated Tribes of the Goshute Reservation, located in east-central Nevada (White Pine County) and west-central Utah (Juab and Tooele Counties) are interested in developing their as yet unused water rights. They have a 1905 decreed surface water right along the Deep Creek system in Utah (Steele 2008, p. 2), and are currently planning to increase Deep Creek basin rights to provide for community development projects (Steele 2008, p. 3). They estimate that up to 50,000 afy will be needed for beneficial uses including expanded crop and livestock irrigation, fishery management, surface water reservoir operation and maintenance, and water pipeline conveyance (Steele 2008, p. 3). The USE is currently reviewing their application to develop 50,000 afy of water from the Deep Creek Valley.

Groundwater Pumping and Effects to Surface Water Resources

Current and historical groundwater pumping has impacted several springs in Snake Valley (Hickman 1989, pp. 16-17; Garland 2007, pers. comm.; Sabey 2008, p. 2). These springs include Knoll Spring near the town of Eskdale, springs on private properties in the town of Callao (Sabey 2008, p. 2) and Needle Point Spring. Knoll Spring and springs on private property near Callao were historically occupied by least chub (Hickman 1989, pp. 16-17; Garland 2007, pers. comm.). Agricultural pumping has dried both of these areas leading to the local extirpation of least chub (Hickman 1989, pp. 16-17; Garland 2007, pers. comm.). Although no least chub historically occurred at Needle Point Spring, the BLM has detailed monitoring information linking nearby groundwater pumping and its effect on the spring's flow. The 2001 decline in groundwater level at Needle Point Spring was likely the result of, and coincides with, increased irrigation in Hamlin Valley approximately 3.2 km (2 mi) west, and not a result of the lowered precipitation (Summers 2008, p. 3).

The direct effects of dewatering on least chub populations were observed in at least one location, and at others drying of habitat due to unknown causes was observed. UDWR observed the direct effects of flow reductions on wild least chub populations at the Bishop Spring population area with desiccation of select habitat that once held viable least chub populations (Wheeler et al.

2004, p. 5). Although the causal effect of groundwater pumping is unknown in the following observations, UDWR has documented decreases in the general amount of habitat at two least chub sites. They recently reported decreases in least chub habitat from springs drying and decreasing in size at the Clear Lake least chub site (LCCT 2008b, p. 2). Average water depth among affected ponds decreased from 0.5 m (1.6 ft) in 2006 to 0.2 m (0.7 ft) in 2008 (LCCT 2008b, p. 2). At the Gandy Marsh site, least chub populations declined by more than 50 percent (from 1993 to 2006) as a result of a reduction in available habitats due to the drying of springs throughout the complex (Wilson 2006, p. 8).

Further Evaluation of the SNWA Project—UGS Monitoring Wells

The Utah Geological Survey (UGS) began evaluating Snake Valley in 2004 due to concern over the proposed groundwater development by SNWA, which at the time, included pumping activities in Spring and Snake Valleys, Nevada (UGS Draft Report, sec. 1.2, p. 4). The proposed SNWA wells in Snake Valley were within 6 miles (9.6 km) of the state line, and some of the groundwater in the Utah part of northern Hamlin Valley and southern Snake Valley is thought to originate in Spring Valley and enter Snake Valley via subsurface interbasin flow in the carbonate-rock aquifer (Gates and Kruer, 1981; Welch et al. 2007 in UGS Draft Report, sec. 1.2, p. 4-5). Therefore, monitoring of baseline groundwater conditions was relevant for future water-management, and in 2007, the Utah Legislature requested the UGS to establish a long-term (50+ years) groundwater-monitoring network in Snake Valley to determine these baseline groundwater conditions and measure changes if future groundwater development were to occur (UGS Draft Report, sec. 1.2, p. 5). The well network was completed in December 2009.

The UGS groundwater-monitoring network consists of piezometers (wells open to the aquifers) to measure groundwater levels and chemistry, and surface-flow gages to measure spring discharge (UGS Draft Report, sec. Abstract, p. 3). The piezometers were placed in carbonate-rock and basin-fill aquifers in areas of mountain-front recharge, valley-floor discharge, agricultural, and interbasin-boundary zones (UGS Draft Report, sec. Abstract, p. 3). The sites are adjacent to the Snake Valley portion of Southern Nevada Water Authority's proposed groundwater-development project; coinciding with areas of current agricultural groundwater pumping, near environmentally sensitive and economically important springs, and along possible areas of interbasin flow (UGS Draft Report, sec. Abstract, p. 3).

UGS found that groundwater-level hydrographs at monitoring sites in the UGS study area vary according to distance from areas of groundwater pumping and by their distance from recharge areas (UGS Draft Report, sec. 5.3.7, p. 35). Groundwater levels at sites within about 5 miles (8 km) of agricultural areas show seasonal response to groundwater pumping by decreasing during the summer irrigation season and recovery to pre-pumping levels during the winter and early spring, whereas groundwater levels at remote sites (disregarding the spring-gradient sites) show slight or no seasonal variation (UGS Draft Report, sec. 5.3.7, p. 35). However, groundwater levels in the Snake Valley agricultural areas declined from the late 1980s to late 2012, by average rates of 0.3 to 2.3 feet per year (0.1 – 0.7 m/yr) depending on location and specific time interval (UGS Draft Report, sec. Abstract, p. 3). Data from remote sites suggest that up to about 0.2 feet per year of this decline represents climatic effects, resulting from relatively lower average annual precipitation and, presumably, recharge rates following several consecutive wet

years in the early 1980s (UGS Draft Report, sec. Abstract, p. 4). Groundwater levels at sites on valley floors far from recharge areas show little or no correlation with precipitation records, whereas those along mountain fronts, especially near perennial streams that run out onto the mountain front, show greater year-to-year variation that is generally correlated with variations in annual precipitation (UGS Draft Report, sec. 5.3.7, p. 35).

The agricultural areas evaluated by UGS include the Callao area in northern Snake Valley, the Eskdale, Tin Shed, Baker, and Garrison areas in south-central Snake Valley, and the Davies Ranch and Granite Peak Ranch areas in southern Snake Valley, the location of least chub sites in relation to these agricultural areas are shown in Figure 6.15 (UGS Draft Report, sec. 5.3.2, p. 11).

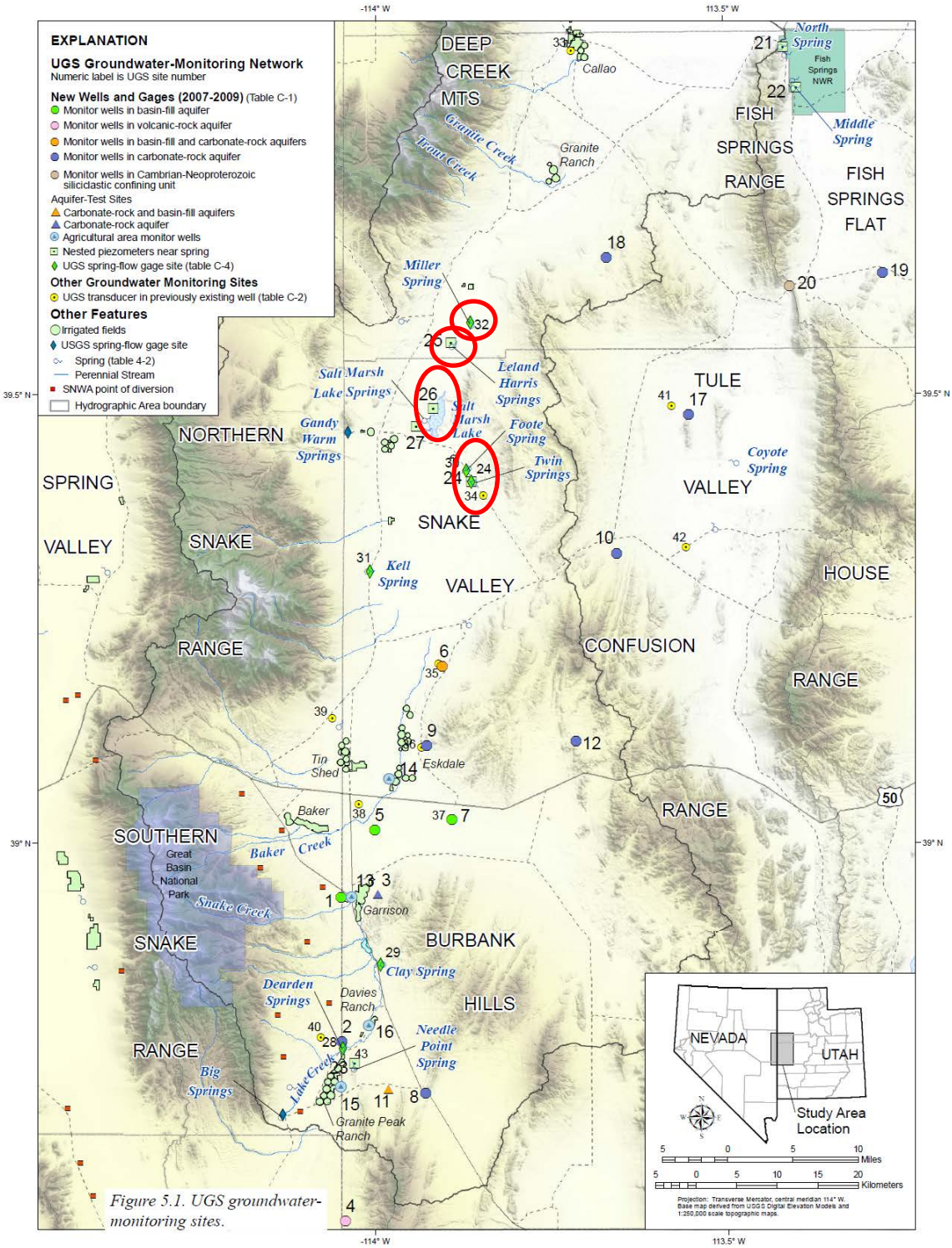


Figure 5.1. UGS groundwater-monitoring sites.

Figure 6.15. UGS groundwater monitoring sites. Least chub sites highlighted by red circles. Source: UGS Draft Report, sec 5, Figure 5.1.

UGS Monitoring Near Least Chub Sites

UGS found that groundwater levels near spring heads fluctuate seasonally by up to 3 feet (0.9 m) per year in response to seasonal changes in evapotranspiration rates, and are not presently declining from year to year (UGS Draft Report, sec. Abstract, p. 3). For spring-gradient sites near least chub populations, groundwater levels in the piezometers fluctuated by about 0.5 to 3 feet (0.15-0.91 m) seasonally, with lowest levels during the summer months and highest levels during the late winter/early spring months, in response to evapotranspiration in the spring-fed wetlands ecosystems that are supported by the spring flow (UGS Draft Report, sec. 5.3.4, p. 29, Figure 6.16). It is likely due to evapotranspiration because the site is far from any site of groundwater pumping for irrigation (UGS Draft Report, sec. 5.3.4, p. 29). In general, the Snake Valley least chub population sites show stable groundwater levels since piezometer installation in 2009 (draft piezometer data, H. Hurlow 2013 pers. comm.), with the exception of Gandy Marsh. Unlike the sites to the north (Leland and Miller) and to the south (Bishop), the Gandy piezometers are displaying downward trends. Hurlow at UGS (2013, pers. comm.), suggests that Gandy's downward trend is likely due to climatic variation, similar to the trends seen in the UGS remote sites (where no groundwater withdrawals are occurring). Hurlow (2013, pers. comm.) also warns that few analyses or interpretations can be made from only four years of data, and recommends that analyses be made on UGS data after at least 10 years of record have accumulated (based on Taylor and Alley, 2001, p. 15-16 *in* UGS Draft Report sec.5.3.7, p. 31).

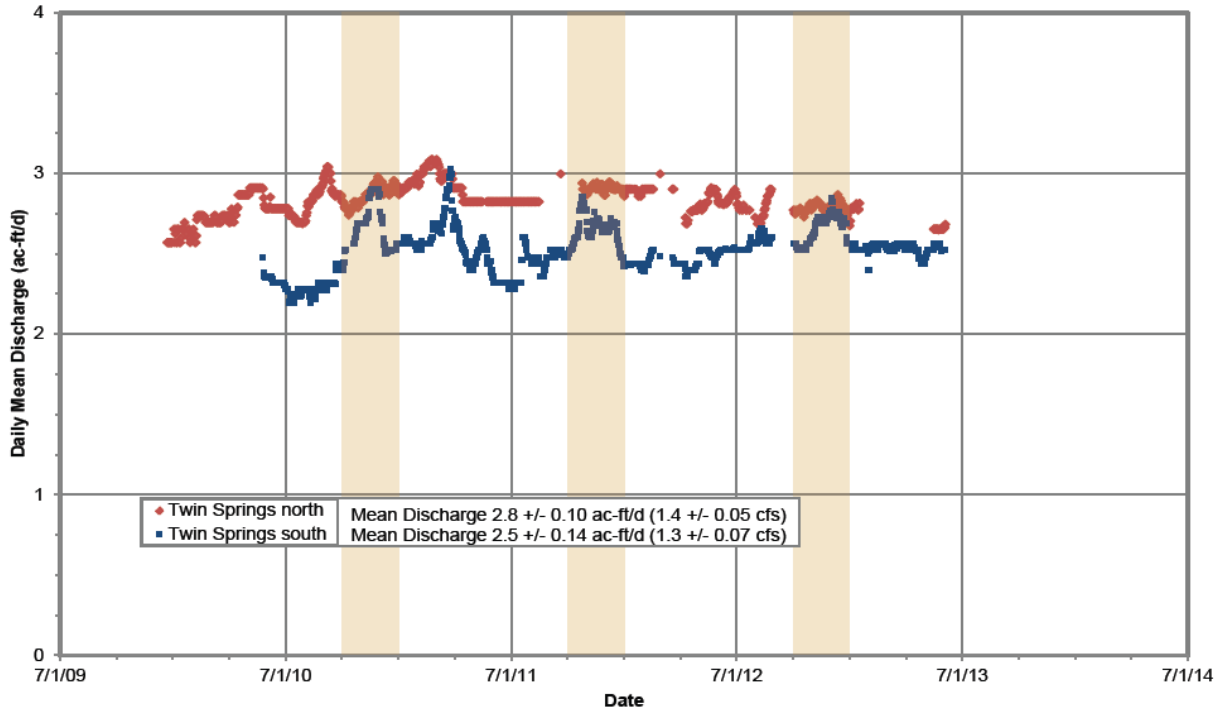


Figure 6.16. Hydrographs for North and South Twin Springs (UGS site 24), at the Bishop Springs least chub population site. Tan shading shows the apparent increase in discharge from the south orifice each fall. Source: UGS Draft Report, sec. 5, figure 5.10.

Status and Future Trends of Groundwater Withdrawals in Snake Valley (UGS)

Declining groundwater levels in areas of current heavy use determined from UGS groundwater monitoring, old groundwater ages, and slow recharge rates in most of the study area suggest that current groundwater use in Snake Valley is removing groundwater from storage in the basin-fill aquifer, and has not yet been balanced by capture of discharge (UGS Draft Report, sec. Abstract, p.7). Thus, declining groundwater levels and reduced spring flow would continue at present pumping rates (UGS Draft Report, sec. Abstract, p.7). Increased future groundwater pumping would increase the rate and area of groundwater-level decline and capture of discharge (UGS Draft Report, sec. Abstract, p.7). Significant additional pumping of groundwater for local agricultural use or export from the hydrographic area would capture groundwater discharge that currently sustains springs, and shallow groundwater that supports sensitive-species habitat and vegetation used for irrigation and grazing (UGS Draft Report, sec. Abstract, p.7).

Substantial (i.e., roughly 10 feet or greater) lowering of groundwater levels and capture of recharge in Snake Valley and adjacent hydrographic areas would adversely impact agricultural and domestic use, habitat for environmentally sensitive species and, potentially, air quality (BLM 2012a, p. 3.3; UGS Draft Report, sec. 1.3, p. 8). Lower groundwater levels and capture of groundwater discharge would lead to decreased spring discharge by reducing the hydraulic head in their source and reducing flow rate to discharge areas (UGS Draft Report, sec. 1.3, p. 8). The proposed pumping may not only affect groundwater conditions near the pumping areas, but also in hydrographic basins adjacent to Snake Valley by virtue of interbasin hydraulic connectivity through deep carbonate-rock aquifers (UGS Draft Report, sec. 1.3, p. 8).

Springs in the UGS study area are used for agriculture, and their pools and the spring-fed wetlands ecosystems supported by their outflow provide habitat for several environmentally sensitive species (UDWR 2011, UGS Draft Report, sec. 1.3, p. 9). Lowering of the water table in the valley centers to depths below the root zones of phreatophyte plants would lead to death of these plants and succession by non-phreatophytic shrub communities (UGS Draft Report, sec. 1.3, p. 9; BLM 2012a, sec. 3.5).

The draft Agreement for Management of the Snake Valley Groundwater System (interstate agreement) (UDWRi, 2010), although currently unsigned, provides a model for potential amounts of future groundwater development (UGS Draft Report, sec. 9.2, p. 3). The draft agreement allows for new development of 35,000 acre-feet per year (43.2 hm3/yr) in Nevada and 6,000 acre-feet per year (7.4 hm3/yr) in Utah, in addition to currently allocated water rights of 12,000 acre-feet per year (14.8 hm3/yr) in Nevada and 55,000 acre-feet per year (67.8 hm3/yr) (including 20,000 acre-feet per year [24.7 hm3/yr] reserved for the Service's water rights for Fish Springs National Wildlife Refuge) (UDWRi, 2010; UGS Draft Report, sec. 9.2, p. 4). Total pumping in the Snake Valley hydrographic area would be 47,000 acre-feet per year (58.0 hm3/yr) in Nevada and 41,000 acre-feet per year (50.6 hm3/yr) in Utah, if the maximum development was allowed (UGS Draft Report, sec. 9.2, p. 4).

UGS suggests that based on the distribution of recent water rights applications, most of the new groundwater development would likely occur in central and southern Snake Valley (UGS Draft Report, sec.9.2, p. 2). Most of the current use is for irrigation in south-central Snake Valley near

Garrison and Eskdale, Utah, and Baker, Nevada, and in southern Snake Valley in Nevada and Utah (UGS Draft Report, sec. 9.2, p.1; Figure 6.15). Discharge from the Snake Valley hydrographic area would increase by approximately 41,000 acre-feet per year (50.6 hm3/yr) at the upper limit allowed by the interstate agreement (after accounting for resident irrigation groundwater which accounts for a small percent of recharge to the aquifer via return flow; Welch et al. 2007, p. 68) (UGS Draft Report, sec.9.2, p. 2).

Welch et al. (2007) subdivided Snake Valley and Hamlin Valley into five hydrogeologic sub-basins, and estimated recharge and discharge for each sub-basin. The majority of current and future groundwater development occurs and expected to occur in Snake Valley sub-basins 3 and 4 (UGS Draft Report, sec. 9.2, p. 2; figure 6.17). Recharge in sub-basins 3 and 4 is about 61,000 acre-feet per year (75.2 hm3/yr), and discharge by evapotranspiration is about 60,000 acre-feet per year (74.0 hm3/yr) (Welch et al., 2007, appendix A), without the addition of groundwater withdrawals (UGS Draft Report, sec. 9.2, p. 2). Discharge by groundwater pumping for irrigation plus evapotranspiration in sub-basins 3 and 4, therefore, exceeds recharge of snowmelt and precipitation, as reflected by gradually declining groundwater levels in areas of current use (UGS Draft Report, sec. 9.2, p. 3). Most of the pumping is from wells that are less than 500 feet deep, based on well-log data available from the Utah Division of Water Rights (http://www.waterrights.utah.gov/) and the Nevada Division of Water Resources (http://water.nv.gov/) (UGS Draft Report, sec. 9.2, p. 2). Additional groundwater pumping would remove additional groundwater from storage and capture groundwater that currently flow to discharge areas and supports phreatophyte growth and spring flow (UGS Draft Report, sec. 9.2, p. 3), however, it is unknown whether the declining groundwater levels in sub-basins 3 and 4 will spread to sub-basin 2, where the Snake Valley least chub populations are located and where less groundwater pumping for irrigation occurs, but it is unlikely given the great distance between these subbasins (Figure 6.17).

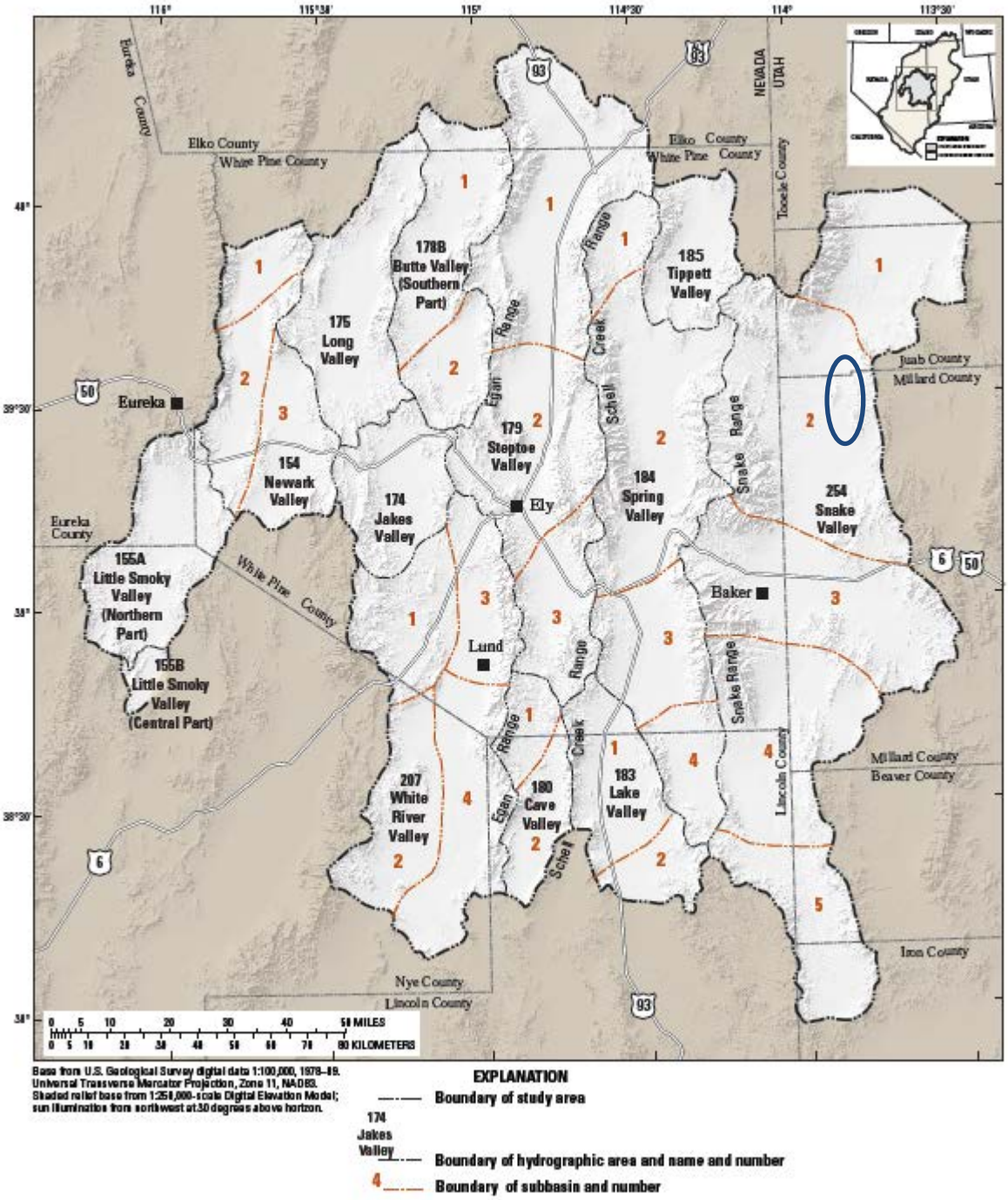


Figure 6.17. Hydrographic areas and sub-basin delineation. Least chub populations are located within the blue oval (and sub-basin 2). Note the boundary sub-basins delineated in red. Source: Welsh et al. 2007, p. 10.

Predictions for Snake Valley Development under the Interstate Agreement

UGS, using the future development described in the interstate agreement (i.e., SNWA Snake Valley project) and the three recent numerical groundwater-flow models, they evaluated potential groundwater-level declines in Snake Valley (SNWA, 2010b; Loy and Durbin, 2010; Halford and Plume, 2011 in UGS Draft Report, sec.9.3, p. 4). The purpose was to provide a first approximation of groundwater level changes from the maximum development allowed in the interstate agreement (UGS Draft Report, sec.9.3, p. 4).

Predictive simulations of groundwater pumping in Snake Valley at current rates plus additional development in central and southern Snake Valley, as permitted by the draft interstate agreement, indicate the following declines in groundwater levels (UGS Draft Report, sec. 9.3, p. 5). After 75 years of pumping, groundwater levels within most of the proposed groundwater-development area (Snake Valley, Nevada) would decline by 20 to 100 feet (6.1 - 30 m) (UGS Draft Report figure 9.1a; Figure 6.18), and groundwater levels would decline by 50 to 200 feet (15 – 61 m) from present-day depths after 200 years (UGS Draft Report figure 9.1b; Figure 6.19). Groundwater-level declines in the rest of sub-basins 3 and 4 (least chub populations are in sub-basin 2) would decrease approximately radially away from the groundwater-development area (UGS Draft Report, sec. 9.3, p. 4, 5). Within about 10 to 12 miles (16 – 19 km) of the wells, predicted drawdown is more than 10 feet after 75 years of pumping and more than 20 feet (6.1 m) after 200 years of pumping (UGS Draft Report, sec. 9.3, p. 4, 5; UGS figure 9.2).

Least chub populations are located in sub-basin 2, outside of the 10 foot drawdown contour, but impacts to spring flow and related spring-fed wetlands ecosystems may also occur in areas having less than 10 feet (3 m) of drawdown (Cooper et al. 2006; Patten et al. 2008 in UGS Draft Report, sec. 9.3, p. 5). Springs and spring complexes in Snake Valley that support wetlands ecosystems and agriculture and are outside of the simulated 10-foot (3 m) drawdown contour, but which could be adversely affected, include Twin Springs and Foote Reservoir Spring, Kell Spring, Salt Marsh Lake spring complex, Leland Harris spring complex, and Miller Spring (UGS Draft Report, sec. 9.3, p. 5). Coyote Spring and Tule Spring in Tule Valley, and the Fish Springs complex in Fish Springs Flat could also experience slightly reduced flow, due to a decrease in regional hydraulic gradient from the lowering of groundwater levels in the groundwater-development area, and by capture of flow from the groundwater-development area to the springs (UGS Draft Report, sec. 9.3, p. 5).

Using SNWA's predictive simulation for alternative A (which includes Snake Valley pumping; BLM 2012a) indicates that flow from Foote Reservoir Spring and Kell Spring would decline by about 1%, whereas Gandy Warm Spring would be unaffected (UGS Draft Report, sec. 9.3, p. 6). Interbasin flow from Snake Valley to Tule Valley would be reduced by about 2% after 75 years and by about 6% after 200 years (UGS Draft Report, sec. 9.3, p. 6). This reduction in interbasin flow would probably cause a slight decline in flow from Coyote Spring and Tule Spring, due to the hydraulic connection between Snake Valley and Tule Valley (UGS Draft Report, sec. 9.3, p. 6). Halford and Plume (2011) suggest that Twin Springs and the Fish Springs complex spring flow would decline by less than 1%. These estimates depend on the hydraulic properties of the faults and hydrogeologic units along the flow paths to the springs, which are highly uncertain.

Impacts to some of these springs could be greater if they lie along north-south striking fault zones or other specific hydrogeologic factors (UGS Draft Report, sec. 9.3, p. 6).

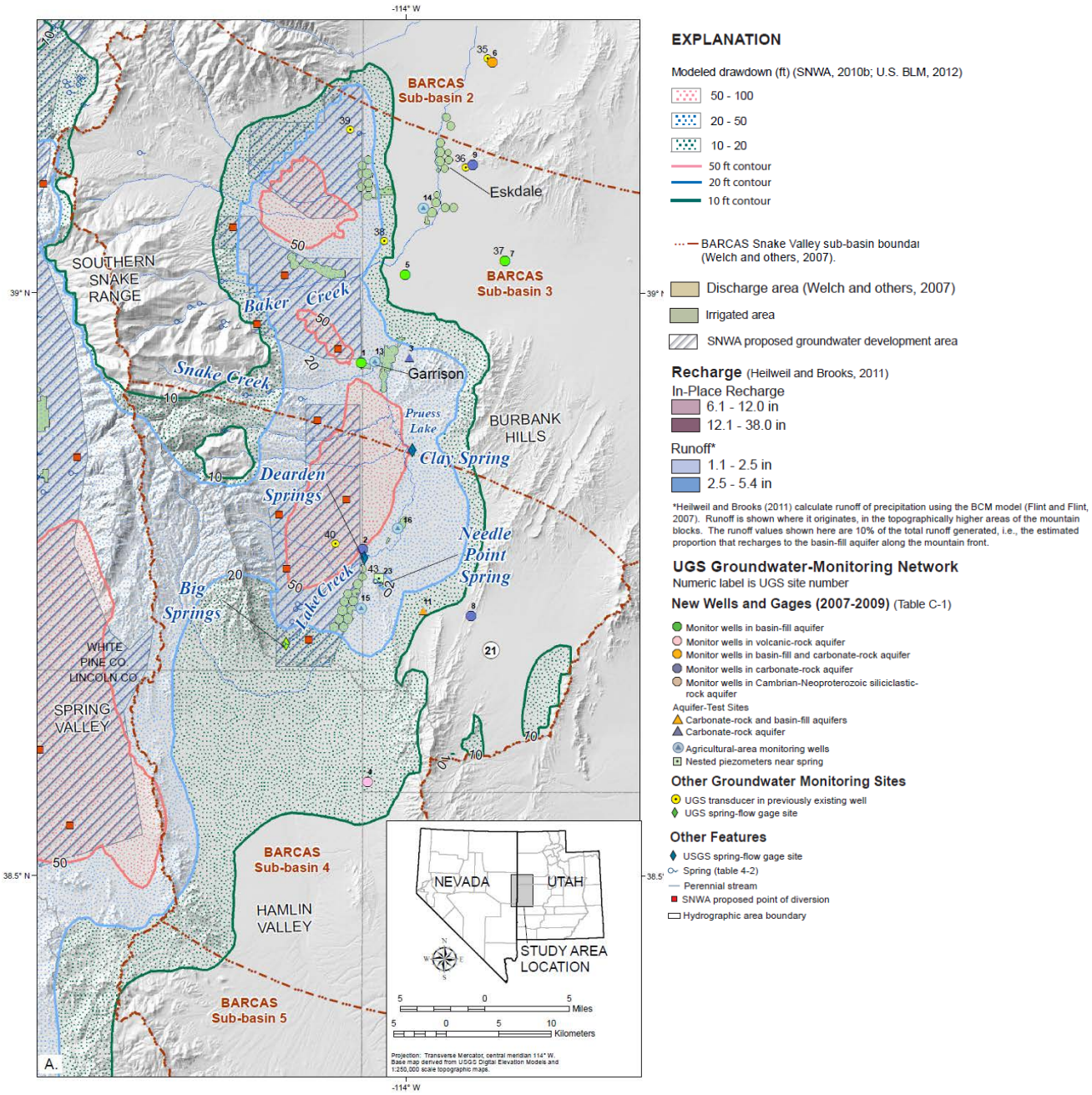


Figure 9.1. Simulated drawdown in Snake Valley by SNWA wells under alternative A plus current use (U.S. Bureau of Land Management, 2012a).
A. Simulated drawdown after 75 years of pumping.

Figure 6.18. Simulated drawdown in Snake Valley after 75 years of pumping. Source: UGS Draft Report, section 9.3.

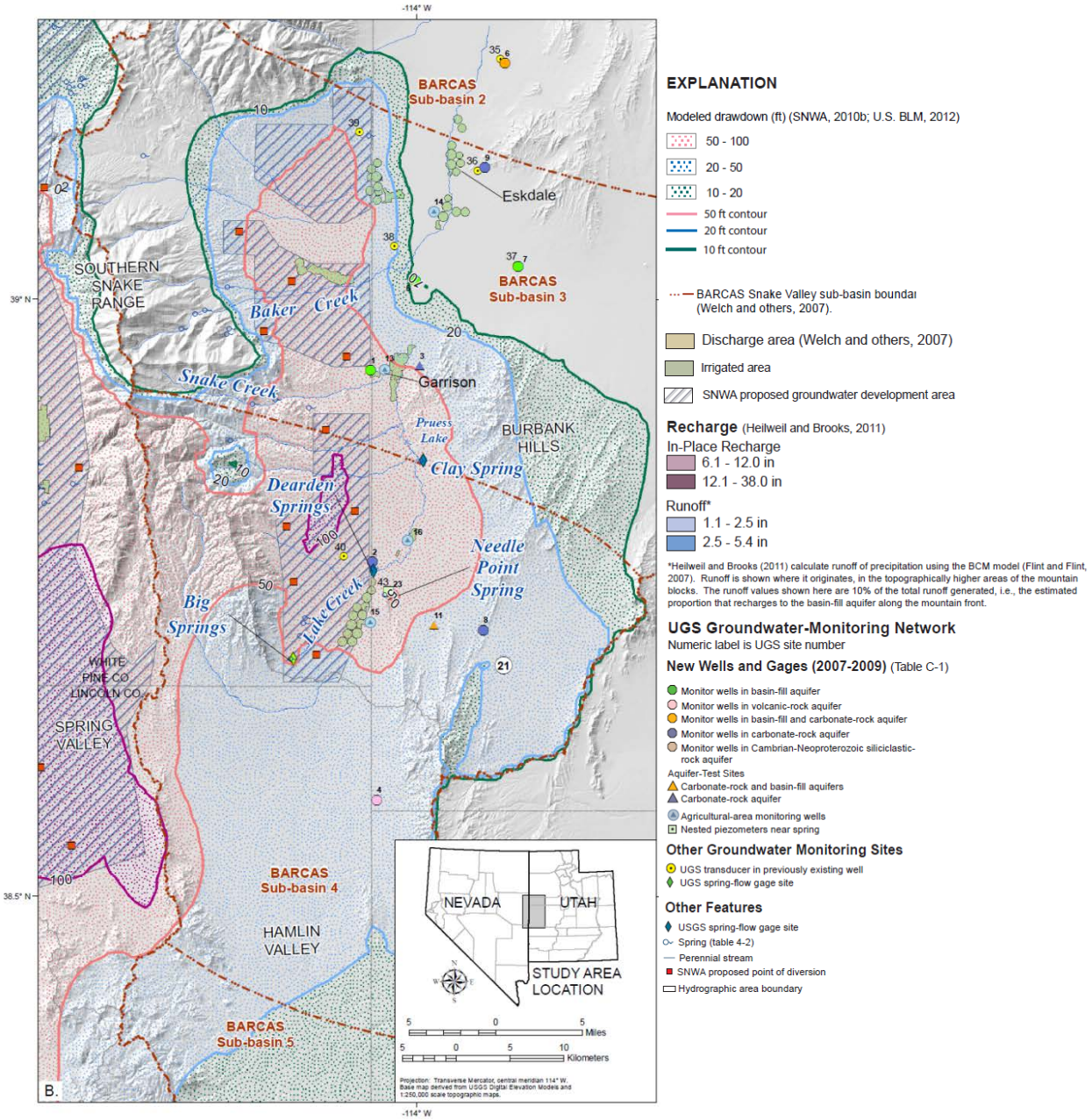


Figure 9.1 (continued). B. Simulated drawdown after 200 years of pumping.

Figure 6.19. Simulated drawdown in Snake Valley after 200 years of pumping. Source: UGS Draft Report, section 9.3.

The effects of small declines in flow at Twin Springs, Salt Marsh Lake spring complex, Leland Harris spring complex, and Miller Spring on aquatic, wetland, and wet-meadow plant communities and sensitive-species habitats are difficult to predict (UGS Draft Report, sec. 9.4, p. 9). Changes in habitat due to decreased spring flow depend on the detailed topography of the outflow area, local stratigraphy, precipitation, magnitude of spring flow, spring-pool morphology, and the relative proportion of upwelling deep groundwater to side-inflow of shallow groundwater (Loheide and others, 2008 in UGS Draft Report, sec. 9.4, p. 9). At several key spring-fed wetlands ecosystems in Snake Valley, Three Parameters Plus (2010) performed baseline physical habitat surveys and vegetation delineations, and shallow-groundwater monitoring is ongoing (Hooker et al. 2011; data are available from the Utah Geological Survey Groundwater Monitoring Data Portal at http://geology.utah.gov/databases/groundwater/projects.php). These data form a framework for potential future modeling studies that may assess the potential effects of small decreases in spring flow on sensitive species habitat (UGS Draft Report, sec. 9.4, p. 9). In addition, UDWR has conducted an in-depth bathymetry study of one least chub population site, Leland Harris, and preliminary findings suggest that the seasonal drawdown in the wetland is not consistent across the area in relation to the piezometer readings, for example, a 1 cm seasonal drawdown in the piezometer may be a 0.1 cm drawdown in one area in the wetland, and 0.5 cm drawdown in another area. (These data are hypothetical examples guided by the preliminary data, but the draft of the project report is expected at the end of January 2014). The preliminary data suggests that there is unique hydrogeology at the site including underground connections, which may be responsible for the differences across the wetland complex.

Current Status of Least Chub Snake Valley Populations

A preliminary Population Viability Analysis was completed for the Snake Valley least chub populations (Peterson and Saenz 2013, entire). Through the analysis, it was recommended that Catch per Unit Effort (CPUE) data not be used to show trends in the population's status over the period of record because the data were highly variable and heavily biased, making CPUE an unreliable indicator of least chub population status and trends (Peterson and Saenz 2013, p. 31). Instead, occupancy trends are a better indicator of status, with multi-states built in: absent, present, abundant, and young-of-year presence (Peterson and Saenz 2013, p. 27; Figure 6.20). These data show that the occupancy rates of Gandy fluctuate far less from year to year than the Bishop population, but are consistently around 30-40% at Gandy and 80% for Bishop from 1994 to 2010. Simulation of patch occupancy at the three Snake Valley least chub wetland populations indicated equilibrium patch occupancy rates (assuming no disturbances or mosquitofish introductions) for Bishop Springs, Gandy Marsh, and Leland Harris Springs Complex and were 71%, 32%, and 69%, respectively (Peterson and Saenz 2013, p. 28; Figure 6.21). These values compare favorably to the average occupancy rates from 1994-2009 at Bishop Springs (77%) and Gandy Salt Marsh (30%) and the estimate at Leland Harris Springs Complex from 1994-2005 (72%) (Peterson and Saenz 2013, p. 28). Therefore, it is believed that the models can reasonably approximate the patch dynamics and occupation of these wetland populations (Peterson and Saenz 2013, p. 28).

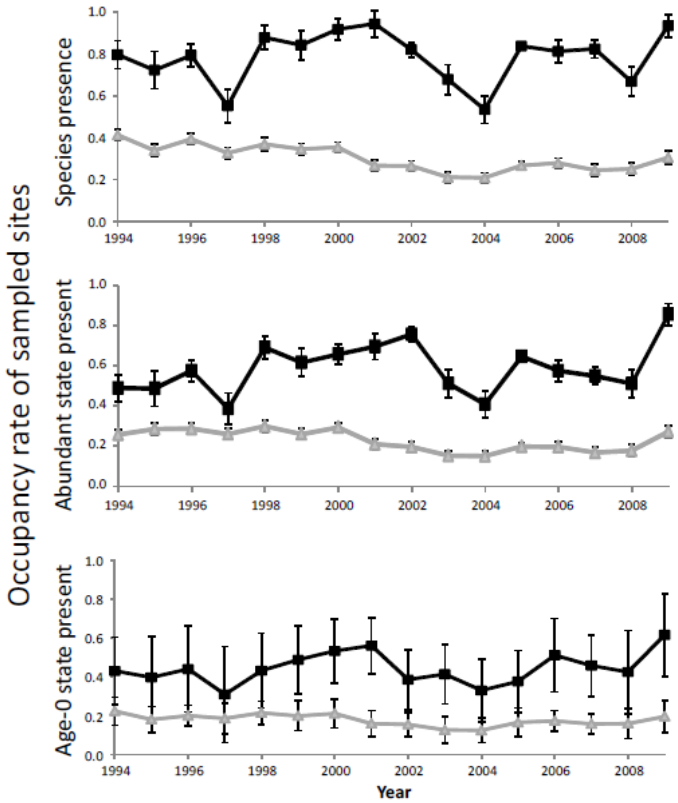


Figure 6.20. Estimated occupancy rate of least chub (top), abundant least chub (middle) and age-0 least chub (bottom) at Bishop Springs (black) and Gandy March (gray) sample sties from 1994-2010, with error bars representing +/- 1 standard deviation. Estimates were made using parameters in the best approximating multistate occupancy models. Source: Peterson and Saenz 2013, p. 69.

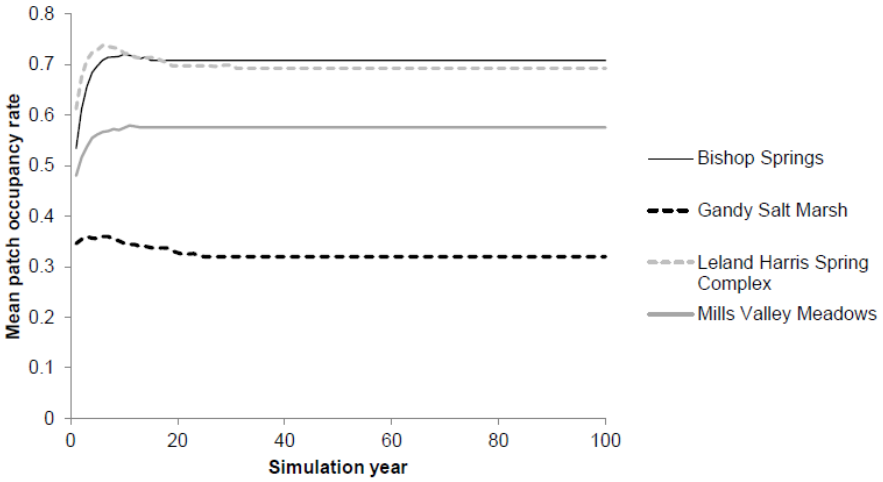


Figure 6.21. Estimated patch occupancy probability for three Snake Valley wetland least chub populations (with Mills Valley, a non-Snake Valley population included). Simulations used baseline values and assumed no mosquitofish introduction and no catastrophic disturbances occurred. Source: (Peterson and Saenz 2013, p. 70).

Future Trends in Snake Valley Populations

Population Viability Analysis

The preliminary PVA analysis simulation of least chub wetland populations showed generally low probabilities of extinction with estimated values of zero in simulations where probability of introduction of exotic species equaled zero (Peterson and Saenz 2013, p. 29; Table 6.3). Simulated probabilities of extinction were low for most populations with the probability of introduction of exotic species at baseline values, with the exception of Leland Harris Springs Complex (Peterson and Saenz 2013, p. 30). The simulations suggested that this wetland population was more vulnerable to invasion by mosquitofish and catastrophic disturbance, which is due a combination of smaller size of the patches and the fewer number of patches compared to other wetland populations (Peterson and Saenz 2013, p. 30). Nonetheless, the simulated mean time to extinction for all populations was greater than 80 years for all populations under most simulated conditions except the extreme catastrophic disturbance probabilities 0.05 (Peterson and Saenz 2013, p. 30). Even under these extreme conditions simulated mean time to extinction exceeded 60 years for all populations (Peterson and Saenz 2013, p. 30).

Table 6.3. Probability of extinction in 100 years for least chub populations in wetland complexes estimated using the 10k iterations of the wetland dynamic model and baseline values and three levels of probability of catastrophic disturbance, Pr(*disturbance*), and probability of mosquito introduction, Pr(MOF). Source: Peterson and Saenz 2013, p. 58.

	Pr(disturbance) = 0			Pr(disturbance) = 0.025			Pr(disturbance) = 0.05		
Population	Pr(MOF) = 0	Pr(MOF) = 0.023	Pr(MOF) = 0.046	Pr(MOF) = 0	Pr(MOF) = 0.023	Pr(MOF) = 0.046	Pr(MOF) = 0	Pr(MOF) = 0.023	Pr(MOF) = 0.046
Mean years to extinction									
Bishop Springs	100	100	86	88	86	83	76	73	73
Gandy Salt Marsh	100	99	93	96	93	93	90	86	85
Leland Harris Spring Complex	100	90	81	93	81	76	86	71	65
Mills Valley Meadows	99	99	99	99	99	99	98	98	98
Mills Valley Meadows (ppt)[1]	94	94	94	93	93	93	86	86	86

[1]Simulations were run using simulated precipitation data from the NOAA weather station used for Gandy Salt Marsh (Partoun).

Simulations of constant reductions in patch depth at a site indicated that least chub at Leland Harris Spring Complex were most sensitive to reductions in average patch depth, whereas Bishop Springs was least sensitive (Peterson and Saenz 2013, p. 30). Simulations of patch dynamics at Leland Harris Spring Complex indicated that extinction probabilities increased rapidly after relatively small reductions (> 0.2 m) in average patch depth (Peterson and Saenz 2013, p. 30). The simulated response of least chub at Gandy Marsh was intermediate to the two

extremes (Peterson and Saenz 2013, p. 30). These simulations suggest that the effects of hypothetical groundwater reductions on least chub wetland populations would be detected first in Leland Harris Spring Complex (Peterson and Saenz 2013, p. 30). They also suggest that evaluations (or models) of groundwater change should have sufficient resolution to be able to predict changes in wetland surface water levels of much less than a meter (Peterson and Saenz 2013, p. 30).

If groundwater reductions were detected at least chub population sites in the Snake Valley, monitoring by UGS suggests that Russian olive (*Eleagnus angustifolia*) removal at the sites may decrease evapotranspiration and increase available water in the wetland complexes. This has been seen at Foote Reservoir where UDWR personnel removed a small forest of Russian olive trees covering about 13 acres around Foote Reservoir and the outlet stream in 2012. A linear regression on pre-tree-removal discharge (Figure 6.22) shows a slight downward trend, whereas the discharge after the trees were removed trends up. Non-native Russian olive and saltcedar trees have been implicated in increased water loss from riparian systems through evapotranspiration in the West since the 1980s (UGS Draft Report 2013, sec. 5.4.3.2, p. 44). Recent research on removal of Russian olive and saltcedar trees on riparian ecosystems in the West (Shafroth et al. 2010 in UGS Draft Report 2013, sec. 5.4.3.2, p. 44) suggests that removal of these two non-native trees may not conserve water in the stream as compared to water consumption by native cottonwood and willow species; however, the Foote Reservoir area did not support large trees before the Russian olive invasion over the past two decades (UGS Draft Report 2013, sec. 5.4.3.2, p. 44). UGS data suggest more water is flowing in the stream channel since the removal of the trees (UGS Draft Report 2013, sec. 5.4.3.2, p. 45). Discharge trends will continue to be closely monitored by UGS.

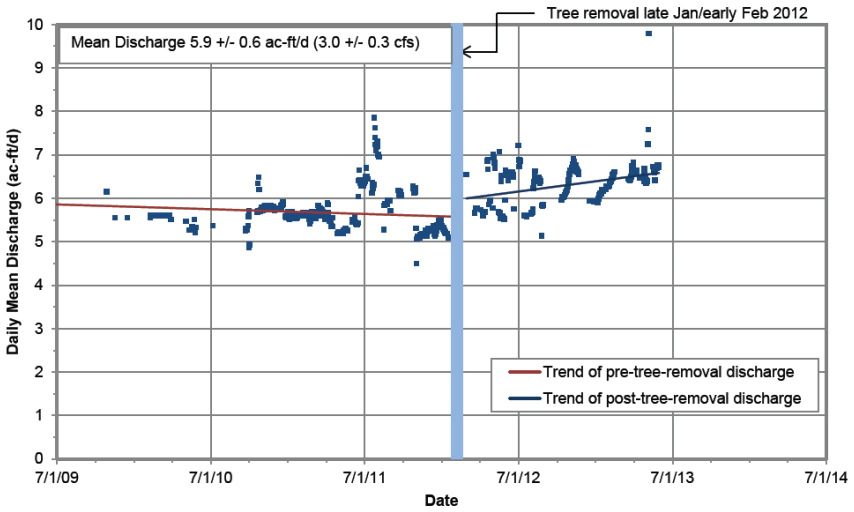


Figure 6.22. Hydrograph for Foote Reservoir Spring. Source: UGS Draft Report 2013, sec. 5.4.3.2, p. 44.

Census

Decennial data from the United States Census from 1980 to 2010 show that the human population is increasing in Juab and Millard counties; nearly doubling in 30 years in Juab (85% increase) and a 40% increase over the same years in Millard County (Figure 6.23). However, when evaluating the block groups (small census units) specific to the least chub population sites, the population has remained steady or decreased slightly (Table 6.4). It is likely the urban centers in the respective counties, although small, are driving the County trends, therefore, over the next 50 years, it is unlikely that the population will increase substantially in the areas surrounding least chub population sites in the Snake Valley.

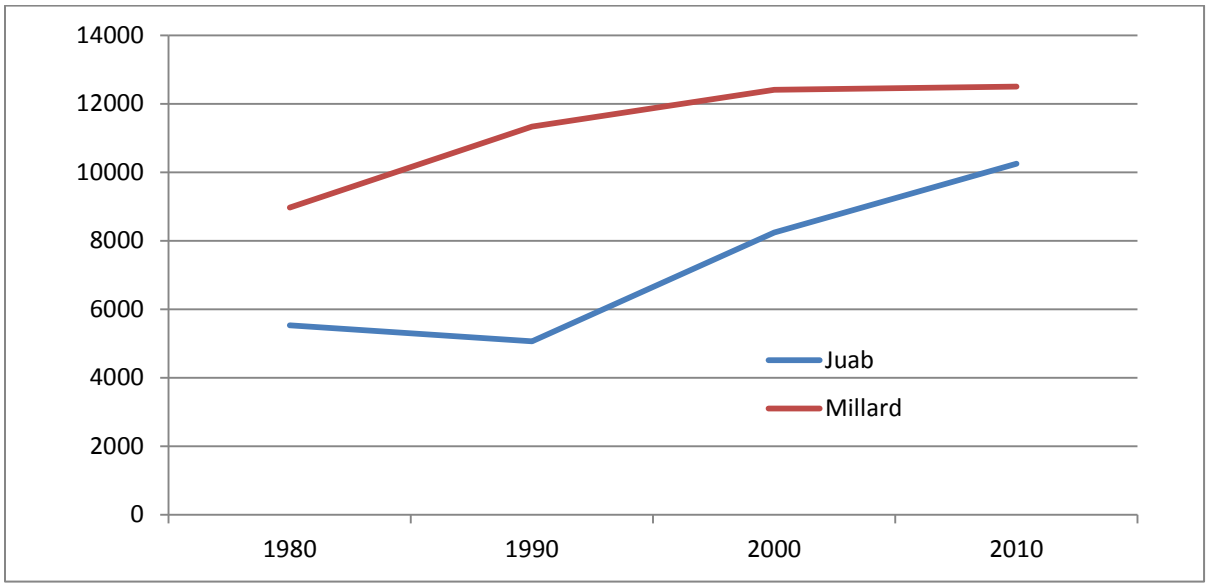


Figure 6.23. Population change in Juab and Millard Counties during the Census counts.

Table 6.4. Population change (represented by number of individuals across years) by block groups encompassing Snake Valley populations.

Block Group #	1980	1990	2000	2010
#490239732002 Juab County	N/A	174	268	187
#490279742003 Millard County	N/A	258	200	160
Snake Valley Water Zone	N/A	N/A	377	260

Although the human population may not increase significantly in the next 50 years, irrigation activities have increased in the Snake Valley (Welsh et al. 2007, p. 66). These activities are primarily located within the agricultural centers of Baker, Garrison, Eskdale, and Callao, but the trend suggests increases in the future (Figure 6.24).

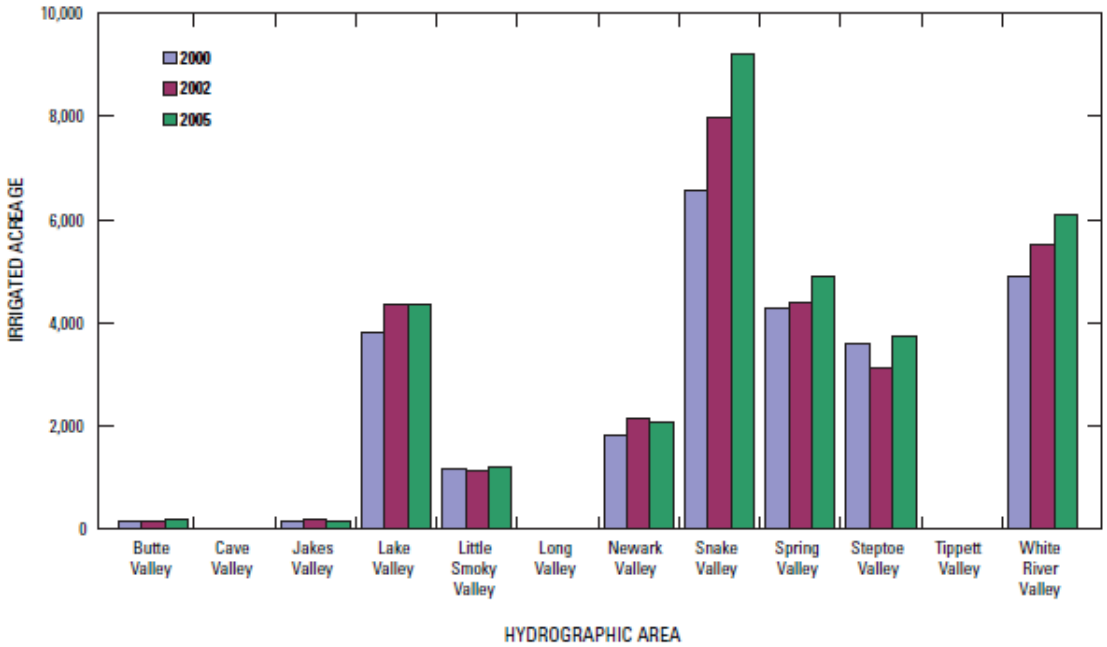


Figure 6.24. Estimates of irrigated acreage by hydrographic area within the carbonate-rock aquifer study area of Nevada and Utah. Source: Welsh et al. 2007, p. 66

Literature Cited

Arnow, T. 1964. Developing a State Water Plan. Ground-water conditions in Utah, spring of 1964. U.S. Geological Survey. Utah Department of Natural Resources Division of Water Resources, Cooperative Investigations Report No. 2. 132 pp.

BLM (U.S. Bureau of Land Management). 2012a, Clark, Lincoln, and White Pine Counties groundwater development project Final Environmental Impact Statement: FES 12-33, Document BLM/NV/NV/ES/11-17+1793, includes Supplements CD. Also available online, http://www.blm.gov/nv/st/en/prog/planning/groundwater_projects/snwa_groundwater_project/final_eis.html.

BLM (U.S. Bureau of Land Management). 2012b, Clark, Lincoln, and White Pine Counties groundwater development project record of decision: FEIS 12-33, Document BLM/NV/NV/ES/11-17+1793, includes Supplements CD. Also available online, http://www.blm.gov/nv/st/en/prog/planning/groundwater_projects/snwa_groundwater_project/record_of_decision.html.

Burden, C. 2013. Ground-water conditions in Utah, spring of 2013. U.S. Geological Survey. Utah Department of Natural Resources Division of Water Resources, Cooperative Investigations Report No. 50. 132 pp.

CSFCT (Columbia Spotted Frog Conservation Team). 2013. Columbia Spotted Frog Conservation Team Meeting Minutes, Annual Meeting, December 10, 2013. Salt Lake City, Utah. 6 pp.

Eychaner J. 1976. Developing a State Water Plan. Ground-water conditions in Utah, spring of 1976. U.S. Geological Survey. Utah Department of Natural Resources Division of Water Resources, Cooperative Investigations Report No. 14. 63 pp.

Garland, C. 2007. Rancher, Snake Valley, Utah. Pers. comm.

Harrill, J.R., Gates, J.S., and Thomas, J.M., 1988, Major ground-water flow systems in the Great Basin region of Nevada, Utah, and adjacent states: U.S. Geological Survey Hydrologic Investigations Atlas HA-694-C, scale 1:1,000,000.

Harrill, J.R., and Prudic, D.E., 1998, Aquifer systems in the Great Basin region of Nevada, Utah, and adjacent states—Summary report: U.S. Geological Survey Professional Paper 1409A, 66 p.

Heilweil, V.M., and Brooks, L.E., editors, 2011, Conceptual model of the Great Basin carbonate and alluvial aquifer system: U.S. Geological Survey Scientific Investigations Report 2010-5193.

Hickman, T.J. 1989. Status report of the least chub, *Iotichthys phlegethontis*, prepared for the U.S. Fish and Wildlife Service. Western Ecosystems, St. George, UT. 20 pp.

Hines, L.C., K.W. Wilson and C. L. Bailey. 2008. Least chub (*Iotichthys phlegethontis*) Conservation agreement and strategy assessment (1998-summer 2007). UDWR Publication number 08-21. 78 pp.

Holmes, W. and Thiros, S. 1990. Ground-Water Hydrology of Pahvant Valley and Adjacent Areas, Utah. USGS; Department Of Natural Resources; Division Of Water Rights, Technical Publication 98, Water Right Area 67.

Kikuchi, T. and B. Conrad. 2009. Press Release: Draft Agreement Released on the Management of the Snake Valley Groundwater System. Utah Department of Natural Resources and Nevada Department of Conservation and Natural Resources. 3 pp.

LCCRDA (Lincoln County Conservation, Recreation and Development Act). 2004. Public Law 108-424. An Act to establish wilderness areas, promote conservation, improve public land and provide for the high quality development in Lincoln County, Nevada, and for other purposes. 108th Congress of the United States of America. 17 pp.

LCCT (Least Chub Conservation Team). 2008a. Meeting minutes. December 17, 2008. pp. 5.

LCCT (Least Chub Conservation Team). 2008b. December 17, 2008. Meeting minutes attachment; Gandy Marsh, Bishop Springs, and Clear Lake least chub field report. 2 pp.

Loy, K., and Durbin, T., 2010, Simulation results report eastern Nevada - western Utah regional groundwater flow model: U.S. Department of Interior, available at http://www.blm.gov/ut/st/en/prog/more/doi_groundwater_modeling.html

Nevada State Engineer (NSE) 2007. The ruling (#5726) in the matter of applications 54003 through 54021, inclusive, filed to appropriate the underground waters of the Spring Valley hydrographic basin (184), White Pine County, Nevada.

NOAA (National Oceanic and Atmospheric Administration). 2013. National Climatic Data Center, accessed December 6, 2013 from http://www.ncdc.noaa.gov/cdo-web/search?datasetid=ANNUAL.

Patten, D. T., L. Rouse, and J. C. Stromberg. 2007. Isolated sprig wetlands in the Great Basin and Mojave Deserts, USA: Potential response of vegetation to groundwater withdrawal. 2008. Environmental Management 41-398-413.

Peterson, J.T. and J. Saenz. 2013. The development of an adaptive, decision-support tool for the conservation and recovery of least chub, *Iotichthys phlegethontis*. Draft interim final report, Oregon State University, December 18, 2013.

Plenert, M.L. 1990. U.S. Fish and Wildlife Service protest of Nevada water right applications. Comment letter. 4 pp.

Prudic, D.E. 2006. Response to memorandum by Rowley and Dixon regarding U.S. Geological Survey report titled “Characterization of surface-water resources in the Great Basin National Park

area and their susceptibility to ground-water withdrawals in adjacent valleys, White Pine county, Nevada". USGS, Open File Report 2006-1342. 16pp.

Sabey, A. 2008. Letter from Callao Irrigation Company president to Nevada State Engineer. 3 pp.

Seventh District Court. 2013. Ruling #6164. 218 pp.

Seiler 1985 Developing a State Water Plan. Ground-water conditions in Utah, spring of 1976. U.S. Geological Survey. Utah Department of Natural Resources Division of Water Resources, Cooperative Investigations Report No. 25. 84 pp.

Southern Nevada Water Authority, 2008a, Baseline characterization report for Clark, Lincoln, and White Pine Counties groundwater development project, in U.S. Bureau of Land Management, 2012, Clark, Lincoln, and White Pine Counties groundwater development project Final Environmental Impact Statement: FES 12-33, Document BLM/NV/NV/ES/11-17+1793, includes Supplements CD. Online, http://www.blm.gov/nv/st/en/prog/planning/groundwater_projects/snwa_groundwater_project/final_eis.html.

Southern Nevada Water Authority, 2009a, Conceptual model of groundwater flow for the central carbonate-rock province – Clark, Lincoln, and White Pine Counties groundwater development project, in U.S. Bureau of Land Management, 2012, Clark, Lincoln, and White Pine Counties groundwater development project Final Environmental Impact Statement: FES 12-33, Document BLM/NV/NV/ES/11-17+1793, includes Supplements CD: Online, http://www.blm.gov/nv/st/en/prog/planning/groundwater_projects/snwa_groundwater_project/final_eis.html.

Southern Nevada Water Authority, 2009b, Transient numerical model of groundwater flow for the central carbonate-rock province - Clark, Lincoln, and White Pine Counties groundwater development project, in U.S. Bureau of Land Management, 2012, Clark, Lincoln, and White Pine Counties groundwater development project Final Environmental Impact Statement: FES 12-33, Document BLM/NV/NV/ES/11-17+1793, includes Supplements CD: Online, http://www.blm.gov/nv/st/en/prog/planning/groundwater_projects/snwa_groundwater_project/final_eis.html.

Southern Nevada Water Authority, 2009c, Water resource plan 09, in U.S. Bureau of Land Management, 2012, Clark, Lincoln, and White Pine Counties groundwater development project Final Environmental Impact Statement: FES 12-33, Document BLM/NV/NV/ES/11-17+1793, appendix A-1: Online, http://www.blm.gov/nv/st/en/prog/planning/groundwater_projects/snwa_groundwater_project/final_eis.html.

Southern Nevada Water Authority, 2010a, Addendum to the groundwater flow model for the central carbonate-rock province - Clark, Lincoln, and White Pine Counties groundwater development project, in U.S. Bureau of Land Management, 2012, Clark, Lincoln, and White Pine Counties groundwater development project Final Environmental Impact Statement: FES 12-33, Document BLM/NV/NV/ES/11-17+1793, includes Supplements CD: Online,

http://www.blm.gov/nv/st/en/prog/planning/groundwater_projects/snwa_groundwater_project/final_eis.html.

Southern Nevada Water Authority, 2010b, Simulation of groundwater development scenarios using the transient numerical model of groundwater flow for the central carbonate-rock province - Clark, Lincoln, and White Pine Counties groundwater development project, in U.S. Bureau of Land Management, 2012, Clark, Lincoln, and White Pine Counties groundwater development project Final Environmental Impact Statement: FES 12-33, Document BLM/NV/NV/ES/11-17+1793, includes Supplements CD: Online, http://www.blm.gov/nv/st/en/prog/planning/groundwater_projects/snwa_groundwater_project/final_eis.html.

SNWA (Southern Nevada Water Authority). 2011, Southern Nevada Water Authority Clark, Lincoln, and White Pine Counties Groundwater Development Project Conceptual Plan of Development: Online, http://www.snwa.com/assets/pdf/wr_gdp_concept_plan_2011.pdf last accessed March 22, 2013.

SNWA (Southern Nevada Water Authority). 2008, Volume 1. Geology of White Pine and Lincoln Counties and Adjacent Areas, Nevada and Utah: The Geologic Framework of Regional Groundwater Flow Systems, January 2008.

SNWA (Southern Nevada Water Authority). 2011, Southern Nevada Water Authority Clark, Lincoln, and White Pine Counties Groundwater Development Project Conceptual Plan of Development March 2011: Online, http://www.snwa.com/ws/future_gdp.html.

Steele R. 2008. Letter from Rupert Steele, Chairman Confederated Tribes of the Goshutes Reservation to Tracy Taylor, Nevada State Engineer. Nevada Division of Water Resources, Carson City, Nevada. 4 pp.

Styler, M. and A. Biaggi. 2009. Draft: Agreement for Management of the Snake Valley Groundwater System. Utah Department of Natural Resources and Nevada Department of Conservation and Natural Resources. 39 pp.

Summers, P. 2008. Hydrogeologic analysis of Needle Point Spring, Fillmore Field Office, Utah. Updated July 18, 2008. BLM National Science and Technology Center, Denver CO. Unpublished Report. 5 pp.

Three Parameters Plus, 2010, Baseline Physical Habitat Conditions of Wetlands in Snake Valley, Utah - Final Report: Contract Report to the Utah Department of Natural Resources, Endangered Species Program: available online from the Utah Department of Natural Resources Library, http://utsl.sirsi.net/uhtbin/cgisirsi/?ps=x7IL9erPnf/DNR/71740053/123.

UDWR (Utah Division of Wildlife Resources). 2011, Utah Sensitive Species List: Online, http://dwrcdc.nr.utah.gov/ucdc/ViewReports/SSLAppendices20110329.pdf, 150 p., accessed January 4, 2012.

UDWRi (Utah Division of Water Rights). 2001. Water Rights Area May with Policy by Area. Accessed March 10, 2014 from http://www.waterrights.utah.gov/wrinfo/policy/wrareas/default.asp

UDWRi (Utah Division of Water Rights). 2009a. Data Printout for Water Rights in Iron County, Utah. http://www.waterrights.utah.gov/wrinfo/query.asp. Accessed online on September 18, 2009. 31 pp.

UDWRi (Utah Division of Water Rights). 2009b. Orders of the State Engineer for Water Right/Claim Nos: 17-77/A57001, 69-69/A56999, and19-330/A57002. 10 pp.

UDWRi (Utah Division of Water Rights). 2009c. Data Print out for Water Rights on SITLA lands within range of the least chub. http://www.waterrights.utah.gov/wrinfo/query.asp. Accessed online on September 18, 2009. 14 pp.

UDWRi (Utah Division of Water Rights). 2009d. http://www.waterrights.utah.gov/wrinfo/policy/wrareas/area53.html. http://www.waterrights.utah.gov/wrinfo/policy/wrareas/area63.html. http://www.waterrights.utah.gov/wrinfo/policy/wrareas/area68.html. http://www.waterrights.utah.gov/wrinfo/policy/wrareas/area18.html. Accessed online on 11/03/2009. 8 pp.

UDWRi (Utah Division of Water Rights). 2013a. Area 18—Snake Valley. Accessed December 19, 2013 from http://www.waterrights.utah.gov/wrinfo/policy/wrareas/area18.asp.

UDWRi (Utah Division of Water Rights). 2013b. Area 53—Goshen and Northern Juab Valleys. Accessed December 19, 2013 from http://www.waterrights.utah.gov/wrinfo/policy/wrareas/area53.asp.

UDWRi (Utah Division of Water Rights). 2013c. Area 66—Lower Sevier River. Accessed December 19, 2013 from http://www.waterrights.utah.gov/wrinfo/policy/wrareas/area66.asp.

UDWRi (Utah Division of Water Rights). 2013d. Area 67—Pahvant Valley. Accessed December 19, 2013 from http://www.waterrights.utah.gov/wrinfo/policy/wrareas/area67.asp.

UDWRi (Utah Division of Water Rights). 2013e. Wells drilled in 2012. Accessed December 19, 2013 from http://www.waterrights.utah.gov/wellinfo/wellstats/wellsPerYear.asp?y=2012

UDWRi (Utah Division of Water Rights). 2013f. Water rights policy, sevier river basin. Accessed December 19, 2013 from http://www.waterrights.utah.gov/wrinfo/policy/sevier.htm

UDWRi (Utah Division of Water Rights). 2014a. Area 15. Accessed March 10, 2014 from http://www.waterrights.utah.gov/wrinfo/policy/wrareas/area15.asp

UDWRi (Utah Division of Water Rights). 2014b. Area 31. Accessed March 10, 2014 from http://www.waterrights.utah.gov/wrinfo/policy/wrareas/area31.asp

UDWRi (Utah Division of Water Rights). 2014c. Area 54. Accessed March 10, 2014 from http://www.waterrights.utah.gov/wrinfo/policy/wrareas/area54.asp

UDWRi (Utah Division of Water Rights). 2014d. Area 59. Accessed March 10, 2014 from http://www.waterrights.utah.gov/wrinfo/policy/wrareas/area59.asp

UDWRi (Utah Division of Water Rights). 2014e. Area 25. Accessed March 10, 2014 from http://www.waterrights.utah.gov/wrinfo/policy/wrareas/area25.asp

UDWRi (Utah Division of Water Rights). 2010. Snake Valley Agreement: Online, http://waterrights.utah.gov/snakeValleyAgreement/default.asp, accessed January 4, 2012.

USFWS (U.S. Fish and Wildlife Service). 2004. Comprehensive conservation plan – Fish Springs National Wildlife Refuge: Online, http://www.fws.gov/mountain-prairie/planning/ccp/ut/fhs/fhs.html.

UGS (Utah Geological Survey). 2013. Draft Hydrogeologic Studies and Groundwater Monitoring in Snake Valley and Adjacent Hydrographic Areas, West-Central Utah and East-Central Nevada.

Welch, A.H., Bright, D.J., and Knochenmus, L.A., 2007, Water resources of the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Scientific Investigations Report 2007-5261, 96 p.

Wheeler, K. K., R. A. Fridell and J. A. Bryant. 2004. Least chub (*Iotichthys phlegethontis*) Monitoring Summary: Snake Valley, 2004. Utah Division of Wildlife Resources, Salt Lake City, Utah. Publication Number 04-33. 28 pp.

Wilson, K.W. 2006. Letter, regarding status of spotted from and least chub relative to potential west desert groundwater pumping. Native Aquatic Species Program Coordinator, UDWR, Salt Lake City, UT. June 27, 2006. 13 pp.