Groundwater Modeling to Assess Water Resources Management Alternatives for the Town of Clarkdale, Arizona

Prepared for

The Town of Clarkdale

by

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Tucson, Arizona

Executive Summary

This study describes Clarkdale's hydrology and municipal water resources, projects future demand and effluent production, and assesses the viability and effectiveness of various water management strategies through groundwater modeling. The main body of the report explores the potential for the Town of Clarkdale to transition to a more sustainable model of water management through reuse and/or recharge of treated effluent. Presently, about 85% of Clarkdale's high-quality treated effluent is lost to evaporation and evapotranspiration (ET) with no direct benefit to the community. This study projects that, as the Town grows, sewering most new residential development could increase the Town's supply of treated effluent from 132 AF/yr to more than 1,000 AF/yr in the next 40 to 50 years. Groundwater simulations incorporating projected potable demand and various options for effluent recharge demonstrate that effluent can protect water supply wells from declining groundwater levels, thereby reducing the Town's operations and maintenance (O&M) burden for water production. Significantly increasing both the volume of treated effluent and the percentage of that effluent that reaches the groundwater system via recharge could measurably reduce Clarkdale's impact on the Verde River over the next several decades. However that impact [estimated at 0.5 to 1 cubic feet per second (cfs), or 360 to 720 acre-feet per year (AF/yr)] is so small relative to Verde River flows that other water management strategies may be more beneficial to the Town's efforts to meet its sustainability goals.

As an alternative to direct recharge, using treated effluent to offset consumptive potable water uses, such as irrigation of Town parks and school grounds, provides the same type of benefit as direct recharge in terms of conservation of diminishing groundwater supplies and reduced utility O&M costs. While initial capital costs for effluent delivery infrastructure may be significant, they may be less than the long-term cost of piping and recharging effluent into the deep aquifer. Other direct use of treated effluent, such as for agricultural irrigation, tourist amenities, or industrial use, may generate revenue to support the Town's water management efforts. In addition to providing an alternative to consumptive use of diminishing groundwater supplies, reuse and/or recharge of treated effluent would align well with Clarkdale's stated Water Resources Management Plan (WRMP) mission (Mott Lacroix, Fullerton, Rupprecht, & Lacher, 2014) and its Sustainable Clarkdale effort (Town of Clarkdale, 2013).

The final section of this report provides a set of recommendations to move the Town forward in its effort to implement strategic planning and use for its high-quality treated effluent.

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Introduction

Water Resource Management Planning

In 2012, the Town of Clarkdale received a grant from the Walton Family Foundation to pursue, in cooperation with the University of Arizona's Water Resources Research Center (WRRC), the development of a Water Resources Management Plan (WRMP) (Filardo, 2012). As part of that process, the Town entered into professional services agreement with Lacher Hydrological Consulting (LHC) to provide groundwater modeling in support of the WRMP development process. The WRRC and the Town invited several experts in the areas of water resources management to serve on a WRMP Advisory Board to guide the WRMP process. The core WRMP working group, which included the WRRC, LHC, and Town of Clarkdale staff, convened several town hall and small-town forums to stimulate the sharing of ideas within the Clarkdale community and between the Town of Clarkdale and other small communities facing similar water related issues.

In December 2014, the WRRC produced its report on water management plan recommendations for the Clarkdale WRMP (Mott Lacroix, Fullerton, Rupprecht, & Lacher, 2014). That report identified a list of water resources issues confronting the Town of Clarkdale, and recommended specific actions designed to move Clarkdale toward its stated WRMP mission: *"Clarkdale provides a water resources management program that meets the needs of residents, businesses and our natural environment equitably in order to be a robust and resilient community."* The issues identified in the WRRC's report include:

- non-revenue water caused by aging infrastructure and municipal interconnections;
- determination of the best uses for treated effluent;
- stormwater management;
- limited revenue due to small town size;
- the impact of small domestic wells;
- decreasing Verde River flows; and
- a limited groundwater supply.

The report recommended the following actions for the Town of Clarkdale:

- develop a comprehensive Water Loss Control program;
- public engagement on water sustainability and values;
- develop a Strategic Plan for the reuse of effluent;
- understand and plan for stormwater and rainwater resources;
- link land-use planning to water management; and
- create a Community Water Budget.

Purpose of This Study

This study describes the key tasks of the hydrological component of the WRMP development process. This task focused on gathering hydrologic and water management information to support groundwater modeling of future development scenarios including minimum, maximum, and probable future demand and effluent production and management scenarios for the Clarkdale area. The groundwater modeling was designed to support and reflect current planning efforts by the Town of Clarkdale to optimize its

water production and use of its current and anticipated future treated effluent to support its WRMP objectives.

Clarkdale's Water Resources

Physiographic and Geologic Setting

Clarkdale's town center, in Yavapai County, lies at approximately 3,475 feet (ft) above mean sea level, on high ground overlooking the Verde River valley to the east and within sight of the mouth of the Verde Canyon to the north. Founded in 1912 to house Jerome mine employees, Clarkdale's long association with the mining industry reflects its position on the edge of a highly faulted area along the western margin of the Verde River basin where hydrothermal activity has produced intense mineralization. Figure 1 shows the Town of Clarkdale boundary overlain on a geologic map. The western boundary of Clarkdale generally aligns with the contact between the Tertiary Verde Formation to the east and Paleozoic bedrock to the west. Lindbergh (2010) provides a detailed discussion of the structural sequence of events that led to today's Verde River graben (structural valley). Figure 2 shows a geologic cross section (Lindbergh, 2010) along the A-A' transect in Figure 1 and identifies the area underlying Clarkdale. Figure 3 provides descriptions of the geologic formations in the Clarkdale area (Lehner, 1958).

Natural recharge to the Verde Valley occurs primarily through infiltration of snowmelt along the Mogollon Rim, discharging as streamflow in Oak Creek and other tributaries on the north and east side of the valley. Blasch, Hoffman, Graser, Bryson, & Flint (2006) suggest that the Black Hills, particularly the Wood Chute and Mingus Mountain areas, also provide recharge along the southwest margin of the Verde Valley. Figure 4 shows potential recharge zones in the upper and middle Verde River basins delineated on the basis of hydrogen and oxygen isotope data (Blasch, Hoffman, Graser, Bryson, & Flint, 2006). The presence of a large fault zone in a recharge zone (eastern margin of Black Hills) provides a good environment for the formation of springs and fracture-flow bedrock aquifers. Haskell Springs in southwest Clarkdale (see Haskell Springs Well in Figure 1) is an example of a highly productive spring (or springs) that produced abundant, high-quality water for many decades [the well was originally developed in 1952 (Arizona Department of Water Resources, 2015)]. That spring, like many others in Arizona, has ceased to flow above ground surface as a result of reduced recharge and possibly other factors, and is now the location of a productive, though limited volume, municipal well for the Town of Clarkdale.

Groundwater

In addition to the Haskell Springs well currently in use by the Town of Clarkdale [production capacity about 250 gallons per minute (gpm) (Yates, 2015)], at least three other wells have been drilled nearby in an attempt to increase production from the prolific fracture zone along the foothills of Mingus Mountain in Clarkdale. Most recently, Southwest Groundwater Consultants (SGC) supervised the drilling of an exploratory well in 2002 less than 0.25 mile from the Town's municipal well (Southwest Ground-water Consultants, Inc., 2002). The 625-foot-deep boring penetrated the Mississippian Redwall Limestone and the Devonian Martin Formation as well as partially penetrating the Cambrian Tapeats Formation. The presence of these Paleozoic formations at this elevation suggest a vertical offset (downdrop) from the top of Mingus Mountain of over 2,000 feet (ft) (see Figure 2). At the time of drilling, the static water level was 197 ft below ground surface, and below the bottom of the karstic Redwall formation. Steep groundwater gradients across the three wells in the small Haskell Springs area (17 ft across a few hundred yards) reported by SGC (2002) also indicate fracture-controlled flow, with production coming from both the Redwall and Martin formations.

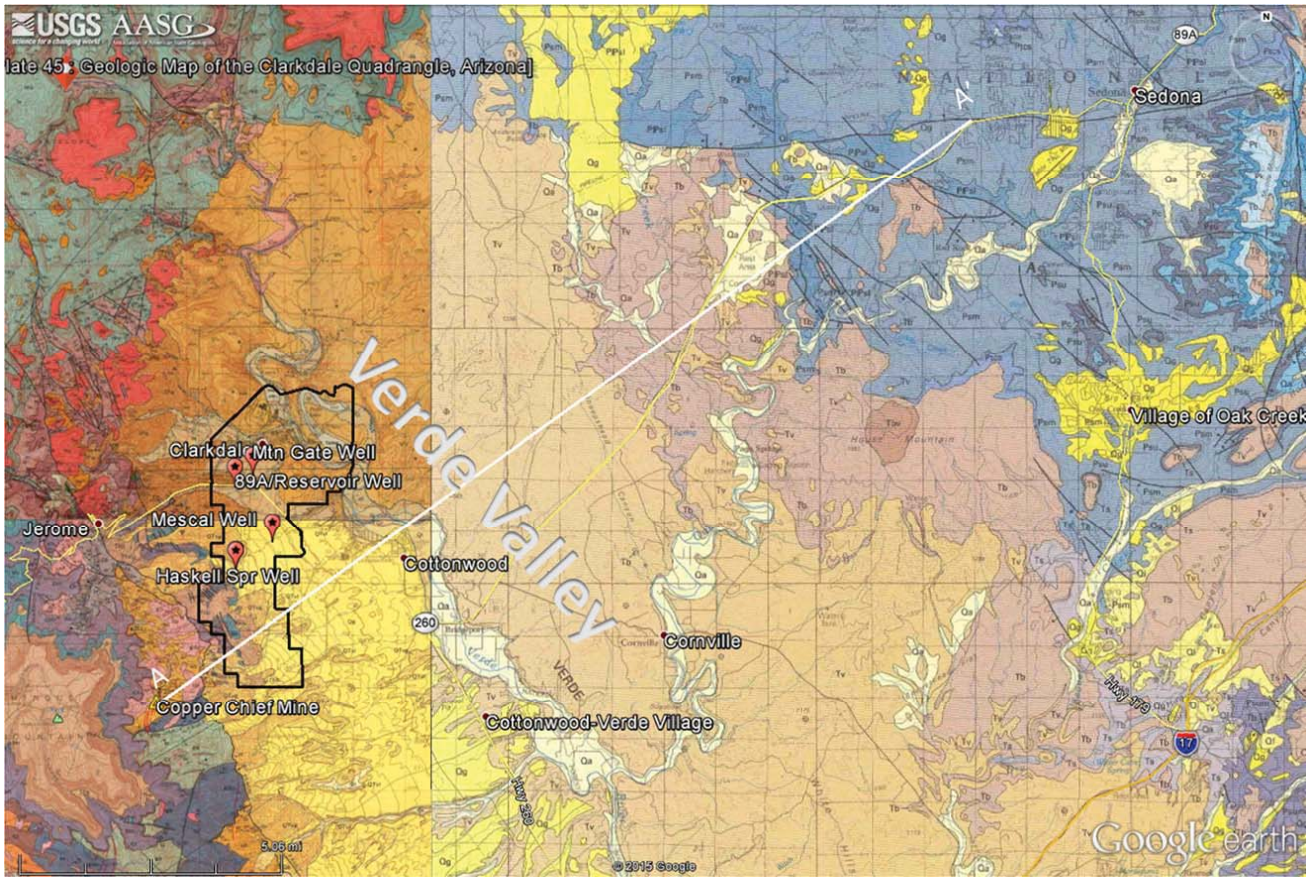

Figure 1. Geologic map of Clarkdale area (adapted from Lehner, 1958; Anderson and Creasey, 1967; Weir, Ulrich, and Nealey, 1989). Clarkdale municipal wells indicated with red pointers).

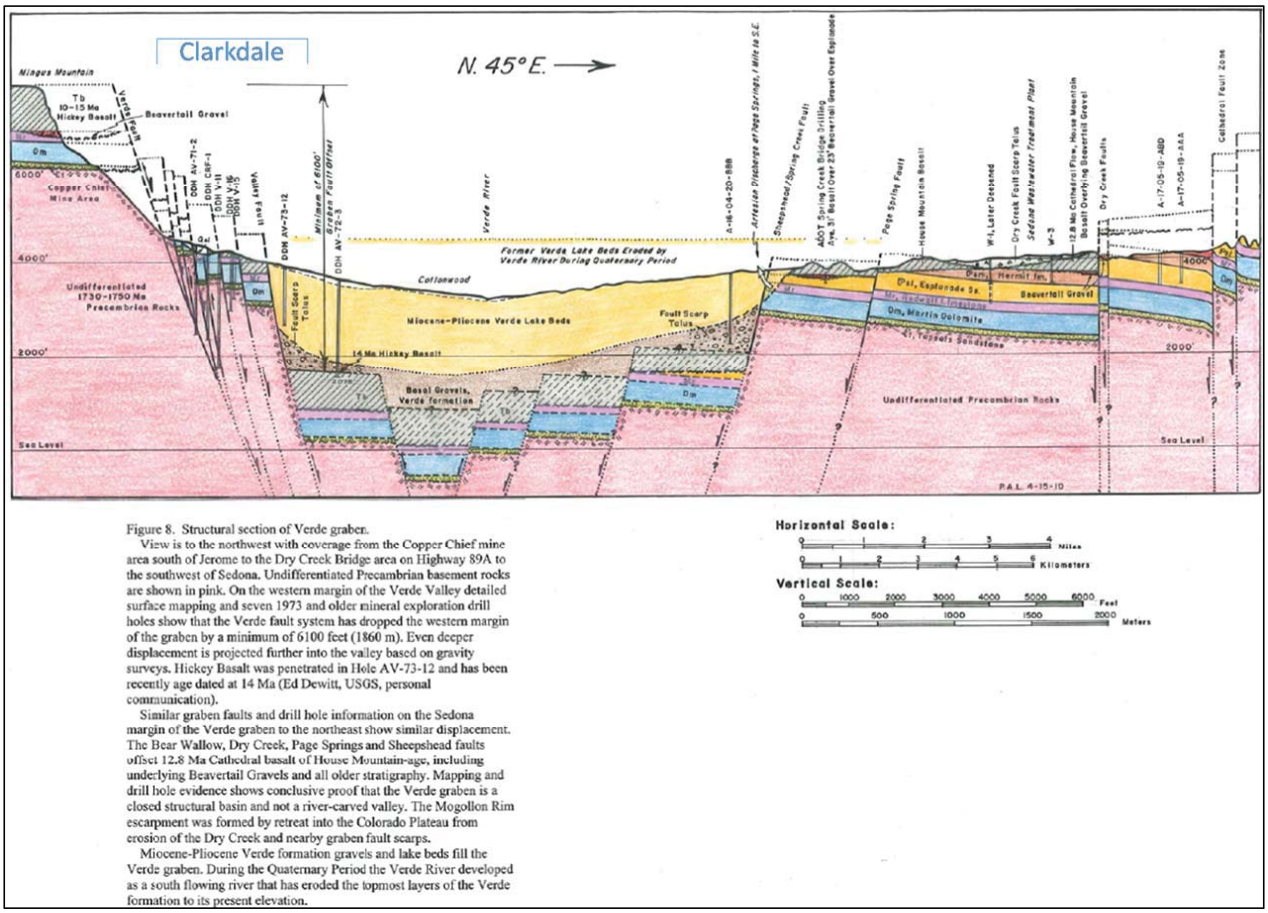

Figure 8. Structural section of Verde graben.

View is to the northwest with coverage from the Copper Chief mine area south of Jerome to the Dry Creek Bridge area on Highway 89A to the southwest of Sedona. Undifferentiated Precambrian basement rocks are shown in pink. On the western margin of the Verde Valley detailed surface mapping and seven 1973 and older mineral exploration drill holes show that the Verde fault system has dropped the western margin of the graben by a minimum of 6100 feet (1860 m). Even deeper displacement is projected further into the valley based on gravity surveys. Hickey Basalt was penetrated in Hole AV-73-12 and has been recently age dated at 14 Ma (Ed Dewitt, USGS, personal communication).

Similar graben faults and drill hole information on the Sedona margin of the Verde graben to the northeast show similar displacement. The Bear Wallow, Dry Creek, Page Springs and Sheepshead faults offset 12.8 Ma Cathedral basalt of House Mountain-age, including underlying Beavertail Gravels and all older stratigraphy. Mapping and drill hole evidence shows conclusive proof that the Verde graben is a closed structural basin and not a river-carved valley. The Mogollon Rim escarpment was formed by retreat into the Colorado Plateau from erosion of the Dry Creek and nearby graben fault scarps.

Miocene-Pliocene Verde formation gravels and lake beds fill the Verde graben. During the Quaternary Period the Verde River developed as a south flowing river that has eroded the topmost layers of the Verde formation to its present elevation.

Horizontal Scale:

0 1 2 3 4 Miles

0 1 2 3 4 5 6 Kilometers

Vertical Scale:

0 1000 2000 3000 4000 5000 6000 Feet

0 500 1000 1500 2000 Meters

Figure 2. Geologic cross-section along A-A' transect in Figure 1 (Lindbergh, 2010).

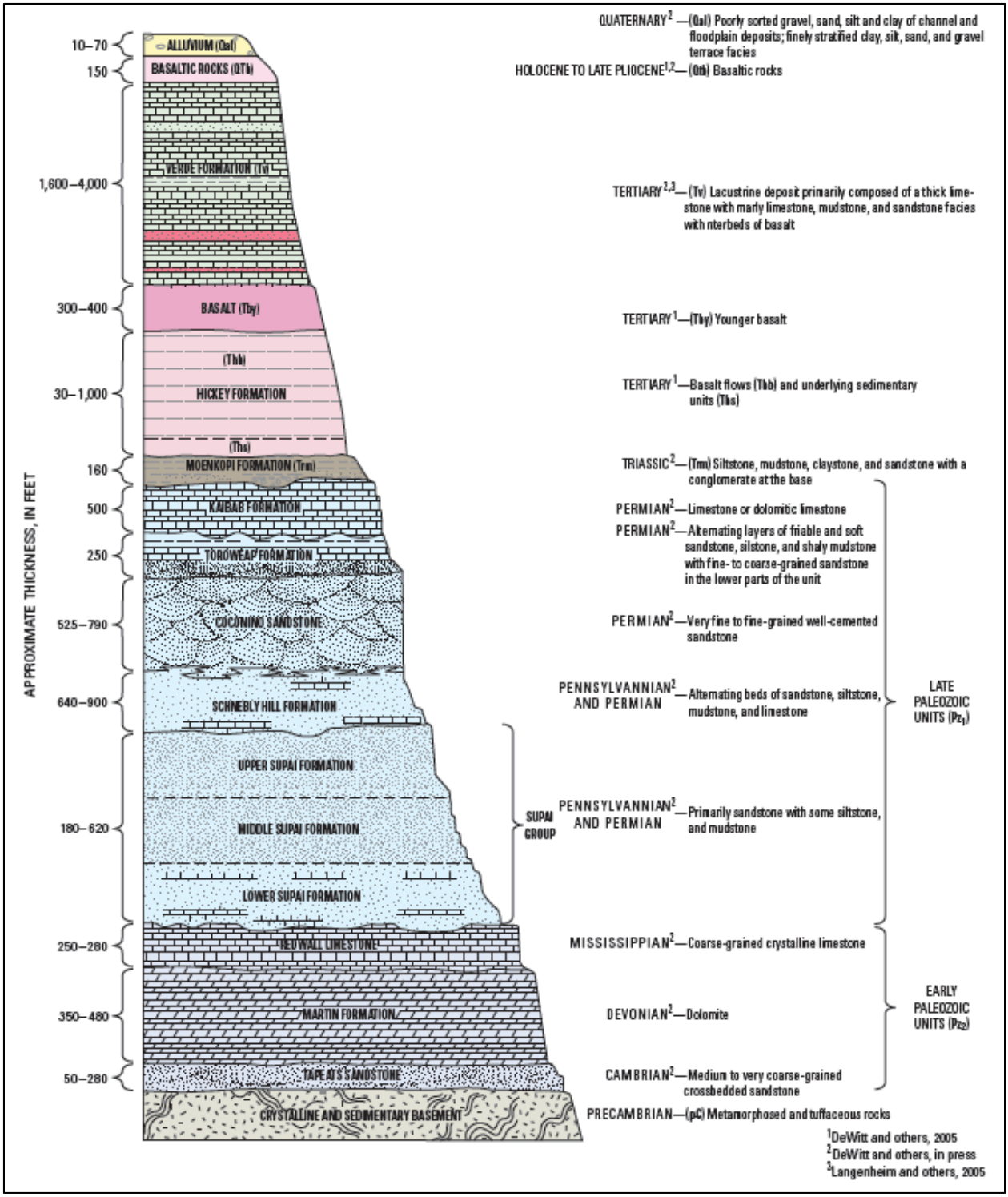

Figure 3. Generalized stratigraphic section of the geologic formations in the Middle Verde River basin, Arizona (Blasch, Hoffman, Graser, Bryson, & Flint, 2006).

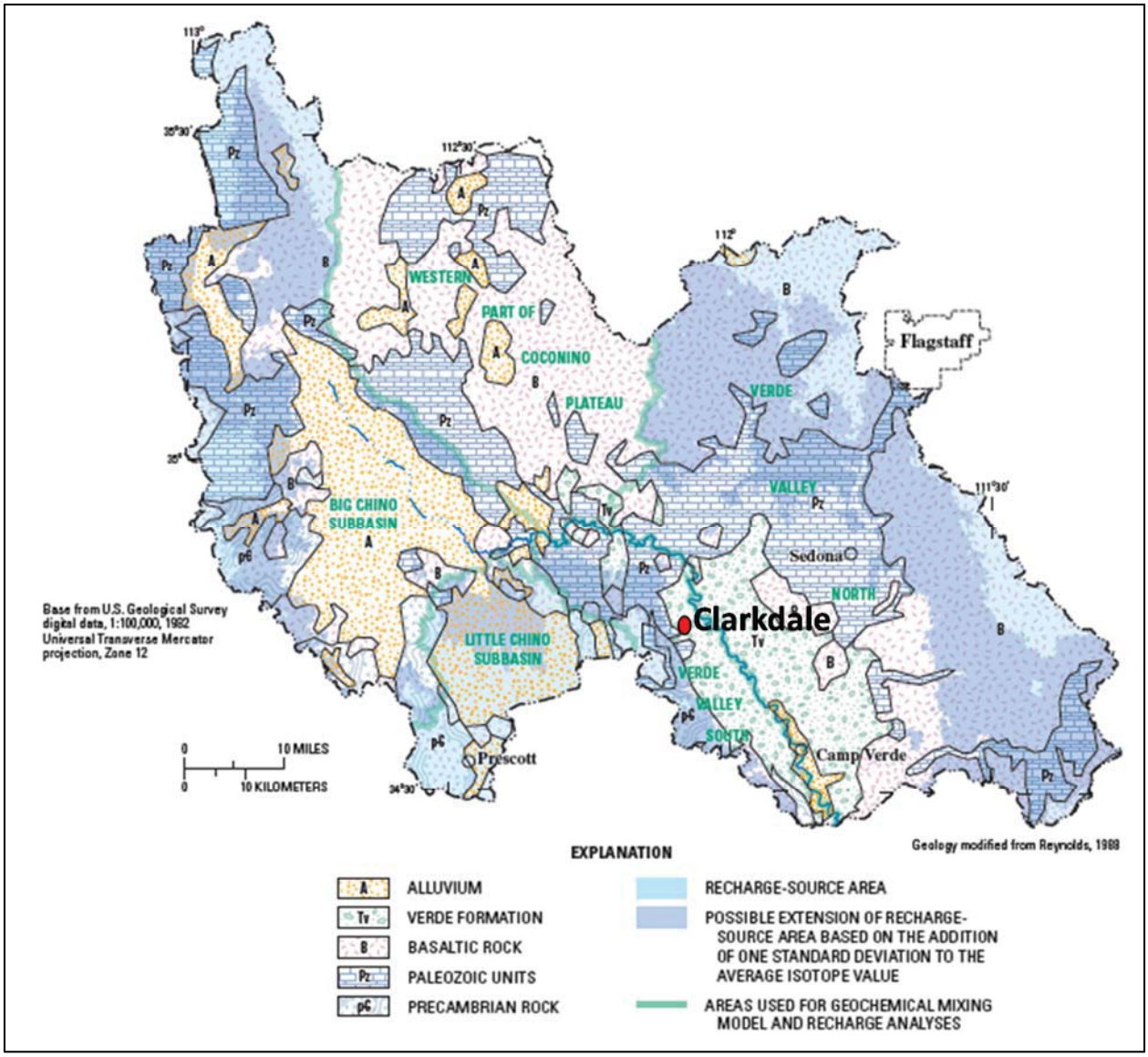

Figure 4. Potential recharge source areas in the upper and middle Verde River basins, Arizona [adapted from Blasch, Hoffman, Graser, Bryson, & Flint (2006)].

In 2004, SGC installed and tested the Mescal Well, farther from the base of Mingus Mountain along Mescal Gulch and about 0.9 miles northeast of Haskell Springs (Figure 5). As indicated in Figure 5, the Mescal Well lies well within the bounds of the Tertiary Verde Formation (QTvl and QTvg). Figure 6 provides construction and hydrogeologic characteristic data from the Mescal Well completion report (Southwest Ground-water Consultants, Inc., 2004). As indicated in Figure 6, the Mescal Well penetrates interbedded alluvium (possibly fanglomerates) and Verde Formation, with its primary production zone from in the lower Verde and underlying alluvial deposits between 635 and 1,300 ft below ground surface. Despite its depth (1,300 ft), the aquifer testing on this well indicates that it has only moderate transmissivity (T = 1,900 gallons per day per foot (gpd/ft) (Southwest Ground-water Consultants, Inc., 2004), which corresponds to a horizontal conductivity (HK) value of about 2.8 ft/d (0.12 m/d). SGC recommended a production rate of 300-400 gallons per minute (gpm) for this well, which remains unused at this time.

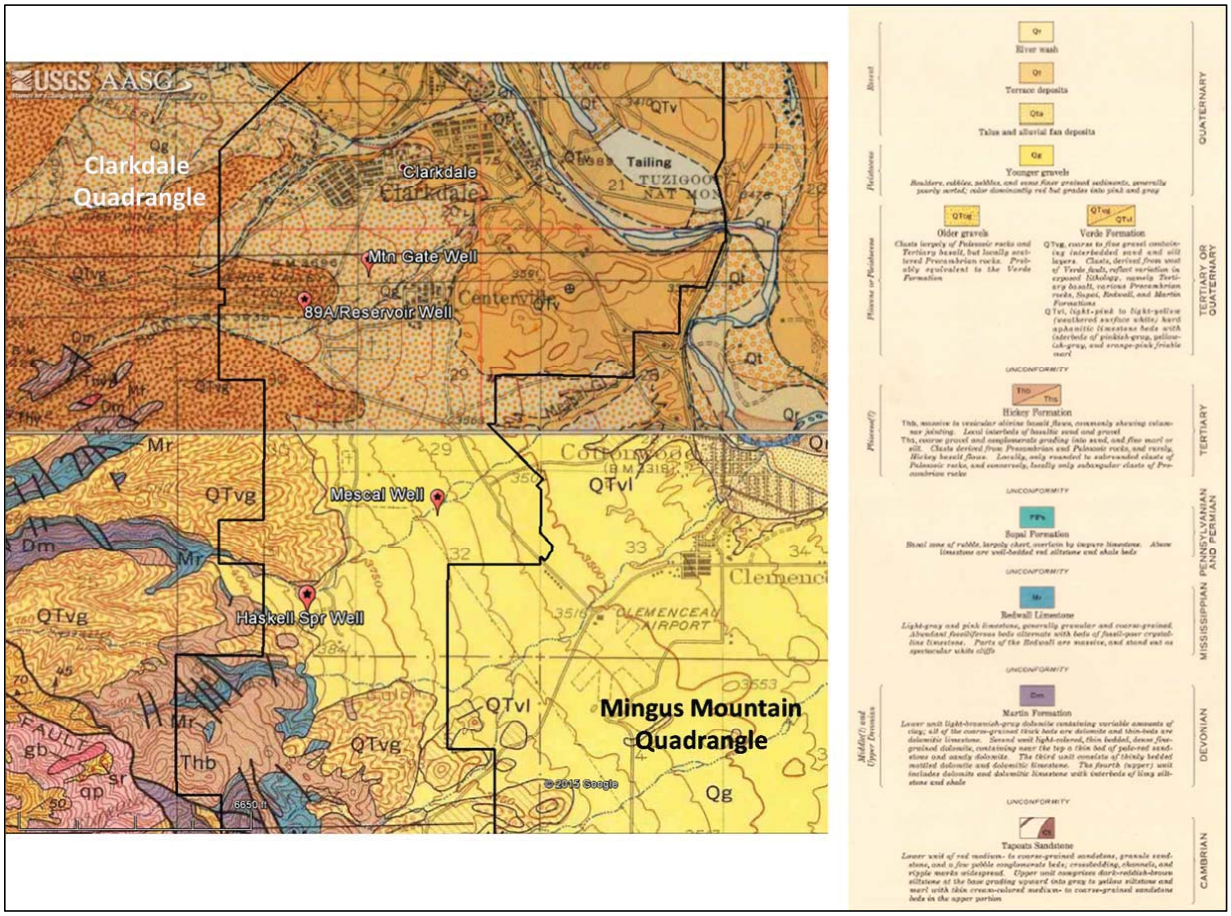

Figure 5. Detailed view of Clarkdale municipal wells overlain on geologic maps of the Clarkdale (Lehner, 1958) and Mingus Mountain (Anderson & Creasey, 1967) quadrangle.

Mescal Well (2004)

DEPTH INTERVAL (ft bgs)	LITHOLOGY
0-250	ALLUIVIUM – Boulders, cobbles, and gravel. Boulders consist of primarily basalt with a moderate amount of limestone. Cuttings are primarily gravel size.
250-390	Sandy MUDSTONE (Verde Formation) – Brown, lightly consolidated mudstone. Sand is fine to very fine.
390-490	ALLUIVIUM – Cemented sand, gravel, and cobbles. Cutting fragments are angular. High percent of basalt.
490-630	Sandy MUDSTONE (Verde Formation) – Brown, lightly consolidated mudstone. Sand is fine to very fine.
630-730	SANDSTONE (Verde Formation) – Light reddish brown. Approximately 60% sand and 40% fines. Sand consists of fine to very fine grains of mixed source. High percent of quartz and moderate percent of basalt. Lightly to moderately consolidated.
730-1,500	ALLUIVIUM – Cemented sand, gravel, and cobbles. High percent of basalt. Moderate percent of limestone and dolomite. Cuttings are primarily sand size.

Recommended production rate: 300 gpm/24 hr (483 AF/yr)

Estimated Aquifer Thickness (b) = (1300'-635') =665'

T=1900 gpd/ft = HKb (from aquifer test)

Estimated HK = 2.85 ft/d (0.12 m/d)

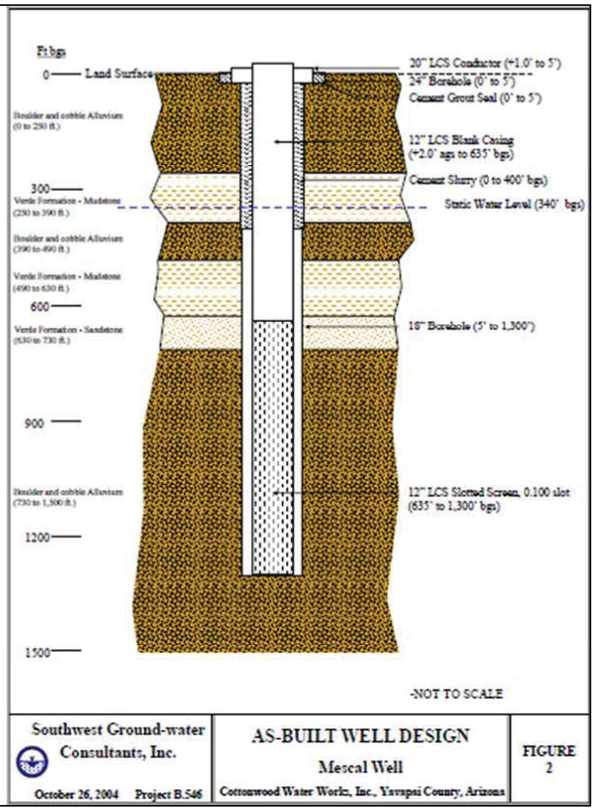

Figure 6. Lithologic log, well-construction diagram, and hydrologic properties of the Mescal Well [adapted from Southwest Ground-water Consultants, Inc. (2004)].

Following the Mescal Well, SGC oversaw the drilling, installation, and testing of the Mountain Gate Well in 2005 (Southwest Ground-water Consultants, Inc., 2005). The Mountain Gate Well is roughly 1.3 miles north-northwest of the Mescal Well and about 0.7 mile south of Bitter Creek (see Figure 1). This well also produces from the Verde Formation and underlying gravels over a zone from 510 ft to 1,377 ft below ground surface (Southwest Ground-water Consultants, Inc., 2005). Figure 7 shows lithologic, well-construction, and hydrologic characteristics data for the Mountain Gate Well from the well completion report (Southwest Ground-water Consultants, Inc., 2005). Despite being screened over a similar interval and lithology as the Mescal Well, the Mountain Gate Well proved to be much more productive, with a T value of 12,000 gpd/ft derived from aquifer test data (Southwest Ground-water Consultants, Inc., 2005). Assuming a saturated thickness of 867 ft, the aquifer HK is approximately 13.8 ft/d (4.2 m/d). SGC suggested a production capacity of about 1,400 gpm for the Mountain Gate Well. Since 2008, Clarkdale has utilized solely the Mountain Gate and Haskell Springs wells for municipal production. SCG also noted an arsenic concentration of 0.031 parts per million (or mg/L) in the Mountain Gate Well at the time of initial sampling, which exceeds the federal drinking water standard of 0.01 ppm. The Town of Clarkdale's arsenic treatment facility treats groundwater from the Mountain Gate Well. The 89A/Reservoir Well shown in Figure 5 is just 0.4 mile from the Mountain Gate Well, but remains out of service due to mechanical issues with the casing (Debrosky W. , 2014). Table 1 provides data from the Arizona Department of Water Resources Wells-55 Registry for all of the non-exempt municipal wells owned by the Town of Clarkdale (Arizona Department of Water Resources, 2015). **Based on the recommended and observed capacities, Clarkdale's municipal wells can produce about 2,050 gpm or 3,300 AF/yr.**

Clarkdale's Community Water Budget

In 2006, the Town of Clarkdale took ownership of the municipal water supply wells within the Town limits. Prior to that time and through 2009, Cottonwood Water Works, a private water company, operated the wells in Clarkdale and those in Cottonwood as part of a combined water supply system for the two communities (Debrosky W. , 2015). The system operated by Cottonwood Water Works consisted of several smaller private water systems combined without the benefit of having been engineered to work as one system (Debrosky W. , 2015). Once the Town of Clarkdale assumed operation of its own water system in 2009, Clarkdale bought water from, and sold water to, the City of Cottonwood (via inter-municipal system connections) to assist in meeting municipal demands in both communities. In 2010, the Town of Clarkdale and the City of Cottonwood entered into an Inter-municipal Agreement metering the Blackhills Drive connection (previously not metered) and setting a water purchase rate between the communities. As of December 2015, Clarkdale still provides water to Cottonwood Ranch, but that transfer is anticipated to cease in the near future (Yates, 2015). Cottonwood is in the process of bringing a new water supply to Cottonwood Ranch, which would obviate its need to purchase water from Clarkdale (Debrosky W. , 2015).

While Clarkdale has made many upgrades to its historic (dating back to 1912) municipal system, information about the interconnections between the Town of Clarkdale and the City of Cottonwood is sparse and some unknown connections may still exist (Debrosky W. , 2014). Although pumping capacity is sufficient for average demand, the Town's distribution of storage capacity has made managing peak-demand periods difficult in times of drought. To address this issue, Clarkdale is installing a duplex booster pump system to transfer water from the 89A Reservoir storage site to the Haskell Springs Reservoir storage tanks, which should eliminate Clarkdale's need to buy water from the City of Cottonwood.

Mountain Gate Well (2005)

DEPTH INTERVAL (ft-bgs)	LITHOLOGY
0-1,030	ALLUIVIUM – Cemented sand, gravel, and cobbles. High percent of basalt. Majority of cuttings are medium to coarse sand size. Moderate amount of fine gravel pieces. Gravel pieces show roundness and calcareous cement.
1,030-1,180	Clayey SANDSTONE (Verde Formation) – Light reddish brown. Approximately 60% sand and 40% fines. Sand consists of fine to very fine grains from a mixed source. High percent of quartz and moderate percent of basalt. Lightly to moderately consolidated.
1,030-1,690	ALLUIVIUM – Boulders, cobbles, and gravel with a clay matrix. Cuttings are predominantly basalt with moderate percentage of limestone and dolomite. Small percentage of fines. Fines are brown, moderately to highly plastic, high to very high dry strength, moderate toughness, and no dilatancy. Cuttings are primarily coarse sand size.

Arsenic concentration = 0.031 mg/L.
Estimated production ≥1400 gpm (2,258 AF/yr)

Estimated Aquifer Thickness (b) = (1377'-510') = 867'

T = 12,000 gpd/ft = HKb (from aquifer test)

Estimated HK= 13.8ft/d (4.2 m/d)

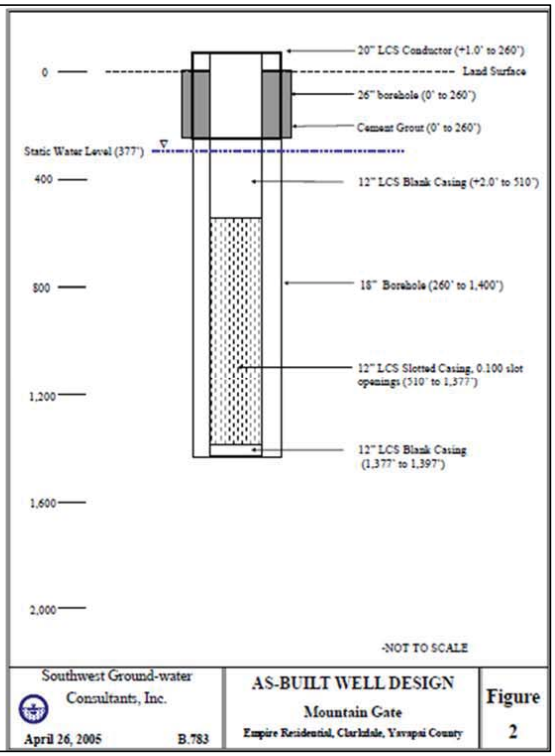

Figure 7. Lithologic log, well-construction diagram, and estimated hydraulic properties for the Mountain Gate Well [adapted from Southwest Ground-water Consultants, Inc., (2005)].

Table 1. Arizona Department of Water Resources Data for Clarkdale Municipal Wells (Arizona Department of Water Resources, 2015).

Clarkdale ID	Reg No.	GWSI Site ID	Cadastral	Owner Name	Well Type	Well Depth (ft)	Casing Depth (ft)	Case Dia (in)	Drill Date	Application Date	Water Level	Pump Capacity (GPM)	Pump Data Available	Comp-letion Report	Log Re-ceived	UTM X (meters)	UTM Y (meters)
Haskell Springs3	503444	344408112035901	A16003031DCA	TOWN OF CLARKDALE	NON-EXEMPT	600	450	14.00	4/12/2001	2/1/2000		700	YES	X	X	402243.50	3844195.00
Haskell Springs1	609073	344409112035901	A16003031DCA	TOWN OF CLARKDALE	NON-EXEMPT	225	150	10.00	1/1/1961	5/14/1982	11.00	470	YES			402243.50	3844195.00
Haskell Springs2	568005		A16003031DCA	TOWN OF CLARKDALE	NON-EXEMPT	540	16		6/29/1999	4/1/1998	110.00		NO		X	402243.50	3844195.00
89A/Reservoir	609072	344533112040001	A16003030ABD	TOWN OF CLARKDALE	NON-EXEMPT	925	925	8.00	1/1/1957	5/14/1982	0.00	200	YES			402276.00	3846803.00
Mtn Gate	202370		A16003020CCC	EMPIRE RESIDENTIAL	NON-EXEMPT	1690	1400	12.00	5/15/2004	2/6/2004	600.00	800	YES		X	402878.10	3847204.00
Mescal	202140		A16003032BAC	TOWN OF CLARKDALE	NON-EXEMPT	1500	1280	12.00	7/2/2004	1/23/2004			NO		X	403247.30	3845198.00

In the presence of ongoing water transactions between Clarkdale and Cottonwood, Clarkdale continues to experience periods of exceptionally high water loss, or "non-revenue" water production (Yates, 2015). Figure 8 shows well production for each of Clarkdale's active municipal wells, total production, and total demand (metered deliveries to customers) from 2007 through 2014. The positive difference between the total production curve (blue) and the total demand curve (grey) is non-revenue water. The fate of this non-revenue water is unknown but it may be lost in an unknown cross connection with Cottonwood (Debrosky W. , 2014).

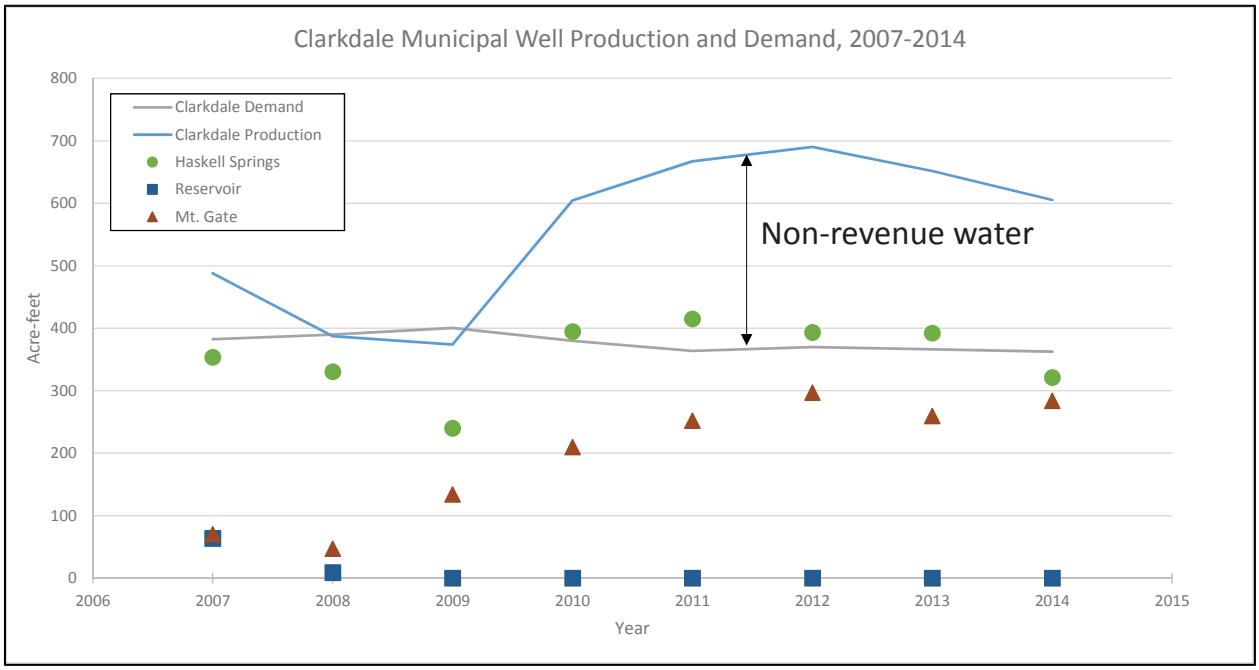

Figure 8. Clarkdale municipal well production and demand, 2007-2014 (Yates, 2015).

The Town has undertaken a strenuous effort to locate the source of water loss in their system through metering and leak-detection surveys, and is now in the final stages of developing a hydraulic model of the municipal water distribution system to identify zones of pressure loss (Debrosky W. , 2014). The Town's 2014 WRMP Recommendations Report identified this problem as the Town's highest priority water issue (Mott Lacroix, Fullerton, Rupprecht, & Lacher, 2014, p.31).

Potable Demand and Wastewater Management

Wastewater from the sewered connections in Clarkdale flows by gravity to the Town's wastewater treatment system near the Verde River (Figure 9). As of December 2014, 1,043 (58%) out of 1,801 municipal water customers were also served by the municipal sewer system. Sewered wastewater is treated at the Town's wastewater treatment facility (WWTF) to Class A^+ quality, suitable for many uses.[1] Presently, Clarkdale is only permitted to dispose of its treated effluent [average flow of 0.35 million gallons per day (MGD)] by land application (spray irrigation) at what is now referred to as the Bitter Creek irrigation area (formerly Verde River Iron Company irrigation site) as per Aquifer Protection Permit No. P-105414, approved October 28, 2013 (Figure 9).

[1] Class A+ effluent meets the highest standard for effluent treatment, including low nitrate concentration and disinfection, defined by the Arizona Department of Environmental Quality (Arizona Administrative Code, 2008).

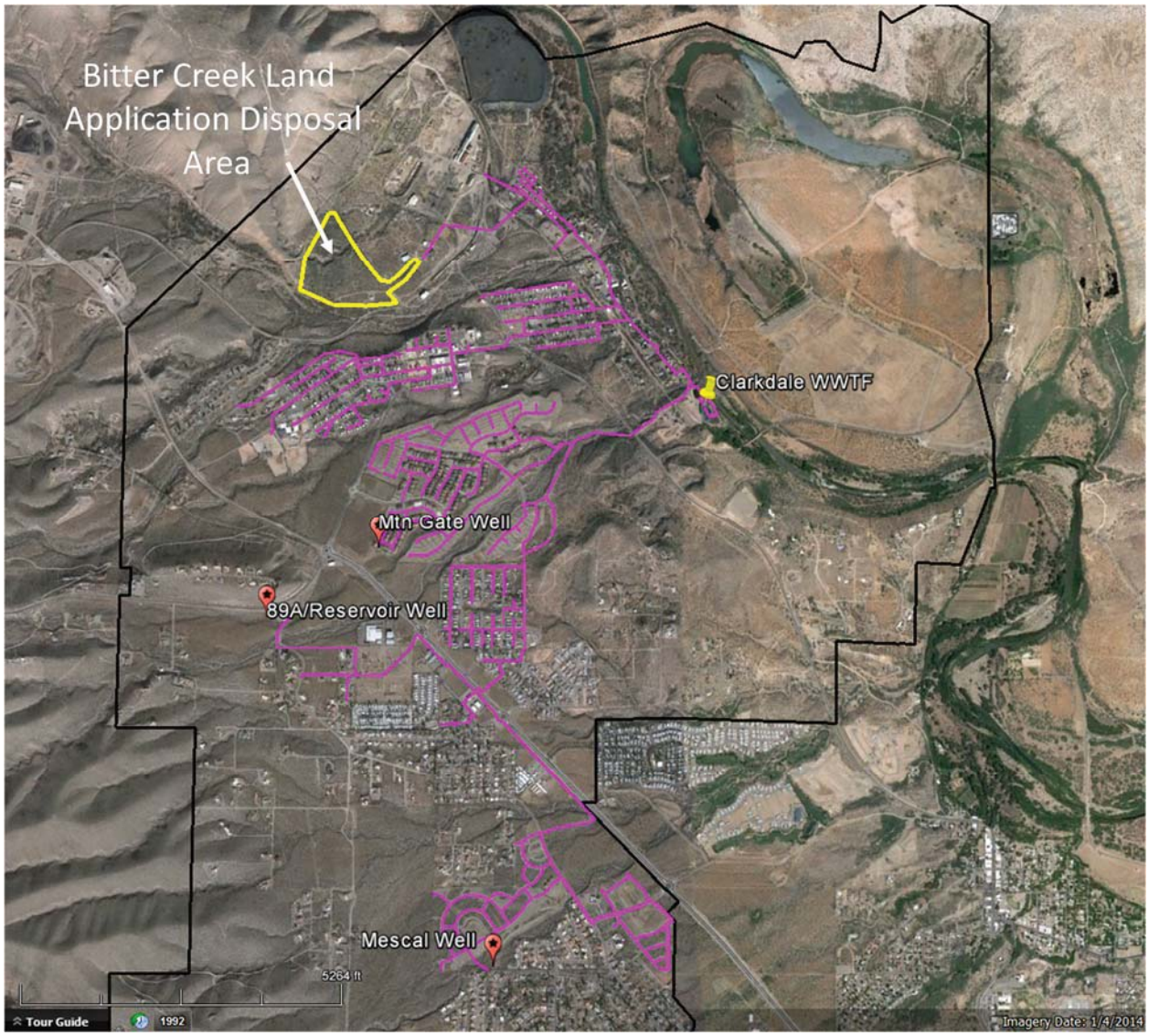

Figure 9. Clarkdale sewer distribution system (purple lines), wastewater treatment facility (yellow pin), and Bitter Creek land-application disposal area for treated effluent (yellow outlined area).

Wastewater disposed of in septic systems is essentially lost to the local water budget because it is not available for any reuse. While a minor fraction of septic system drainage may infiltrate deep enough to eventually recharge groundwater, that process would take many years because of the deep water tables (several hundred feet except near the Verde River) in the Clarkdale area. The remainder of the septic system outflow is consumed by evaporation or remains locked in storage in the unsaturated zone above the water table.

The first two rows of Table 2 and Figure 10 show Clarkdale's 2014 residential and non-residential municipal demand (water sold) for June and December. June is the warmest month of the year and generally precedes the onset of monsoon season, so outdoor water use is generally at its maximum.

Table 2. Clarkdale municipal water demand and treated effluent production

2014 Municipal Water Demand and Total Effluent Production (gallons)				
	June	**December**	**June - December**	**Consumptive Use (JUN-DEC) as % of June Demand**
Residential Demand	10,808,129	7,788,027	3,020,102	28%
Non-residential Demand	2,037,654	566,128	1,471,526	72%
Total Demand	12,845,783	8,354,155	**4,491,628**	35%
Total Effluent	4,689,250	4,921,572	(232,322)	n/a
Total Consumptive Use + Unsewered Wastewater	8,156,533	3,432,583	**4,723,950**	n/a
Estimated TOTAL CONSUMPTIVE USE			**4,607,789**	**36%**

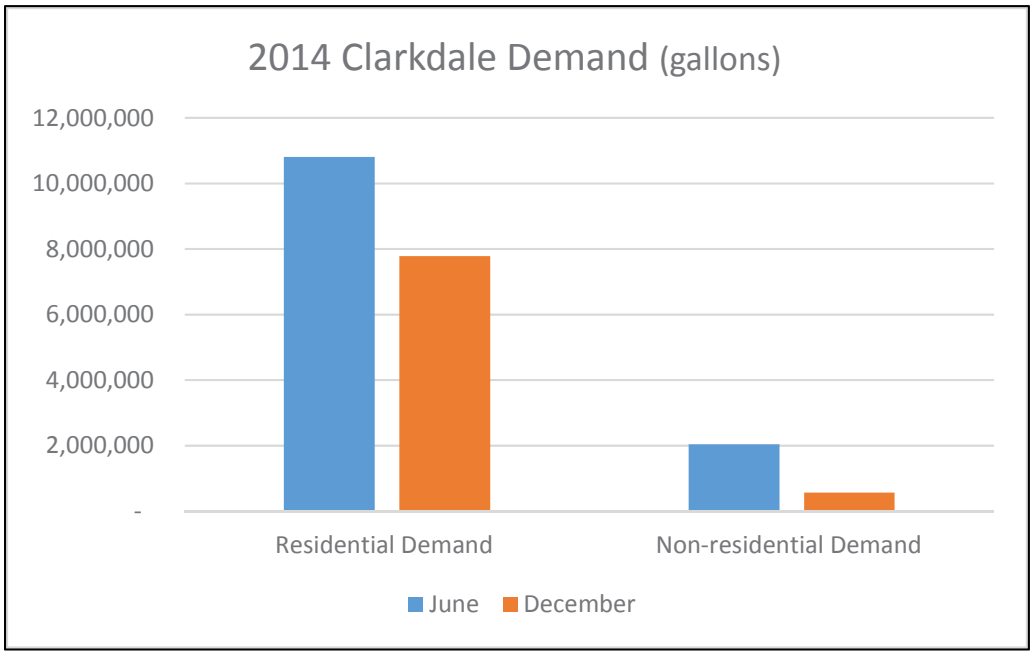

Figure 10. Clarkdale municipal demand and treated effluent production for June and December 2014 (Yates, 2015).

December is representative of winter water use, when most outdoor plants are dormant and consumptive use (water lost to evaporation or evapotranspiration) is minimal. Essentially all water demand in the winter months is for indoor water uses, of which nearly all is converted to wastewater. Subtracting December water demand from June demand provides an approximate value for seasonal consumptive use (e.g., outdoor watering, pools, etc.). The last column of the table shows this consumptive use as a percentage of June demand. For residential customers, seasonal consumptive use accounts for 29% of June demand, compared with 73% for non-residential customers. **Treated effluent production increases slightly from summer to winter, averaging about 4.8 million gallons (MG) year-round.**

The last three lines of Table 2 and Figure 11 present total demand, total treated effluent, and total consumptive use for all municipal water and sewer customers. Total demand declines from 12.8 MG in

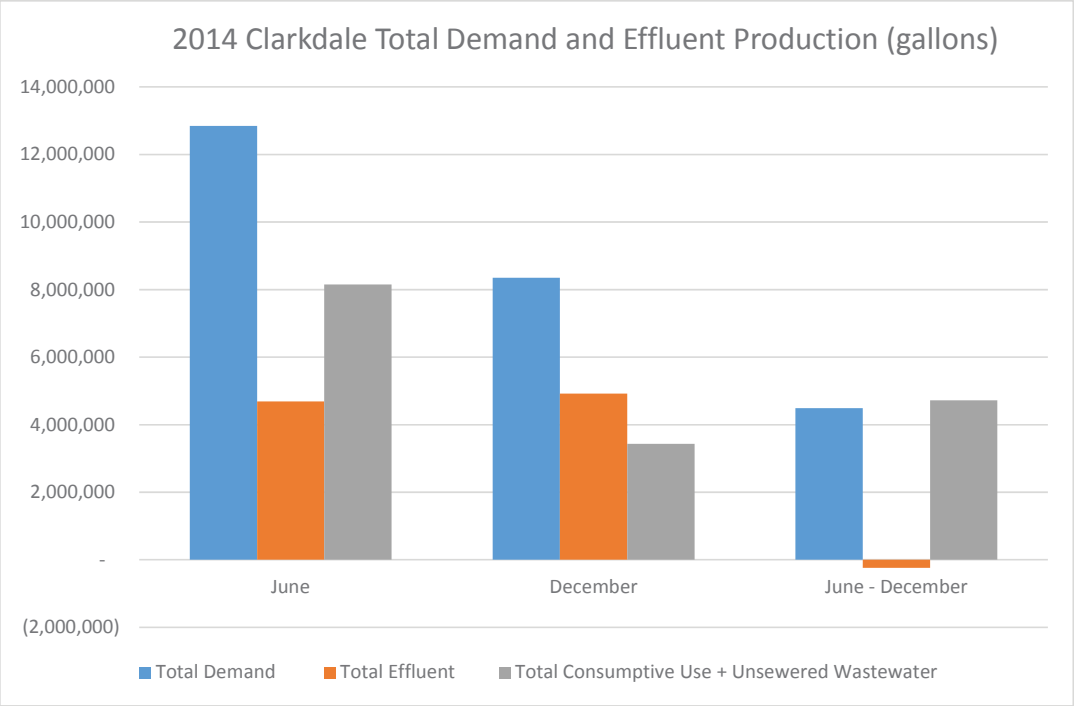

Figure 11. Clarkdale total municipal demand and effluent production (in gallons) for June and December 2014 (Yates, 2015). Grey bars are the difference between demand and effluent production, and represent all consumptive use and unsewered wastewater.

June to 8.3 MG in December, meaning that about 35% (4.5 MG) of total June demand is for consumptive purposes. The last line of Table 2 shows "Total Consumptive Use + Unsewered Wastewater." Because not all water customers have sewer service, this difference includes wastewater discharged to septic systems. This value is determined by subtracting Total Effluent from Total Demand in June (8.1 MG) and in December (3.4 MG), and represents the total potable water lost from the local water budget. The December value (3.4 MG) provides an estimate of unsewered wastewater since consumptive use is near zero in the winter. The difference between June and December demand values provides another estimate of annual consumptive use (4.7 MG). Averaging the two different methods for computing **consumptive use** yields total consumptive use value of 4.6 MG, which **constitutes 36% of total annual June demand**.

Figure 10 shows that, while residential demand makes up the majority of Clarkdale's total municipal demand, non-residential water use is more consumptive than residential water use. Figure 12 shows Clarkdale's water use by sector for June and December 2014. As shown in these two charts, residential water use makes up the bulk of Clarkdale's water demand. The difference between these two pie charts is total seasonal consumptive use (4.5 MG). This graphic shows that government water use (grey) has the largest seasonal variation of all non-residential uses. Government water use includes watering grass turf in parks and water use at the Clarkdale-Jerome School (Yates, 2015). The school irrigates most of its turf with water from the "Josephine Tunnel" ditch originating in Jerome, but some of it landscaping is watered with municipal water.

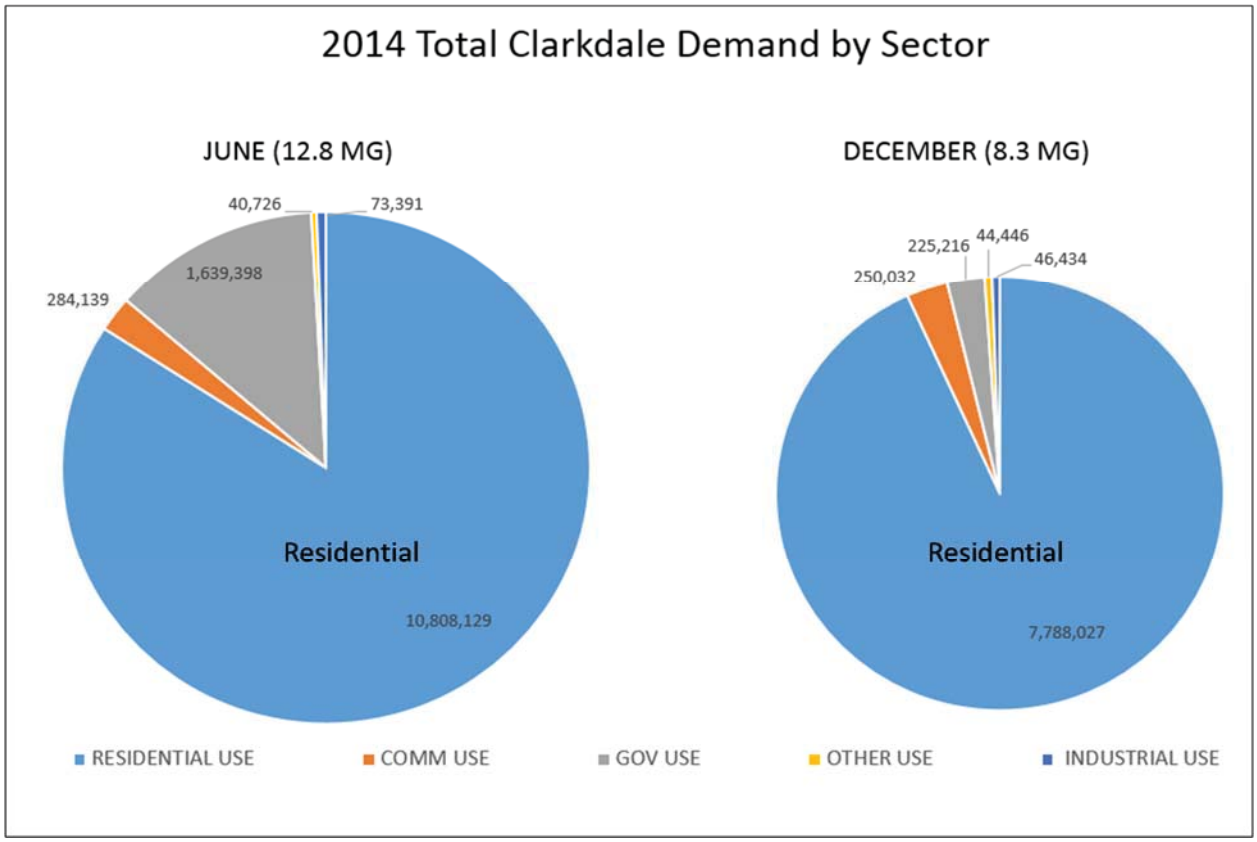

Figure 12. Total Clarkdale demand by sector for June and December 2014.

Projected Future Demand and Effluent Production

The 3.4 MG (0.11 MGD) of unsewered effluent estimated from the December value for "Total Consumptive Use + Unsewered Wastewater" in Table 2 represents a potential resource for the Town of Clarkdale. The Clarkdale WWTF is permitted for an average flow of 0.35 MGD, but December's treated effluent totaled just 4.9 MG, or 0.16 MGD. If all of the water customers were connected to the sewer system, the additional 0.11 MGD would increase effluent flow to the WWTF by 70%, bringing the total flow up to 0.27 MGD during December (a high effluent flow month).

In order to better understand the potential rate of growth in treated effluent production and demand from *new* development[2], planning and zoning maps and input from Town Planning and Economic Development staff were used to create a very general conceptual plan of projected sewer system growth in Clarkdale over the next 50 years. Appendix A provides background data and a description of the method used to develop the values in Table 3. Table 4 provides 2014 influent and effluent production statistics for the Town used to develop future influent and effluent production rates. The "Currently Sewered" section in Table 3 shows that actual influent to the Clarkdale WWTF for 2014 for all wastewater accounts totaled 160 AF. Using the estimation method described in Appendix A, which is based on monthly and

[2] Replacement of septic systems in existing homes with sewer connections is a potential source of additional effluent, but this component was not included in future projections as it represents a small and uncertain component of the potential future water budget of the Town of Clarkdale.

Table 3. Actual and estimated influent production for categories of sewer connection.

Estimated and Projected Clarkdale Influent Production			
Currently Sewered			
2014 Sewer Connections	**Number of Wastewater Accounts**	**Annual Influent Production**	
		gals	**AF**
Actual Influent Production	1,043	53,201,813	160
Estimated Influent Using 2014 Influent as % Demand	1,043	57,803,076	174
Projected Future Influent Production			
Sewer Connection Status	**Number of New Residential Units**	**Annual Influent Production**	
		gals	**AF**
Near-term	1,429	79,195,202	238
Foreseeable	1,790	99,201,827	299
Distant Future	1,789	99,146,407	298
Existing unsewered homes - TOTAL	669	37,075,990	112
Potential Additional Future Influent		314,619,427	947

Table 4. 2014 Town of Clarkdale Influent and Effluent Production Statistics

2014 Values			
2014 Raw influent production per wastewater account (gals)	Jun-14	Dec-14	**Average**
	4,518	4,719	**4,618**
Annual influent as % demand	44%		
Annual effluent treatment loss rate	18%		

annual total influent production[3] reports from the Town of Clarkdale, a value of 174 AF (9% higher than actual) was estimated for the 1,043 sewer connection accounts existing in 2014. This error results from attributing all reported wastewater influent to residential users despite the fact that: a) not all residential customers were sewered in 2014, and b) some wastewater accounts were non-residential. Applying the average value of 4,618 gallons (gals) of influent produced per wastewater account (see Table 4) to the estimated new residential connections in Table 3 yields the projected annual influent production rates for the various sewer connections status categories in the lower part of Table 3 (Near-term, Foreseeable, and Distant Future). The total potential additional future influent for all new development and existing unsewered homes is 947 AF per year.

Table 5 uses the resulting raw influent values from Table 3 to estimate values for projected treated effluent based on the 18% treatment loss rate observed in 2014 (Table 4). The sewer connection categories in Table 5 are assigned starting years for the purpose of groundwater simulation. Projected influent values are then used to estimate future potable water demand based on the 2014 relationship between total Clarkdale demand and influent production [44% of demand (Table 4)]. As Table 5 shows, future effluent production is projected to grow by about 200 to 250 AF for each sewer connection category (Near-term, Foreseeable, and Distant Future). Cumulative demand is projected to grow from about 400 AF/yr (2015) to almost 2,300 AF/yr by 2055 (Table 5). For the Town's 2010 application to the Arizona

[3] Wastewater influent data provided by the Town were not separated by account type.

Table 5. Estimated influent and effluent production and estimated potable water demand for sewer connection categories.

Approximate Starting Year	Sewer Connection Category	Future INFLUENT		Future EFFLUENT (18% loss rate)		Estimated Demand (Influent/0.44)	
		Incremental	Cumulative	Incremental	Cumulative	Incremental	Cumulative
		AF/yr	AF/yr	AF/yr	AF/yr	AF/yr	AF/yr
2015	Currently Sewered	174	174	143	143	392	392
2025	Near-term	238	412	196	340	538	930
2035	Foreseeable	299	711	246	585	673	1603
2055	Distant Future	298	1009	246	831	673	2276

Department of Water Resources for a Designation of Water Adequacy, SGC used US Census data to project 2030 demand at 1,666 AF/yr (Southwest Ground-water Consultants, Inc., 2010). Figure 13 plots incremental and cumulative projected effluent production (left axis) and cumulative projected potable water demand for Clarkdale (right axis) for the period 2015-2055. From this plot and from Table 5, this study's estimated 2030 demand is roughly 1,600 AF/yr and 2055 demand is about 2,300 AF/yr, not accounting for new commercial demand. **Based on an estimated production capacity of 3,300 AF/yr, Clarkdale's production capacity should be sufficient to meet its demand for the next 40 to 50 years.**

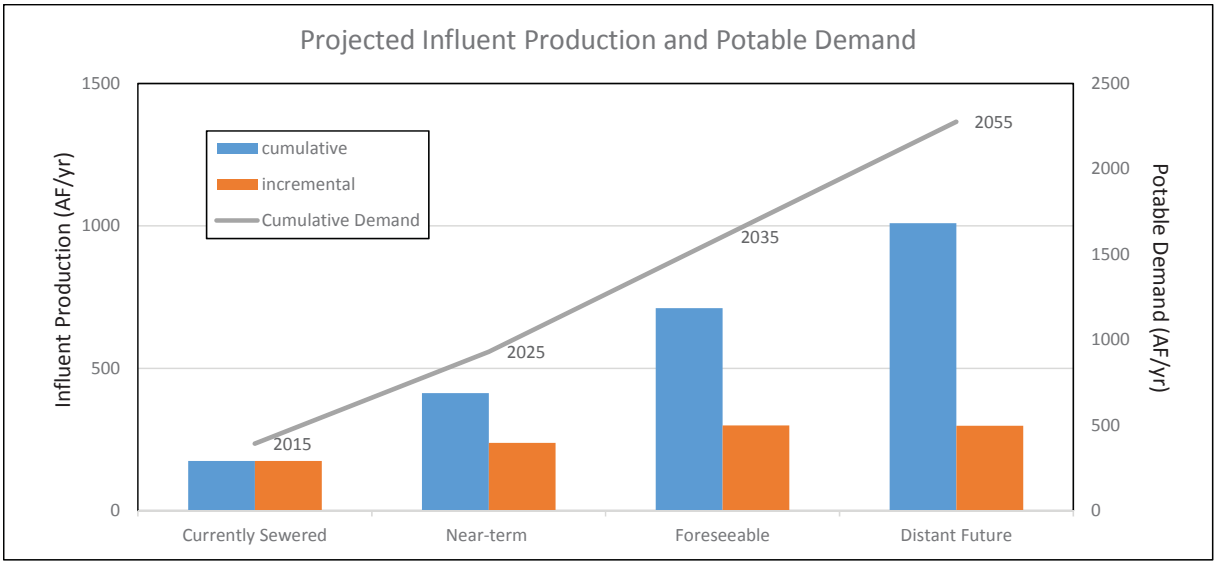

Figure 13. Current and projected cumulative and incremental wastewater influent production for four sewer connection categories.

Treated Effluent Recharge

Under the terms of its APP with the Arizona Department of Environmental Quality, the Town of Clarkdale applies all of its treated effluent (132 AF in 2014) to surface irrigation via sprinkler heads on a 50-acre parcel on the north side of Bitter Creek (Figure 9). While recharge was not a stated objective during the APP application process, the spray irrigation may produce some incidental recharge to the groundwater system. In order to estimate recharge from the irrigation practice at Bitter Creek, the average application rate of treated effluent, which is fairly constant year-round, was compared to the reference

evapotranspiration rate (ET_0)[4] for the Bowie, Arizona meteorological station. Despite being located in Cochise County in southeast Arizona, the Bowie station has similar precipitation characteristics to the Tuzigoot weather station (3,470 ft. elevation) near Clarkdale, and lies at a similar elevation (3,800 ft). Figure 14 plots average monthly precipitation for the Tuzigoot and Bowie stations for the period 2000-2013. Both stations have mean values of 11.2 inches, as indicated by the horizontal lines. The Bowie station is part of the University of Arizona Cooperative Extension Service's "Arizona Meteorological Network," also known as AZMET. AZMET station data are processed to include calculated ET_0 values (University of Arizona College of Life Sciences/Cooperative Extension Service, 2016). Table 6 presents average monthly ET_0 values (in inches) for the Bowie station. The yellow highlighted rows indicate the winter months where ET_0 is lowest.

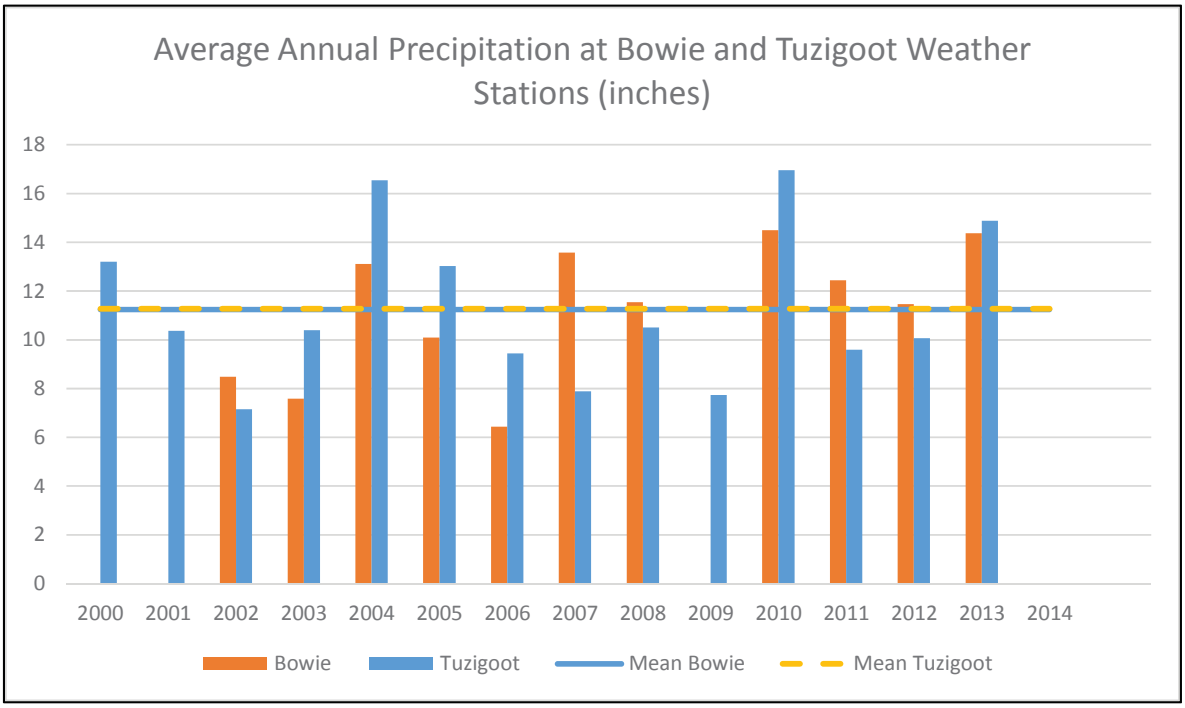

Figure 14. Average annual precipitation for Bowie and Tuzigoot weather stations in Arizona for the period 2000-2013 (National Oceanic and Atmospheric Administration, 2016).

Recharge can be estimated as:

$$Recharge = Irrigation\ water\ applied - ET_0 \qquad [1]$$

ET_0 is provided as a depth (inches), so applied irrigation water must be converted from a volumetric rate (AF/yr) to a depth in order to solve for recharge in equation [1]. Dividing the irrigation rate (AF/yr) by the application area (acres), provides recharge depth (ft). In order for recharge to occur, the irrigation rate per area must exceed ET_0. Table 7 provides the values used to estimate both effluent recharge volume

[4] Reference ET (ET_0) is defined as the ET rate from a uniform surface of dense, actively growing vegetation having a specified height and surface resistance (to transfer of water vapor), not short of soil water, and representing an expanse of at least 100 m of the same or similar vegetation (Allen, et al., 2005).

Table 6. Average monthly reference evapotranspiration for Bowie, Arizona (2005-2015) (University of Arizona College of Life Sciences/Cooperative Extension Service, 2016).

ET_0 Summary (Avg 2005-2015)	
Bowie Station (Elev 3,800 ft)	
Monthly Total*	**ET_0 (inches)**
Jan	2.54
Feb	3.45
Mar	5.65
Apr	7.26
May	8.66
June	9.51
July	8.05
Aug	6.73
Sept	5.44
Oct	4.57
Nov	3.00
Dec	2.19
* Calculated by Penman-Monteith Method	

Table 7. Estimated recharge of treated effluent at the Bitter Creek site in Clarkdale in 2014.

Estimated Effluent Recharge (2014)		
Description	**Value**	**Units**
Winter $ET_{0\ (Bowie)}$	0.93	ft (Nov-Feb)
Recharge Area	30	acres
2014 Annual Application Volume	132	AF over 30 ac
Annual Applic. Depth	4.40	ft
Estimated Winter Application Depth	1.47	ft (Nov-Feb)
Estimated Winter Recharge Depth (Applic. Depth - ET_0)	0.53	ft (Nov-Feb)
Estimated Winter Recharge Volume (Recharge Depth * Area)	**16.0**	**AF (Nov-Feb)**
Current Demand	377	AF/yr
% Effluent Recharged	12.2%	
% Demand Recharged	4.3%	

and effluent recharge as a percent of demand in Clarkdale in 2014. From Table 6, Bowie's winter (November – February) ET_0 is (3.00 + 2.19 + 2.54 + 3.45 =) 11.2 inches, or 0.98 ft. Using Clarkdale's total effluent production for 2014 of 132 AF (see Table A- 7), and an average irrigation area of 30 acres, the annual irrigation depth is 2.93 ft. For the four winter months (November – February), the irrigation depth is 0.98 ft. Subtracting the winter ET_0 value (0.93 ft) from the winter irrigation depth yields a winter recharge depth of 0.05 ft. Multiplying this depth by an irrigation area of 30 acres[5] yields a recharge volume

[5] Actual irrigated area estimated from Google Earth® imagery.

of 16 AF for 2014. This estimated recharge volume equals 12.2% of all treated effluent and 4.3% of Clarkdale's 2014 potable demand (377 AF).

Because the exact area of irrigation may vary and may not fully cover the 50-acre parcel at Bitter Creek at times, recharge volume may vary over time. Figure 15 plots recharge volume (left axis) and recharge volume as a percent of potable water demand and as a percent of total effluent (right axis) versus irrigation area. All three curves show a linear inverse relationship with irrigation area. As irrigation area approaches 50 acres, recharge drops below zero. If irrigation area is reduced to 10 acres, recharge volume increases to 35 AF, amounting to more than 9% of potable demand (double the current rate). In general, Clarkdale's irrigated area appears to be close to 30 acres, but as Figure 15 indicates, an acre of added irrigation area translates to about a 1 AF reduction in recharge. These estimates also do not account for any vegetation (eg, cottonwood trees) growing at Bitter Creek that may consume more water than the reference grass crop represented by ET_0.

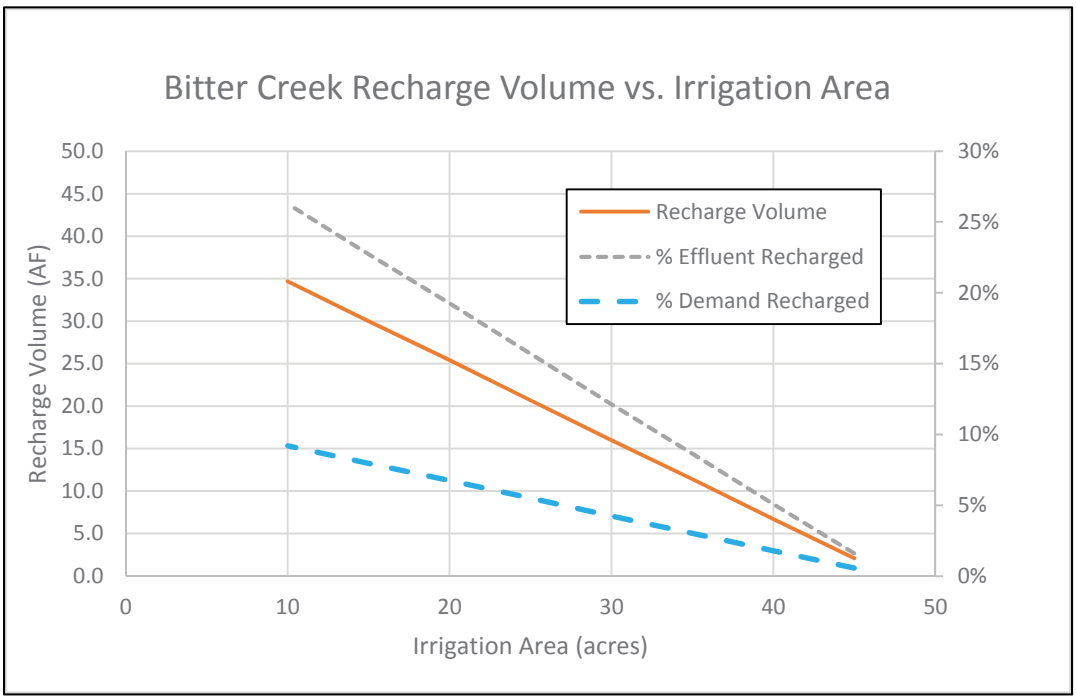

Figure 15. Estimated winter recharge at Bitter Creek, percent of effluent recharge, and % of demand recharged versus irrigation area.

Groundwater Modeling

Background and Purpose

Groundwater modeling provides a method for simulating different water management scenarios and testing outcomes of alternatives. In this study, groundwater modeling was designed to assist the Town of Clarkdale in its water management efforts. In particular, modeling addressed a number of specific questions, including:

- What is the status of Clarkdale's groundwater system?
- How does Clarkdale's water use impact the Verde River?
- How would projected growth impact Clarkdale's water supply (aquifers and infrastructure)?

- How would various changes in treated effluent production and use affect Clarkdale's water resources and the Verde River?

The approach to answering these questions started with an implementation of the recently published "Regional Groundwater-Flow Model of the Redwall-Muav, Coconino, and Alluvial Basin Aquifer Systems of Northern and Central Arizona" (Pool, Blasch, Callegary, Leake, & Graser, 2011), commonly referred to as the Northern Arizona groundwater flow model, or NARGFM. The NARGFM is the largest groundwater model to cover the major aquifer systems in northern and central Arizona, and is designed for simulating groundwater movement on regional-scale. Figure 16 illustrates the area covered by the NARGFM. Clarkdale and the Verde Valley lie near the south-central edge of the model area.

Results from LHC's initial work with the unmodified NARGFM in the Clarkdale area were presented to the public at a town hall forum in Clarkdale on August 7, 2013, and are available at on the Town's website in a presentation titled, "Groundwater in Clarkdale- Today and in the Future" (http://www.clarkdale.az.gov/water_resource_management.htm).

Following the initial use of the NARGFM, LHC conducted extensive evaluation of, and made some modifications to, the model to improve its performance in the Clarkdale area. Lacher (2015) provides a detailed discussion of the methods used to implement model changes for this study. These changes include:

- Updating simulated pumping values in Clarkdale (2006-2014).
- Corrections to simulated pumping wells (mislocated, duplicate, or incorrect pumping rates);
- Extension of simulation period from 2000 to 2076;
- Application of future recharge to reflect climate change (9% reduction from period of record);
- Local recalibration (automated and manual) of horizontal conductivity and specific yield near Haskell Springs;
- Correction to spring elevations in Clarkdale; and
- Grid refinement in Clarkdale area.

Groundwater Pumping Scenarios

In addition to efforts to improve the model's performance in the Clarkdale area, three demand scenarios examined the potential range of impacts to the groundwater system and the Verde River from different levels of groundwater extraction. The three demand scenarios include:

1. Minimum Demand: constant pumping and recharge from 2006 to 2076.
2. Maximum Demand: Central Yavapai Highlands Water Resources Management Study (CYHWRMS) projected demand and artificial recharge across all communities in the Verde Basin planning area (2014-2076).
3. Projected Demand: potable demand projected on the basis of Clarkdale development maps and effluent production projections described earlier in this report ("Projected Future Demand and Effluent Production").

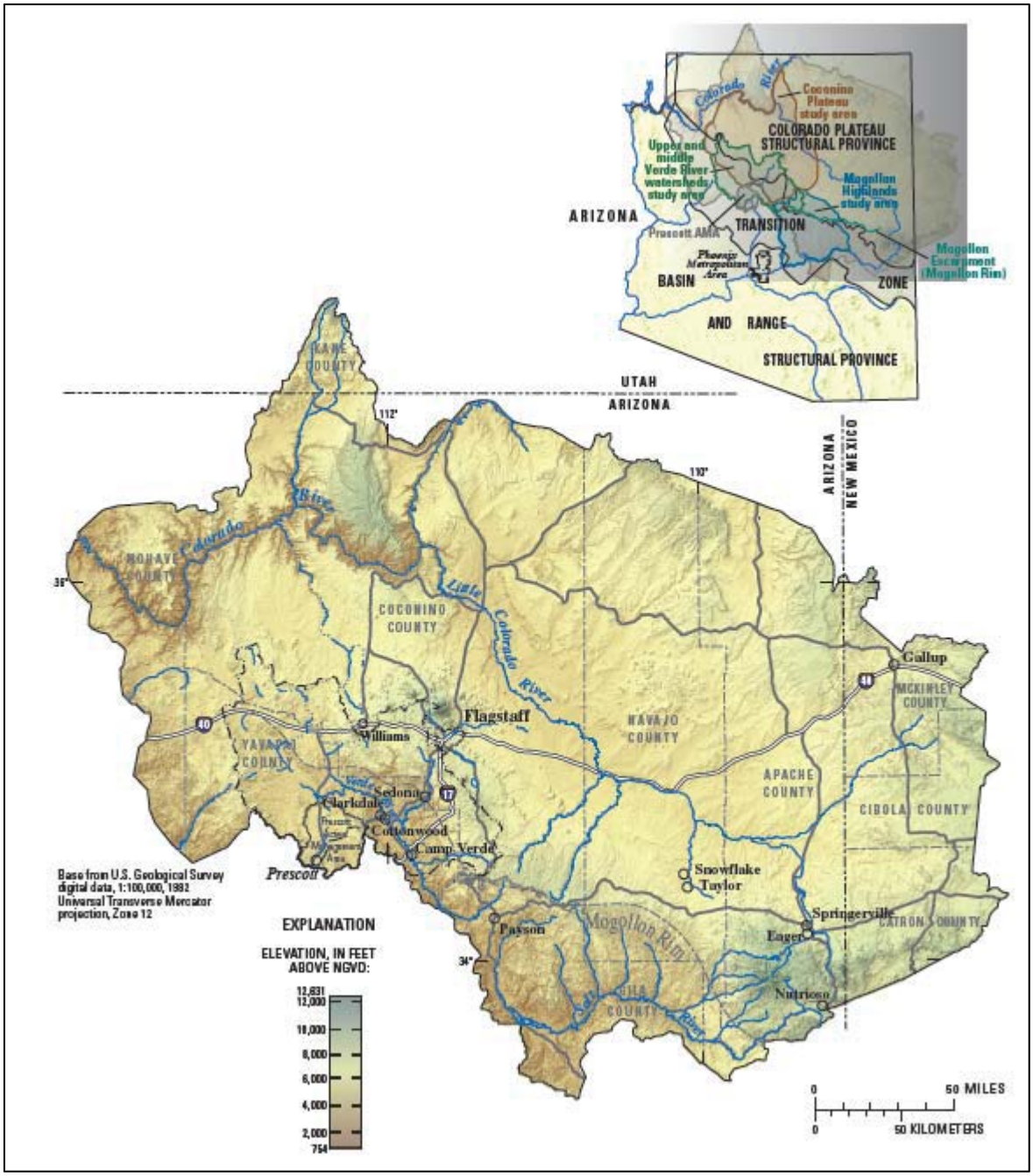

Figure 16. NARGFM study area [adapted from Figure 1 in (Pool, Blasch, Callegary, Leake, & Graser, 2011)].

The "Minimum Demand" scenario holds pumping and artificial recharge constant at the final (2005) rates in the published NARGFM (Pool, Blasch, Callegary, Leake, & Graser, 2011). This scenario may be interpreted in several ways – no growth, growth with decreased per capita demand, or growth with replacement water supply. If simulated pumping wells in the local area near Clarkdale went dry as a result of long-term pumping, those pumping stresses were relocated in the model to ensure that the pumping continued until 2076. Natural recharge for the period 2016-2076 replicated recharge simulated in the 1910-1970 period. The net impact of this repeated pattern was that the mean natural recharge value for the simulation period (1910-2076) declined by about 9% from its previous mean (over the 1910-2005

period of record). This decline is consistent with recent projections for flows on the Colorado River Basin at Lee's Ferry (U.S. Bureau of Reclamation, 2012).

The "Maximum Demand" scenario applied demand projections provided by the communities within the CYHWRMS study area. That study area includes all of the Verde River basin above and including Camp Verde as well as all of the Prescott Active Management Area (U. S. Bureau of Reclamation, 2011). For this scenario, pumping stresses in the model were separated into CYHWRMS Planning Area groups, and projected demand growth was applied uniformly to all of the wells within a Planning Area. Natural recharge was applied in the same way as described for the "Minimum Demand" scenario above. Appendix A provides additional details on the implementation of this scenario. This scenario was used to explore Clarkdale's current and potential future impact on the Verde River under various water management scenarios. These modeling results were presented at an "Experts Meeting" in April 2014 and are provided in **Error! Reference source not found.**. Figure A- 3 (1) shows that **Clarkdale's present impact on the Verde River (pumping-induced capture of baseflow) is simulated at roughly 0.3 cubic-feet per second (cfs), which would increase to 0.5 cfs with no increase in pumping by 2076**. Other water management scenarios produce simulated baseflow impacts of up to 1.3 cfs by 2076.

The "Projected Demand" scenario uses Clarkdale's planning maps and projected effluent production from new development to estimate future demand (see Table 5 and Table 8)Table 8. This scenario attempts to apply a realistic growth rate to both groundwater extraction and artificial recharge of treated effluent in the Clarkdale area. The same rate of growth in pumping and artificial recharge (excluding agricultural pumping and recharge) is applied throughout the NARGFM. While the projected growth rate developed for this scenario is specific to Clarkdale, it represents a moderate rate of growth that falls between the "Minimum" and "Maximum" demand scenarios. Table 8 compares projected demand to CYHWRMS demand for Clarkdale, and shows that projected demand averages 61% of CYHWRMS demand. Figure 17 plots simulated pumping in the Clarkdale municipal wells for the constant-, projected-, and CYHWRMS-pumping scenarios. Figure 18 plots projected and CYHWRMS demand for the entire model area. Figure 19 shows the distribution of pumping among Clarkdale municipal wells for the projected and CYHWRMS demand scenarios.

Table 8. Projected demand and CYHWRMS demand for sewer connection categories.

Projected Clarkdale Demand				
Simulation Period	**Sewer Connection Category**	**Actual and Projected Demand***	**CYHWRMS Demand**	**Projected Demand as % of CYHWRMS**
		AF/yr	**AF/yr**	
2006-2014	Currently Sewered	377	710	53%
2014-2025		392	1143	34%
2026-2035	Near-term	930	1620	57%
2036-2045	Foreseeable	1603	2053	78%
2046-2055		1603	2685	60%
2056-2065	Distant Future	2276	2918	78%
2066-2075		2276	3351	68%
*does not include non-revenue water				avg 61%

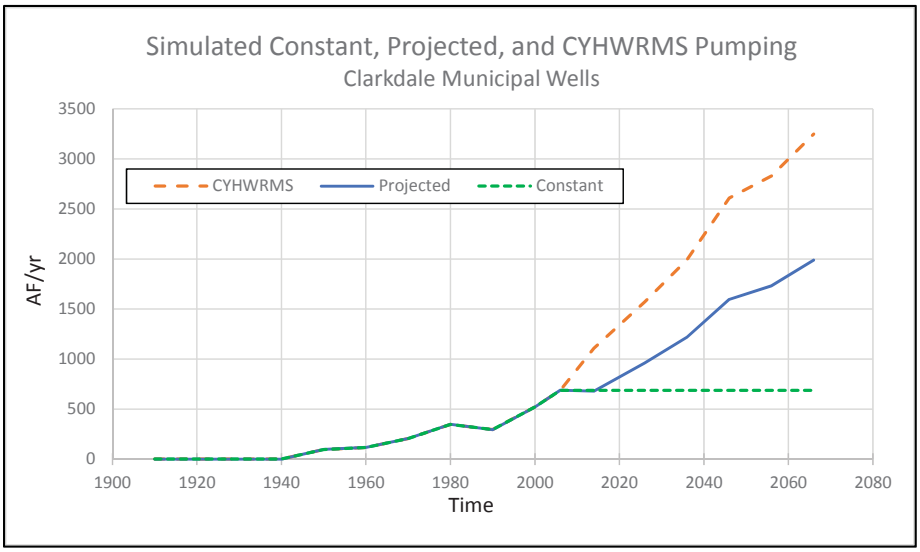

Figure 17. Simulated pumping in Clarkdale for constant-, projected-, and CYHWRMS-demand scenarios.

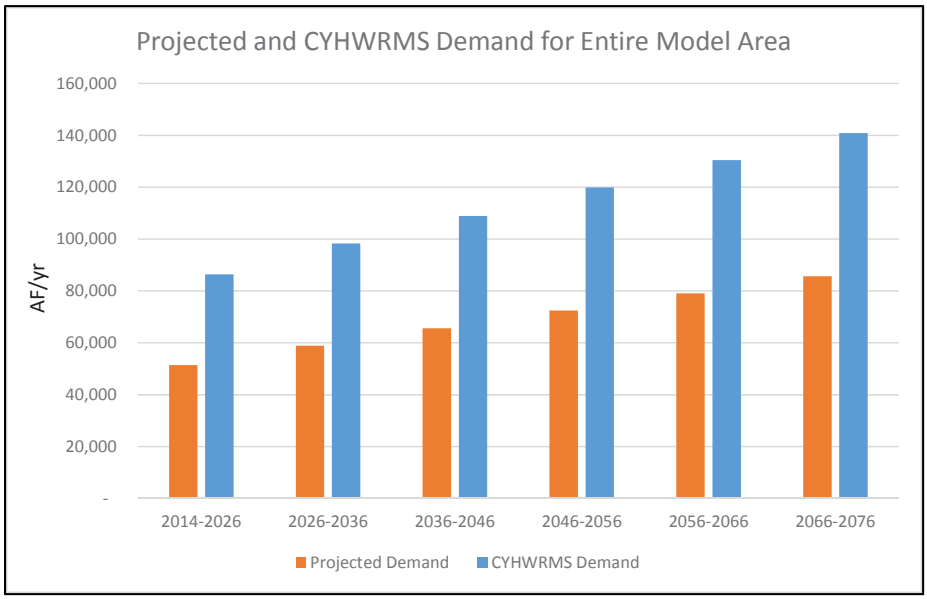

Figure 18. Projected and CYHWRMS demand for entire model area.

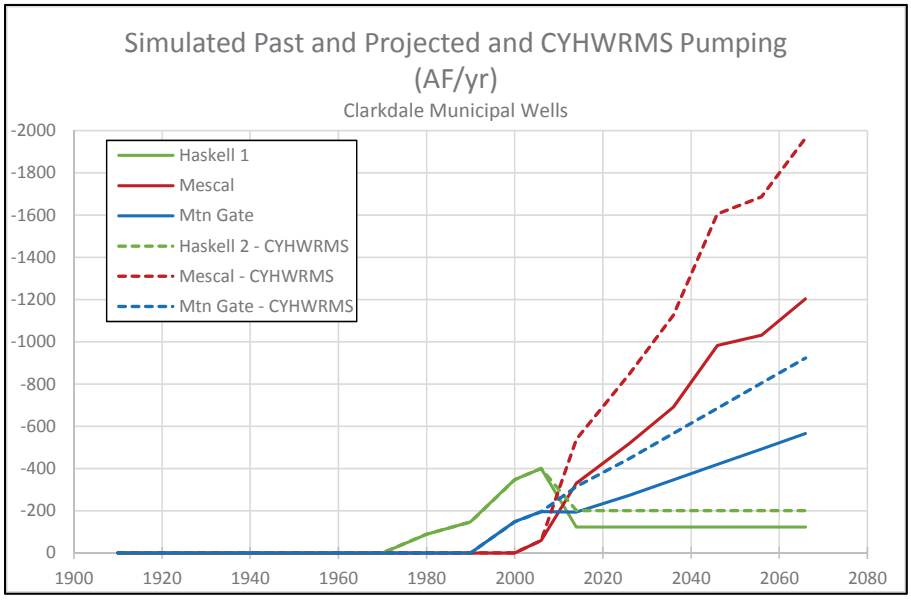

Figure 19. Pumping rates (negative values indicate extraction in the groundwater model) for projected Clarkdale demand and for CYHWRMS demand scenarios.

Effluent Management Scenarios

During the course of the WRMP planning process, development of an effluent reuse plan was identified as a priority action item for Clarkdale (Mott Lacroix, Fullerton, Rupprecht, & Lacher, 2014). Over the course of the next year, effluent reuse planning emerged as the highest priority water resource issue for LHC's groundwater modeling and resource evaluation efforts. While demand scenarios assisted in revealing the range of impacts likely to occur from future growth (see Appendix B), Clarkdale's immediate concern lies in determining the most beneficial way to handle its Class A+ effluent.

The Town's decision about how and when to implement effluent reuse will entail a careful study of the costs and benefits of any change to the existing effluent disposal system. The current system is relatively inexpensive, but the benefits are minimal. The current rate of recharge is likely less than 15% of the total effluent produced (Table 7), so 85% of the effluent is lost to evaporation and evapotranspiration (ET). Implementing an effluent reuse system to utilize substantially more of the treated effluent produced by the Town will incur some costs and deliver some benefits. Table 9 lists some of the identified costs and benefits of effluent reuse in Clarkdale. The most significant costs associated with effluent reuse are likely to be associated with modifications to existing effluent delivery and recharge infrastructure. These costs may range from hundreds of thousands of dollars for an injection well and associated pipelines from the WWTF to a few thousand dollars for a simple recharge basin. The nature of the reuse will dictate the cost of additional treatment (if any) and infrastructure modifications required. The largest benefits will derive from replacing consumptive uses of potable water with non-potable sources.

The benefits associated with even modest changes to the current practice of spray irrigation could be substantial. As indicated in Figure 15, reducing the area receiving spray irrigation by 10 acres would yield an additional 10 acre feet (AF) of recharge each year. Other more significant changes, such as replacing potable water used for irrigating parks and school landscaping with effluent, could significantly reduce consumptive demand during peak summer months. Reducing peak summer demand has the double benefit of reducing production well O&M costs as well as protecting the aquifer that helps sustain Verde

River baseflows and provides Clarkdale with its only source of potable water. All of these benefits would also bring Clarkdale into better alignment with its own Sustainable Clarkdale initiative (Town of Clarkdale, 2013).

Table 9. Costs and benefits of effluent reuse/recharge in Clarkdale.

COSTS	BENEFITS
Infrastructure modifications (eg, purple pipes, lift stations, meters, recharge basins, injection wells)	Lower O&M on production well infrastructure
APP permit modification for reuse	Slower rate of aquifer depletion
Additional treatment (dechlorination, polishing) for some uses	Reduced impact to Verde River from pumping wells
Potentially reduced recharge at Bitter Creek site	Potential revenue from lease of recharge site for agricultural and/or industrial purposes
◊	Potential revenue from lease/sale of effluent for industrial and/or agricultural purposes
◊	Alignment with Sustainable Clarkdale initiative

In order to quantify the hydrologic benefits of various effluent recharge[6] scenarios, groundwater simulations were designed to examine the impacts of several effluent recharge strategies. Table 10 shows the volumes of effluent projected to be generated under each sewer connection category, as well as the simulation period associated with each category. For each sewer connection category, two sets of effluent recharge scenarios are defined: 1) 30% effluent recharge, and 2) 60% effluent recharge. Both of these scenarios represent a marked increase in effluent recharge from the current estimated rate of less than 15% (Table 7). Figure 20 plots 30% and 60% Clarkdale effluent recharge rates as well as the CYHWRMS effluent recharge rate in Clarkdale. Use of a groundwater model for these scenarios means that only groundwater and stream baseflow benefits are quantified. Indirect benefits from increased groundwater levels, such as reduced pumping costs, must be determined through separate external analyses not addressed in this study.

Table 10. Simulated volumes for 30% and 60% effluent recharge.

Simulated Effluent Recharge				
		EFFLUENT	RECHARGE AF/yr	
Simulation Period	Sewer Connection Category	AF/yr	30%	60%
2014-2025	Currently Sewered	143	43	86
2026-2035	Near-term	340	102	204
2036-2055	Foreseeable	585	176	351
2056-2075	Distant Future	1009	249	499

[6] Recharge and reuse are both considered beneficial effluent management strategies. The simulations in this study focus on potential benefits of recharge. Reuse benefits would translate to lower demand.

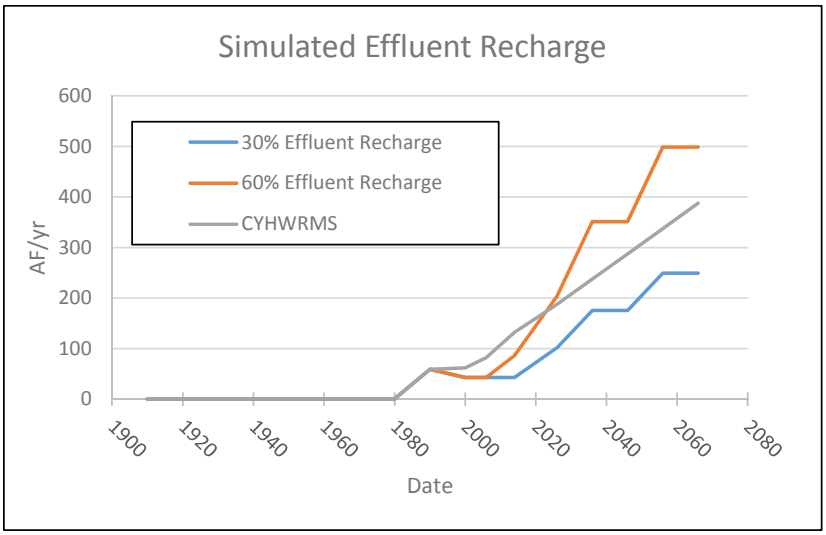

Figure 20. Simulated effluent recharge in Clarkdale for 30% and 60% recharge of projected effluent and for CYHWRMS effluent recharge.

For each recharge scenario (30% and 60% effluent recharge), two different recharge locations were simulated: one at the Bitter Creek irrigation site and one at the 89A/Reservoir well (inactive). Figure 21 shows these two simulated recharge locations and the four head-observation points used in the simulations (Mescal Well, Mountain Gate Well, 89A/Reservoir Well, and Bitter Creek irrigation site).

Results

Groundwater Heads

Figure 22 plots simulated change in head at each of the four head-observation sites identified in Figure 21. The two recharge sites (89A Well and Bitter Creek) are shown in the right two graphs. The 89A Well site shows the most sensitivity to effluent recharge (via injection). At the 60% effluent recharge rate of injection, simulated heads at this site remain 184 ft. above the baseline level represented by the "no effluent recharge" scenario and the curves showing 30% effluent recharge at Bitter Creek. Reducing the effluent recharge at 89A Well from 60% to 30% of treated effluent lowers the simulated head at that site by roughly 100 ft. Simulated heads at the Mountain Gate Well and Mescal Well show a similar pattern in response to recharge at the 89A Well. However, the improvement in head is about 90 ft. over baseline (no effluent recharge) by 2076 at the Mountain Gate Well and just 43 ft. at the more distant Mescal Well. Again, reducing recharge by 50% (from 60% to 30%) reduces the impact on simulated heads at the Mountain Gate and Mescal wells by 50%, yielding head improvements of just 45 and 21 ft., respectively, by 2076.

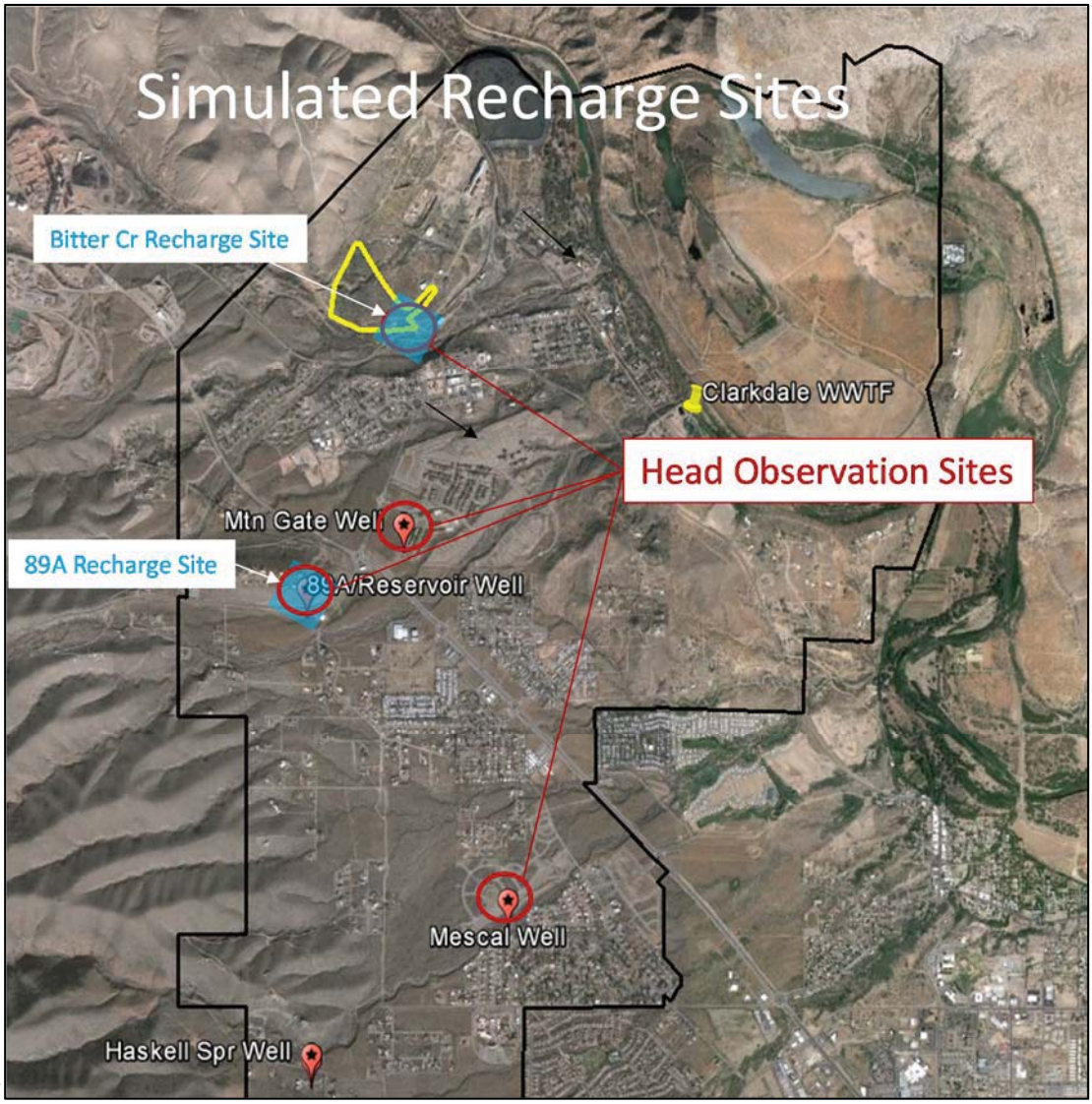

Figure 21. Simulated recharge sites at Bitter Creek and at 89A/Reservoir well in Clarkdale.

Recharge at Bitter Creek had no measurable impact on any of the observation well sites. However, the 30% and 60% effluent recharge scenarios yielded increases in simulated heads at Bitter Creek of 53 and 107 ft., respectively, by 2076. The Bitter Creek site was insensitive to recharge at the 89A site. Bitter Creek was also the only site where recharge reversed the trend of declining heads over time with both 30% and 60% recharge of treated effluent. The dashed green line in the four plots in Figure 22 represents surface recharge at Bitter Creek for 30% of treated effluent. This simulation tested the sensitivity of the hydrologic system to surface recharge versus simulated injection into wells. Figure 22 shows that this simulated change in recharge mechanism had little bearing on the simulated heads, and that the difference was only discernable at the Bitter Creek site.

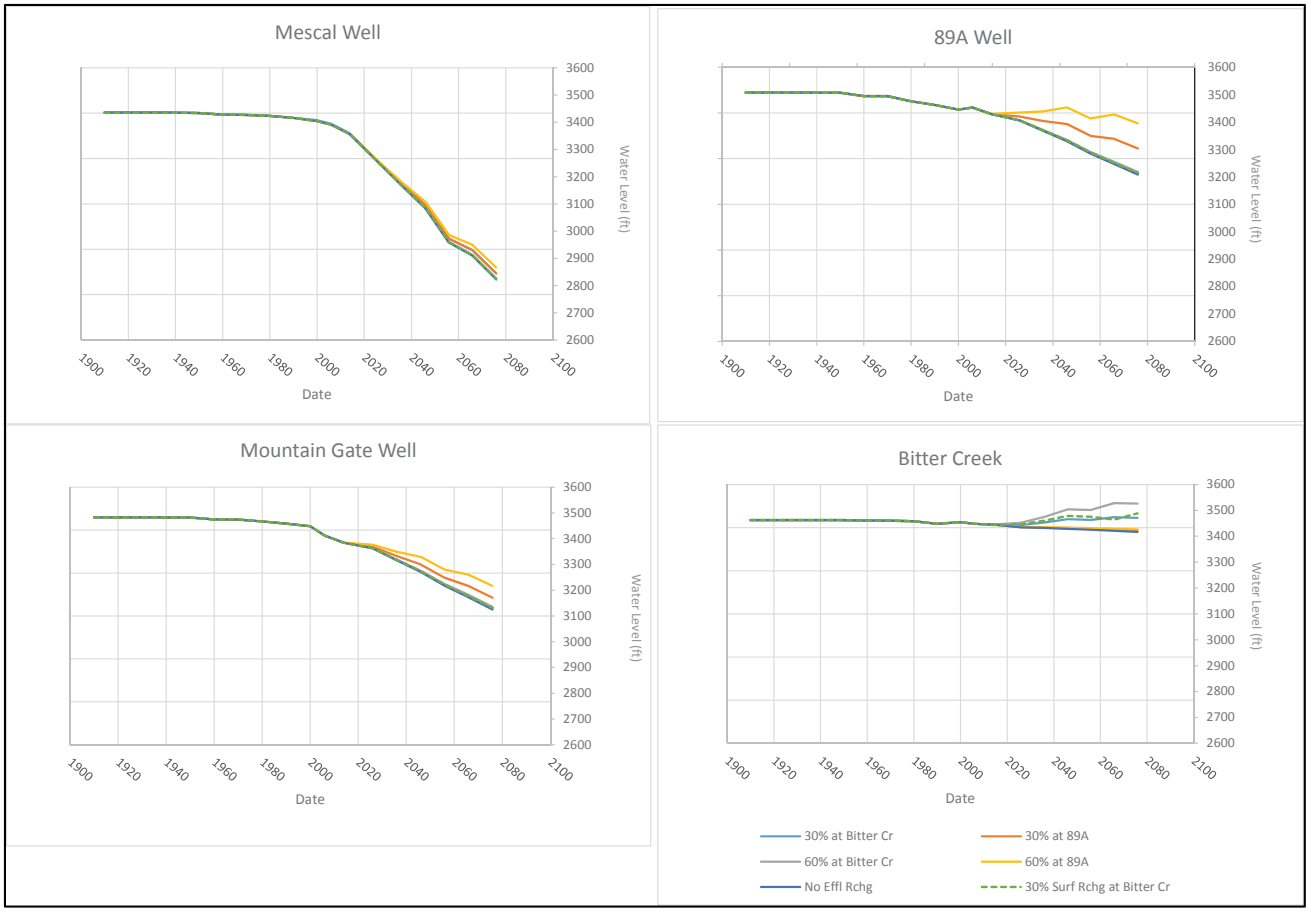

Figure 22. Simulated heads for 30% effluent recharge and 60% effluent recharge at Bitter Creek site and 89A Well site.

Table 11 presents a summary of simulated change in head at the four head-observation sites in Figure 21. For each of the head-observations sites, the smallest head change is assigned a multiplier of 1.0. The other results for that site are then expressed as multiples of the smallest head change to more easily demonstrate the range of results for the six scenarios. For instance, the "60% at 89A" scenario produced a head change of -559.78 ft. This value is assigned a multiplier of 1.0. The "No Effluent Recharge" scenario produced a head change of -600.63 ft. at the Mescal site, which is 1.08 times the smallest head change (-559.78 ft) for this site. By contrast, the smallest head change (-110.21 ft) at the 89A Well occurred for the same "60% at 89A" recharge scenario and was assigned a multiplier of 1.0. However, the largest head change (-289.48 ft) at the 89A site resulted from the "30% at Bitter Creek" recharge scenario. This change in head is 2.63 times larger than the smallest head change observed at the 89A Well for all six recharge scenarios. While Mescal Well experienced the largest simulated decline in heads of all four sites (due to a large simulated pumping rate), the Bitter Creek site experienced the greatest relative sensitivity to recharge. Compared with the 8.29-ft head increase produced by the "30% at Bitter Creek" scenario, the "60% at Bitter Creek" scenario produced a simulated head change (62.45 ft.) that was 7.53 times the smallest head-change result.

Table 11. Summary of simulated head change at four observation sites for 6 recharge scenarios. Multipliers reflect relative change from smallest head change value at each site.

Simulated Head Change (ft) 1910-2076								
Scenario	*Mescal*	*Muliplier*	*89A*	*Muliplier*	*Mtn Gate*	*Muliplier*	*Bitter Creek*	*Muliplier*
30% at Bitter Cr	-581.35	1.04	-289.48	2.63	-346.62	1.33	**8.29**	**1.00**
30% at 89A	-581.52	1.04	-200.46	1.82	-306.53	1.17	-40.47	-4.88
60% at Bitter Cr	-598.98	1.07	-284.69	2.58	-341.64	1.31	62.45	7.53
60% at 89A	**-559.78**	**1.00**	**-110.21**	**1.00**	**-261.28**	**1.00**	-35.54	-4.28
No Effl Rchg	-603.09	1.08	-294.29	2.67	-351.62	1.35	-45.42	-5.48
30% Surf Rchg at Bitter Cr	-600.63	1.07	-288.47	2.62	-345.49	1.32	25.27	3.05

Baseflows

Figure 23 shows the locations of the two baseflow-observation cells along the Verde River downstream of Clarkdale. These two sites were chosen a representative of the Clarkdale to Oak Creek reach and the reach downstream of Oak Creek. The two graphs in Figure 23 plot simulated change in baseflow at each stream site for each of the five recharge scenarios compared to the "No Effluent Recharge" scenario. For both sites, the "60% at Bitter Creek" recharge alternative (labeled "60%") produced the largest baseflow response (0.4 to 0.45 cfs), and the "30% at 89A Well" alternative produced the smallest baseflow response (0.14 to 0.15 cfs) by 2076. The "60% at 89A Well" recharge scenario produced a slightly greater simulated baseflow response than the "30% surface recharge at Bitter Creek" scenario, and both were 0.05 to 0.1 cfs greater than the simulated response for the 30% at Bitter Creek scenario. Table 12 summarizes the simulated baseflow change at the two stream observation points shown in Figure 23. As indicated by the multipliers, the largest baseflow response (from 60% recharge at Bitter Creek) was 2.9 times the smallest response (from 30% recharge at 89A Well).

Discussion

The preceding analyses explore the impacts of two levels of effluent recharge (30% and 60% of total effluent production) at two locations within the Town of Clarkdale. The scenarios demonstrate the sensitivity in the groundwater system and in the baseflow of the Verde River to both recharge location and recharge magnitude. These simulations show that recharge at the 89A well has the potential to significantly reduce drawdown (pumping-induced head declines) at the recharge well and as far away as the Mountain Gate Well, but that it would not significantly improve water levels at the Mescal Well or at Bitter Creek. Recharge at the 89A Well also has the capacity to increase baseflows, but only by a minor amount (0.14 to 0.3 cfs). Simulated recharge at Bitter Creek has the potential to impact baseflows in the Verde River by a slightly larger amount (0.2 to 0.4 cfs), but would have virtually no impact on Clarkdale's municipal wells.

These simulations demonstrate the tradeoffs involved in major decisions about implementing an effluent reuse or recharge plan. The current level of incidental recharge that may be occurring at the Bitter Creek site is so small that changing the land application practice there would have essentially no negative consequences to the hydrologic system. Other alternatives that utilize effluent for consumptive purposes (such as watering parks or irrigating commercial agriculture) would have a similar hydrological impact to injection well recharge if they afforded a reduction in potable water production. **Using effluent to replace potable water uses is probably the most cost-effective method of reuse because it avoids the expense and complexities of recharge operations.**

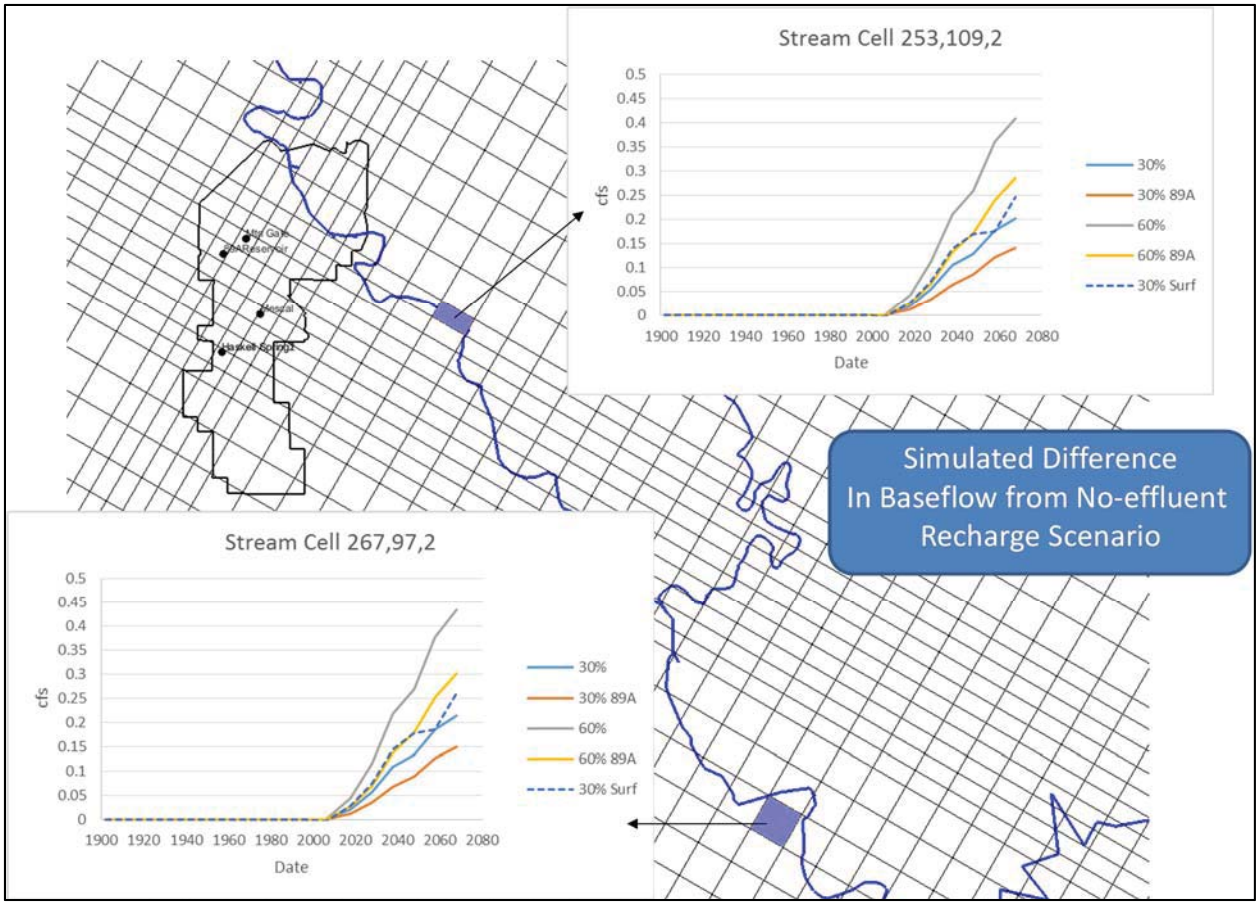

Figure 23. Simulated change in baseflow in two select stream cells on the Verde River downstream of Clarkdale.

Table 12. Summary of simulated baseflow change in two select stream cells for 6 recharge scenarios.

Simulated Baseflow Change 1910-2076		
Scenario	**Baseflow Change (cfs)**	**Multipliers**
Stream Cell 253,109,2		
30% at Bitter Cr.	0.20	1.4
30% at 89A	**0.14**	**1.0**
60% at Bitter Cr.	0.41	2.9
60% at 89A	0.29	2.0
30% on Surface at Bitter Cr.	0.25	1.7
Stream Cell 267,97,2		
30% at Bitter Cr.	0.21	1.4
30% at 89A	**0.15**	**1.0**
60% at Bitter Cr.	0.43	2.9
60% at 89A	0.30	2.0
30% on Surface at Bitter Cr.	0.26	1.7

The projected water demand developed by assuming sewer connections for anticipated new development suggests that Clarkdale's current wells will likely be able to meet demand for many decades, a finding supported by the Town's application to the Arizona Department of Water Resources for a Designation of Water Adequacy (Southwest Ground-water Consultants, Inc., 2010). However, if

production exhibits unexpectedly rapid declines, then sustaining groundwater levels near production wells may become a priority for effluent reuse.

Summary and Conclusions

This study explores the potential for the Town of Clarkdale to transition to a more to a more sustainable model of water management through reuse and/or recharge of treated effluent. Presently, about 85% of Clarkdale's high-quality treated effluent is lost to evaporation and ET with no direct benefit to the community. This study projects that, as the Town grows, sewering most new residential development could increase the Town's supply of treated effluent from 132 AF/yr today to more than 1,000 AF/yr in the next 40 to 50 years. Groundwater simulations incorporating projected potable demand and various options for effluent recharge demonstrate that effluent can protect water supply wells from declining groundwater levels, thereby reducing the Town's O&M burden for water production. Significantly increasing both the volume of treated effluent and the percentage of that effluent that reaches the groundwater system via recharge could measurably reduce Clarkdale's impact on the Verde River over the next several decades. However that impact (estimated at 0.5-1 cfs or 360-720 AF/yr) is so small relative to Verde River flows that other water management strategies may be more beneficial to the Town's efforts to meet its sustainability goals (Town of Clarkdale, 2013).

As an alternative to direct recharge, using effluent to offset consumptive potable water uses, such as irrigation of Town parks and school grounds, provides the same type of benefit as direct recharge in terms of conservation of diminishing groundwater supplies. While initial capital costs for effluent delivery infrastructure may be significant, they may be less than the long-term cost of piping and recharging effluent into the deep aquifer. Other direct use of treated effluent, such as for agricultural irrigation, tourist amenities, or industrial use, may generate revenue for new effluent collection and reuse infrastructure. In addition to providing an alternative to consumptive use of diminishing groundwater supplies, reuse and/or recharge of treated effluent would align well with Clarkdale's stated WRMP mission (Mott Lacroix, Fullerton, Rupprecht, & Lacher, 2014) and its Sustainable Clarkdale effort (Town of Clarkdale, 2013).

Recommended Next Steps

The Town of Clarkdale is poised to make significant advances in water resources management in the next few years. Formalizing the water purchasing agreement with Cottonwood and ceasing routine water delivery to Cottonwood is expected to reduce non-revenue water and extend the life of the Town's potable water supply and infrastructure (Yates, 2015). Efforts to develop a plan for effluent reuse/recharge are already underway. Local grape growers have expressed interest in working with the Town to grow wine grapes on the Town's Bitter Creek site, where effluent is already available. Increasing the wine industry in Clarkdale and advancing tourism opportunities are two stated goals under "Business Retention, Expansion & Attraction" in the Town's Strategic Plan (Town of Clarkdale, 2013). Goals for the Sustainable Clarkdale component of the Town's Strategic Plan include: a) establishment of a water resource management program, b) promotion of the Sustainable Clarkdale Initiative, and c) continuously improving Clarkdale's exceptional quality of life. Effluent reuse provides an excellent opportunity to use wise water management to achieve business development and sustainability goals.

Recommended Steps (Near term):

1. Pursue business relationships with wine growers. Support their needs to collect water quality, soil, and weather data on available land and from the Town's treated effluent system.
2. Pursue green infrastructure planning and design grants and low-cost loans from WIFA for effluent reuse projects starting with "purple-pipe" and other reuse infrastructure to facilitate use of effluent to irrigate Town parks and other government facilities
3. Use revenue from vineyard leases to further develop reuse projects at the Bitter Creek site.
4. Use treated effluent to create tourist amenities such as:
    a. Open-water wetlands for bird watching;
    b. Linear constructed wetlands (e.g., artificial streams) with water-drop features for aesthetic and passive water-polishing value;
    c. Shaded walking paths from the Verde Canyon Railway to Clarkdale, possibly coordinated with vineyard activities.
5. Use effluent reuse projects as education opportunities. Place educational signs along paths and water features to help community members and visitors value effluent.

At intermediate steps along the path to full effluent reuse, excess effluent should be managed for maximum recharge to the groundwater system.

Recommended Steps (Near to Intermediate Term):

6. Shrink the area receiving spray irrigation at the Bitter Creek site. If necessary, use larger spray nozzles in fewer zones. Try to bring irrigated area down to 20 acres or less.
7. Conduct a site investigation to evaluate the potential for one or more rapid infiltration basins on the lower-angle areas of the Bitter Creek site.

As business development opportunities for effluent reuse evolve, determining the value of treated effluent will become critical. Here, "value" includes market price and opportunity costs of failing to develop effluent as a resource. Once an appropriate value is placed on Clarkdale's Class A+ effluent, Town leadership will be in a better position to determine the costs and benefits associated with developing new sewer and effluent reuse infrastructure.

Recommended Steps (Near to Intermediate Term):

8. Conduct a cost-benefit analysis to determine the merits of sewering existing unsewered neighborhoods as well as areas currently viewed as "difficult to sewer" on Town planning maps.
9. Develop a long-term funding strategy to support ongoing wastewater collection and reuse infrastructure.

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Appendix A

Development of Conceptual Model of Projected Treated Effluent and Potable Water Demand in Clarkdale

This Appendix describes the development of a conceptual model for how treated effluent production and potable water demand may evolve in the Town of Clarkdale over the next 50 years (2015-2065). Table A- 1 presents potential wastewater connections in Clarkdale based on existing unsewered homes and homes awaiting construction in approved subdivisions with water and sewer infrastructure. Table A- 2 lists residential properties in Clarkdale available for development. These two tables provided a basis for estimating the number of potential future sewer connections and their spatial distribution (Figure A- 1). Using Figure A- 2 to identify areas unlikely to be sewered in the near term, and with input from Town of Clarkdale Senior Planner, Beth Escobar, Table A- 4 was developed to group developable residential properties into three categories of likely sewer connection time frame: 1) near term (10-20 years), 2) foreseeable future (20-40 years), and 3) distant future (40-50 years).

Table A- 5 and Table A- 6 show monthly utilities reports for June and December 2014, respectively, for the Town of Clarkdale. Table A- 7 shows annual potable water production, total demand, and raw wastewater influent to the Clarkdale WWTF and treated effluent output from the WWTF for the years 2007-2014. These annual data, combined with the monthly values for June and December 2014, were used to compute a relationship between potable residential demand and total raw influent to the WWTF which were, in turn, used to develop projected demand and effluent for groundwater simulations (see “Future Demand and Effluent Production” in main body of this report).

Table A- 1. Potential Wastewater Connections for Existing Homes and Homes Awaiting Construction in Clarkdale (Escobar, 2015).

Town of Clarkdale Potential Wastewater Connections	
Existing homes in platted subdivisions	**Number of Lots**
Mingus Shadows I, II & III	187
Black Hills Estates I & II	146
Haskell Springs I & III	47
Black Hills Terrace	18
Foothill Terrace	137
Mingus View Estates	70
Existing Homes in metes and bounds developments	
Mescal Spur Neighborhood	39
North Old Jerome Higway	25
Total	669
Homes awaiting construction in approved subdivisions with water/wastewater infrastructure in place	
Mountain Gate	405
Crossroads	241
Total potential connections	1984
Other	
Sienna Canyon Estates - approved subdivision not yet recorded. Will be required to connect to wastewater and water systems.	45
Eleven acres of commercial in Crossroads at Mingus with infrastructure in place	
NOTE: Future residential subdivisions and commercial development are not included.	

Table A- 2. Residential Properties Available for Development in Clarkdale (Escobar, 2015).

Town of Clarkdale Residential Property available for development							
	Subdivision/Area	**Platted**	**Number of Lots available for development**	**Undeveloped acres**	**Zoning**	**Residential Units per Acre**	**Maximum Residential Units**
1	Haskell Springs Area	No		76	R1-L	1	76
2	Abbey Road North	No		42	R1-L	1	42
3	Vincent/Vinterra property north of Black Hills Drive	No		40	R1-L	1	40
4	Haskell Springs Phase 3	Yes	150		R1		150
5	West of Minerich	No		50	R1-L	1	50
6	Radley Subdivision	Yes		80	R1	4	320
7	Mescal Spur area	No		15	R1	4	60
8	Mountain north to Peaks View	No		30	R1-L	1	30
9	Old Jerome Highway between Lemar & Kerrie Lee Road	No		7	R1	4	28
10	Classic Court	No		2.4	R1	4	10
11	Valley View area	No		8	R1	4	32
12	North of Peaks View	No		42	R	4	168
13	Sienna Canyon Subdivision			45	R1	4	450
14	Wildhorse Acres Subdivision		4		R1		4
15	West of Desert Sky			34	R1	4	136
16	Along SR 89A to Clarkdale Parkway	No		44	R1	4	176
17	Panorama Subdivision	Yes	5				5
18	YA Nation property west of Cement Plant Road	No		45	R2	10	450
19	North of SR 89A and west of Cement Plant Road	No		18	R1	4	72
20	Salt River PimaMaricopa (SRPM) Indian Community property east of Cement Plant Road (two parcels)	No		57	R2	10	570
21	SRPM property behind CJ School	No		18	R1	4	72

Table A- 3 (cont'd). Residential Properties Available for Development in Clarkdale.

Town of Clarkdale Residential Property available for development							
	Subdivision/Area	**Platted**	**Number of Lots available for development**	**Undeveloped acres**	**Zoning**	**Residential Units per Acre**	**Maximum Residential Units**
22	Mongini property west side of Clarkdale Parkway	No		20	R1	4	80
23	Rob Greene property east of Fire Station	No		6	R1	4	24
24	DeBlanc property north of Patio Park	No		2	R3	14	28
25	Tevis property east of Patio Park	No		5.5	R3	14	77
26	East of Broadway between Main and Park			22.6	R1		23
27	Rio Vista Subdivision	Yes		2.5	R2	10	25
28	West of Broadway between Elks Lodge and Cottonwood boundary	No		224.5	R1	4	898
29	Palisades Subdivision	Yes	8		R1		8
30	Paz & Cota	Yes		19	R2	10	190
	remaining single family lots		14		R1	1	14
31	Bent River Area north	No		22	R1-L	1	22
32	Bent River area south of El Ranch Rd	No		6.6	R2	10	66
	Subdivisions under development						
	Mountain Gate	Yes	393				393
	Crossroads	Yes	233				233
	Total potential residential units						5021

Various parcels have not been included due to location in flood plain, topography, or ownership (school, national forest)

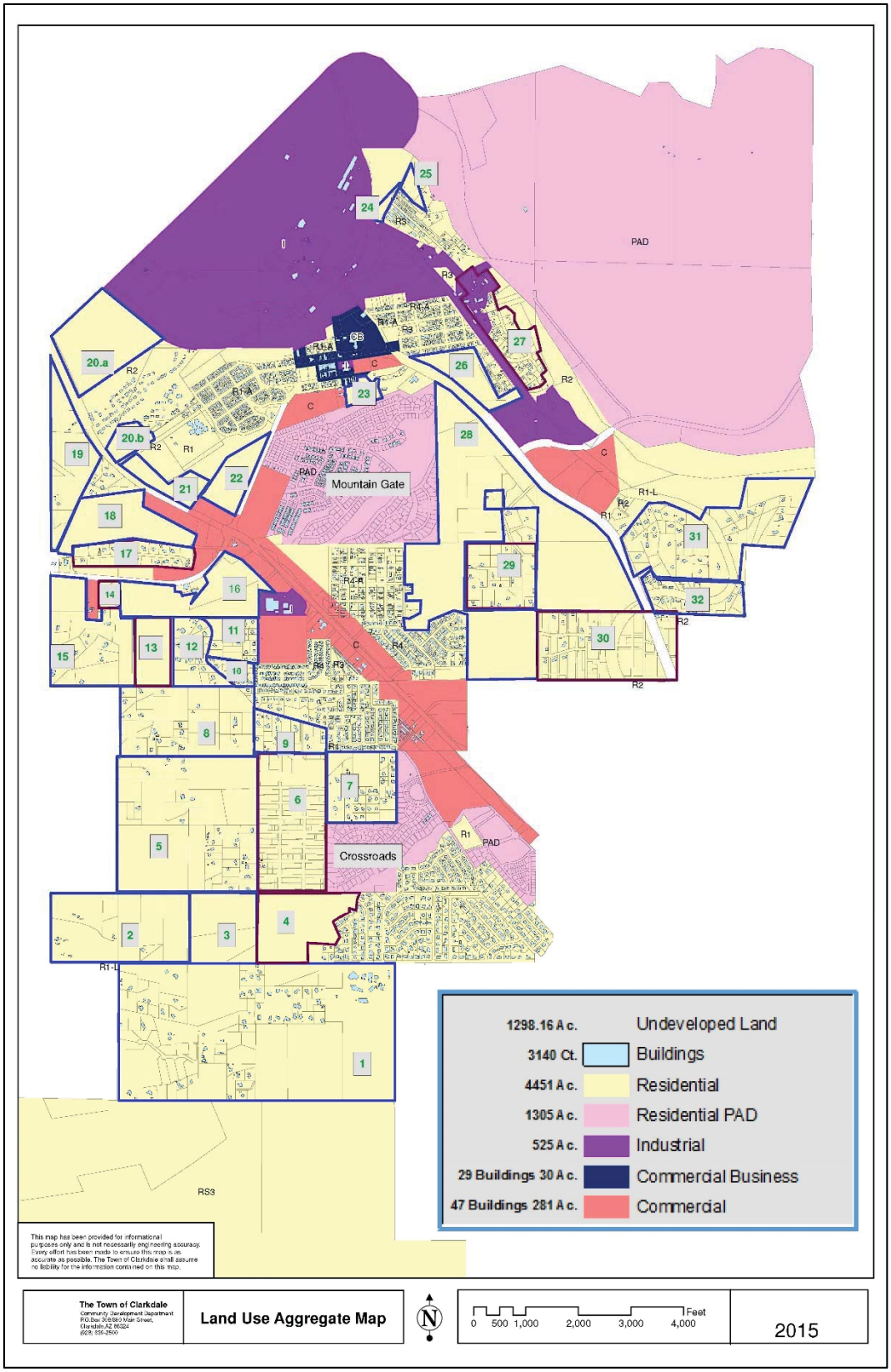

Figure A- 1. Clarkdale land use map with parcels numbers corresponding to Table-A2 (Espolt, 2015).

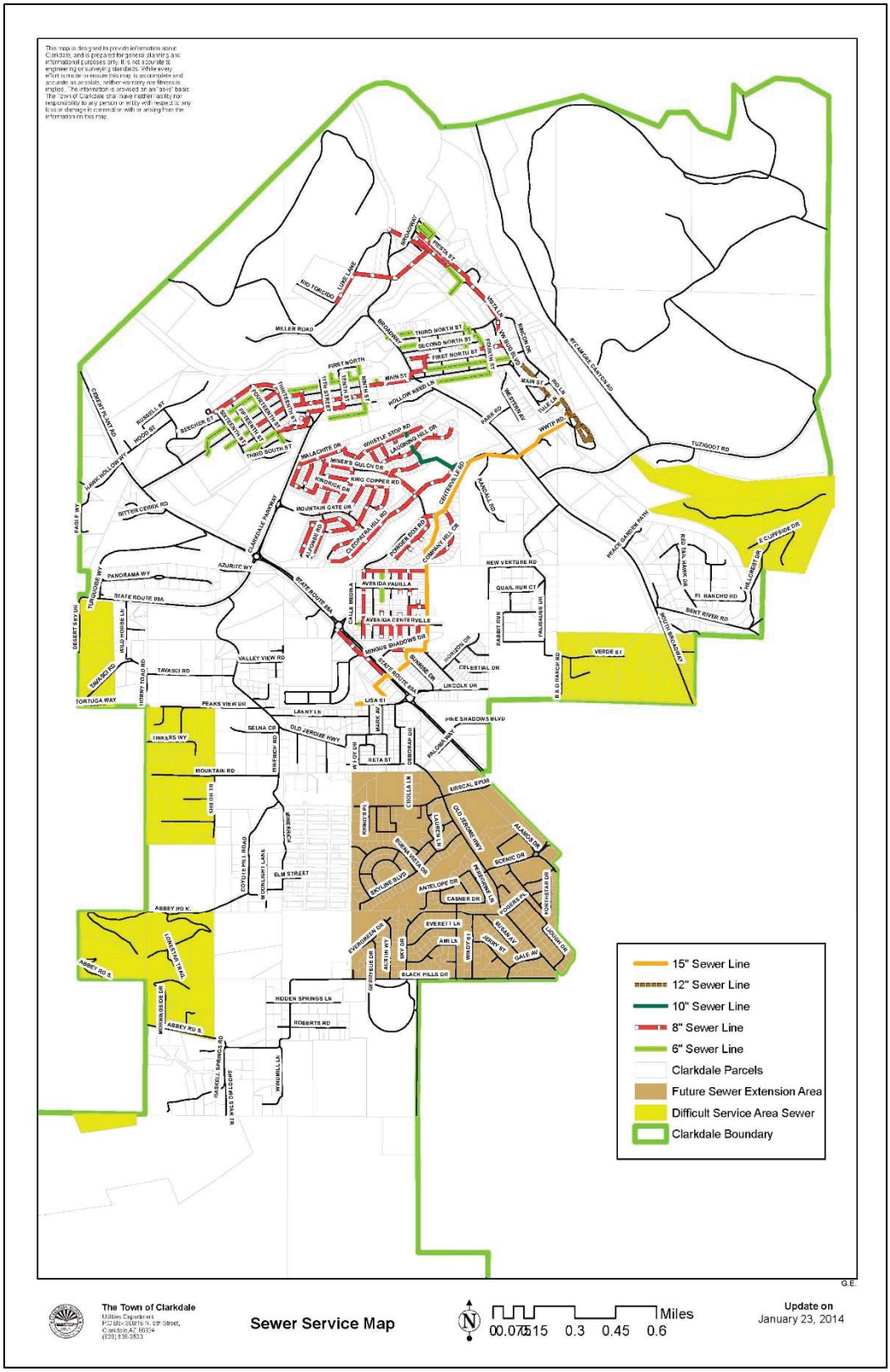

Figure A- 2. Clarkdale sewer service map identifying areas of planned sewer extension and areas difficult to service (Espolt, 2015).

Table A- 4. Conceptual plan for projected future sewer connections in Clarkdale. Yellow rows are viewed as likely to be sewered in the next 10 to 20 years. Green rows represent areas more likely to be sewered over a longer term (20 to 40 years). Grey rows include properties more likely to be sewered in the next 40 to 50 years.

Potential Residential Sewer Hook-ups in Clarkdale					
		Likely to be Connected to Sewer			
ID no.	Subdivision/Area	Max Resid. Units	Soon	Foreseeable Future	Very Distant Future/Never
7	Mescal Spur area	60	X		
9	Old Jerome Highway between Lemar & Kerrie Lee Road	28	X		
10	Classic Court	10	X		
11	Valley View area	32	X		
12	North of Peaks View	168	X		
16	Along SR 89A to Clarkdale Parkway	176	X		
21	SRPM property behind CJ School	72	X		
22	Mongini property west side of Clarkdale Pkwy	80	X		
23	Rob Greene property east of Fire Station	24	X		
24	DeBlanc property north of Patio Park	28	X		
25	Tevis property east of Patio Park	77	X		
26	East of Broadway between Main and Park	23	X		
27	Rio Vista Subdivision	25	X		
33	Mountain Gate	393	X		
34	Crossroads	233	X		
6	Radley Subdivision	320		X	
13	Sienna Canyon Subdivision	450		X	
18	YA Nation property west of Cement Plant RD	450		X	
20	Salt River PimaMaricopa (SRPM) Indian Community property east of	570		X	
1	Haskell Springs Area	76			X
2	Abbey Road North	42			X
3	Vincent/Vinterra property north of Black Hills Dr	40			X
4	Haskell Springs Phase 3	150			X
5	West of Minerich	50			X
8	Mountain north to Peaks View	30			X
14	Wildhorse Acres Subdivision	4			X
15	West of Desert Sky	136			X
17	Panorama Subdivision	5			X
19	North of SR 89A and west of Cement Plant Rd	72			X
28	West of Broadway between Elks Lodge and Cottonwood boundary	898		X	X
29	Palisades Subdivision	8			X
30	Paz & Cota	190			X
31	Bent River Area north	22			X
32	Bent River area south of El Ranch Rd	66			X

Table A- 5. June 2014 Clarkdale utilities report (Yates, 2015).

JUNE 2014 WATER USE	LAST MO.	SAME MO. LAST YEAR	YTD
# RESIDENTIAL ACCTS	1,715	1,704	
# COMM ACCTS	27	32	
# GOV ACCTS	25	18	
# OTHER ACCTS	8	26	
# INDUSTRIAL	5		
TOTAL ACCTS	**1,780**	**1,780**	
RESIDENTIAL USE	10,808,129	11,919,507	**44,694,477**
Resid. demand (gals)/account	6,302		
COMM USE	284,139	455,289	1,465,551
GOV USE	1,639,398	2,019,067	5,655,499
OTHER USE	40,726	1,626,707	760,704
INDUSTRIAL USE	73,391		253,968
TOTAL CLARKDALE USE	**12,852,085**	**16,020,570**	**52,830,199**
Cottonwood Ranch	2,774,000	1,914,000	13,874,000
Backwash	**431,200**		**1,824,850**
TOTAL USE	**16,057,285**	**17,934,570**	**68,529,049**
Wastewater System	ALL WASTEWATER TREATED IN GALLONS (INFLUENT)		
			YTD
	LAST MO.	SAME MO. LAST	
# ACCTS	**1,038**	**1,023**	
WASTEWATER TREATED	**4,689,250**	**3,943,286**	**26,515,592**
Influent gals/acct	4,518		

Table A- 6. Clarkdale utilities report for December 2014 (Yates, 2015).

DECEMBER 2014 WATER USE		LAST MO.	SAME MO. LAST YEAR	YTD
# RESIDENTIAL ACCTS		1,735	1,709	
# COMM ACCTS		29	30	
# GOV ACCTS		25	18	
# OTHER ACCTS		8	16	
# INDUSTRIAL		4	5	
TOTAL ACCTS		**1,801**	**1,778**	
RESIDENTIAL USE		7,788,027	6,440,064	**102,523,480**
Residential Demand (gals/acct)		4,489		
COMM USE		250,032	204,724	3,394,822
GOV USE		225,216	739,705	10,419,837
OTHER USE		44,446	224,585	1,001,762
INDUSTRIAL USE		46,434	34,655	740,746
TOTAL CLARKDALE USE		**8,358,644**	**7,643,733**	**118,080,647**
Cottonwood Ranch		1,407,000	1,925,000	25,361,000
TOTAL OTHER USE				
TOTAL USE		**9,765,644**	**9,568,733**	**143,441,647**
Wastewater System	ALL WASTEWATER TREATED IN GALLONS (INFLUENT)			
				YTD
		LAST MO.	SAME MO. LAST	
# ACCTS		**1,043**	**1,033**	
WASTEWATER TREATED		**4,921,572**	**4,085,623**	**53,201,813**
Influent gals/account		4,718.67		

Table A- 7. Potable Water Production, Demand, and Wastewater Influent and Effluent for the Town of Clarkdale, 2007-2014 [adapted from (Yates, 2015)].

WELL PRODUCTION & WASTEWATER PRODUCTION														
Year	**Haskell Springs (gal)**	**Reservoir/ 89A (gal)**	**Mt. Gate (gal)**	**All Wells (gal)**	**All Wells (AF)**	**From Cottonwood**	**Clarkdale Revenue Water (gal)**	**Demand (AF)**	**Effluent (gals)**	**Effluent (AF) (outlet of WWTP)**	Treated Effluent as % of Demand	Raw Influent into WWTP (AF) compiled fr monthly util rpts	Influent as % of Demand	Effluent treatment losses (% of raw)
2007	115,187,400	20,840,600	22,976,000	159,004,000	488.14		124,642,154	382.65	37,752,626	115.90	30%			
2008	107,752,000	2,958,772	15,429,000	126,139,772	387.25		127,030,275	389.98	41,149,553	126.33	32%			
2009	78,175,470		43,720,000	121,895,470	374.22	11,143,152	130,410,456	400.36	39,839,066	122.31	31%	135.44	34%	10%
2010	128,661,000		68,386,000	197,047,000	604.93	14,189,000	123,772,817	379.98	39,409,731	120.99	32%	139.18	37%	13%
2011	135,290,000		82,126,000	217,416,000	667.47	12,103,000	118,541,192	363.92	36,278,791	111.38	31%	125.29	34%	11%
2012	128,160,000		96,792,700	224,952,700	690.60	9,000	120,496,121	369.92	43,728,500	134.25	36%	131.51	36%	-2%
2013	127,849,000		84,535,000	212,384,000	652.02	2,836,000	119,310,883	366.28	43,130,436	132.41	36%	150.62	41%	12%
2014	104,747,000		92,527,000	197,274,000	605.63	3,481,000	118,080,647	362.51	43,119,754	132.38	37%	160.77	44%	18%
2015	52,490,000		68,151,000	120,641,000	370.37	11,241,000			24,924,170	76.52				

Appendix B

Simulation of Baseflow Capture Under Six Water Management Scenarios

Summary of Simulated Water Management Scenarios for Clarkdale

In order to evaluate the sensitivity of Verde River baseflow to potential water management actions taken by the Town of Clarkdale, the following scenarios were studied using the northern Arizona regional groundwater-flow model (NARGFM) published by the USGS in 2011:

1. Status Quo: All municipal (muni) and non-municipal pumping and artificial recharge in Clarkdale remains constant from 2014-2076. Non-muni pumping is 5% of muni pumping after 2014. Clarkdale's wastewater treatment facility (WWTF) recharge is 9% of total pumping, as in the NARGFM.
2. CYHWRMS Projected Demand: Clarkdale muni pumping is increased linearly from 700 AF/yr in 2014 to 2218 AF/yr in 2050, in accordance with CYHWRMS projected demand. Simulated pumping after 2050 is grown at half the rate of the 2014-2050 rate of growth. Two new wells were required to meet Clarkdale demand. WWTF recharge is 30% of total pumping. Non-muni pumping is held constant as in the status-quo scenario, so it drops as a percentage of total pumping from 5% in 2014 to 1% in 2076.
3. CYHWRMS with RIVER Recharge: Same as scenario 2 except that all Clarkdale WWTF recharge is moved from its present location to a site adjacent to the river (and the existing treatment plant).
4. CYHWRMS with WELL-FIELD Recharge: Same as scenario 2 except that WWTF recharge is moved to the 89A municipal well (no longer in service).
5. 50% CYHWRMS Demand: Same as scenario 2 except with 50% of projected CYHWRMS demand and WWTF recharge from 2014-2076. No change in non-muni pumping from status-quo, so non-muni pumping drops from 5% to 3% of total Clarkdale pumping from 2014 to 2076.
6. Total Reuse: Same as status-quo scenario except that municipal pumping is reduced by half from 2014-2076 and WWTF recharge ceases after 2014.

- All scenarios apply a natural recharge pattern that includes the current (2000-2014) drought, and then repeats the simulated recharge regime of the 1910-1970 period in the NARGFM.
- Some simulated pumping outside of Clarkdale was moved to deeper aquifer layers in order to prevent any model cells in the vicinity of Clarkdale from drying up and limiting pumping.

Summary of Results

Location of pumping and recharge are important factors in Clarkdale's net effect on Verde baseflows. Of the three highest-pumping/highest recharge scenarios (2-4), scenario 4 had the greatest negative impact on the Verde River because recharge occurred near the pumping center rather than near the river. The lowest-pumping scenario (6) still produced some impact on the Verde because no recharge occurred after 2014. The moderate-pumping scenario (5) was nearly as protective of the Verde River as the status-quo scenario (1), even with higher pumping and even though recharge was maintained at its present location in Bitter Creek rather than being moved next to the river. This result indicates that the quantity of recharge and the location of recharge, together, are more significant than the amount of pumping for the time period of this simulation. Scenario (3) exhibits the greatest aquifer storage loss but, as in all of the scenarios, storage loss begins to taper near the end of the simulation period in response to increased stream capture and WWTF recharge.

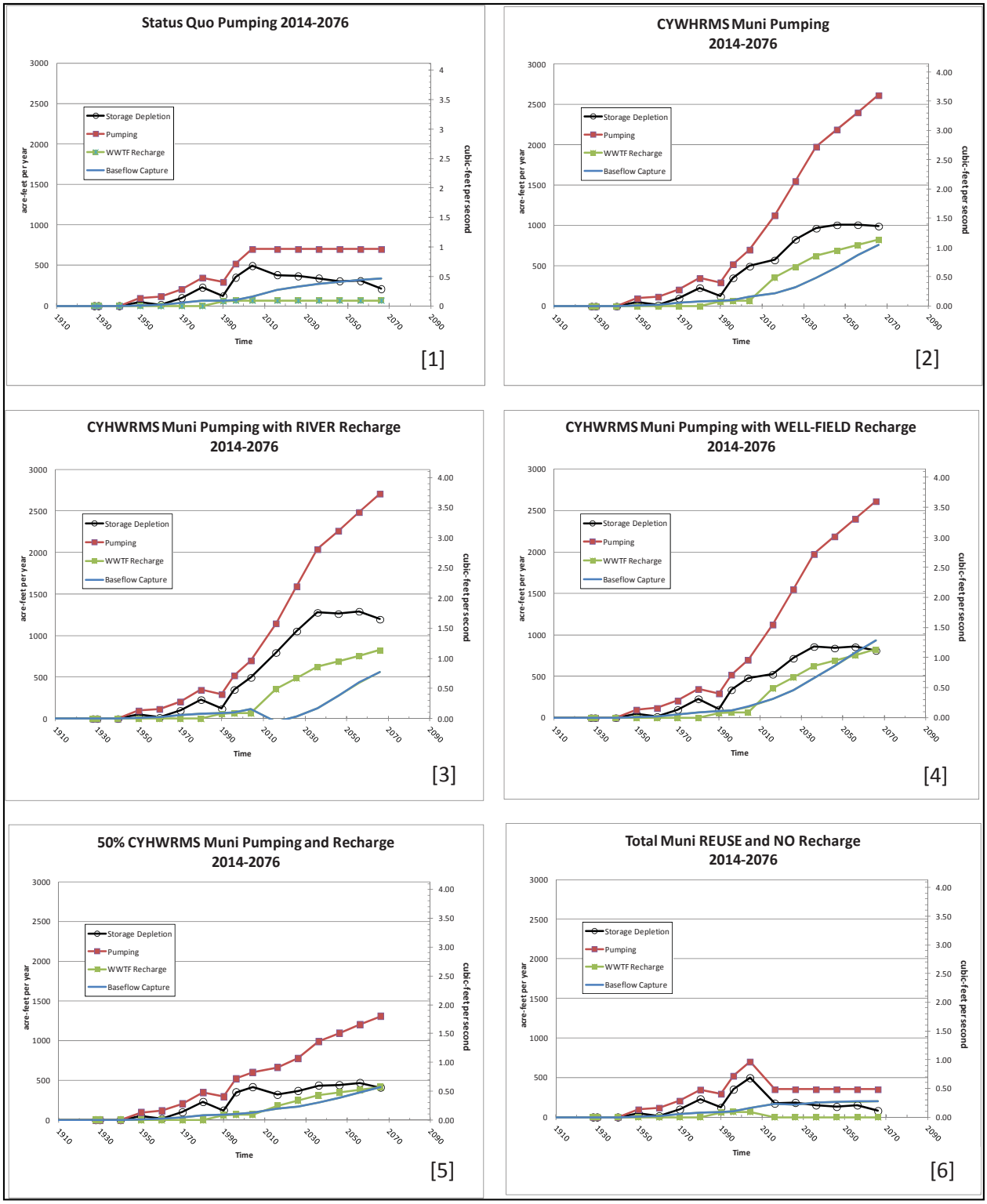

Figure A- 3. Six water demand and treated effluent management alternatives used to simulate groundwater storage and baseflow capture in Clarkdale.

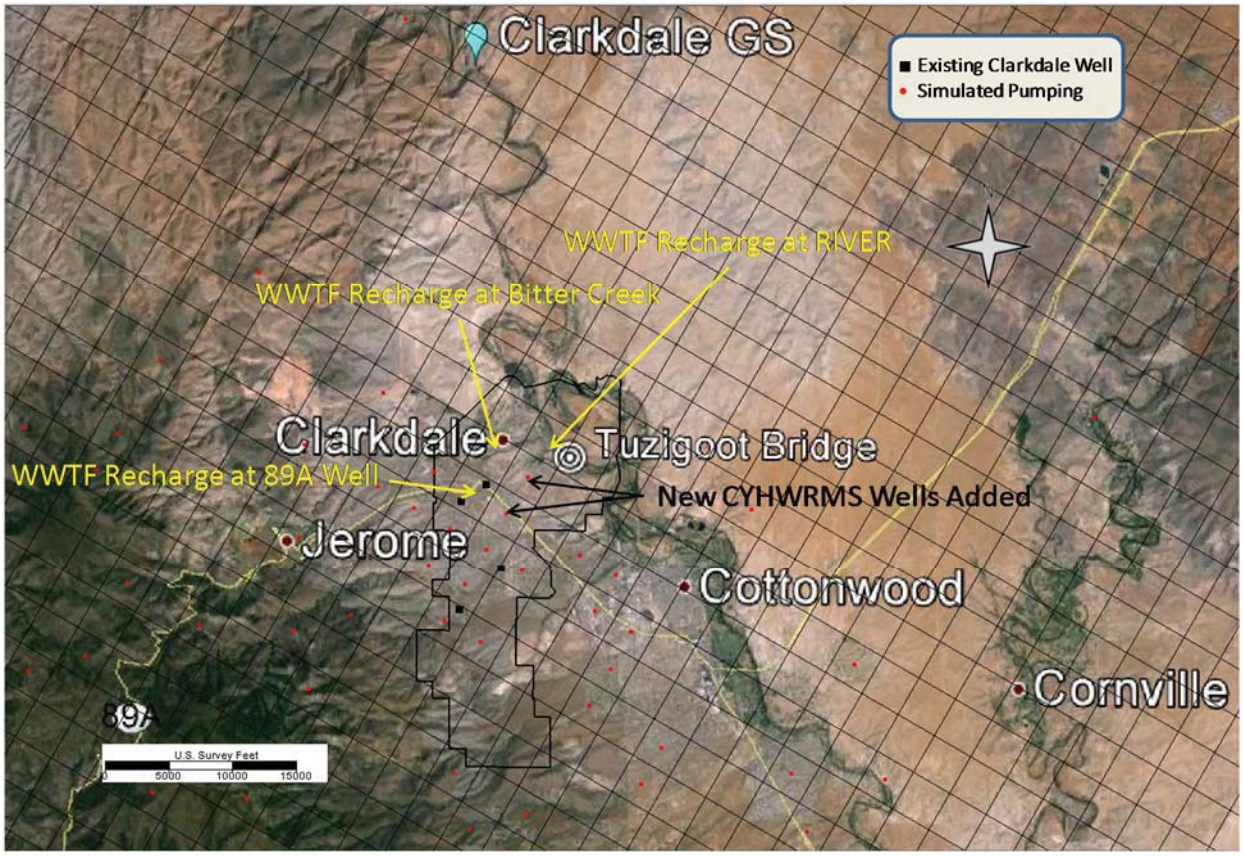

Figure A- 4. Location of simulated effluent recharge sites.