TRUCKEE MEADOWS WATER AUTHORITY

2016-2035

WATER RESOURCE PLAN

APPENDIX 2

APPENDIX 2-1

2006 Climate Change Study

Potential Climate Change and Impacts on Water Resources

prepared by

Mark Stone, Ph.D.
Division of Hydrologic Sciences
Desert Research Institute

Hilary Lopez, Ph.D.
Truckee Meadows Water Authority

prepared for

Truckee Meadows Water Authority
1355 Capital Boulevard
Reno, NV 89520

July 2006

Potential Climate Change and Impacts on Water Resources

Abstract

As a natural process of the climate system, the Earth's climate has been forever changing. Climate change in the last 100 years, however, is thought to have been influenced by human activities, in particular greenhouse gas (GHG) emissions. Early signs of this change, such as increased mean annual temperatures and thinner sea ice, have been observed in many regions of the world. According to global climate models, continued increases in greenhouse gas emissions could cause further changes in temperature, with the global mean temperature potentially rising by approximately 2.7 to 10.4º F by 2100. This potential change in climate could cause changes in atmospheric and oceanic circulation patterns, and in the hydrologic cycle, leading to altered patterns of precipitation and runoff. Warmer temperatures will potentially increase moisture availability and precipitation. However in mountainous regions, such as the Sierra Nevada, a larger fraction of the total precipitation could be in the form of rain, resulting in shorter snow accumulation periods, reduced annual snowpacks, earlier spring melting, and reduced summer flows. To plan effectively, it is important to understand how and why climate may change in the future and how that may affect water resources. The goal of this document is to summarize the current state-of-knowledge of climate change as it relates to water resources in the western United States.

Climate Change and Global Warming

As a natural process of the climate system, the Earth's climate has been forever changing. Most recently, within the past 100 years, scientists have witnessed a general warming trend in temperatures termed "global warming." Additionally, this "warming" seems to have accelerated during the past two decades. While natural processes contribute to global warming, it is also widely believed that human activities are attributing to the rapid temperature rise. A majority of scientists contend that human activities have "altered the chemical composition of the atmosphere through the buildup of greenhouse gases – primarily carbon dioxide, methane, and nitrous oxide" – and that this buildup has resulted in rising global temperatures (US EPA). However, it is important to point out that within the scientific community controversy continues regarding the extent and effects of human impacts on global climate change.

Atmospheric Greenhouse Gas and Aerosol Concentrations

The major greenhouse gasses, carbon dioxide, methane, nitrous oxide and water vapor, occur naturally in the atmosphere. These greenhouse gases trap and retain energy in the Earth's atmosphere and help keep temperatures hospitable. When there is an elevated buildup of these gases in the atmosphere, however, problems may arise. Human activities are releasing large quantities of these substances into the atmosphere. For example, according to the US Environmental Protection Agency (US EPA) since the beginning of the industrial revolution atmospheric concentrations of carbon dioxide have increased nearly 30%, methane concentrations have more than doubled, and nitrous oxide concentrations have risen by about 15%.

While concentrations of carbon dioxide (CO_2) have increased, the exact source of the recent rise in atmospheric CO_2 has not been determined with certainty. It is likely caused by an interacting combination of natural and anthropogenic forces. This appears reasonable because the magnitudes of human release and atmospheric rise are comparable, and the atmospheric rise has occurred contemporaneously with the increase in production of CO_2 from human activities following the Industrial Revolution (Soon *et al.* 1999). However, the factors that influence CO_2 concentrations are not fully understood. The current increase in CO_2 follows a 300 year warming trend following a Little Ice Age (Keigwin 1996). Some have hypothesized that the recent changes in atmospheric CO_2 can be explained by the oceans emitting gases naturally as temperatures rise following the Little Ice Age (Segalstad 1998). However, the expected associated drop in ocean CO_2 concentrations has not been observed (Sabine *et al.* 2004).

Human activities have also increased concentrations of atmospheric aerosols (microscopic, airborne particles) since pre-industrial times. Aerosols are emitted by industrial processes (fossil-fuel combustion and biomass burning) and their increased concentration offsets simultaneous warming by reducing solar radiation to the ground. Unlike greenhouse gases, which are generally long-lived, aerosols fall out of the atmosphere fairly rapidly, either dry (through sedimentation) or within rain (as condensation nuclei), and therefore are not uniformly mixed across the globe.

Atmospheric composition will continue to change throughout the 21st century. The Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES)(IPCC 2000) summarizes the results of global climate models that were used to forecast atmospheric concentrations of greenhouse gases based upon a range of emission scenarios. According to the IPCC report, emissions of CO_2 due to fossil fuel burning will strongly influence trends in atmospheric CO_2 concentration during the 21st century. By 2100, atmospheric CO_2 concentrations are projected between 540 to 970 ppm (90 to 250% above the concentration of 280 ppm in the year 1750). These projections include land and ocean climate feedbacks.

Global Temperature Records

Records show a measurable warming trend in the Earth's surface temperature over the past 100 years, with a rapid acceleration in warming over the past two decades (Figure 1). Over the past century, the global average surface temperature has increased by approximately 1º F (0.5º C). Further, 9 of the 10 warmest years on record have occurred since 1995. According to recent data released by the National Climatic Data Center (www.ncdc.noaa.gov), 2005 was likely the warmest or second warmest year in the global instrumental temperature record.

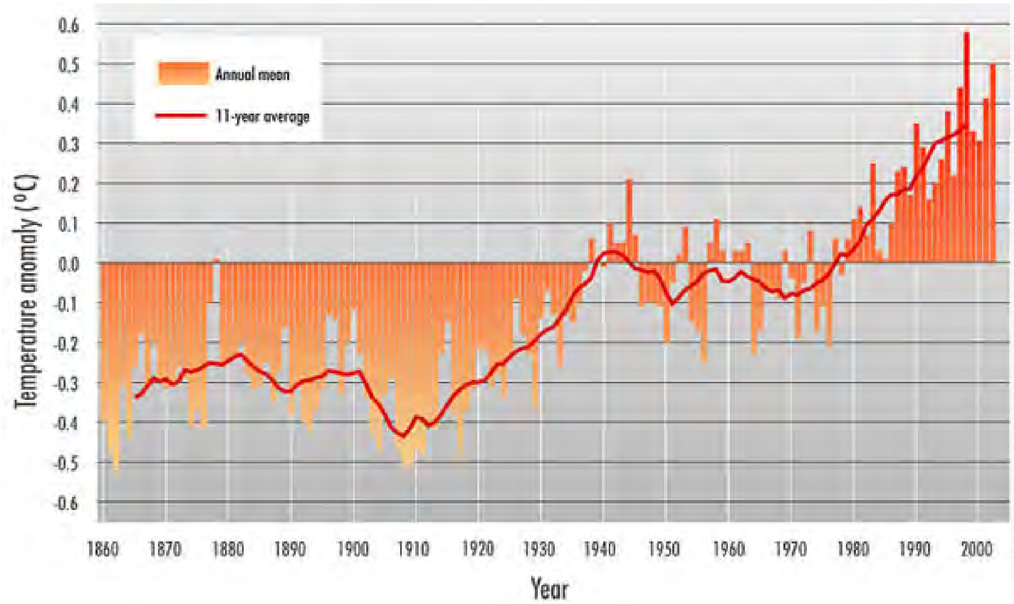


Figure1. Global mean land and sea-surface temperature anomalies for the duration of the instrumental record (Australian Bureau of Meteorology).

The Earth's surface temperature varies naturally over a wide range, but available temperature records are spatially and temporally limited. Records going back longer than 350 years are reconstructed from proxies. Reconstructed data produced from tree ring width, ice cores, and sedimentary deposits contain important limitations due to their required interpretation. For example, tree width and density have become less sensitive to changes in temperature over the last few decades (Briffa *et al.* 1998). The limited spatial extent of surface records results in only 18.4% of the Earth's surface being accurately described by direct measurement (Michaels *et al.* 2000). Further, the influence of land use change on temperature records is known to affect measurements through the urban heat island phenomenon. This systematic error has been extensively studied and debated. Peterson *et al.* (2003) found a bias in urban stations after 1990 at several stations. The researchers described the need to reassess designations of surface temperature stations as urban, suburban, or rural on a periodical basis.

Complex three-dimensional coupled ocean-atmosphere general circulation models (GCMs) can be used to predict future climate conditions under various greenhouse gas emission scenarios. Using an ensemble of GCMs and emission scenarios, the IPCC (IPCC WGI 2001) produced the range of predicted CO_2 and temperature changes shown in Figure 2. The globally averaged surface temperature is projected to increase by 2.7° to 10.4°F (1.4 to 5.8°C) over the period of 1990 to 2100. The projected rate of warming is much larger than the observed changes during the 20th century and very likely would be without precedent during at least the last 10,000 years. However, these models contain sources of uncertainty and there is a variety of debate with regards to these model predictions. An overview of the sources of uncertainty and debate is provided below.

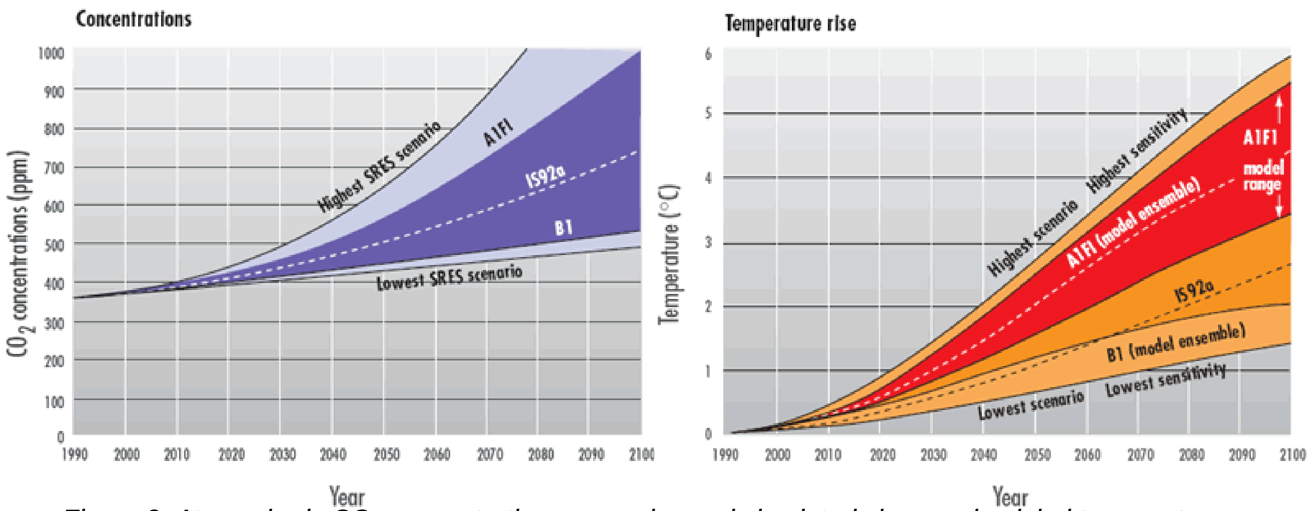


Figure 2. Atmospheric CO_2 concentrations scenarios and simulated changes in global temperature (Australian Bureau of Meteorology).

Sources of Uncertainty

As discussed above, the IPCC estimates that global average temperature will rise by between 2.7° to 10.4°F by the year 2100. Although climate models estimate that temperatures may warm, opponents of global warming theories point out that climate science cannot make definitive predictions yet because many of the physical processes modeled are only rudimentarily understood and are variously parameterized. Because the climate is a coupled, non-linear dynamic system, the climate models have many uncertainties. Without experimental validation of the models, the calculation of the climate response to increased anthropogenic atmospheric CO_2 will remain in doubt. For example, opponents of global warming theories that attribute temperature rise to human activities argue that the correlation between rising temperatures and CO_2 concentrations following the Industrial Revolution does not prove causation. The US EPA further reiterates the warning provided by all climate modelers to people considering the impacts of future climate change: *the projections of climate change in specific areas are not forecasts but are reasonable examples of how the climate might change* (US EPA).

The two primary sources of uncertainty are 1) forecasts of future greenhouse gas emissions; and 2) the nature of many feedback processes in the climate system. Future GHG emissions depend on the rate of growth of the world's economy and population, generation of energy technology, land use changes, and policies aimed at reducing emissions. Feedback processes may strongly influence global warming. For example, increased atmospheric water vapor may amplify warming, while changes in the extent of cloud cover and the characteristics of clouds may either enhance or diminish warming. Soon *et al.* (1999) discussed the following six important areas of uncertainty and error in climate modeling.

1) *Water vapor feedback* - The feedback process starts with increasing temperature that increases atmospheric water vapor concentration. Water vapor is itself a strong greenhouse agent, which in turn could amplify the warming caused by elevated CO_2. The model parameterization used to

describe this feedback mechanism is complex and has received criticism (e.g. Renno *et al.* 1994). Without adequate observations, it is difficult to determine the correct parameterization.

2) *Cloud forcing* – Climate models produce different projected temperature changes because they incorporate different estimates of the parameters that describe the behavior of cloud formation. Clouds are known to have an important influence on surface temperatures. However, current GCMs over-predict the coverage of high clouds by a factor as large as 2 to 5. The spatial distribution of clouds is also incorrect. Therefore, the parameterization of radiative, latent and convective effects of cloud forcing needs further improvements.

3) *Ocean-atmospheric interaction* – The dynamic nature of air-sea coupling is complex and requires intense *in situ* and satellite observations of heat, momentum, and freshwater fluxes. This is an active area of GCM research.

4) *Sea-ice-snow feedback* – Currently, GCM results under-predict the variance of sea-ice thickness in the Arctic on decadal to century time scales. This result emphasizes the importance of including realistic surface fluxes and modeling of convective overturning and vertical advection in both the Arctic and adjacent oceans.

5) *Biosphere-atmosphere-ocean feedbac*k – Biospheric feedback influences the global carbon budget because enhanced plant growth will sequester CO_2. Understanding this feedback holds the promise of an internally consistent description of the relationship of CO_2 to climate change.

6) *Flux errors* – Many models have substantial flux errors for which calibration adjustments are introduced into the calculations. One important consequence is the dampening of low-frequency variability in the simulation of climate state due to over stabilization.

The impacts of feedback mechanisms on predicted temperature are shown in Figure 3. Accounting for the range of uncertainty in these feedback processes results in a range of possible changes in global average temperatures for any given change in GHG concentrations. The range of temperature changes projected by the IPCC reflects the combined effects of all of these sources of uncertainty. Further, even greater uncertainty exists in regional predictions of climate change. Regional projections of impacts are most needed by decision-makers, and yet are not easily extracted from global climate model simulations. Results can sometimes even be contradictory at the regional scale, with either wetter or drier conditions predicted depending on the model used for the simulation.

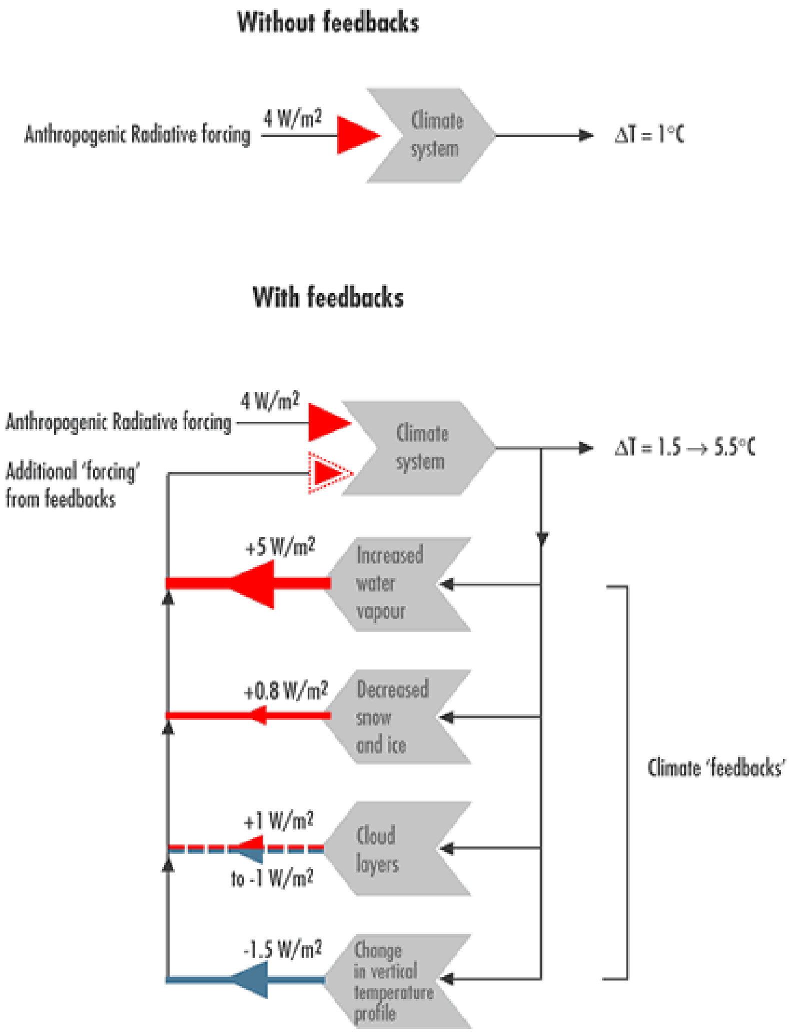


Figure 3. Schematic showing the influence of climate feedbacks on radiative forcing driving a climate model. The arrows are indicative of the magnitude and sign of individual feedbacks (Australian Bureau of Meteorology).

Potential Impacts of Climate Change on Water Resources

Although the science of climate change and predictions of future temperature and precipitation remain largely uncertain (particularly at the regional level), it is still appropriate to consider the potential impacts of such change on water resources. This information will enhance our ability to respond to change as the science advances and uncertainty is reduced. In this section, observed changes in hydrologic processes corresponding with recent warming trends in the western U.S. and potential impacts of future climate change on hydrologic processes are discussed.

Potential changes to the climate will likely alter the hydrologic cycle in ways that impact water resources. Regional climate-change projections are uncertain. However, the magnitude of projected warming combined with a strong regional reliance on mountain snowpack creates some consistency in the implication of climate change for the western U.S. The amount, intensity, and temporal distribution of precipitation could potentially change. Recent research suggests an intensification of the global hydrological cycle, leading to more intense but possibly less frequent periods of precipitation (longer periods of drought alternating with spells of heavy rainfall) (Trenberth 2003). In the west, warmer temperatures could affect the proportion of winter precipitation falling as rain or snow, accumulation of snowpack, and snowmelt timing. Evapotranspiration could change with changes in soil moisture availability, and plant responses to elevated CO_2 concentrations. In addition, changes in the quantity of water percolating to groundwater storage could result in changes in aquifer levels, in base flows entering surface streams, and in seepage losses from surface water bodies to the groundwater system.

The overall scientific consensus is that globally the Earth will be warmer with higher globally averaged precipitation. However, current scientific understanding does not provide confident projections of the magnitude or precise nature of changed precipitation patterns. Unlike the projections of precipitation change, climate models are fairly consistent in predictions of regional surface temperature. Because temperature is central in determining the accumulation and melting of snow and ice, these scenarios are especially relevant to regions where snowpack dominates the hydrology. Even with wetter winters, a warmer climate will result in a greater portion of winter precipitation falling as rain rather than snow, an elevated winter snowline, and a decrease in the snow-covered areas and total winter snowpack (Figure 4). Some of the most sensitive areas are where winter temperatures are now only slightly below freezing. Temperature also determines the timing of melt-off, and a warmer climate will likely result in an earlier melt season. Many regions are likely to see an increase in winter or early spring stream flows and reduced summer flows.

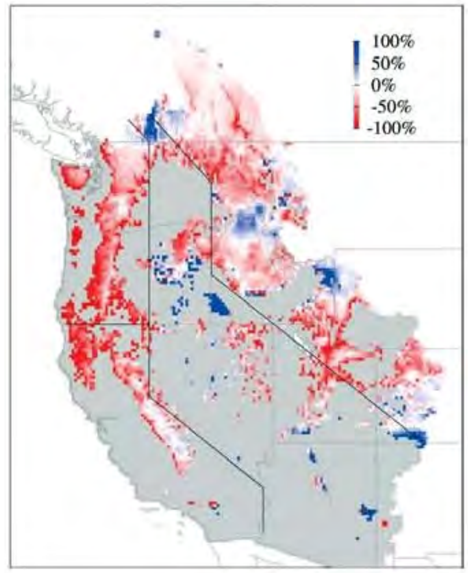


Figure 4. Linear trends in 1 Apr SWE for 1950–97 from a hydrologic simulation (Mote et al. 2003).

The results of warmer temperatures have been observed across the western U.S. Winter and spring temperatures have increased in western North America during the twentieth century (Folland *et al.* 2001), and there is a large body of evidence suggesting this widespread warming has produced changes in hydrology and plants. In the western U.S and southwestern Canada, spring snowpacks have been smaller and have been melting earlier in most mountain areas. Snow extent and depth have generally decreased in the west (Mote 2003). These declines have often occurred despite increases in total winter precipitation in those locations. The timing of spring snowmelt-driven streamflow has shifted earlier in the year (Cayan *et al.* 2001; Stewart *et al.* 2005), as is expected in a warming climate (Figure 5). There has also been a century-long downward trend in late spring and early summer flow as a proportion of total annual flow (Dettinger and Cayan 1995). Earlier spring melting and reduced spring snowpacks have been especially evident in the Cascade and northern Sierra Nevada Mountains, where winter temperatures are relatively mild. Some higher elevation mountain locations in the Southern Sierra Nevada and Rocky

Mountain ranges have shown an increasing trend in April 1 snowpacks, but even there the peak in spring runoff is generally occurring earlier (Stewart *et al.* 2004).

Dettinger *et al.* (2004) completed a simulation of hydrologic response to climate variation and change in three Sierra Nevada watersheds (including the Carson River watershed). The research used climate predictions from a GCM coupled with a hydrologic model to investigate future changes in streamflow. Although the climate model projections were near the lower edge of the available climate change simulations, in terms of warming and changes in precipitation, the results still showed significant and disruptive changes in the hydrology and ecosystems of the simulated basins. Predicted outcomes included large and clear trends towards earlier snowmelt runoff and reductions in summertime low flows and soil moisture. They found that snowmelt and streamflow could arrive about one month earlier by 2100 in response to an increased proportion of rain to snow and earlier snowmelt episodes.

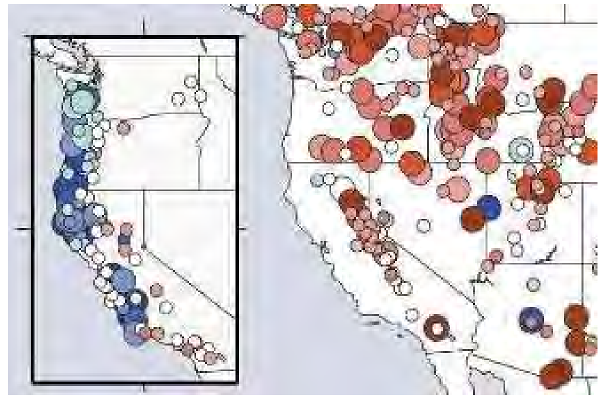


Figure 5. Trends in the date of center of mass of annual flow for snowmelt- and (inset) non-snowmelt-dominated gauges. Shading indicates magnitude of the trend expressed as the change (days) in timing over the 1948–2000 period (red negative and blue positive) (Stewart et al. 2005).

Warming of the climate could increase total evaporation from open water, soil, shallow groundwater, and water stored on vegetation, along with transpiration through plants. The interplay between atmospheric energy, moisture, and turbulence, and plant water use efficiency under different water, energy, nutrient, and CO_2 levels is complex and not yet fully understood. In dry regions, water availability, surface temperature and wind are important determinants of actual evaporation. Increases in surface temperature and higher wind speeds promote potential evaporation, while the greatest change will likely result from an increase in the water-holding capacity of the atmosphere.

The loss of snowpack could have a greater impact on groundwater recharge than estimates based only on changes in the amount of precipitation would indicate. Because snowmelt yields more recharge per unit amount of precipitation than rain, even if total precipitation remains constant, a shift from snow to rain could cause significantly decreased recharge (Earman *et al.* 2006). While the lessened amount of snowfall would be one contributor to loss of recharge, the changed conditions could also reduce the recharge efficiency of snow compared to that observed today. Thinner snowpacks subjected to increased temperatures would melt more rapidly than at present, increasing the likelihood of the melt running off rather than infiltrating.

Future climate change could influence municipal and industrial water demands, as well as competing agricultural irrigation demands. Municipal demand depends on climate to a certain extent, especially for garden, lawn, and recreational field watering, but rates of use are highly dependent on utility regulations. Shiklomanov (1999) notes different rates of use in different climate zones, although in making comparisons between cities it is difficult to account for variation in non-climatic factors. Studies in the UK (Herrington 1996) suggest that a rise in temperature of about 1.1°C by 2025 would lead to an increase in average per capita domestic demand of approximately 5 percent – in addition to non-climatic trends – but would result in a larger percentage increase in peak demands, since demands for landscape watering may be highly concentrated.

This section highlights some of the potential changes that could occur if regional climatic shifts occur as predicted from current climate models. While it is prudent to understand these potential impacts, further analyses are needed prior to concluding that global warming is impacting the Truckee Meadows region and implementing changes to water resource management.

Appendix

Long-term records of temperature and greenhouse gases

In order to provide context for recent changes in climate, it is helpful to investigate long-term climatic patterns. There is strong evidence that the Earth has experienced long periods during which average global temperatures were much colder and much warmer than today. Changes in the Earth's climate system throughout geologic time can be linked to changes in the components of the climate system, changes in the composition of the atmosphere, and the seasonal distribution and total amount of incoming solar energy.

The composition of the atmosphere has changed as a result of biological and geophysical processes, including storage of carbon in the ocean and its subsequent release, volcanic eruptions, and the occasional sudden release of methane from ocean floor sediments.

Three long-term cycles in the Earth's orbit combine to give a complicated pattern. Eccentricity is the change in the shape of the earth's orbit around the sun. Over a 95,000 year cycle, the earth's orbit around the sun changes from a thin ellipse to a circle and back again. When the orbit around the Sun is most elliptical, there is larger difference in the distance between the Earth and Sun at perihelion (period when the Earth is closet to the Sun) and aphelion (period when the Earth is farthest from the Sun). The Earth is currently in a period of low eccentricity (nearly circular). Obliquity describes the slight change in the Earth's tilt (22.1° and 24.5°) over a cycle that lasts about 42,000 years. When the tilt is larger, seasons are stronger and less snow melts in the polar regions because of the shorter days and reduced sunlight, allowing glaciers to form and spread. The Earth's tilt is currently 23.5°. The third type of orbital change is called precession, the cyclical wobble of Earth's axis in a circle. One complete cycle for Earth takes about 26,000 years. Precession does not directly cause temperature changes, but rather it changes the portion of the orbit at which a given season occurs. The current axis results in the Earth being closest to the Sun during the North American winter, resulting in milder seasonal fluctuations. This is important because glaciers require land on which to form. Most of the land surface on Earth is now in the northern hemisphere. Therefore, when the Earth's axis is oriented for northern winters to occur on the cooler part of the orbit, glaciers will tend to grow.

Changes in the seasonal distribution of incoming solar energy may have triggered the beginning and end of previous ice ages. However, the solar impacts were greatly amplified by positive feedbacks within the climate system, including changes in the reflection of sunlight back into space by ice-covered areas, changes in ocean circulation, and dramatic changes in atmospheric concentrations of greenhouse gases, especially CO_2 and CH_4.

Ice cores from glaciers and ice sheets around the world provide some of the best records of environmental conditions and climate change. In January 1998, the collaborative ice-drilling project between Russia, the United States, and France at the Vostok station in East Antarctica yielded the deepest ice core ever recovered, reaching a depth of 3,623 m (Petit *et al.* 1999). The Vostok ice-core record extends through four climate cycles, with ice slightly older than 420,000 years (Figure 6). The

Vostok data revealed a high correlation between GHG concentrations and temperature variations through four glacial cycles (Shackleton 2000). Atmospheric carbon dioxide concentrations varied from about *180 parts per million* (ppm) at the height of each glaciation to about *310 ppm* at the peak of each warming. Similarly, methane concentrations varied from approximately *350* to *800 parts per billion (ppb)*. The current atmospheric CO_2 concentration is approximately *375 ppm* and the methane concentration is approximately *1800 ppb* (Figure 3).

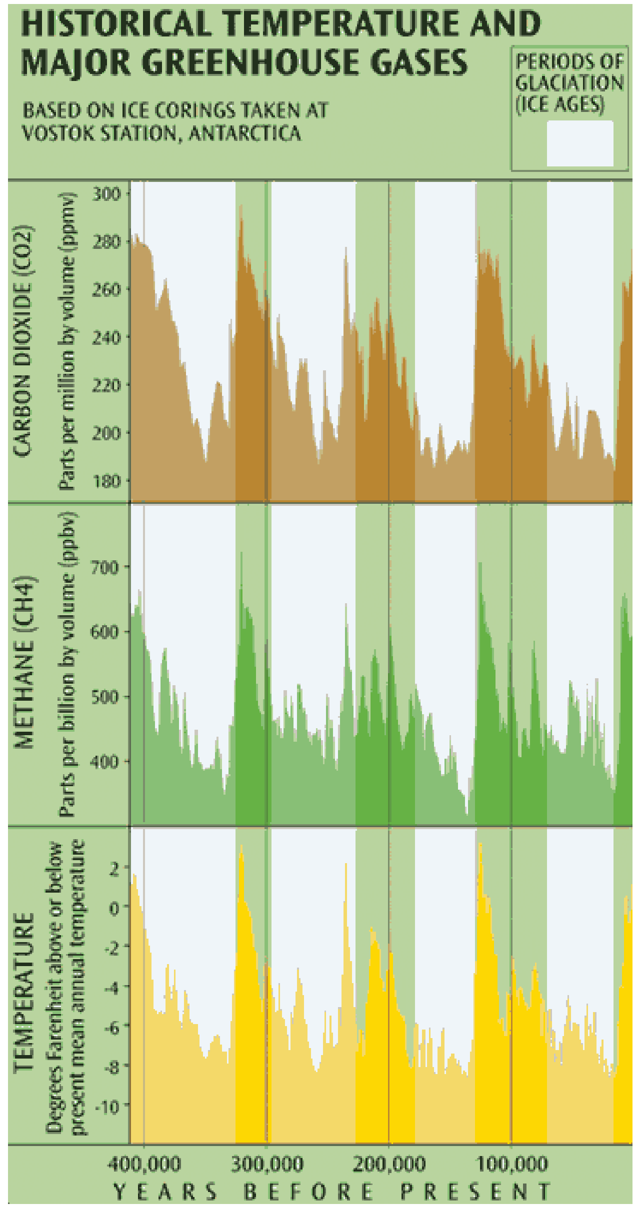


Figure 6. Temperature and GHG records from the Vostok Ice Corps (Petit et al. 1999).

Ocean Circulation Patterns

In addition to GHG concentrations, several natural processes influence the Earth's climate over various periods of time. Recent studies have shown the influence of coupled oceanic-atmospheric variability on climate of regions around the world. The most widely understood oceanic and atmospheric phenomenon is the El Niño-Southern Oscillation (ENSO). Other large-scale climate occurrences include the Pacific Decadal Oscillation (PDO), the Atlantic Multidecadal Oscillation (AMO), and the North Atlantic Oscillation (NAO).

ENSO is a major source of inter-annual climate variability in the western United States. ENSO variations are more commonly known as El Niño (the warm phase of ENSO) or La Niña (the cool phase of ENSO). An El Niño is characterized by stronger than average sea surface temperatures in the central and eastern equatorial Pacific Ocean, reduced strength of the easterly trade winds in the Tropical Pacific, and an eastward shift in the region of intense tropical rainfall (Figure 7). A La Niña is characterized by the opposite – cooler than average sea surface temperatures, stronger than normal easterly trade winds, and a westward shift in the region of intense tropical rainfall. Although ENSO is centered in the tropics, the changes associated with El Niño and La Niña events affect climate around the world. These events are typically on the order of 6 and 18 months in length (Tootle and Piechota 2004).

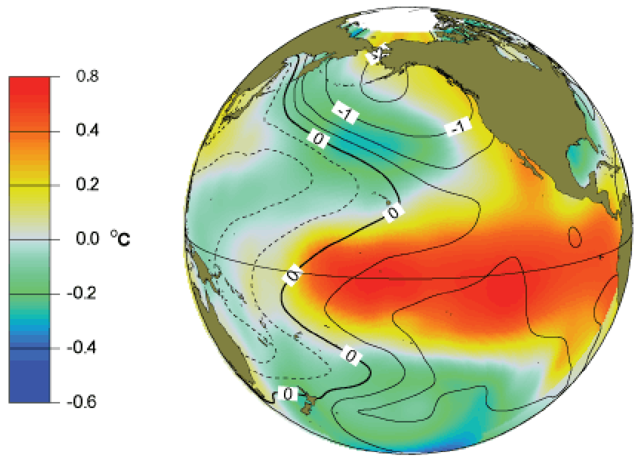


Figure 7. ENSO warm phase (http://www.cses.washington.edu/cig/).

The PDO is an oceanic-atmospheric phenomena associated with persistent, bimodal climate patterns in the northern Pacific Ocean that oscillate with a characteristic period on the order of 50 years (Mantua and Hare 2002). When the PDO is in its positive coastal warm phase, as it was for most of the period from 1977 through the mid-1990s, sea surface temperatures along the west coast of North America are unusually warm, the winter Aleutian low intensifies, and the Gulf of Alaska is unusually stormy. The slowly evolving state of the ocean, as measured by the PDO, interacts with the more rapid ENSO-related changes to influence storm tracks and, thus, the likelihood of unusually heavy or light seasonal precipitation. For example, a positive PDO appears to reinforce the effects of an El Niño, making wet winter conditions in the southwestern United States and dry conditions in the Pacific Northwest more likely than would be the case if the PDO were in the negative (coastal cool) phase.

The North Atlantic Oscillation (NAO) is associated with a meridional oscillation in atmospheric mass between Iceland and the Azores and has displayed quasi-biennial and quasi-decadal behavior since the late 1800s (Hurrell and Van Loon 1997) and its behavior is generally referred to as decadal. A positive NAO pattern drives strong, westerly winds over northern Europe, while southern Europe, the Mediterranean and Western Asia experience unusually cool and dry conditions. In the negative phase, winter conditions are unusually cold over northern Europe and milder than normal over Greenland, northeastern Canada, and the Northwest Atlantic. The Atlantic Multidecadal Oscillation (AMO) is observed through North Atlantic Ocean sea surface temperature variability with a periodicity of 65–80 years (Gray *et al.* 2004).

Thermohaline circulation in the World's oceans provides the connection between the movement of cold, salty water in the oceans' depths and the movement of warm, less saline water at the surface (Broecker 1997). Warm, low-salinity water from the tropical Pacific and Indian Oceans flows around the tip of South Africa and ultimately joins the Gulf Stream to transport heat from the Caribbean to Western Europe. As the water moves northward, evaporative heat loss cools the water and leaves it saltier and more dense. The cold, salty water sinks in the North Atlantic and flows back toward Antarctica, thus pushing the conveyor along. It is likely that increased high-latitude runoff and ice-melt caused by human-induced climate change will slow the thermohaline circulation. However, the impacts on projected temperature changes for Europe and the northern latitudes are not clear (IPCC WGI 2001).

References

Australian Bureau of Meteorology. 2006. http://www.bom.gov.au/publications.

Briffa, K. R., Jones, P. D., Schweingruber, F. H. and Osborn, T. J. 1998. Influence of volcanic eruptions on Northern Hemisphere summer temperature over the past 600 years. Nature, 6684: 450-454.

Broecker, W.S. 1997. Thermohaline Circulation, the Achilles Heel of Our Climate System: Will Man-Made CO2 Upset the Current Balance? Science, 278(5343): 1582 – 1588.

Cayan, D.R., Kammerdiener, S.A., Dettinger, M.D. and Caprio, J.M. 2001. Changes in the Onset of Spring in the Western United States. Bulletin of the American Meteorological Society, 82(3): 399-416.

Dettinger, M. D., Cayan, D. R., Meyer, M. K., and Jeton, A. E. 2004. Simulated Hydrologic Responses to Climate Variations and Change in the Merced, Carson, and American River Basins, Sierra Nevada, California, 1900-2099. Climatic Change, 62(1): 283-317.

Dettinger, M. D. and Cayan, D. R. 1995. Large-Scale Atmospheric Forcing of Recent Trends toward Early Snowmelt Runoff in California. Journal of Climate, 8(3): 606.

Earman, S., Campbell, A.R., Phillips, F.M. and Newman, B.D. 2006. Isotopic exchange between snow and atmospheric water vapor: Estimation of the snowmelt component of groundwater recharge in the southwestern U.S.A. Accepted for publication in Journal of Geophysical Research.

Folland, C. K., Rayner, N. A., Brown, S. J., Smith, T. M., Shen, S. S. P., Parker, D. E., Macadam, I., Jones, P. D., Jones, R. N. and Nicholls, N. 2001. Global temperature change and its uncertainties since 1861. Geophysical Research Letters, 28(13): 2621-2624.

Gray, S. T., Graumlich, L. J., Betancourt, J. L. and Pederson, G. T. 2004. A tree-ring based reconstruction of the Atlantic Multidecadal Oscillation since 1567 A.D. Geophysical Research Letters, 31(12): 12205.

Herrington, P. 1996. Climate change and the demand for water. Great Britain Dept. of the Environment, London. ISBN: 0117531383.

Hurrell, J.W. and Van Loon, H. 1997. Decadal Variations in Climate Associated with the North Atlantic Oscillation. 36(3): 301-326.

IPCC WGI. 2001. Third Assessment Report – Summary for Policymakers. http://www.ipcc.ch/pub/spm22-01.pdf.

IPCC. 2000. Special report on emissions scenarios : a special report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, UK. http://www.grida.no/climate/ipcc/emission.

Keigwin, L. D. 1996. The Little Ice Age and Medieval Warm Period in the Sargasso Sea. Science, 5292: 1504-1507.

Mantua, N. J. and Hare, S. R. 2002. The Pacific Decadal Oscillation. Journal of Oceanography, 58(1): 35.

Michaels, P.J., Knappenberger, P.C. and Davis. R.E. 2000. The way of warming. Regulation 33:10-16.

Mote, P.W. 2003. Trends in snow water equivalent in the Pacific Northwest and their climatic causes. Geophysical Research Letters, 30(12): 3-58.

Petit, J. R., Jouzel, J., Raynaud, D., Barkov, N. I., Barnola, J.-M., Basile, I., Bender, M., Chappellaz, J., Davis, M. and Delaygue, G. 1999. Climate and atmospheric history of the past 420,000 years from the Vostok Ice core, Antarctica. Nature, 6735: 429-436.

Peterson, T.C. 2003. Assessment of Urban Versus Rural In Situ Surface Temperatures in the Contiguous United States. Journal of Climate, 16(18): 2941-2959.

Renno, N. O., Stone, P. H. and Emanuel, K. A. 1994. Radiative-convective model with an explicit hydrologic cycle, 2, Sensitivity to large changes in solar forcing. Journal of Geophysical Research, 99(D/8): 17001.

Segalstad, T.V. 1998. Carbon cycle modelling and the residence time of natural and anthropogenic atmospheric CO2. Global Warming the Continuing Debate. Cambridge Press, Cambridge, UK.

Sabine, C. L., Feely, R. A., Gruber, N., Key, R. M., Lee, K., Bullister, J. L., Wanninkhof, R., Wong, C. S., Wallace, D. W. R. and Tilbrook, B. 2004. The Oceanic Sink for Anthropogenic CO2. Science, 305(5682): 367-370.

Shiklomanov, I.A. 1999. World Water Resources and their Use. Database on CD Rom. Paris, UNESCO.

Soon, W., Baliunas, S. L., Robinson, A. B. and Robinson, Z. W. 1999. Environmental effects of increased atmospheric carbon dioxide. Climate Research, 13(2): 149-164.

Stewart, I.T., Cayan, D.R. and Dettinger, M.D. 2004. Changes in Snowmelt Runoff Timing in Western North America under a `Business as Usual' Climate Change Scenario. Climatic Change, 62(3): 217-232.

Stewart, I.T., Cayan, D.R. and Dettinger, M.D. 2005. Changes toward Earlier Streamflow Timing across Western North America. Journal of Climate, 18: 1136.

Shackleton, N. J. 2000. The 100,000-Year Ice-Age Cycle Identified and Found to Lag Temperature, Carbon Dioxide, and Orbital Eccentricity. Science, 5486: 1897-1901.

Tootle, G.A. and Piechota, T.C. 2004. Evaluation of climate factors to forecast streamflow of the Upper Truckee River. Journal of the Nevada Water Resources Association, 1(1): 7-19.

Trenberth, K. E. 2003. The Changing Character of Precipitation. Bulletin of the American Meteorological Society, 84(9): 1205-1218.

U.S. EPA. 2006. Global Warming-Climate. http://yosemite.epa.gov/oar/globalwarming.

Hydrologic Trend Analyses for the Truckee Meadows Region

prepared by

Mark Stone, Ph.D.
Division of Hydrologic Sciences
Desert Research Institute

Hilary Lopez, Ph.D.
Truckee Meadows Water Authority

prepared for

Truckee Meadows Water Authority
1355 Capital Boulevard
Reno, NV 89520

July 2006

Hydrologic Trend Analyses for the Truckee Meadows Region

Executive Summary

Environmental change can result from a wide range of human induced activities and natural processes including land use change, resource management, and potential global climate change. These changes can influence all aspects of the hydrologic cycle including the magnitude, timing, and forms of precipitation, snowfall, streamflow, and lake volumes. The objective of this project was to investigate climate and hydrologic data in the Truckee Meadows region in order to reveal potential signs of environmental change that may be consistent and coincident with global warming. The analyses included investigations of temperature, precipitation, snow water equivalent, streamflow volume and timing, and reservoir volumes for the for the Lake Tahoe and Truckee River hydrographic basins.

Linear regression analyses were used to identify the following data trends:

- Temperature data revealed a slight trend towards increased minimum and maximum temperatures at most gages. However, a few stations showed trends towards decreased temperatures and year to year variability was quite high at all stations.
- Annual precipitation showed very high variability with an overall trend towards slightly reduced winter precipitation.
- Snow water equivalent (SWE) showed very high variability with some stations reporting a trend towards increased snowpack and others showing reduced snowpack trends.
- The SWE trends were highly correlated with instrument elevation, where high elevation stations observed increased SWE and the low elevation stations observed reduced SWE.
- Mean annual streamflow data varied widely between water years.
- Long-term streamflow volume and timing trends were investigated through linear regressions of the cumulative streamflow volumes. The records revealed no consistent trends in streamflow volume or timing for the period of record.
- Cumulative volume linear regression analyses were also used to investigate trends in reservoir volumes. The reservoir volumes displayed an obvious dependence on precipitation, as periods of drought strongly influenced reservoir volumes.

In order to investigate correlations between hydrologic variables and possible modifications in hydrologic processes, the following double-mass analyses were conducted:

- Relationships between streamflow and precipitation were studied at four paired stations. The results confirmed the expected high degree of correlation between these variables. The functions between precipitation and streamflow remained consistent throughout the records, indicating no observed modifications in large scale precipitation-runoff-streamflow processes at un-dammed gages.
- Double mass analysis of precipitation and reservoir volumes further demonstrated the high degree of correlation between these variables.
- Analyses of SWE and streamflow data revealed a slight deviation from historical trends over the past four water years.
- No consistent departures from long term patterns were observed between streamflow and reservoir volumes.
- Patterns between SWE and reservoir volumes remained consistent throughout the period of record.

To summarize, no significant changes were found in the climatic and hydrologic variables over the period of record. Temporal trends in temperature, winter precipitation, and SWE were observed at some stations. However, very high year-to-year variability was observed for all stations and parameters.

Methodology

Volume and timing analyses were performed on historic gage records throughout the region. A Geographic Information Systems (GIS) based inventory was produced containing regional weather stations, snowcourses, stream gages, and reservoir levels. Details of the database components are given below. The database was then used to investigate changes in precipitation, snowpack, streamflow volume and timing, and reservoir volumes over the period of record. This investigation was conducted using mass and double-mass analyses of the climate and hydrologic variables. The analyses are summarized in Table 1. The details of the analyses for specific variables are given within the discussion of results.

Table 1. Summary of mass and double-mass analyses

Mass Analyses	**Double-Mass Analyses**
- Temperature	- Precipitation vs. Snowpack
- Precipitation	- Precipitation vs. Streamflow
- Snowpack	- Precipitation vs. Reservoir Volumes
- Streamflow	- Streamflow vs. Snowpack
- Reservoir Volumes	- Streamflow vs. Reservoir Volumes
	- Reservoir Volumes vs. Snowpack

Database Development

Weather Stations

A GIS database was developed to store, retrieve, and analyze climate and hydrologic data. GIS shapefiles were obtained from Truckee Meadows Water Authority (TMWA), Environmental Protection Agency (EPA), and the United States Geologic Survey (USGS). Climate data were compiled from the National Weather Service (NWS) Cooperative Observer Program (COOP). Weather station records included precipitation and minimum and maximum temperature data. All COOP gages within 50 miles of the Truckee and Carson River basins were identified. The Carson River basin was included in this study to augment the limited number of qualified gages in the Truckee River basin, particularly for the double mass analyses. This process revealed approximately 35 gages. The study gages were filtered both geographically and according to available period of record. Filtering resulted in 11 gages being considered in the study (Figure 1). The station locations were added to the GIS database and the historical data was requested from the Western Regional Climate Center. The time series data were linked to the GIS database in a hyperlink format. Details of the gage records can be found in Appendix L.

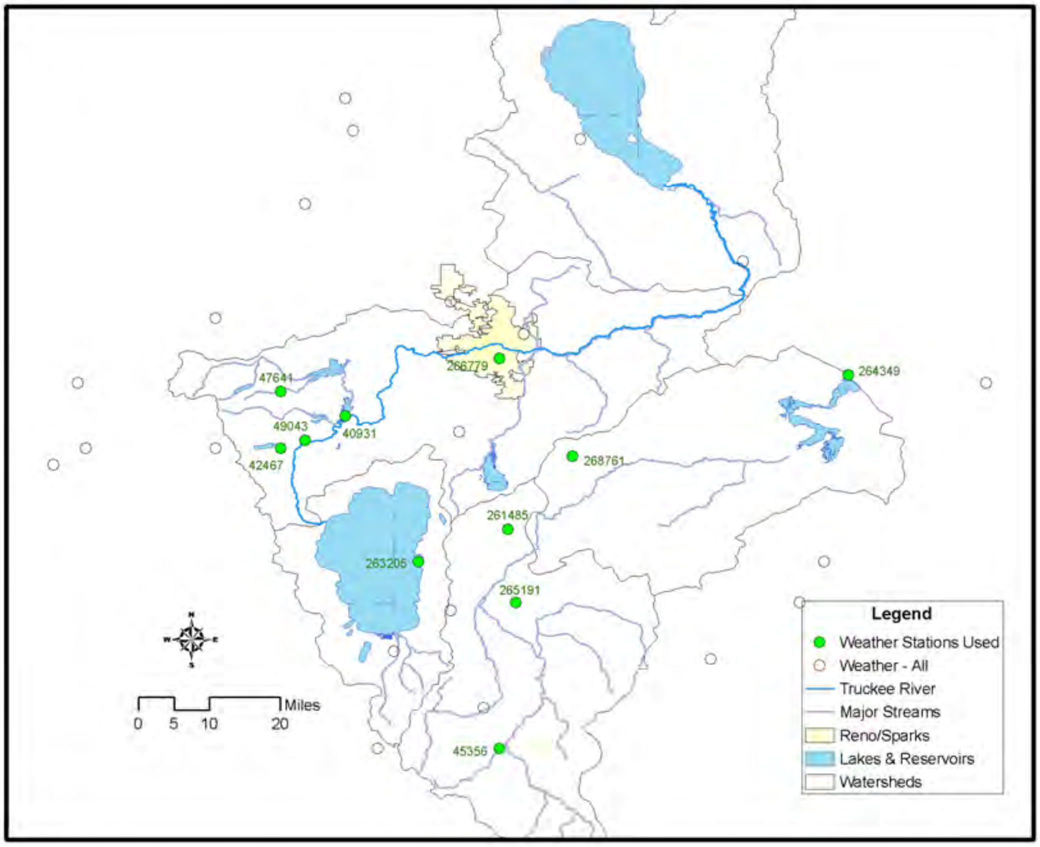


Figure 1. Truckee and Carson River basins and locations of study weather stations.

Reservoir Volume and Stream Discharge

Daily and monthly records of lake and reservoir storage volumes for all major water bodies were requested from the USGS and the data were linked to the GIS database. Daily historical streamflow records were downloaded from the USGS NWISWeb Water Data website. As with the climate data, data records and station coordinates were obtained for all stream gage stations in the region. The potential gages were then filtered to identify the gages with adequate periods of record. This resulted in 24 gages to be considered in the analysis (Figure 2). The time series data were linked to the GIS database in a hyperlink format. Details of the reservoir and stream gage records can be found in Appendix L.

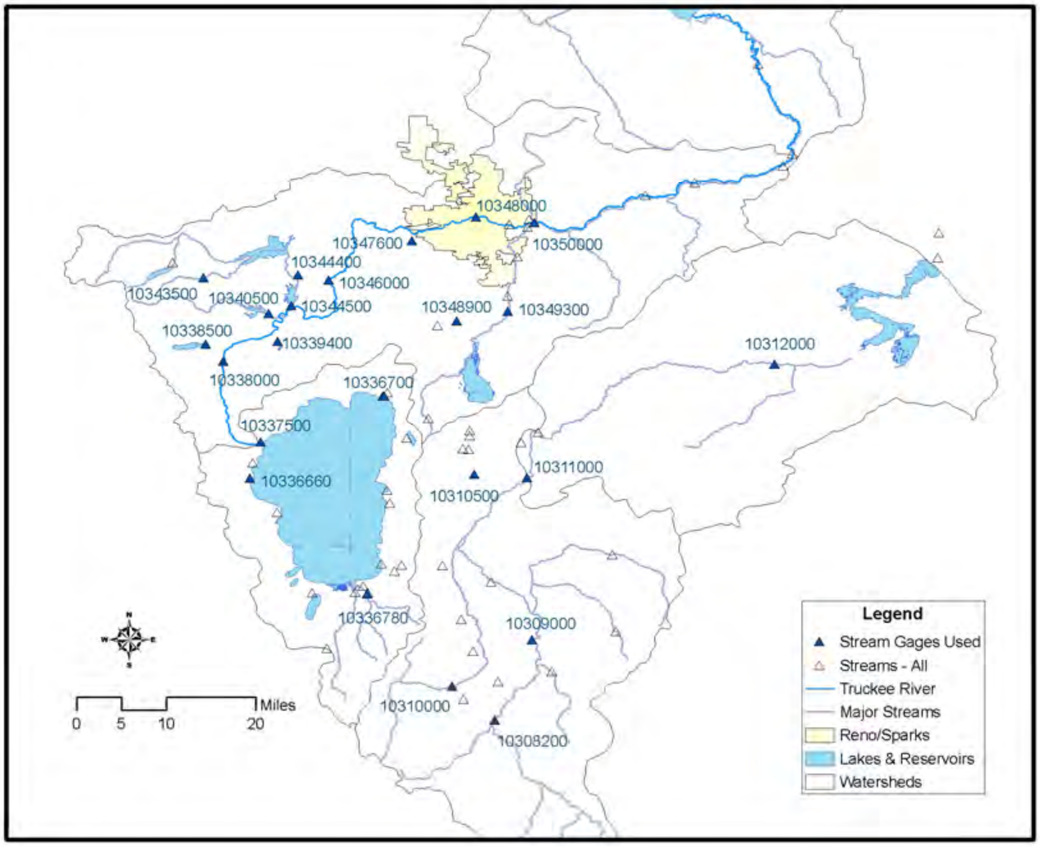


Figure 2. USGS streamgage stations for the Truckee and Carson River Basins.

SNOTEL and Snowcourse Data

Snow water equivalent data were first obtained for all regional NRCS SNOTEL stations. However, the SNOTEL data were only available from 1980 forward. To extend the period of analysis, historical snowcourse data were also obtained. Although the snowcourse data are only available at a limited temporal resolution, the periods of record extend back more than 50 years at many of the stations. The snowcourse stations used in the study are shown in Figure 3. The snowcourse data were linked to the GIS database in a hyperlink format. Details of the snowcourse records can be found in Appendix L.

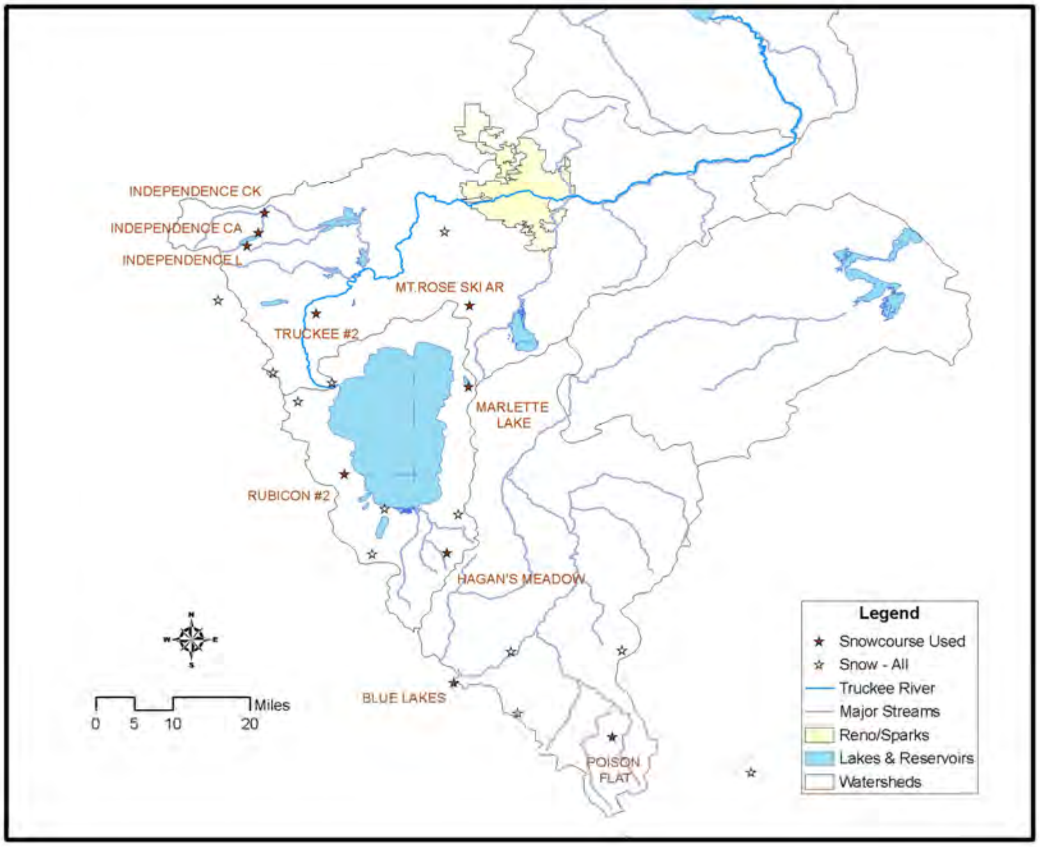


Figure 3. Snowcourse station locations in the Truckee and Carson River basins.

Results

Temperature Data

Linear regressions were used to evaluate trends in annual minimum and maximum temperature at eight weather stations. As an example of the regression results, Figure 4 shows temperature data for the Truckee Ranger Station. Results for the remaining stations can be found in Appendix A. The data revealed a slight trend towards increased minimum and maximum temperatures at five gages. However, three stations showed a trend towards decreased temperatures and year to year variability was quite high at all stations. The regional temperature trends were overall less than the observed global increase in surface temperature of approximately 1º F over the past century.

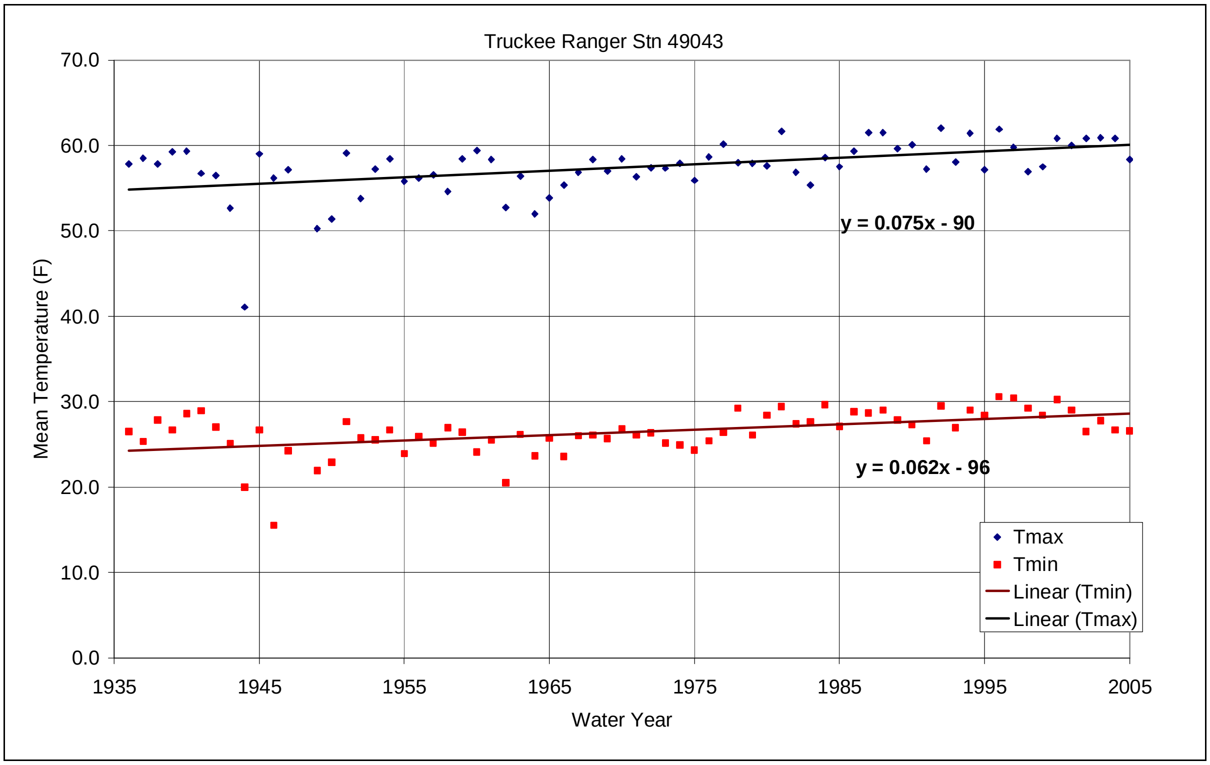


Figure 4. Mean annual maximum and minimum temperature at Truckee Ranger Station, 49043.

Precipitation

Precipitation data were examined over a range of temporal scales. Figures 5 and 6 contain seasonal precipitation trends for the Sagehen Creek and the Reno Airport, respectively. The seasons were defined as Winter (October through March) and Summer (April through September). The precipitation showed very high year-to-year variability at all stations. Winter precipitation displayed a slight decreasing trend for seven out of the nine stations. Little or no trend was observed in mean summer precipitation. Results for the remaining precipitation trends are shown in Appendix B.

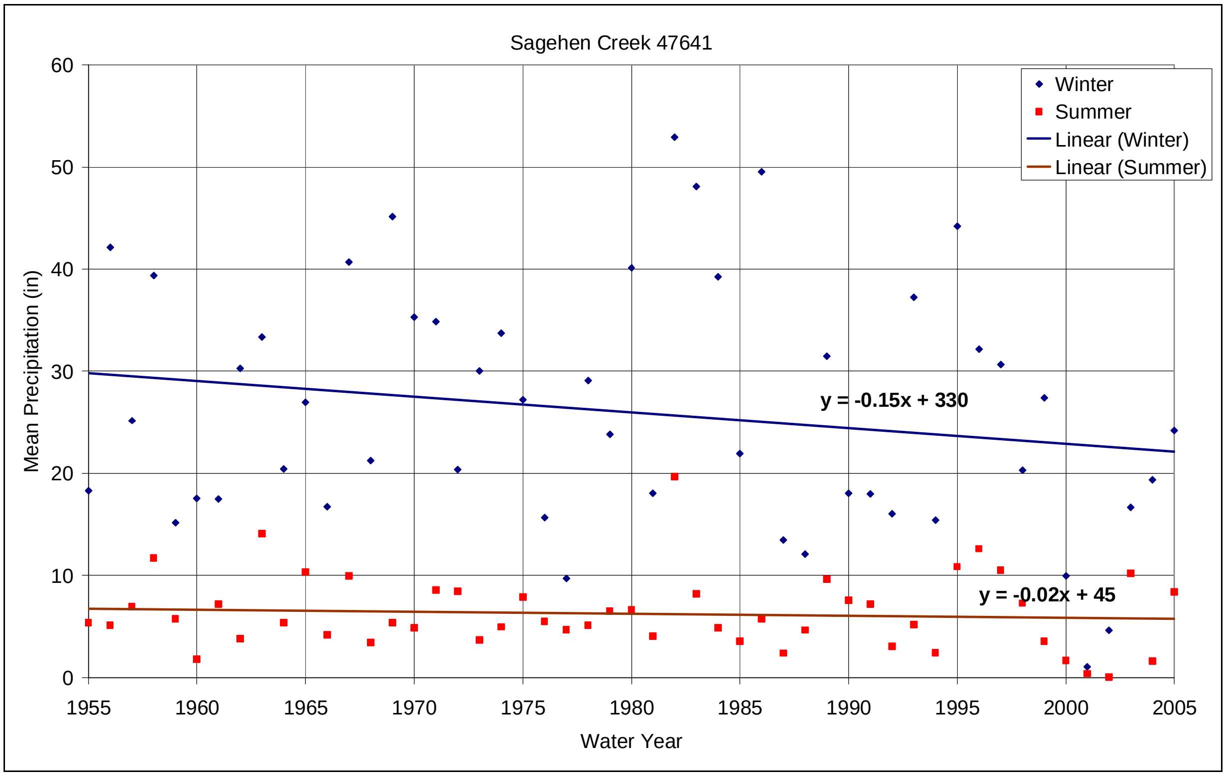


Figure 5. Mean winter and summer precipitation at Sagehen Creek 47641.

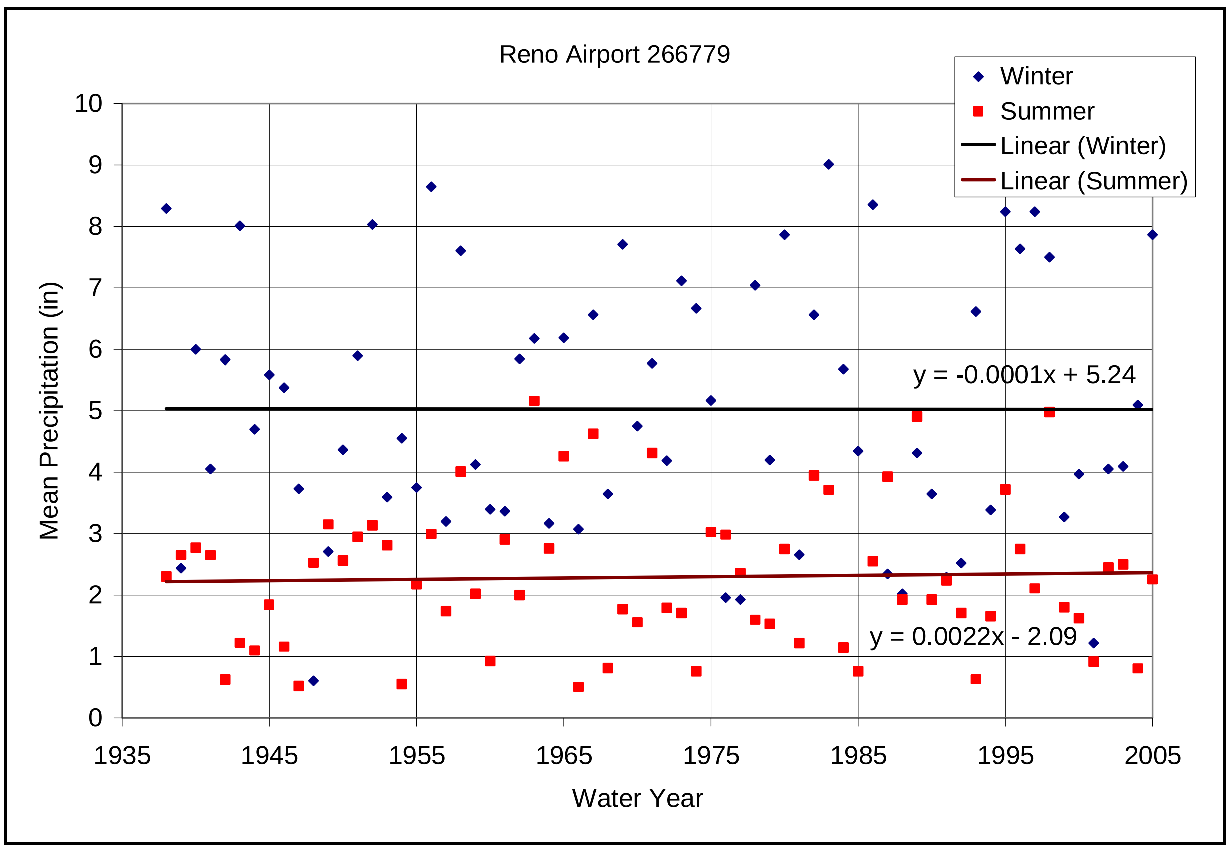


Figure 6. Mean winter and summer precipitation at the Reno Airport 2666779.

Snow Water Equivalent

Snow water equivalent (SWE) showed very high variability with some stations reporting a slight trend towards increased snowpack and others showing reduced snowpack trends. For example, SWE trends for Independence Creek and Mt. Rose Ski Area snowcourse stations are shown in Figures 7 and 8, respectively. Although SWE trends were very small, and variability was very high, the trends were highly correlated with instrument elevation. High elevation stations observed increased SWE and the low elevation stations observed reduced SWE (Figure 9). Although this observation is consistent with expectations for climate change, further investigations of precipitation and temperature trends in the Truckee Meadows (discussed above) did not corroborate this hypothesis. For example, high elevation weather stations did not observe increased precipitation and temperature changes were not correlated with elevation. The remaining SWE data can be found in Appendix C.

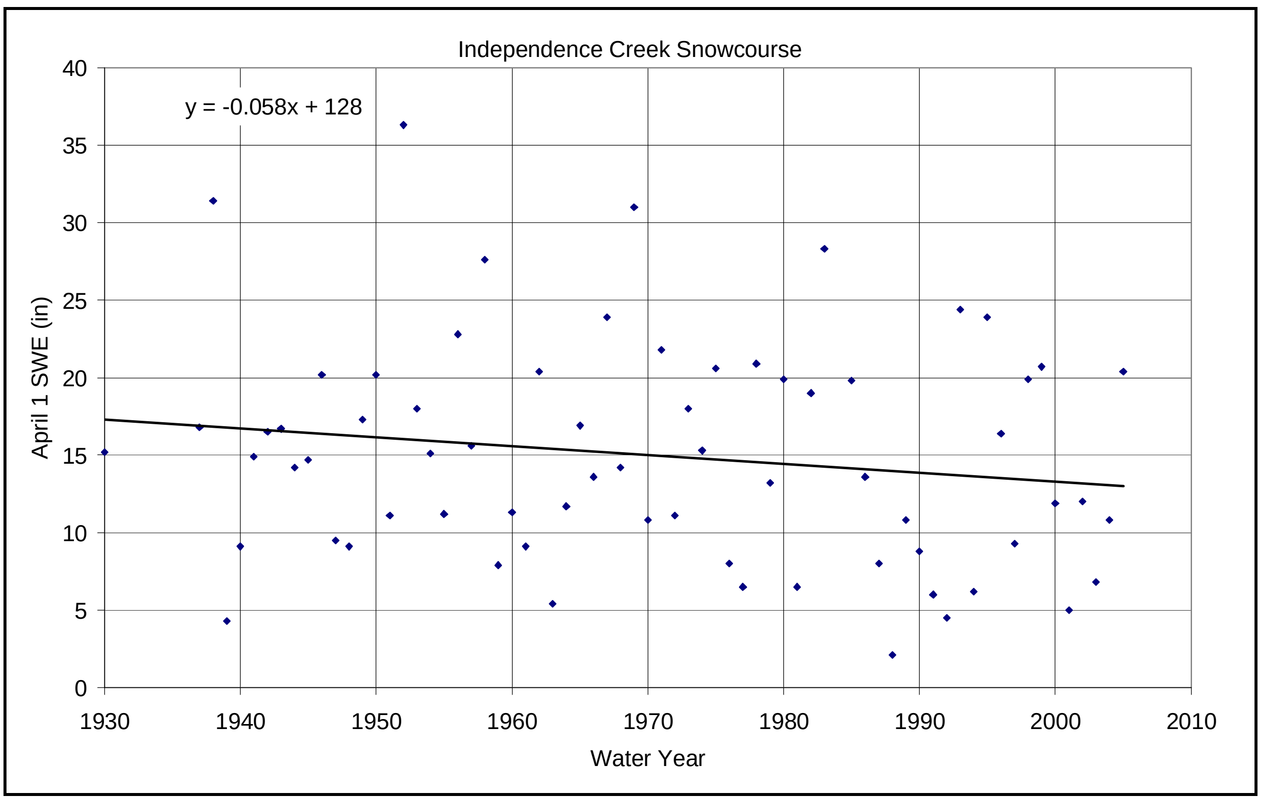


Figure 7. Annual April 1st SWE at the Independence Creek snowcourse station.

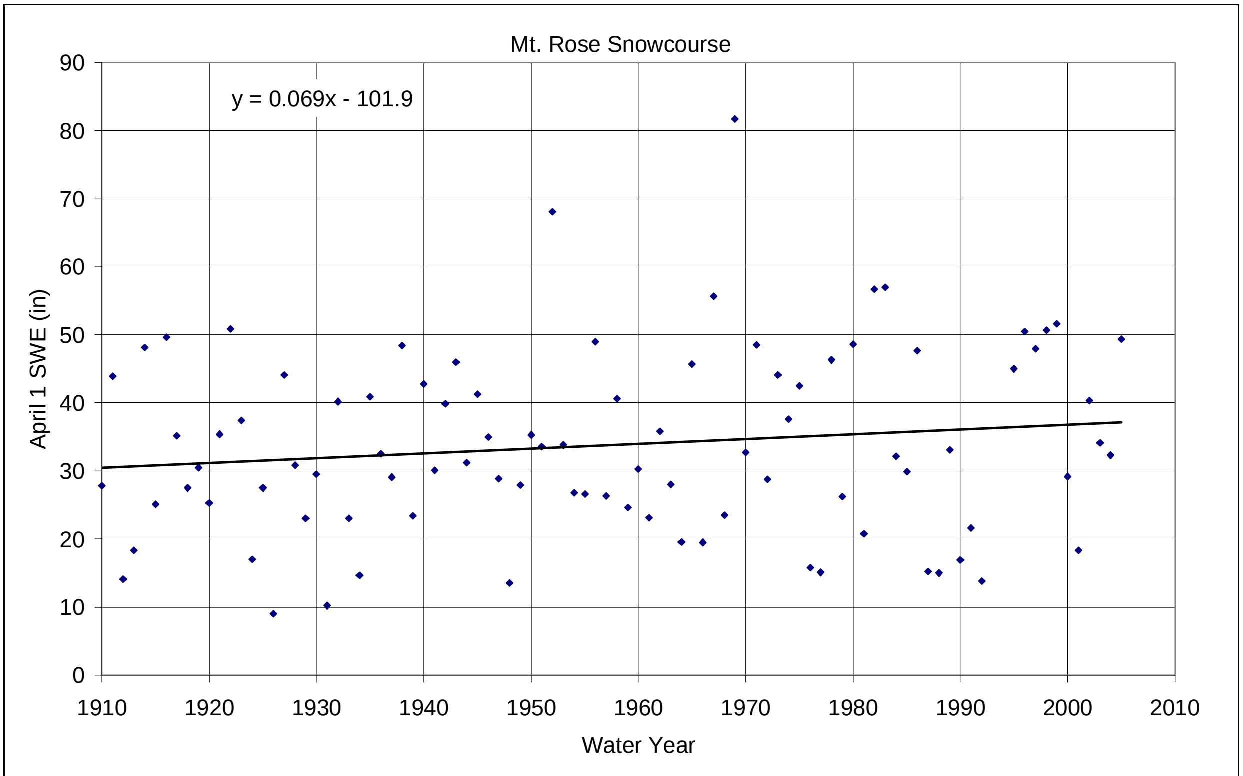


Figure 8. Annual April 1st SWE at the Mt Rose Ski Area snowcourse station.

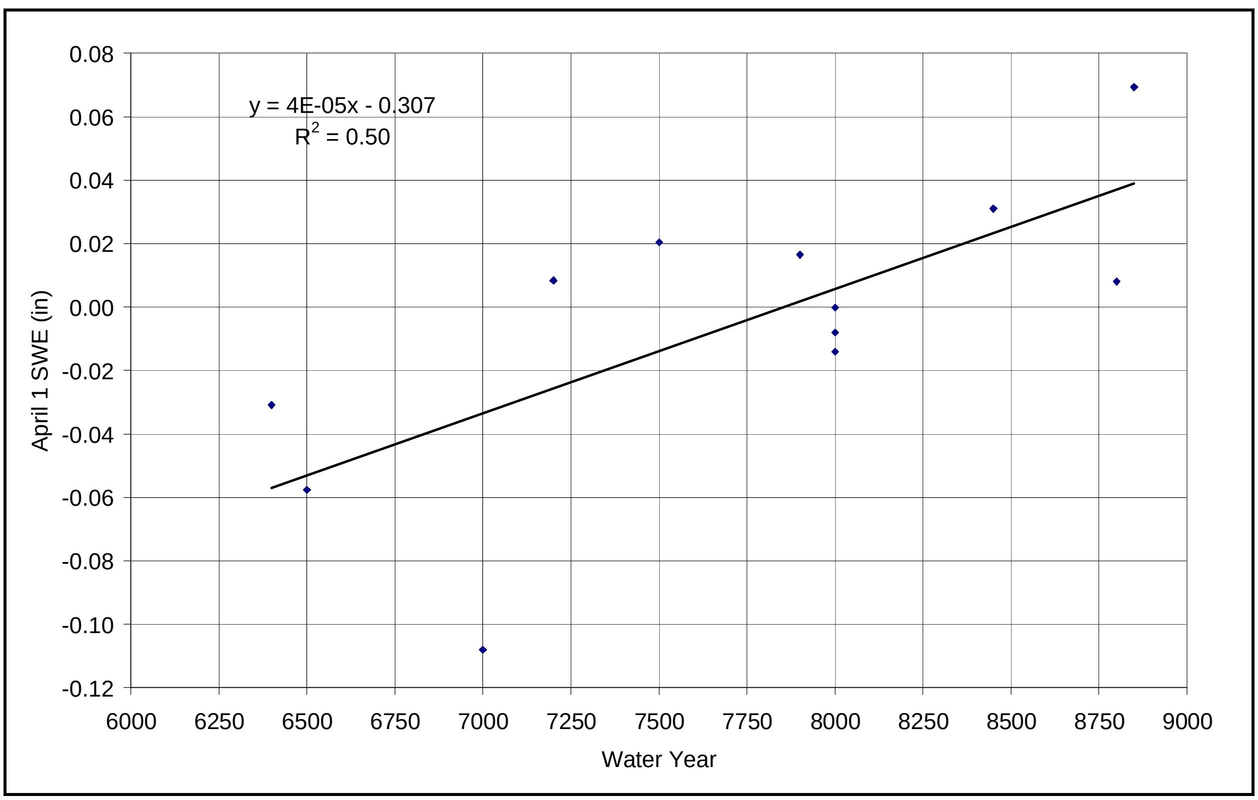


Figure 9. Trends in April 1 SWE snowcourse data as a function of station elevation.

Streamflow

Long term streamflow trends were investigated through a linear regression of the cumulative streamflow volumes. As expected, mean annual streamflow data varied widely between water years. The records revealed no observable trends over the period of record. Figure 10 contains an example of the streamflow data for the Truckee River at Reno. All other streamflow data can be found in Appendix D.

In addition to the streamflow volume analyses, streamflow timing was also studied. The timing was studied by investigating trends in the date at which the center of mass of the annual hydrograph occurred. As with the volume data, the center of mass data showed high year-to-year variability. A trend towards an earlier occurring date for the center of mass was observed for 14 out of the 21 stations. Figure 11 contains the center of mass data for the Little Truckee River above Boca Reservoir.

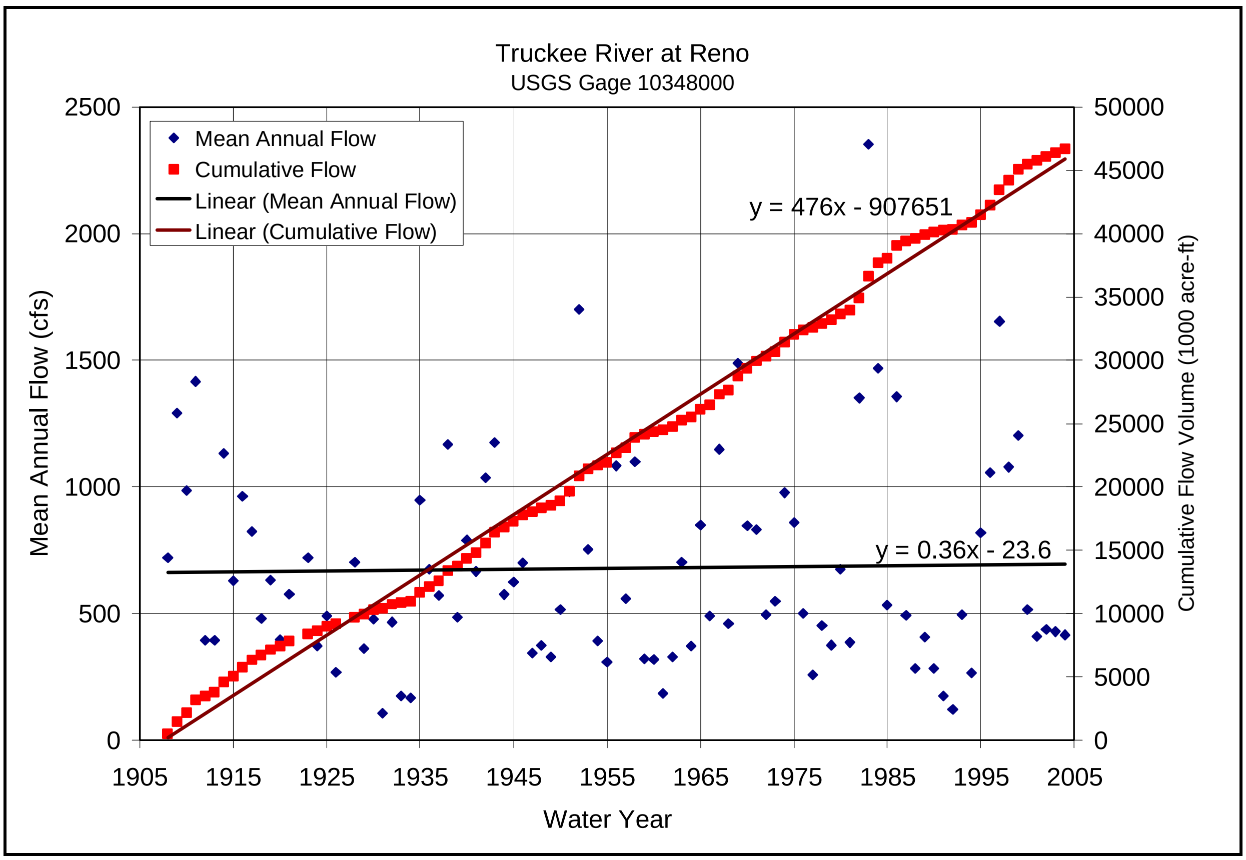


Figure 10. Mean annual streamflow and cumulative flow volumes for the Truckee River at Reno.

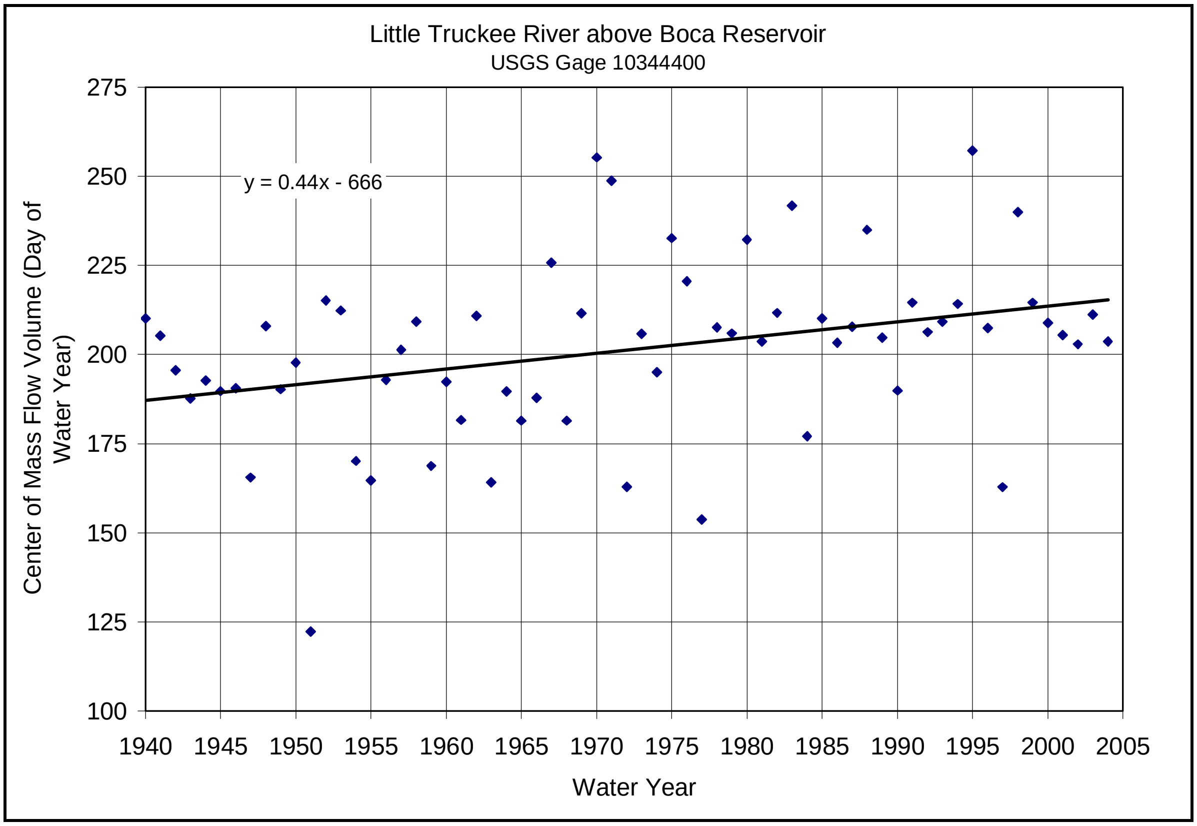


Figure 11. Little Truckee River above Boca Reservoir streamflow center of mass.

Reservoir Volumes

Mean annual reservoir storage volumes and cumulative mean annual storage were also investigated. The reservoir volumes displayed an obvious dependence on climate, as periods of drought clearly influenced reservoir volumes. This dependence is demonstrated by Figure 12, which contains data for Boca Reservoir. In periods of high precipitation and streamflow (e.g. 1972 to 1986), the reservoir volume was high and the cumulative volume climbed faster than the historical trend. However, during periods of drought (e.g. 1987 to 1995) the reservoir volumes dropped dramatically, and the cumulative storage volumes climbed slower than the historical trend. For Lake Tahoe, the storage volume became negative as the lake level fell below its natural rim. During this period, the cumulative storage volume trend was actually negative. Lake Tahoe trends, along with the other major regional reservoirs, are shown in Appendix E.

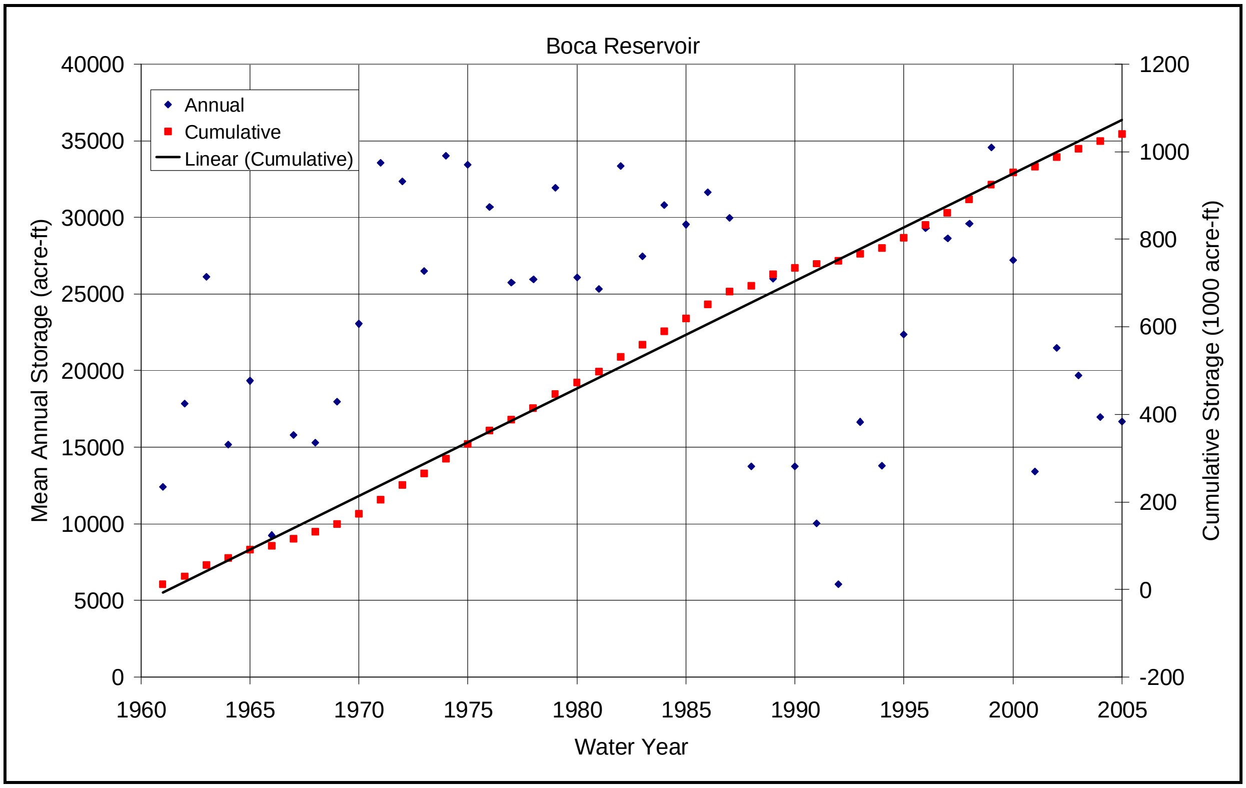


Figure 12. Mean annual storage and cumulative storage for Boca Reservoir.

Precipitation and Snowpack

Double mass analyses were conducted on precipitation and snowpack data at two sets of gages. Although snowfall and SWE is reported at the COOP stations, this data is considered less reliable than snowcourse stations. Thus, the analysis was restricted to COOP precipitation and snowcourse stations that were in close proximity. The results for the double mass analysis between annual precipitation at the Truckee Ranger Station and April 1st SWE at the Truckee #2 Snowcourse station are shown in Figure 13. The data reveals a very consistent trend between precipitation and SWE throughout the periods of record. This suggests that the form of precipitation and snowmelt patterns have not changed noticeably.

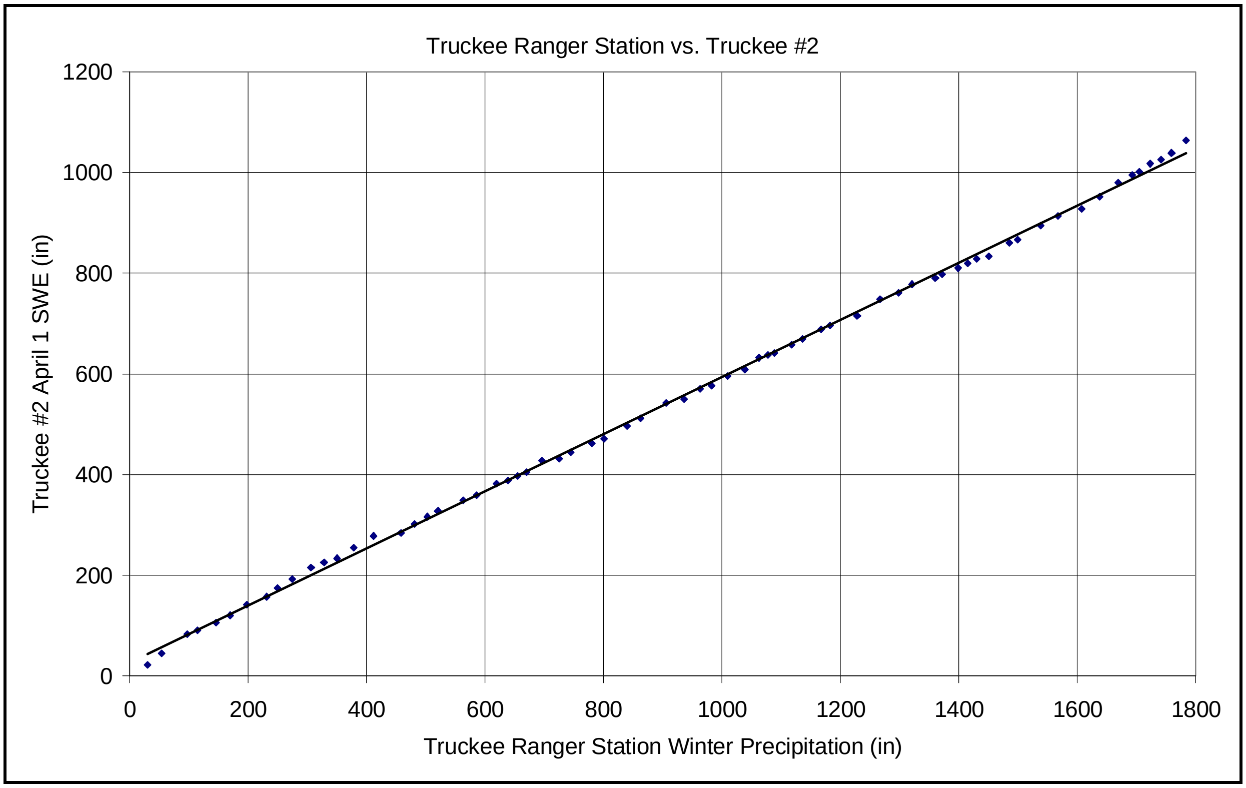


Figure 13. Double mass curve for Truckee #2 snowcourse station April 1 SWE and Truckee Ranger Station winter precipitation.

Precipitation and Streamflow

Relationships between streamflow and precipitation were studied at four paired stations. The stations were selected so that the gaged precipitation was 'representative' of the observed streamflow. Also, streamflow records that were influenced by reservoir construction and other local human activities were not considered. The results confirmed the expected high degree of correlation between precipitation and streamflow. The function between precipitation and streamflow remained consistent throughout the period of record, indicating no observed modifications in large scale precipitation-runoff-streamflow processes at un-dammed gages. Figure 14 contains the results of the double mass analysis for the Donner State Park weather station and the Donner Creek streamgage. The results of the remaining three analyses are shown in Appendix G.

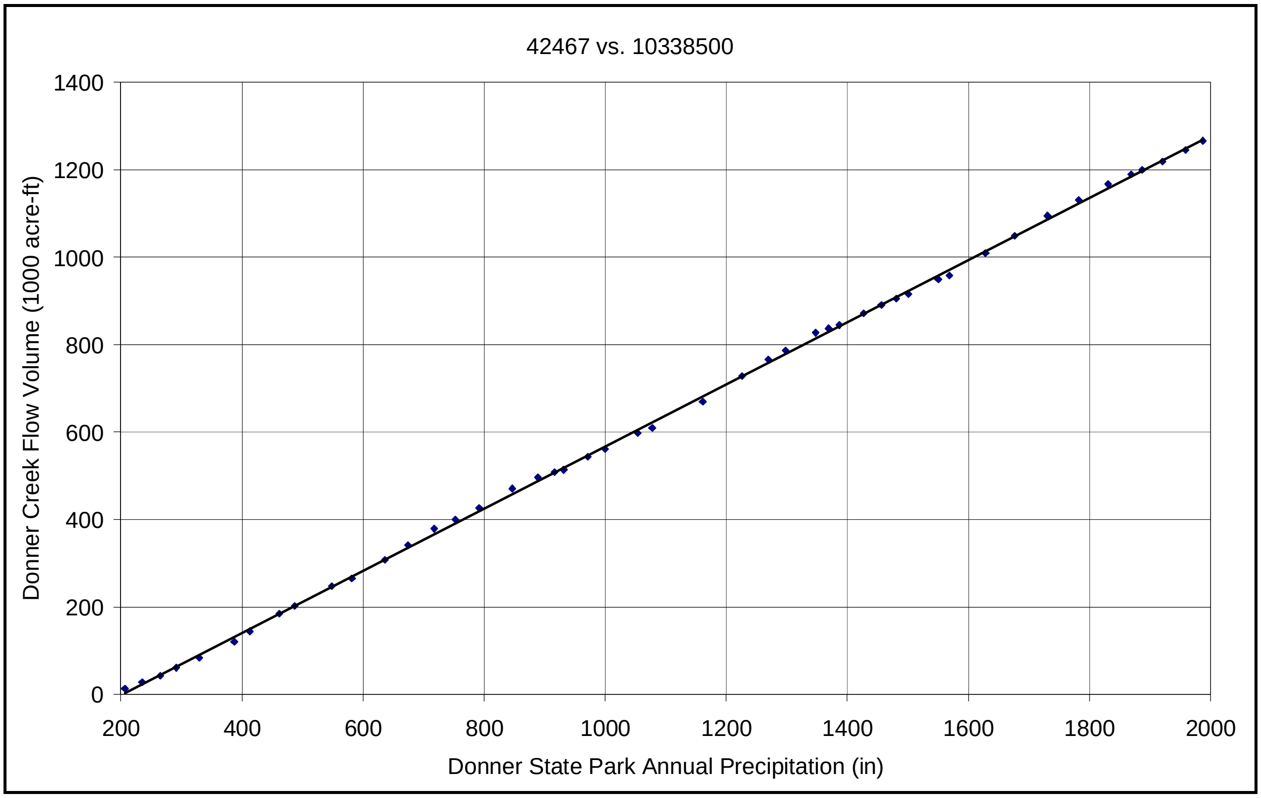


Figure 14. Double mass curve for streamflow volume for Donner Creek and annual precipitation at Donner State Park.

Precipitation and Reservoir Storage Volume

Double mass analysis of precipitation and reservoir storage volumes further demonstrated the high degree of correlation between these variables. The analyses were completed for five paired stations and the results can be found in Appendix H. An example of this data is shown in Figure 15, which contains the analyses between Boca Reservoir storage volumes and annual precipitation at the Boca weather station. The consistent linear long-term trend between these variables indicates that the underlying processes have not influenced by potential climate change.

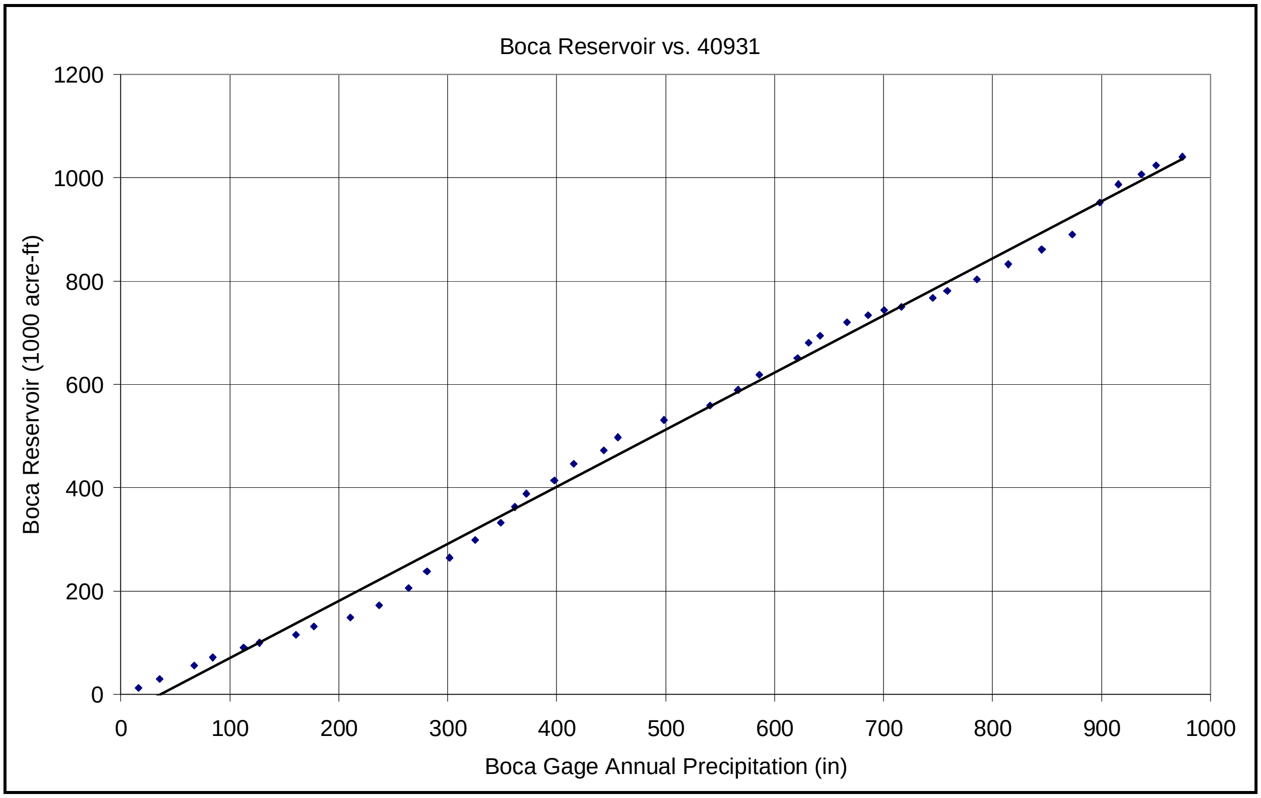


Figure 15. Double mass curve of Boca Reservoir storage and Boca annual precipitation.

Snow Water Equivalent and Streamflow

Relationships between streamflow and SWE were studied at six paired stations. The stations were selected so that the gaged SWE was representative of the observed streamflow. Figure 16 shows the results of the analysis between Independence Lake SWE and Sagehen Creek streamflow. The results for the remaining analyses can be found in Appendix I. The data showed a high degree of correlation between SWE and streamflow. Recent data showed no strong departure from long term trends. These results indicate that the processes of snowfall, snow accumulation, snowmelt, and runoff have remained relatively consistent throughout the period of record.

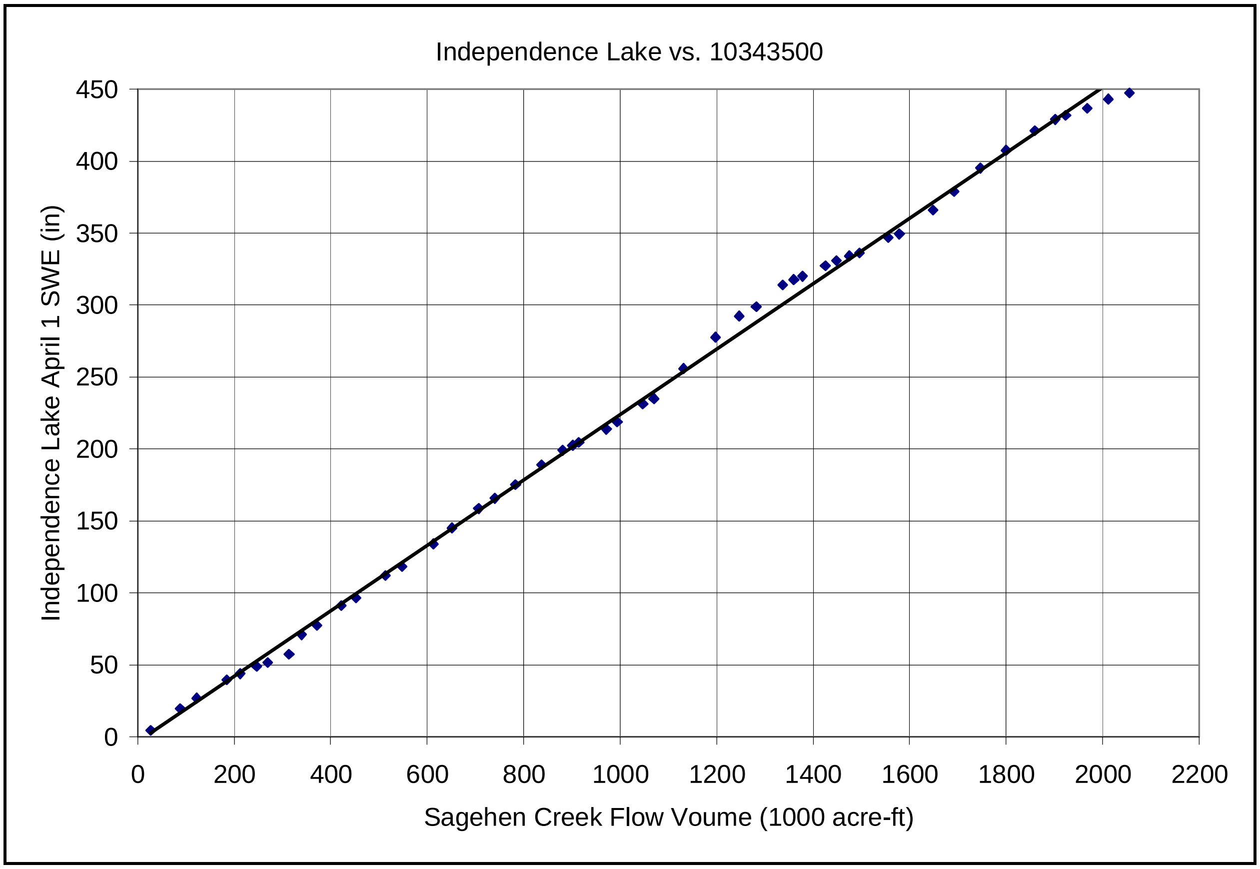


Figure 16. Independence Lake SWE and Sagehen Creek streamflow volumes.

Streamflow and Reservoir Volumes

Double mass analyses were conducted for Boca Reservoir, Donner Lake, Stampede Reservoir and Lake Tahoe. For Boca Reservoir and Lake Tahoe, inflow and outflow streams were both considered. Results of the Boca Reservoir Analysis are shown in Figure 17, and all other analyses can be found in Appendix J. No consistent departures from long term patterns were observed between streamflow and reservoir volumes. Further, consistent trends were observed between upstream and downstream streamflow records.

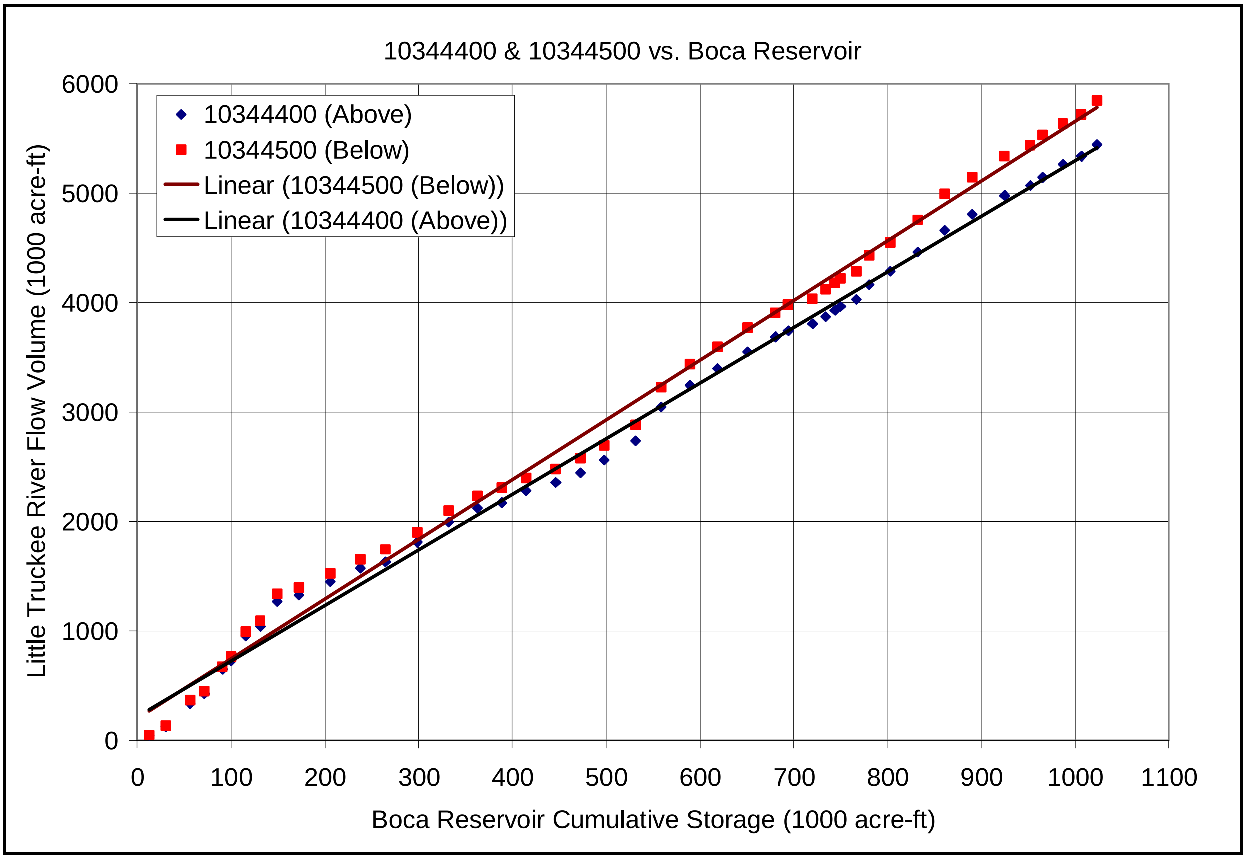


Figure 17. Little Truckee River streamflow volume and Boca Reservoir storage.

Snowpack and Reservoir Storage Volumes

Double mass analysis of April 1 SWE and reservoir storage volumes demonstrated the expected high degree of correlation between these variables. The analyses were completed for four paired stations and the results can be found in Appendix K. Figure 18 contains the double mass analysis of Lake Tahoe storage volume and Hagen's Meadow April 1 SWE. The data not only reveals the correlation between these datasets, but it also shows the impacts of major drought events that caused the Lake Tahoe volume to drop below its natural rim. After these events, SWE continues to accumulate while Lake Tahoe cumulative storage volumes actually decrease.

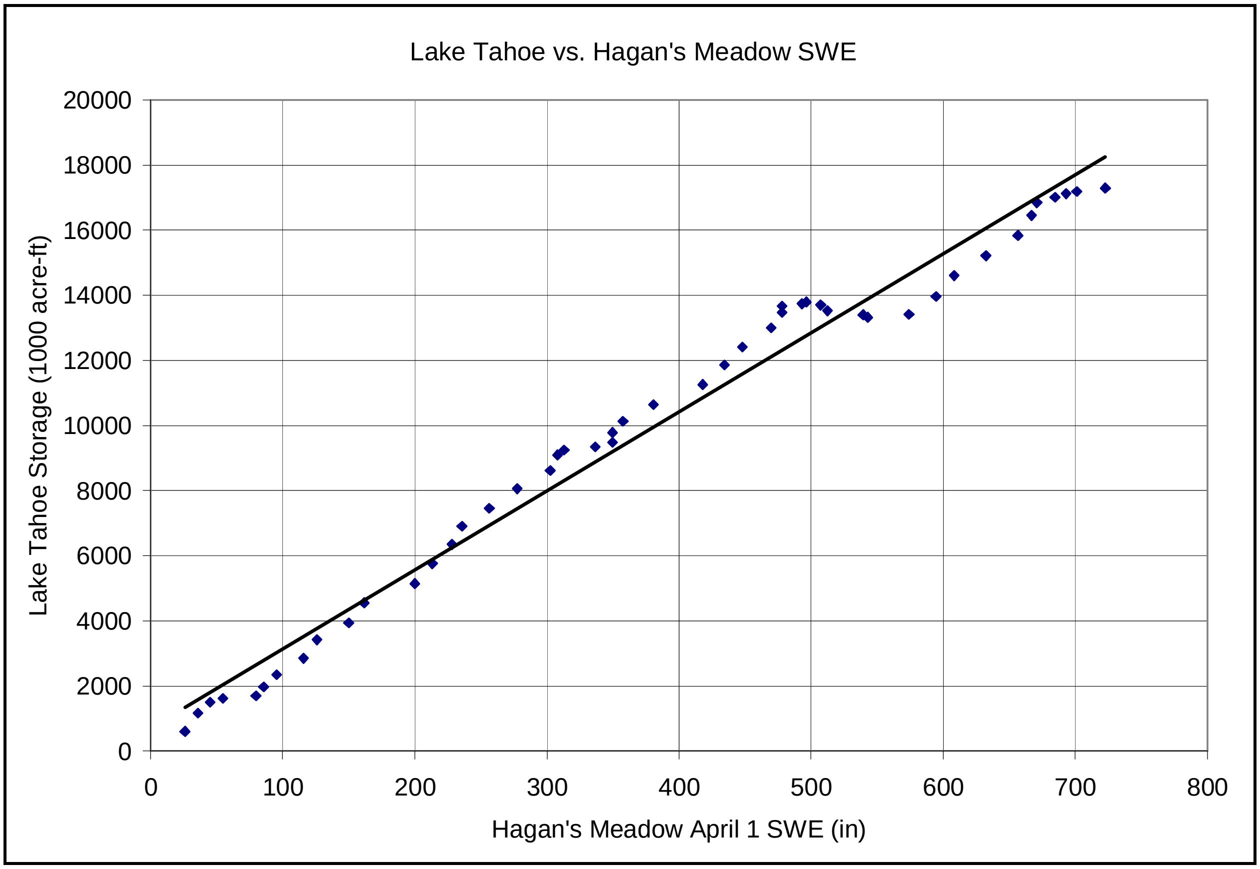


Figure 18. Lake Tahoe storage and April 1 SWE at Hagen's Meadow snowcourse station.

Summary

In order to reveal potential signs of environmental change in the Truckee Meadows region that may be consistent and coincident with global warming, historical climate and hydrologic data were evaluated. The data were compiled in a GIS database and linear regression and double mass analyses were performed. For all variables, year-to-year variability was very high; making it difficult to identify data trends. No consistent or prevalent changes in temperature, precipitation, SWE, hydrograph volume/ timing, or reservoir storage volumes were found. Further, relationships between variables appeared to remain consistent over time. No clear evidence of global warming or associated changes in volume or timing of hydrologic variables was found.

Appendix A

Temperature

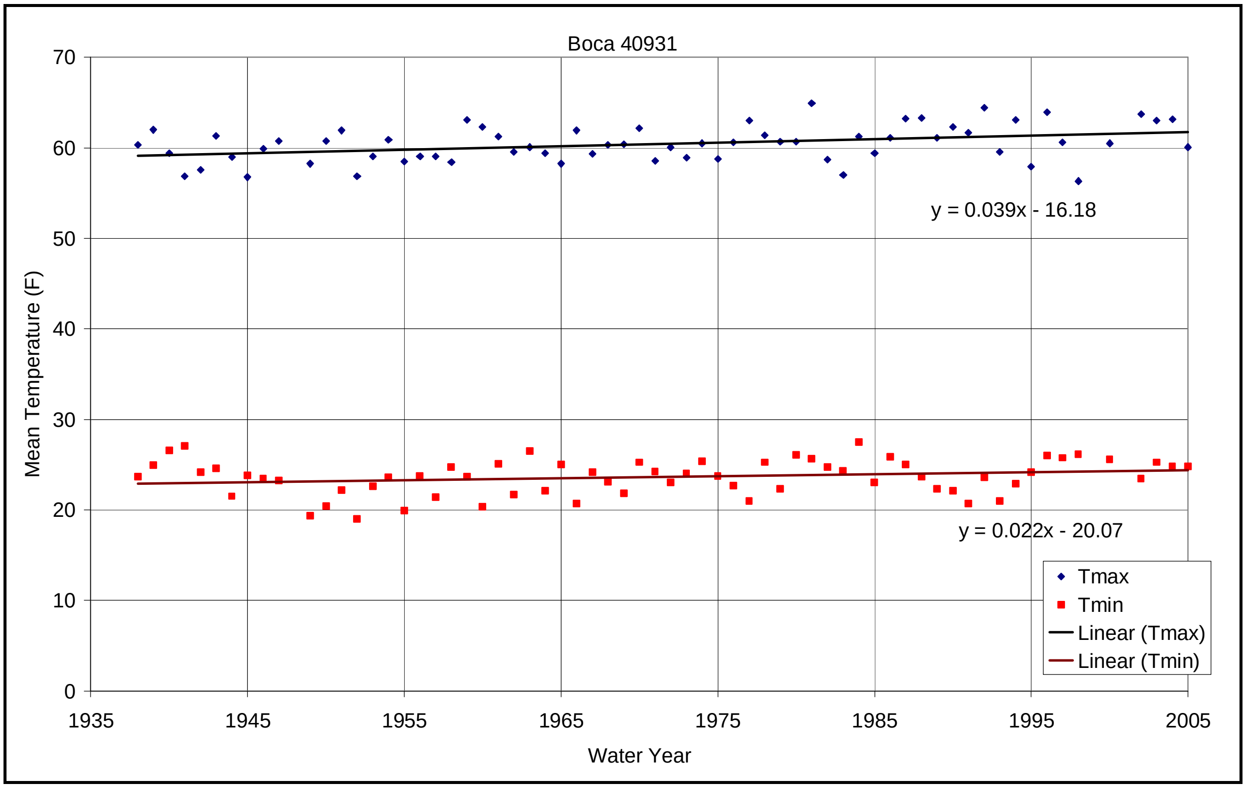


Figure A1. Mean annual maximum and minimum temperature at Boca Gage 40931.

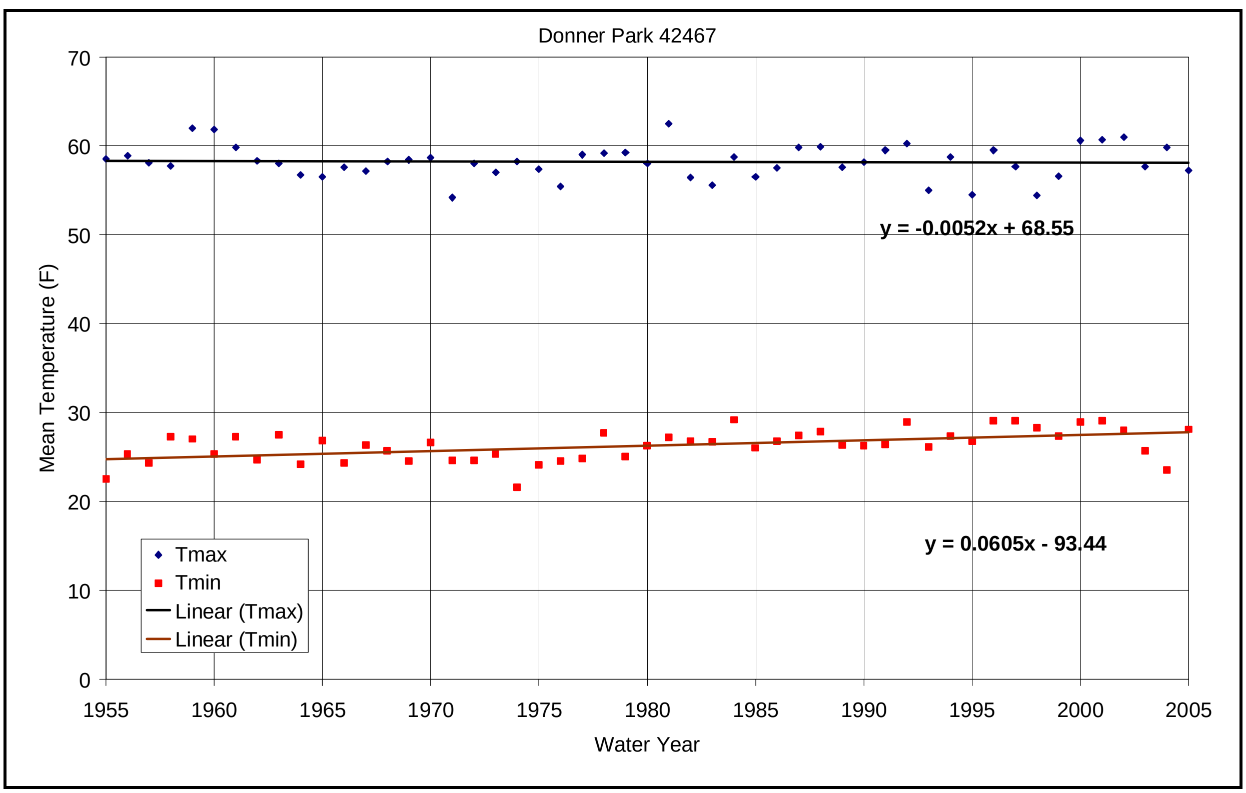


Figure A2. Mean annual maximum and minimum temperature at Donner Park 42467.

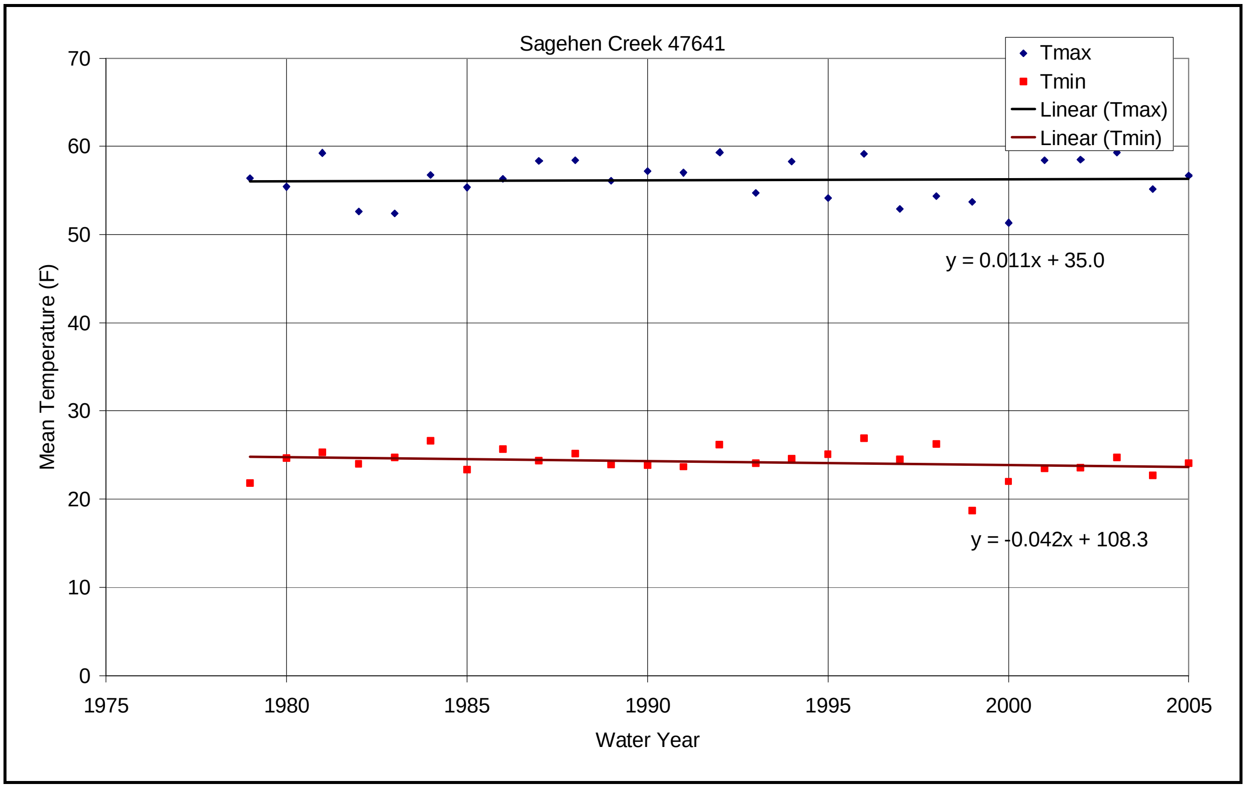


Figure A3. Mean annual maximum and minimum temperature at Sagehen Creek 47641.

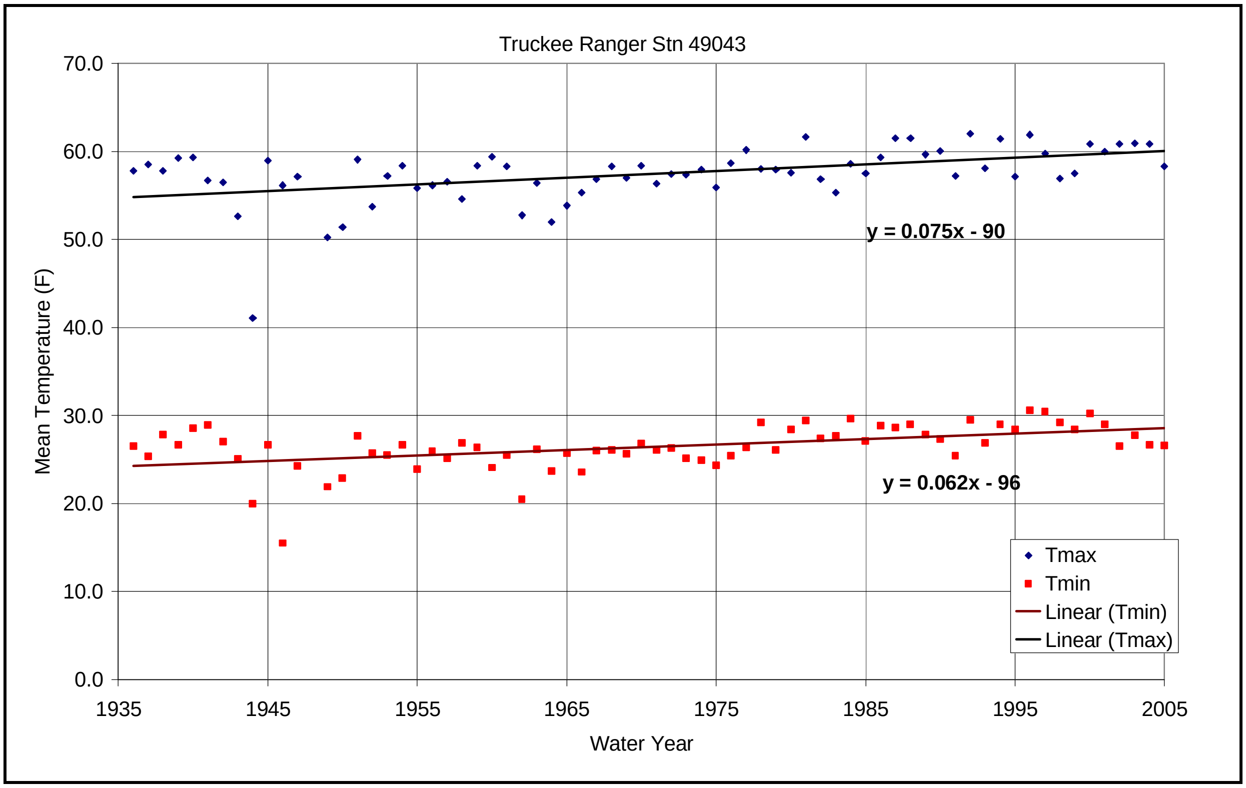


Figure A4. Mean annual maximum and minimum temperature at Truckee Ranger Station 49043.

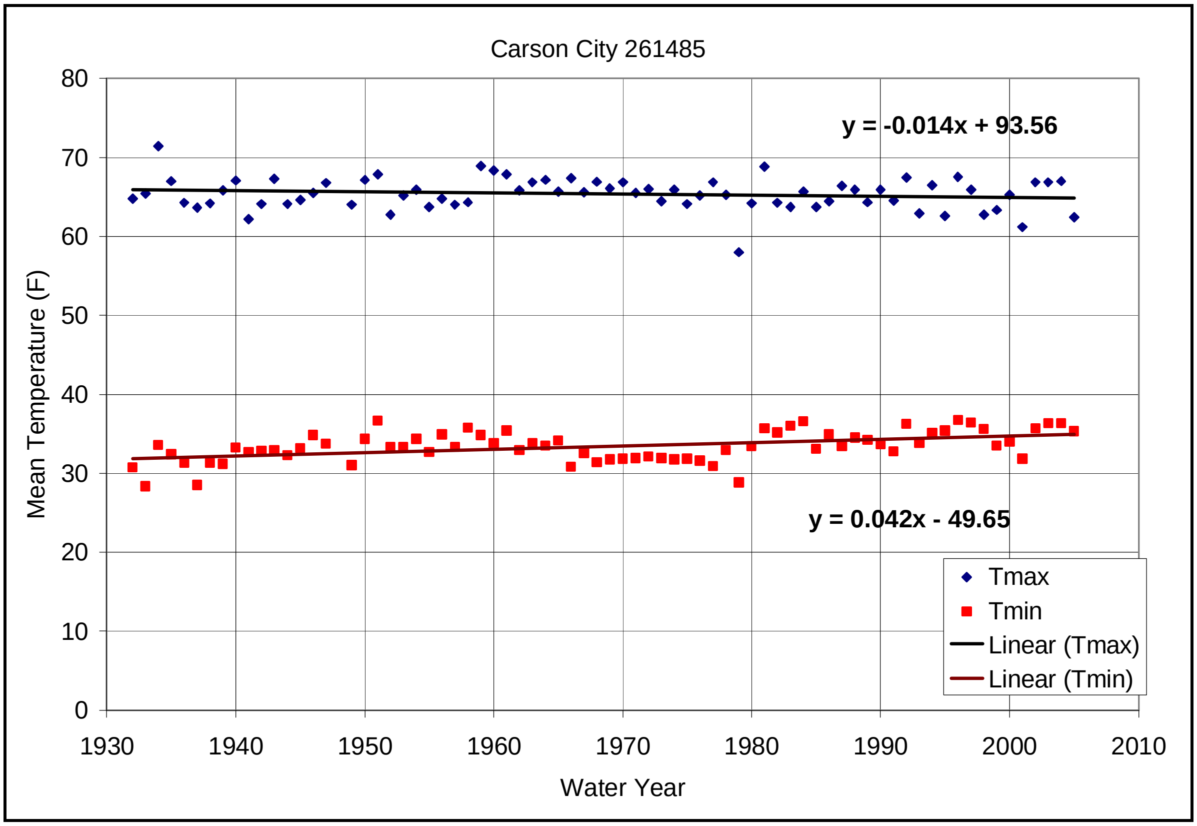


Figure A5. Mean annual maximum and minimum temperature at Carson City 261485.

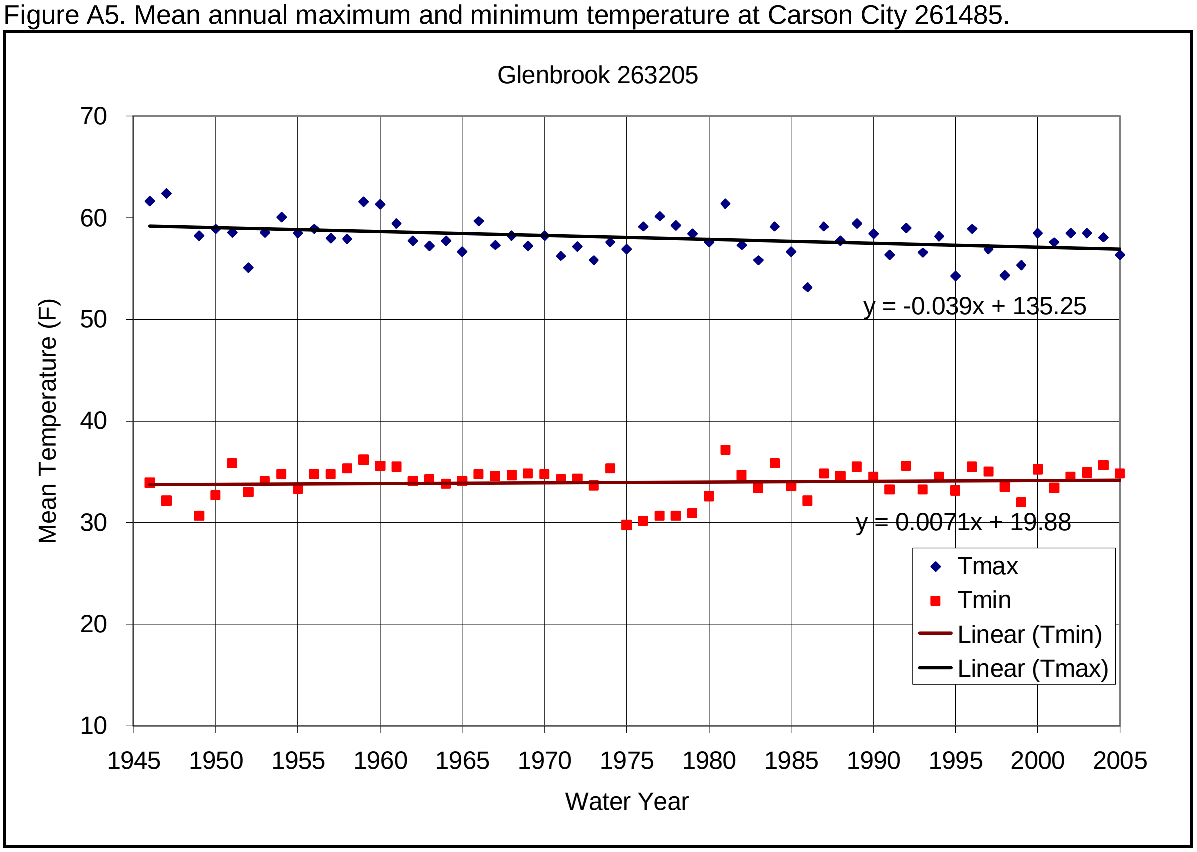


Figure A6. Mean annual maximum and minimum temperature at Glenbrook 263205.

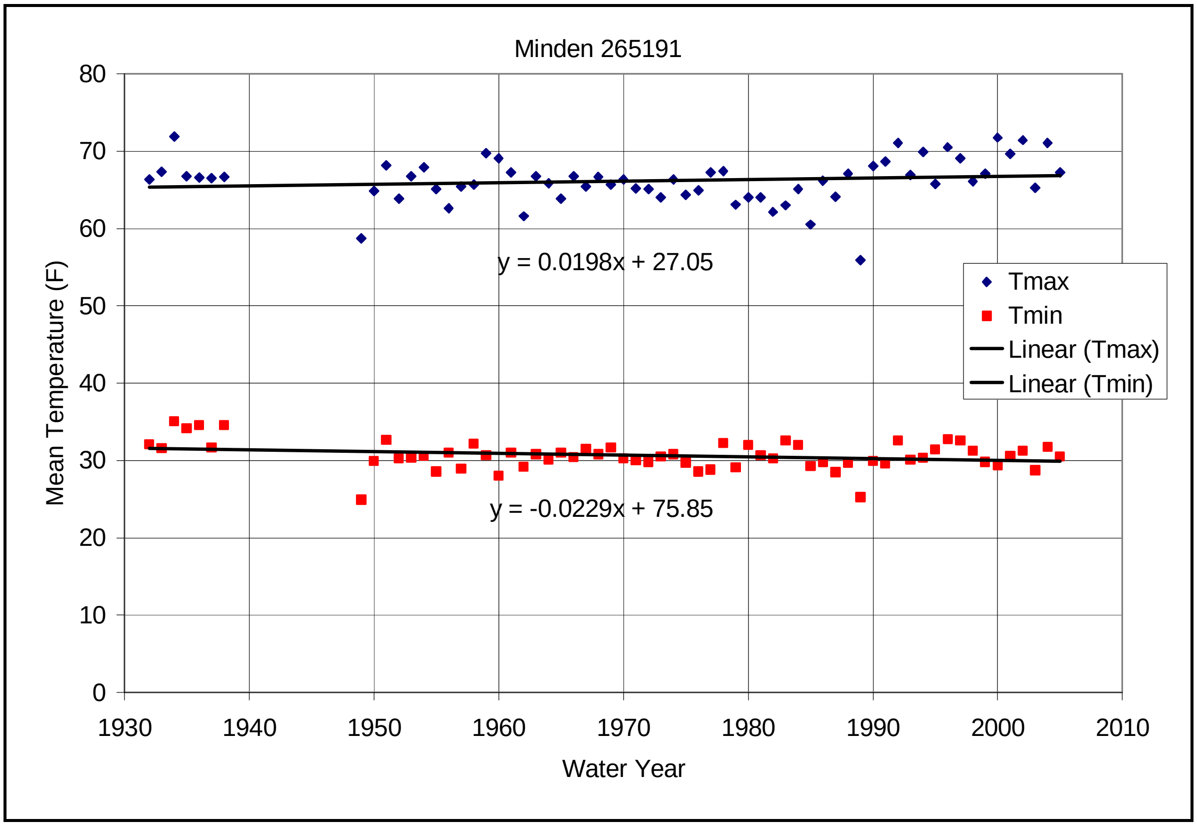


Figure A7. Mean annual maximum and minimum temperature at Minden 265191.

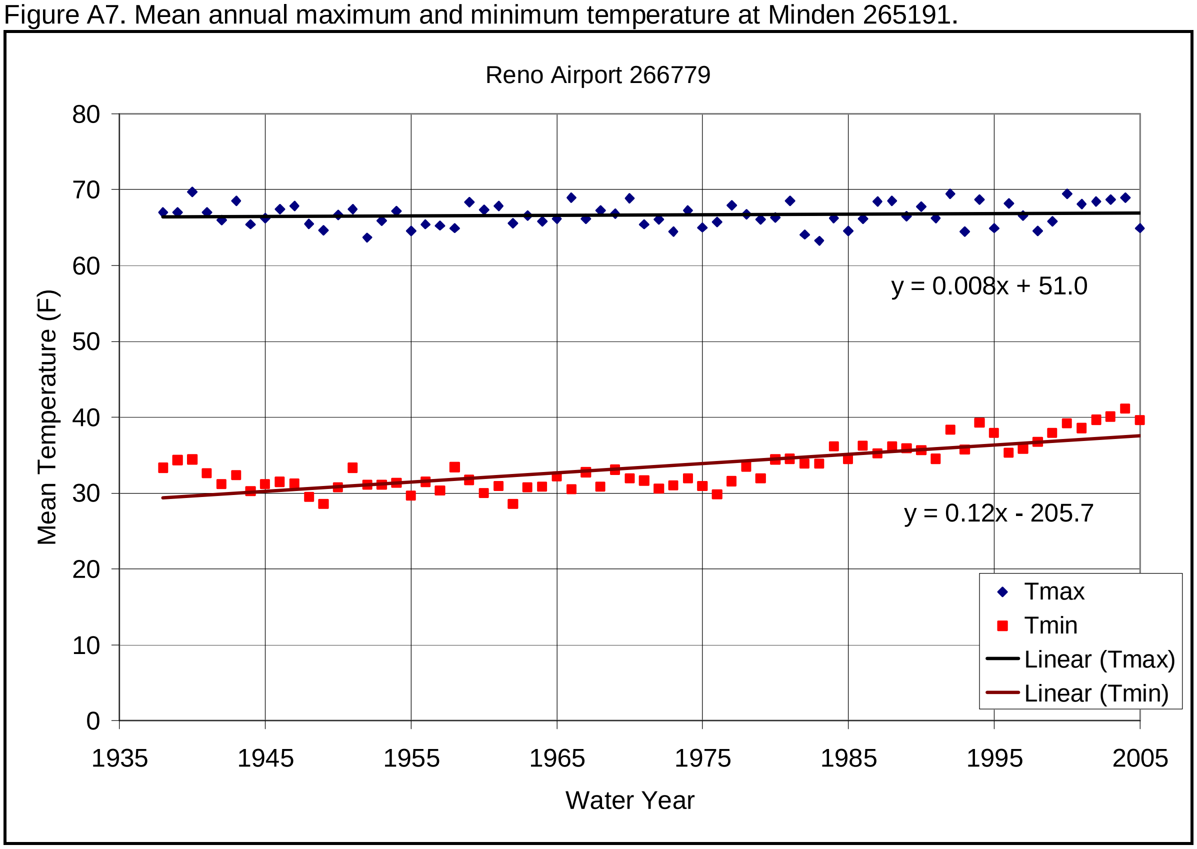


Figure A8. Mean annual maximum and minimum temperature at Reno Airport!266779.

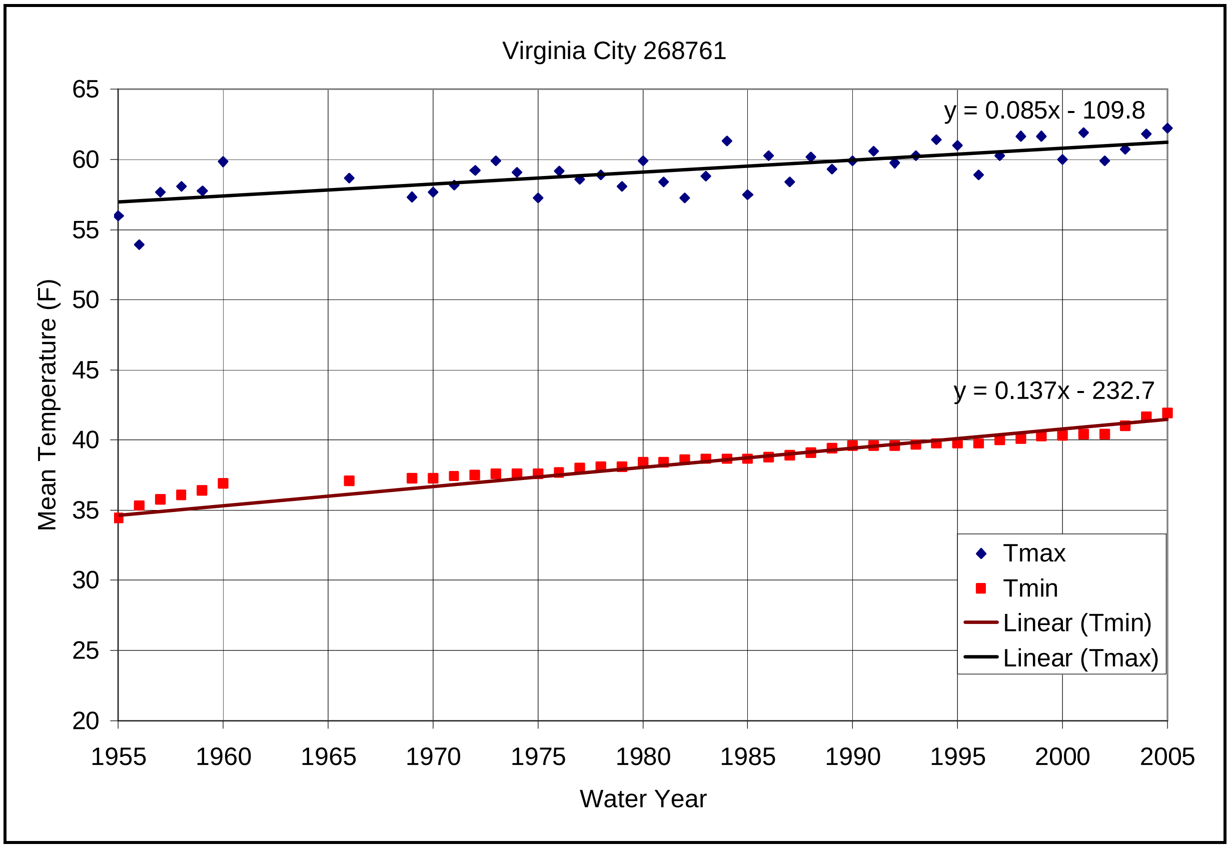


Figure A9. Mean annual maximum and minimum temperature at Virginia City 268761.

Appendix B

Precipitation

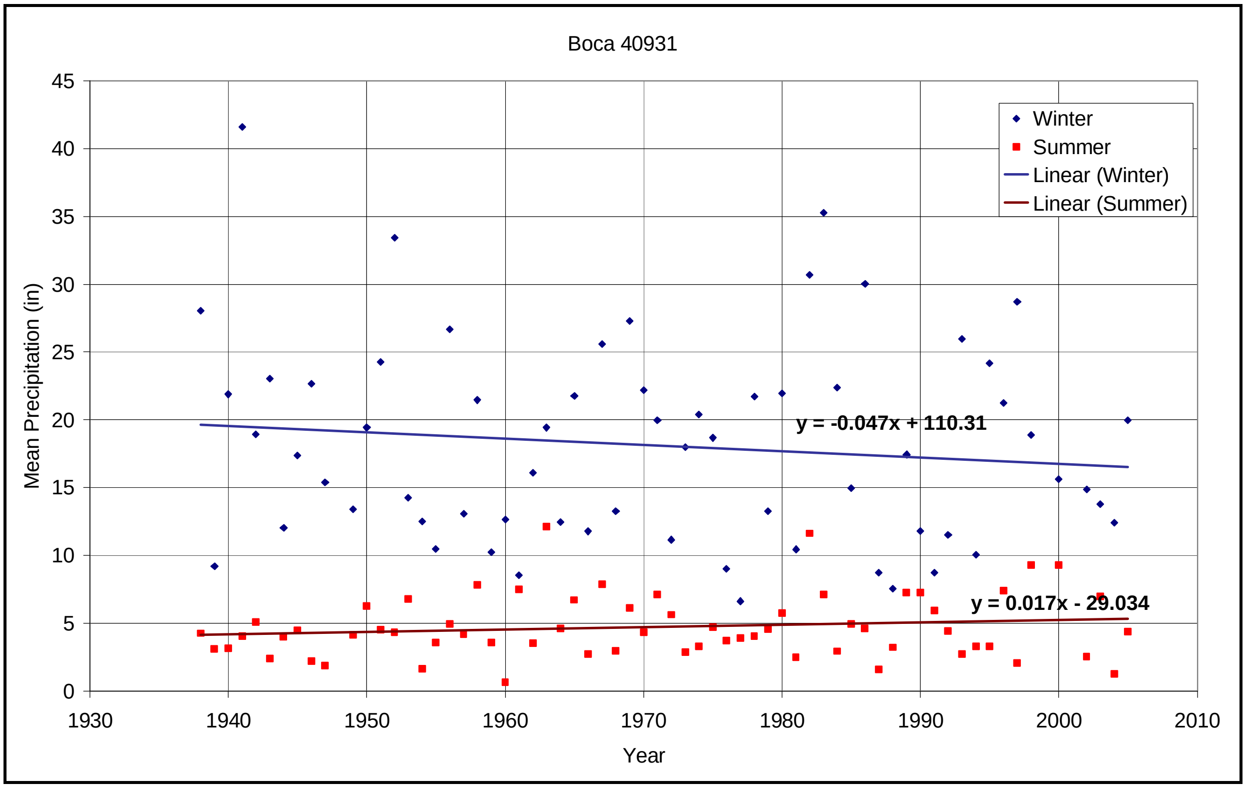


Figure B1. Mean winter (Oct-March) and summer (April-September) precipitation at Boca Gage 40931.

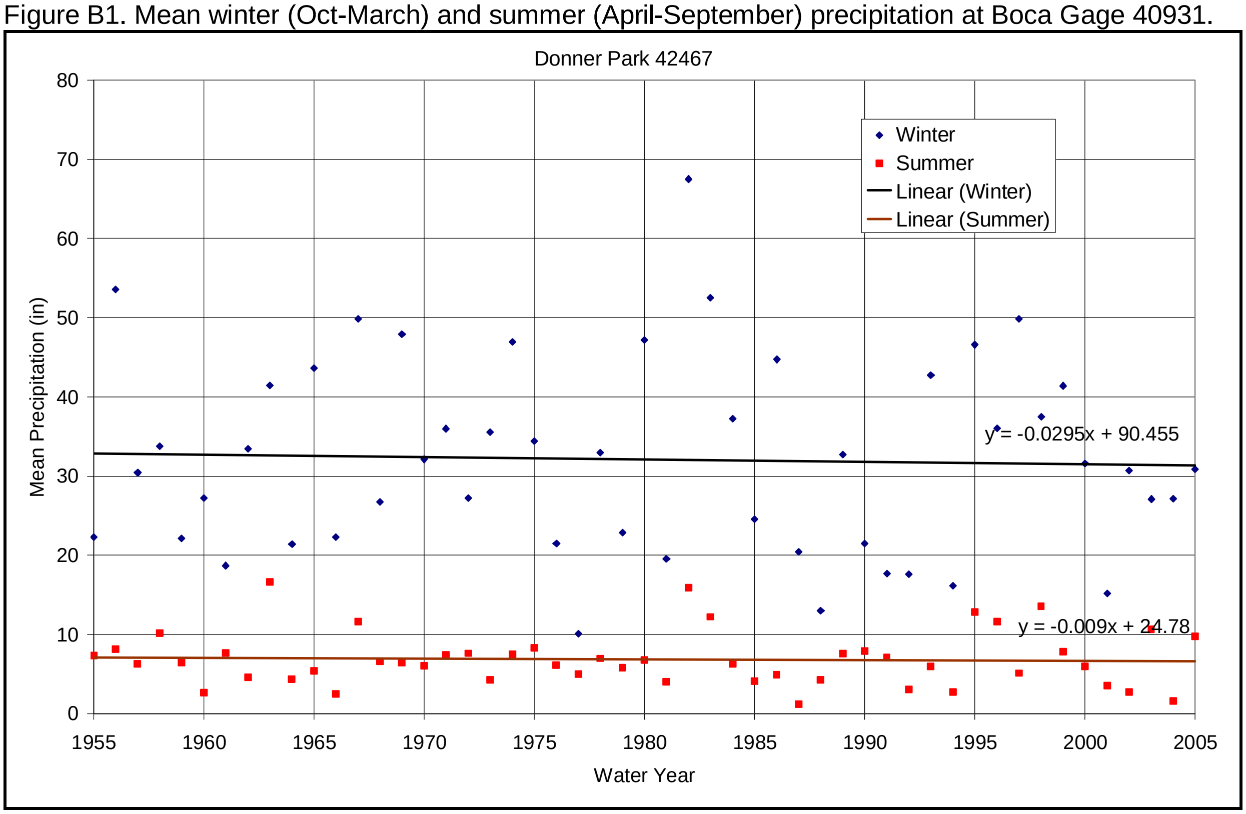


Figure B2. Mean winter and summer precipitation at Donner Park 42467.

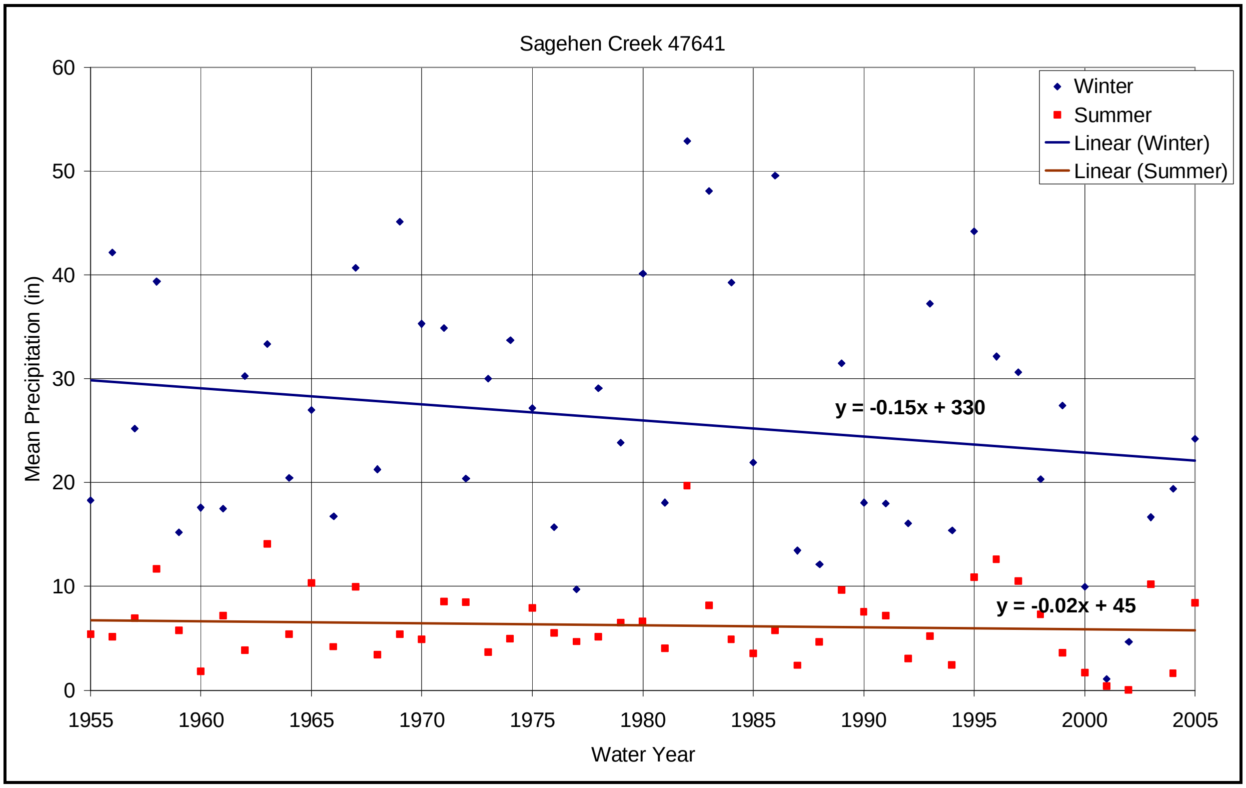


Figure B3. Mean winter and summer precipitation at Sagehen Creek 47641.

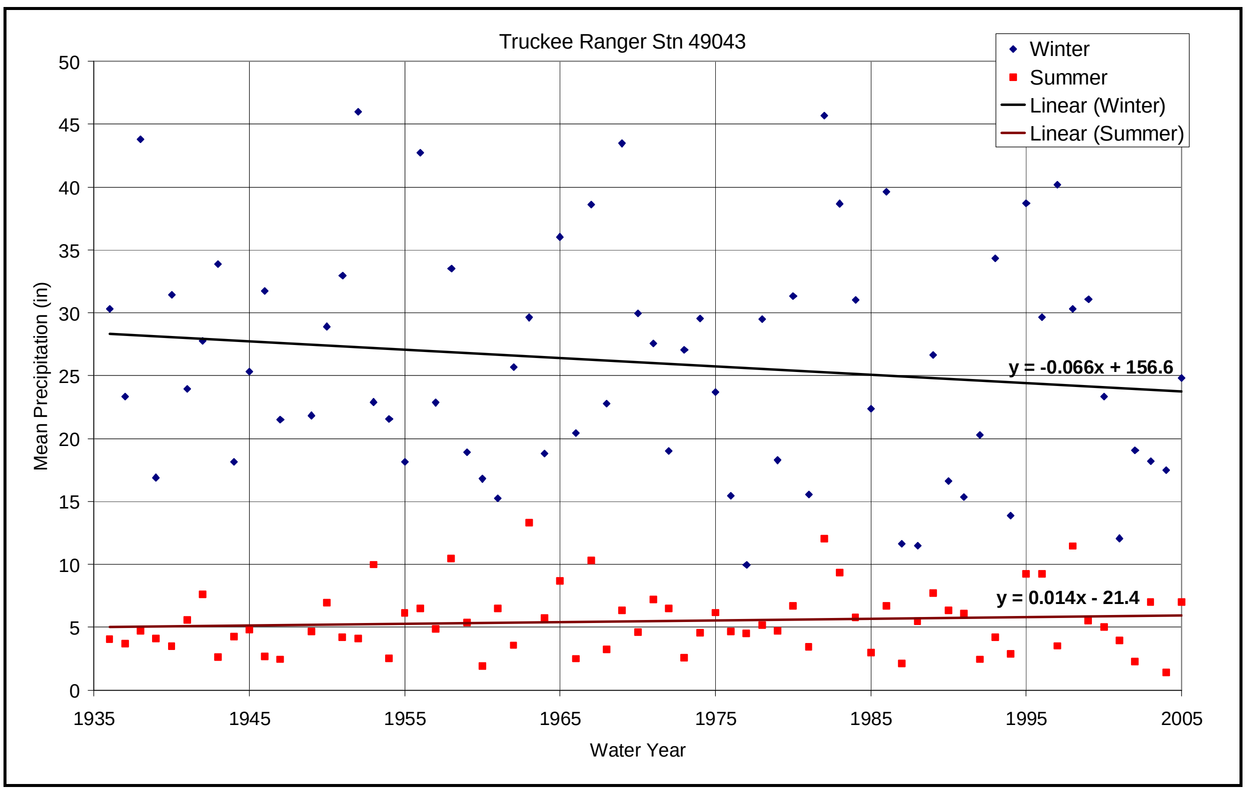


Figure B4. Mean winter and summer precipitation at Truckee Ranger Station 49043.

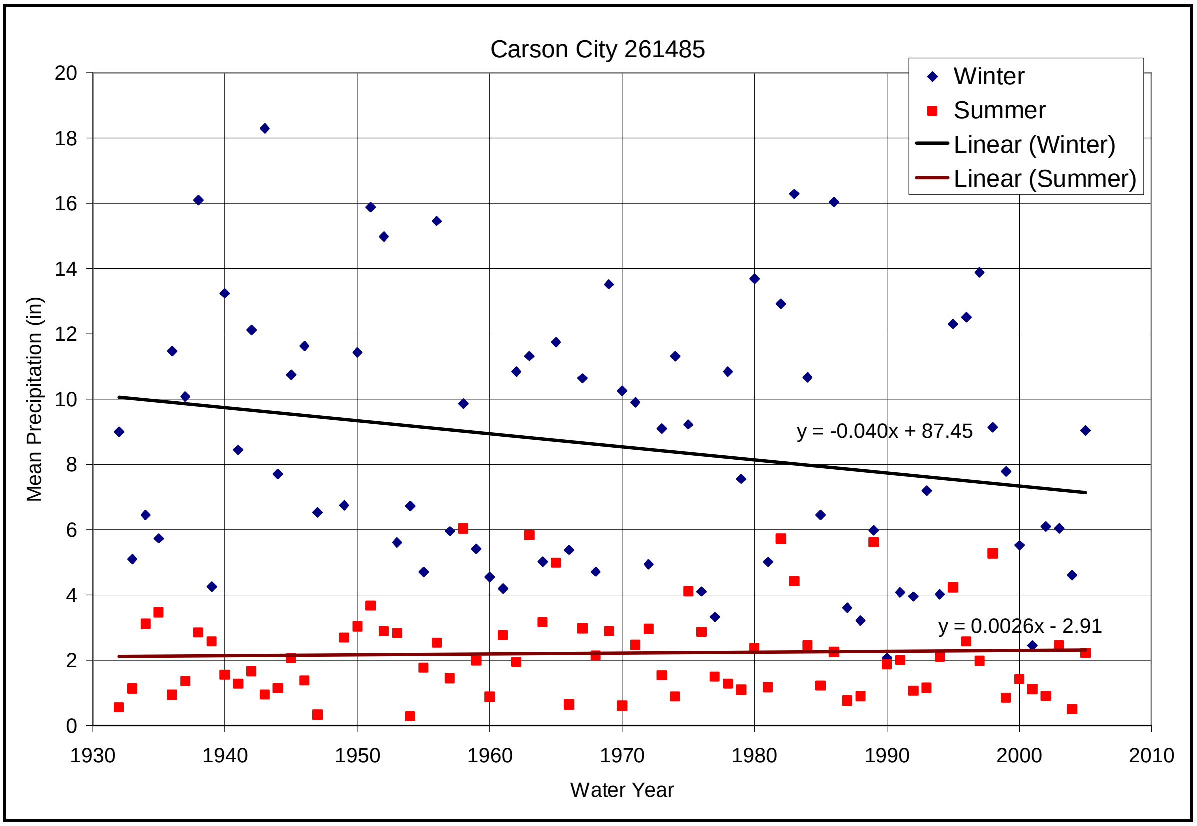


Figure B5. Mean winter and summer precipitation at Carson City 261485.

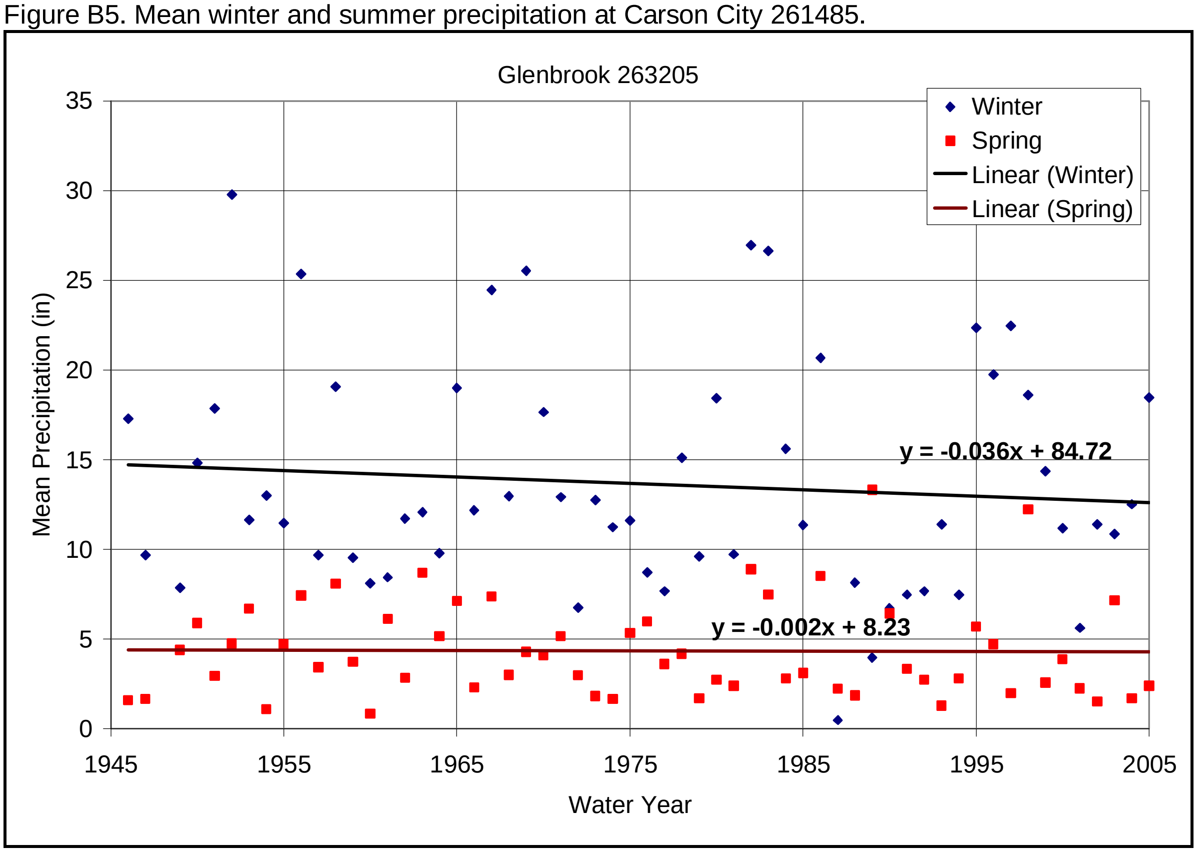


Figure B6. Mean winter and summer precipitation at Glenbrook 263205.

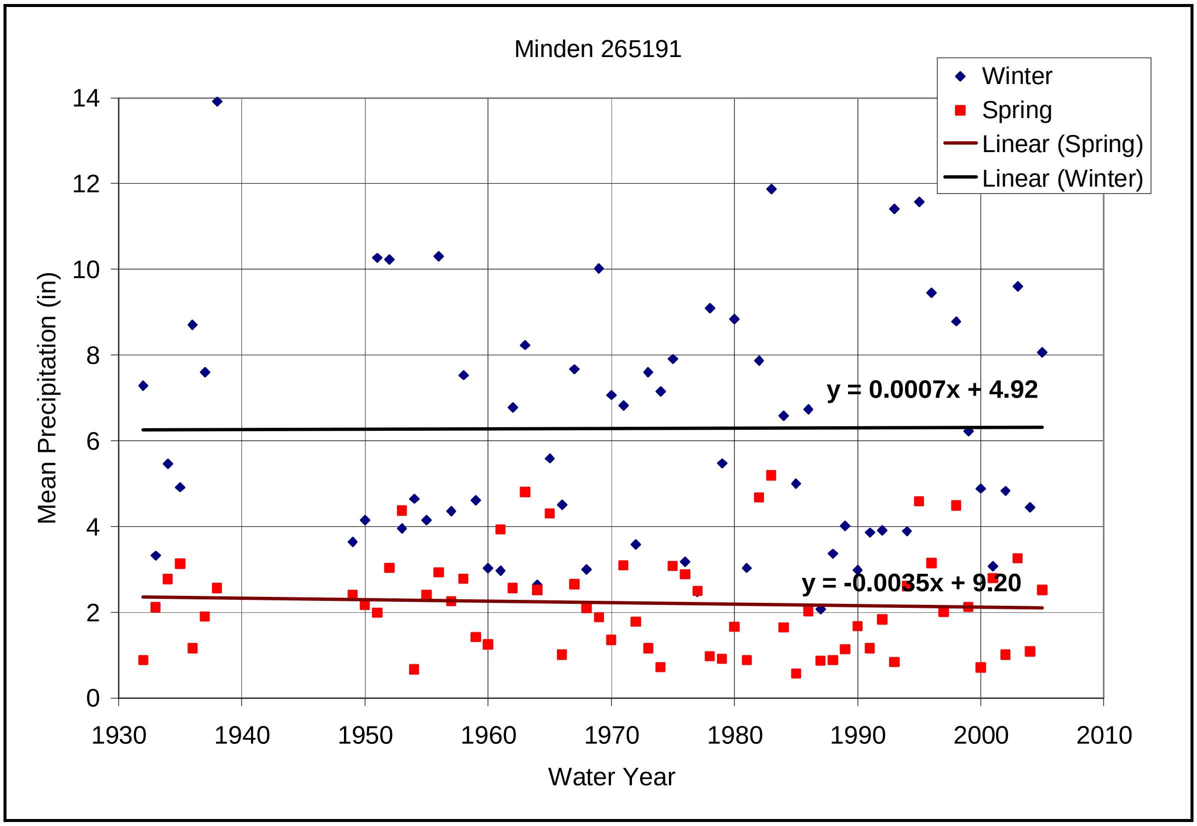


Figure B7. Mean winter and summer precipitation at Minden 265191.

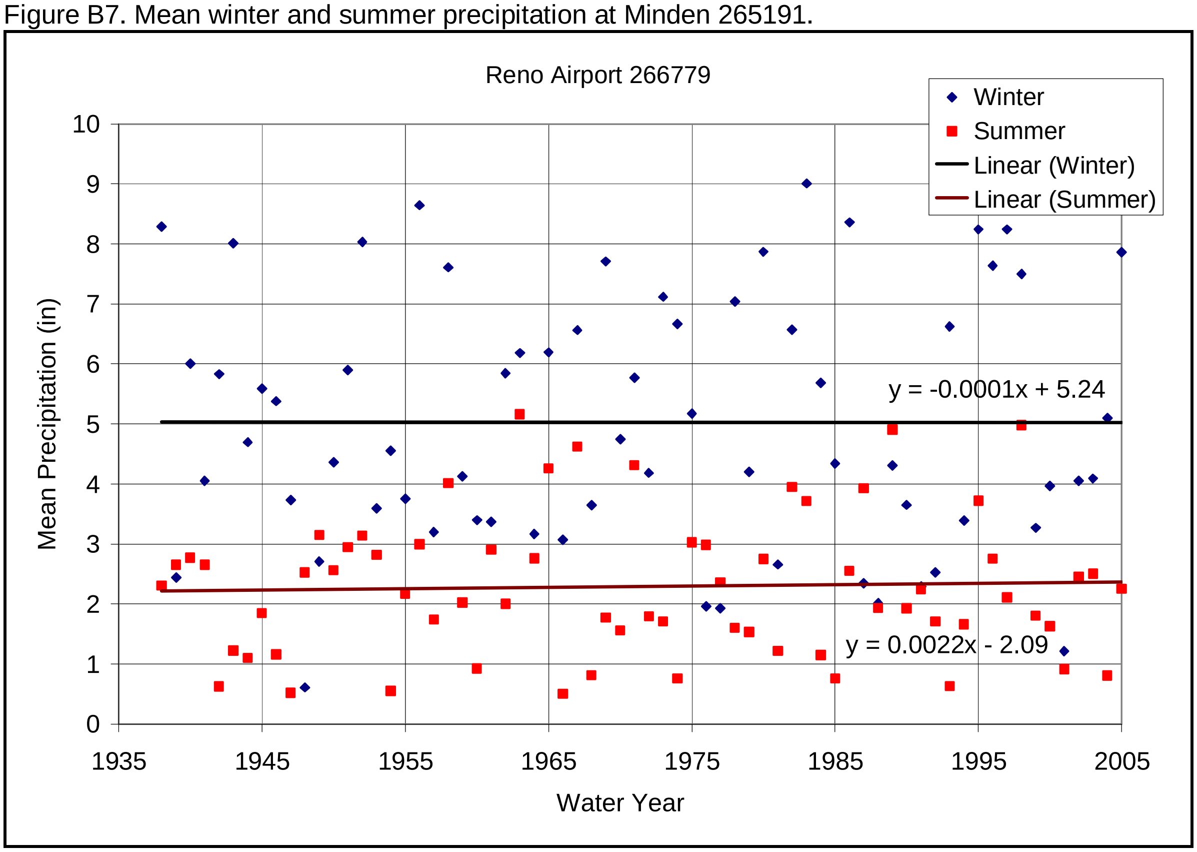


Figure B8. Mean winter and summer precipitation at the Reno Airport!2666779.

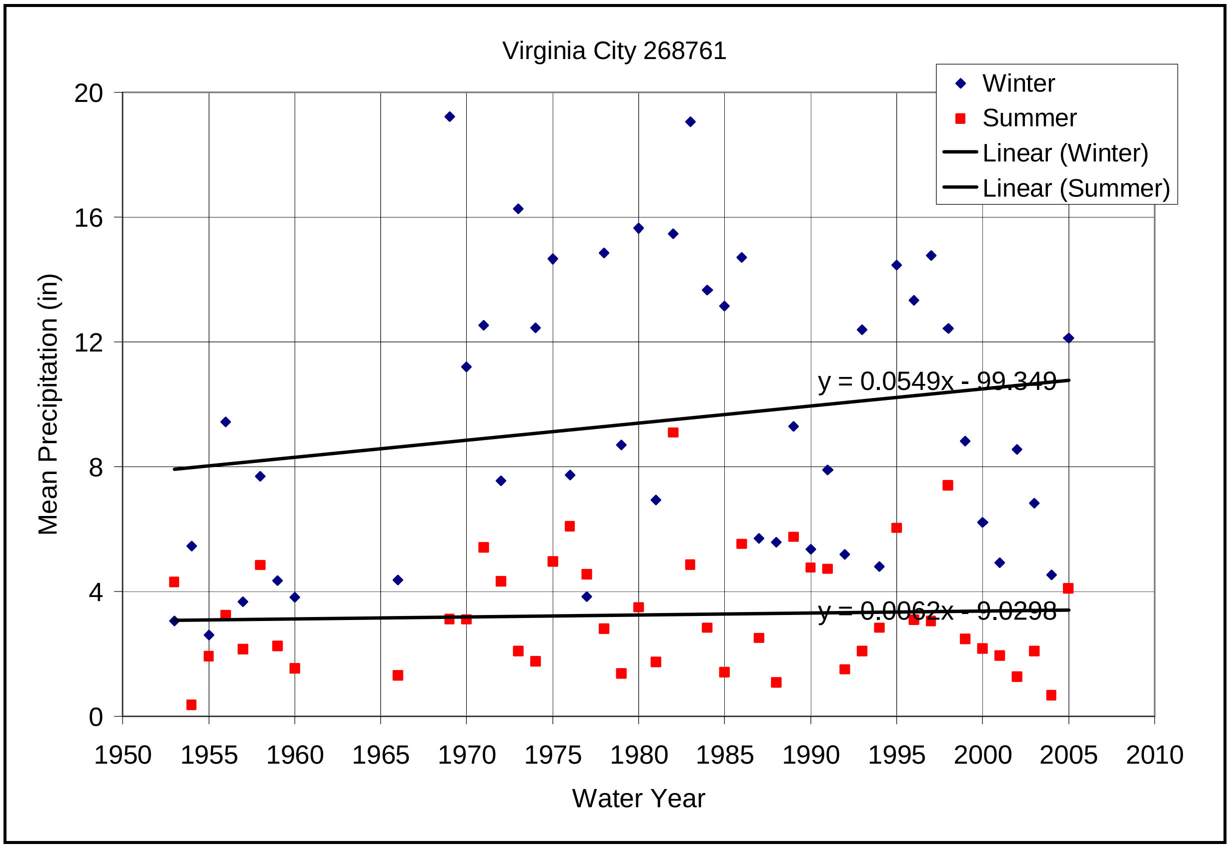


Figure B9. Mean winter and summer precipitation at Virginia City 268761.

Appendix C

Snowpack

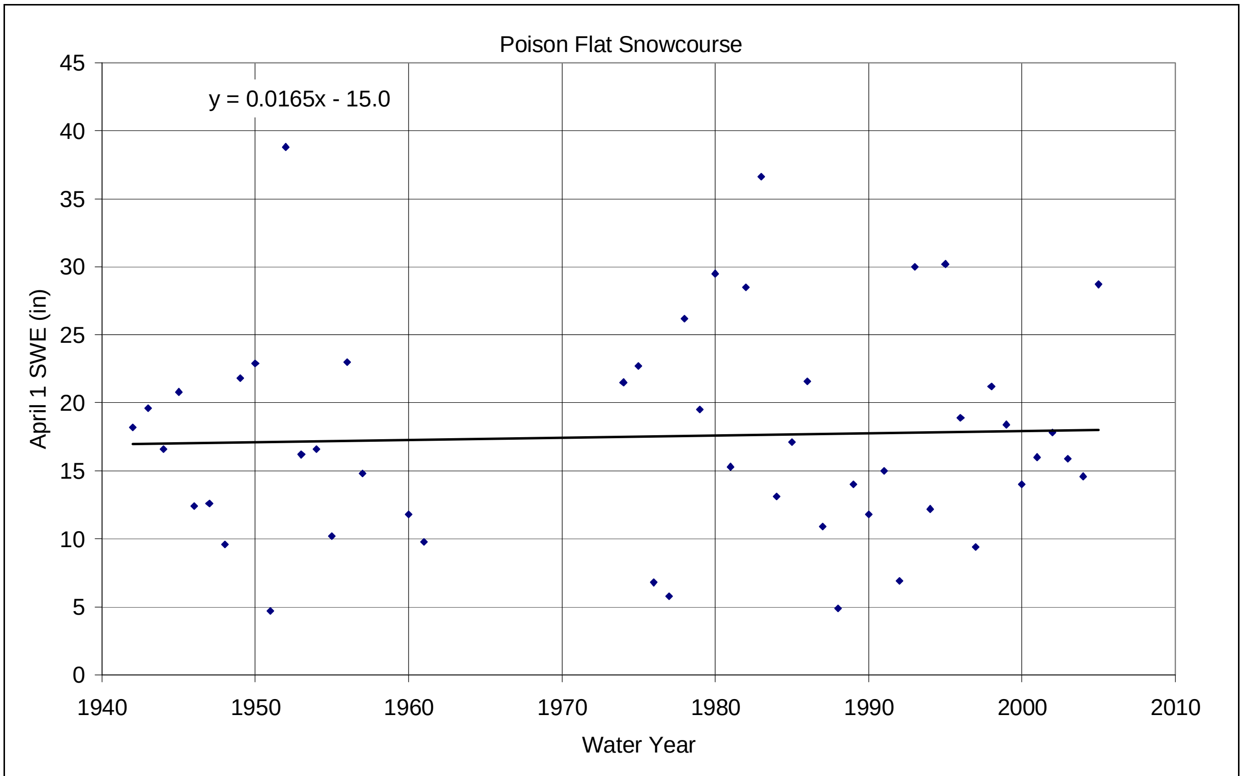


Figure C1. Poison Flat snowcourse station April 1st SWE.

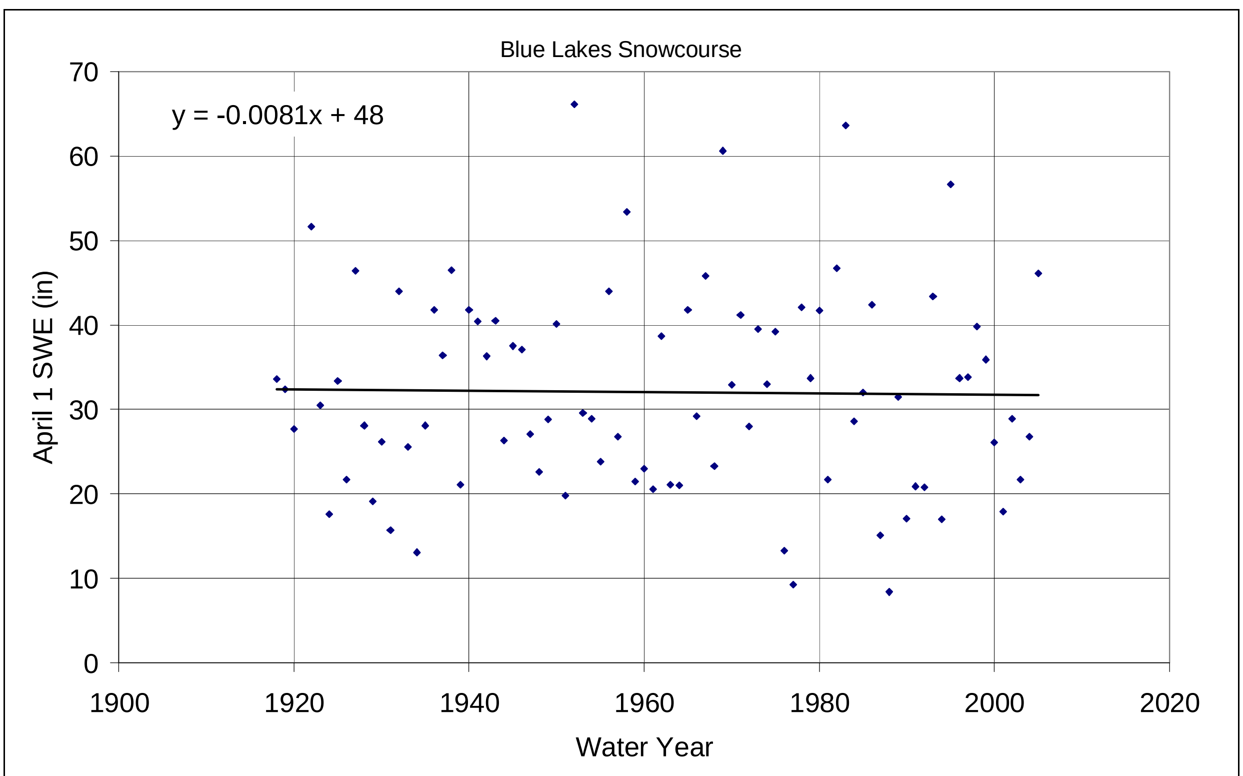


Figure C2. Blue Lakes snowcourse station April 1st SWE.

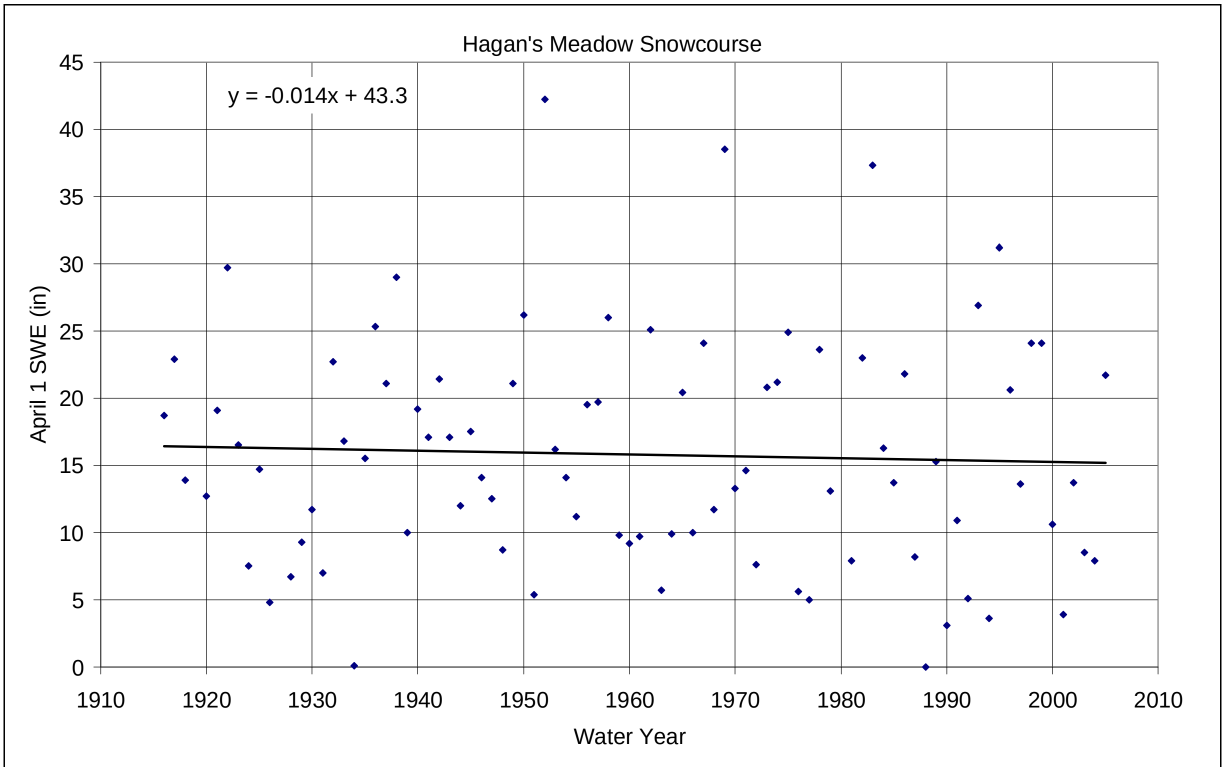


Figure C3. Hagan’s Meadow snowcourse station April 1st SWE.

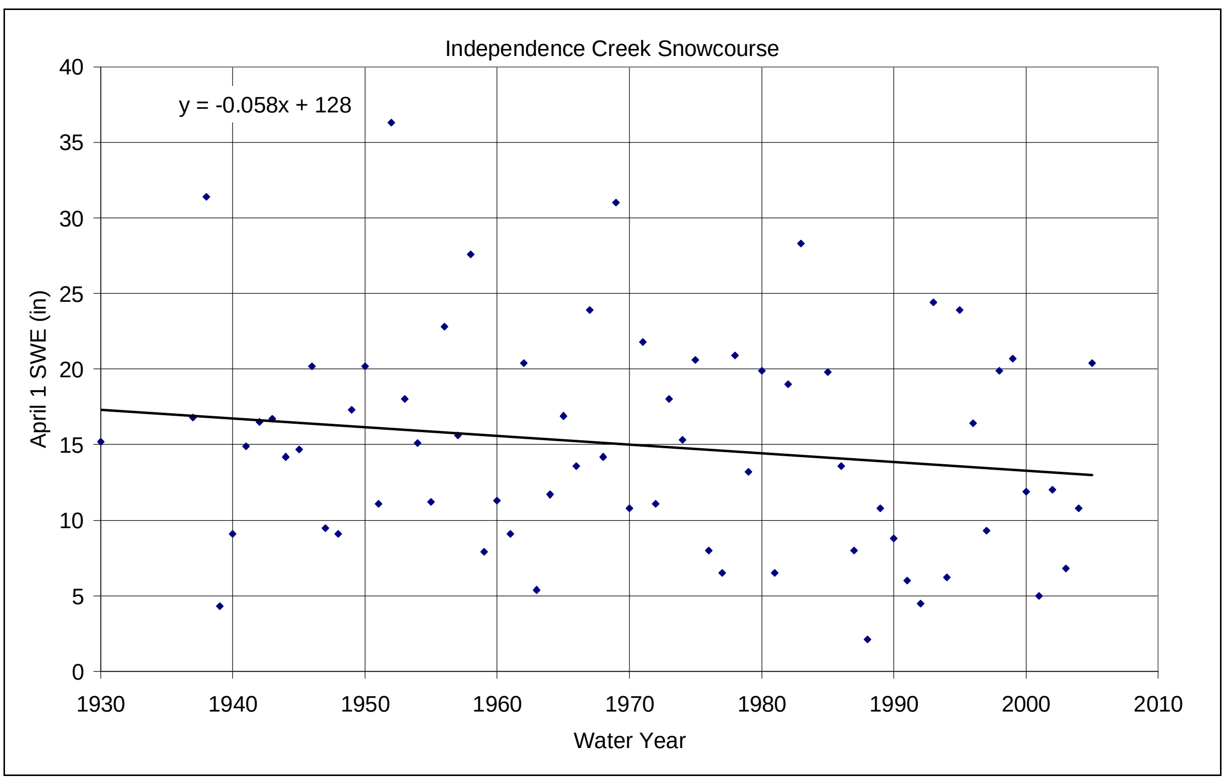


Figure C4. Independence Creek snowcourse station April 1st SWE.

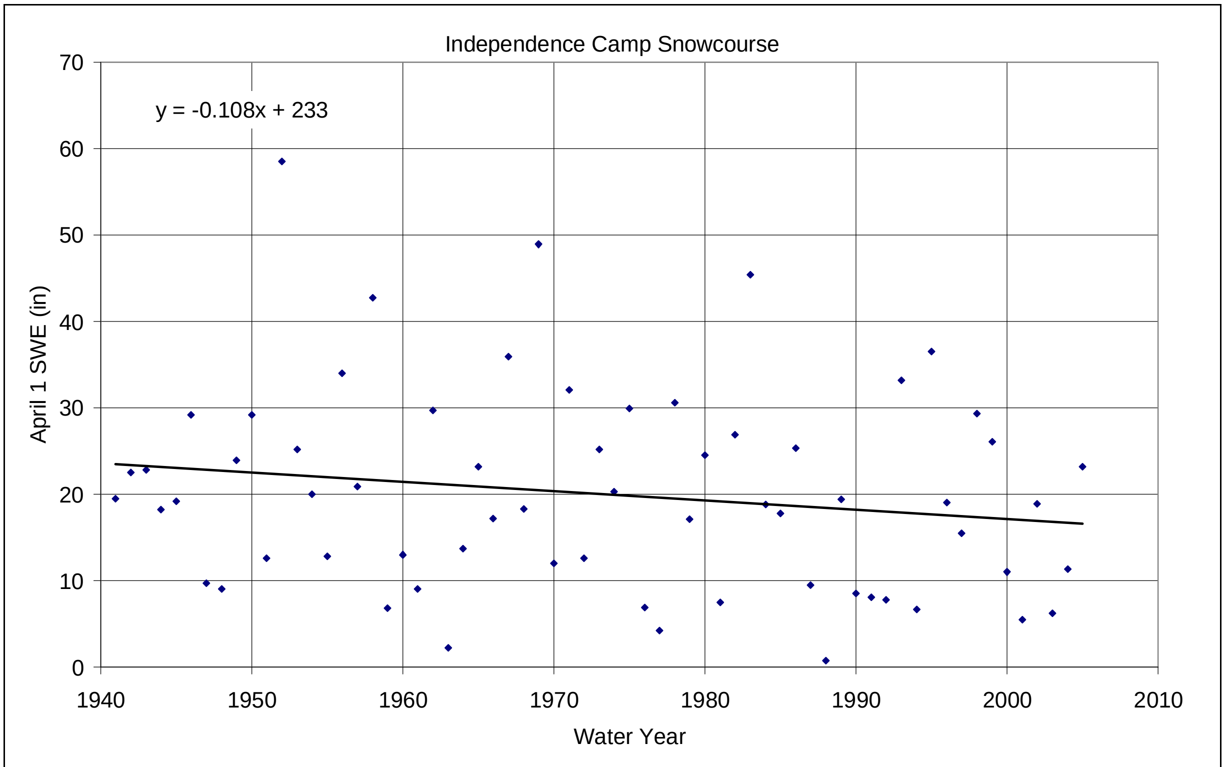


Figure C5. Independence Camp snowcourse station April 1st SWE.

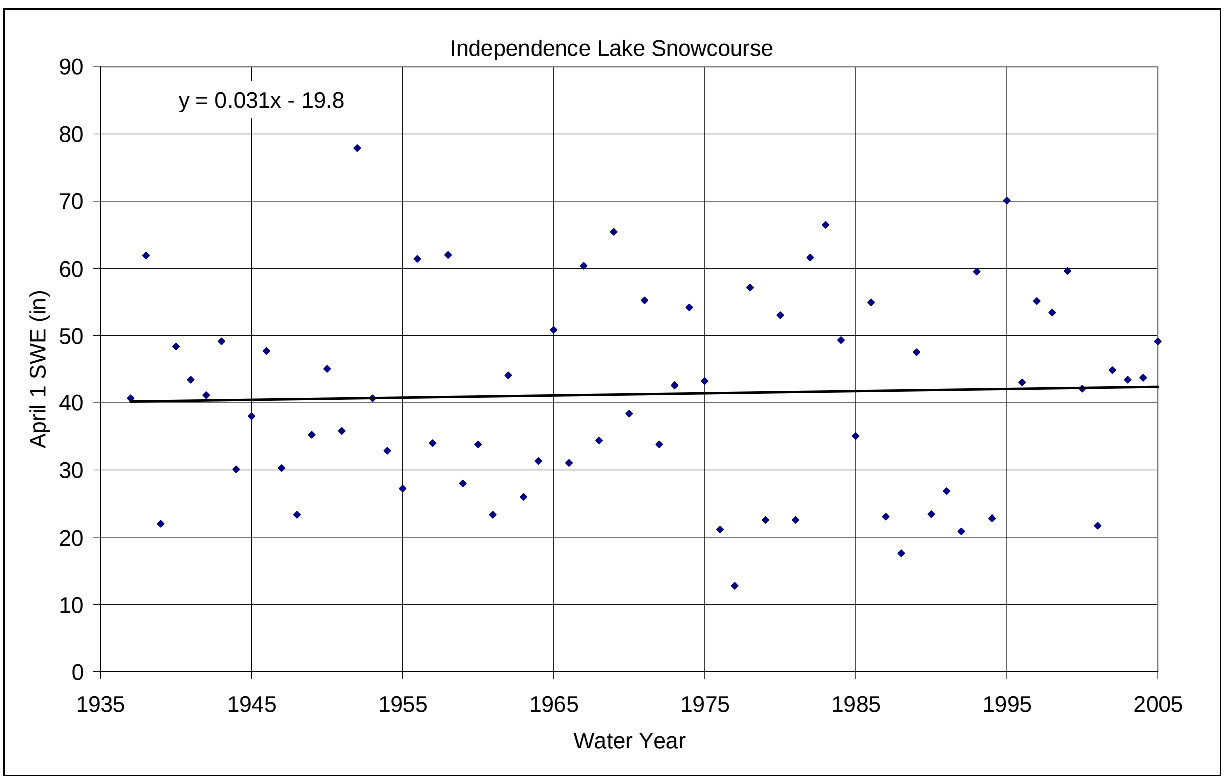


Figure C6. Independence Lake snowcourse station April 1st SWE.

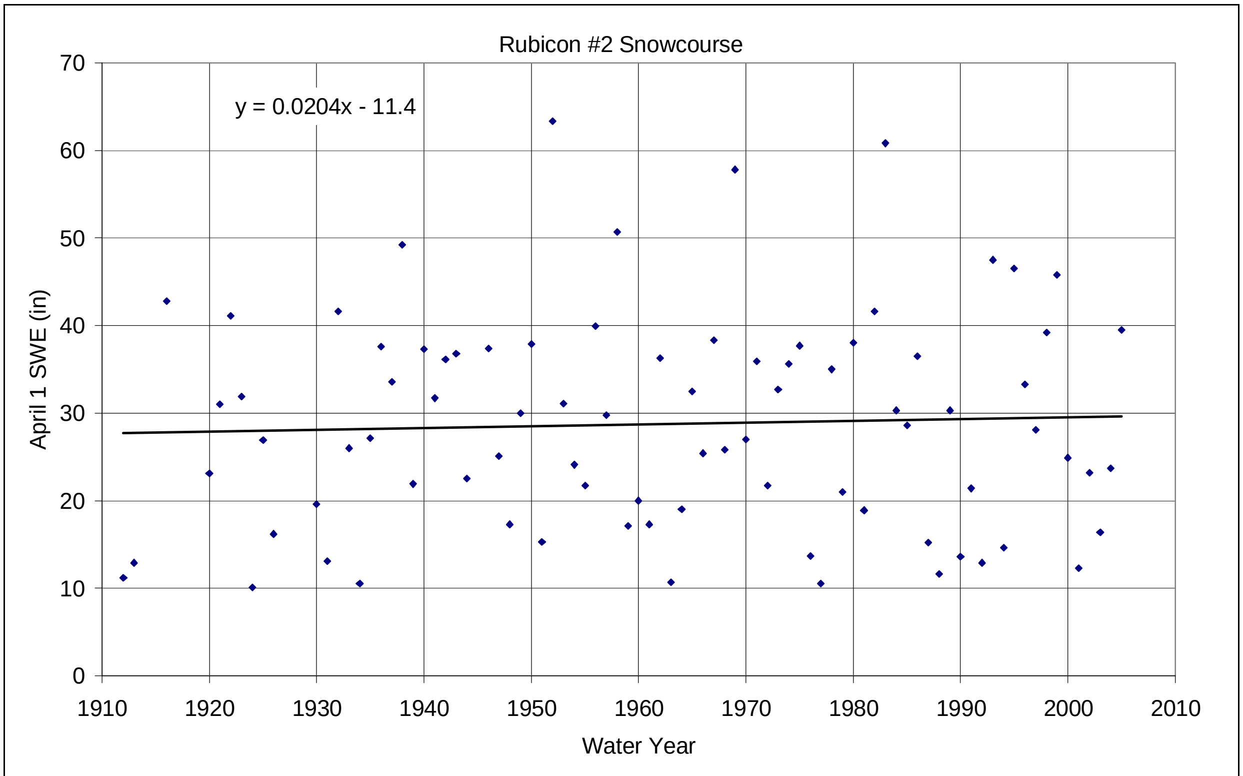


Figure C7. Rubicon #2 snowcourse station April 1st SWE.

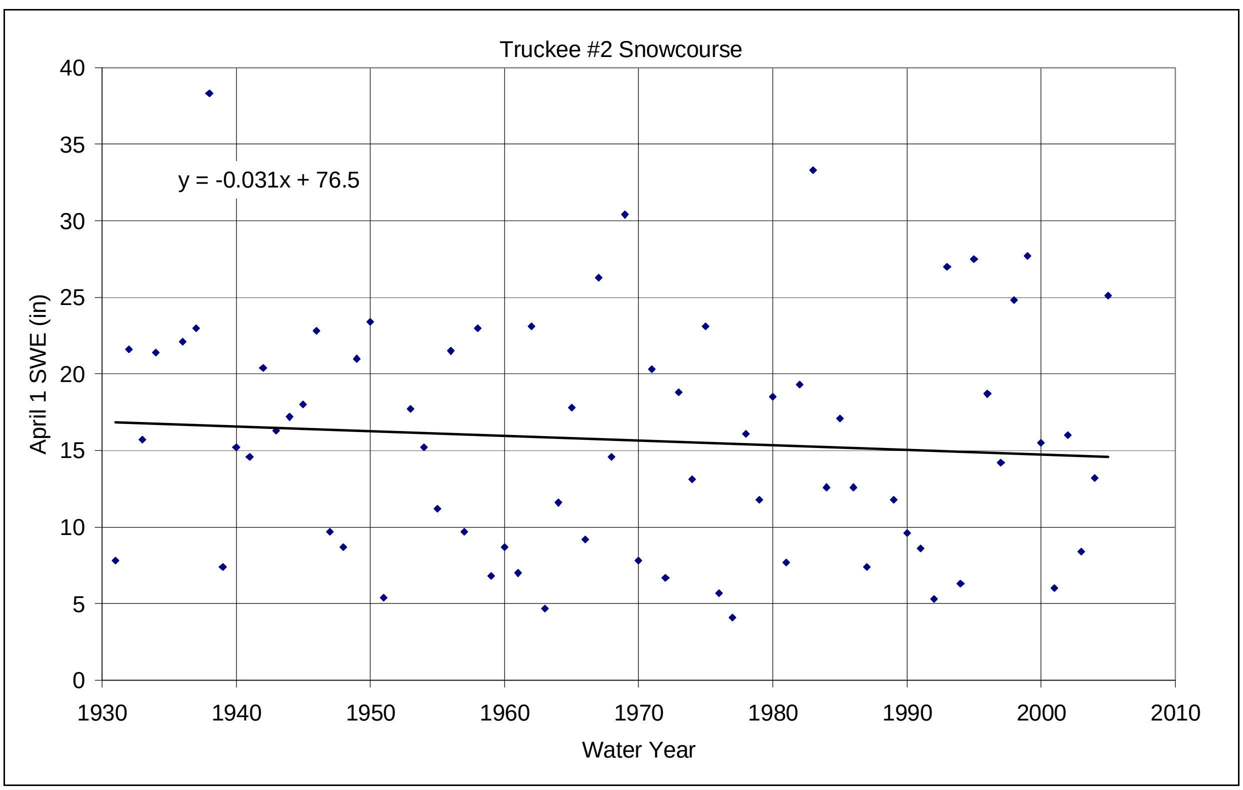


Figure C8. Truckee #2 snowcourse station April 1st SWE.

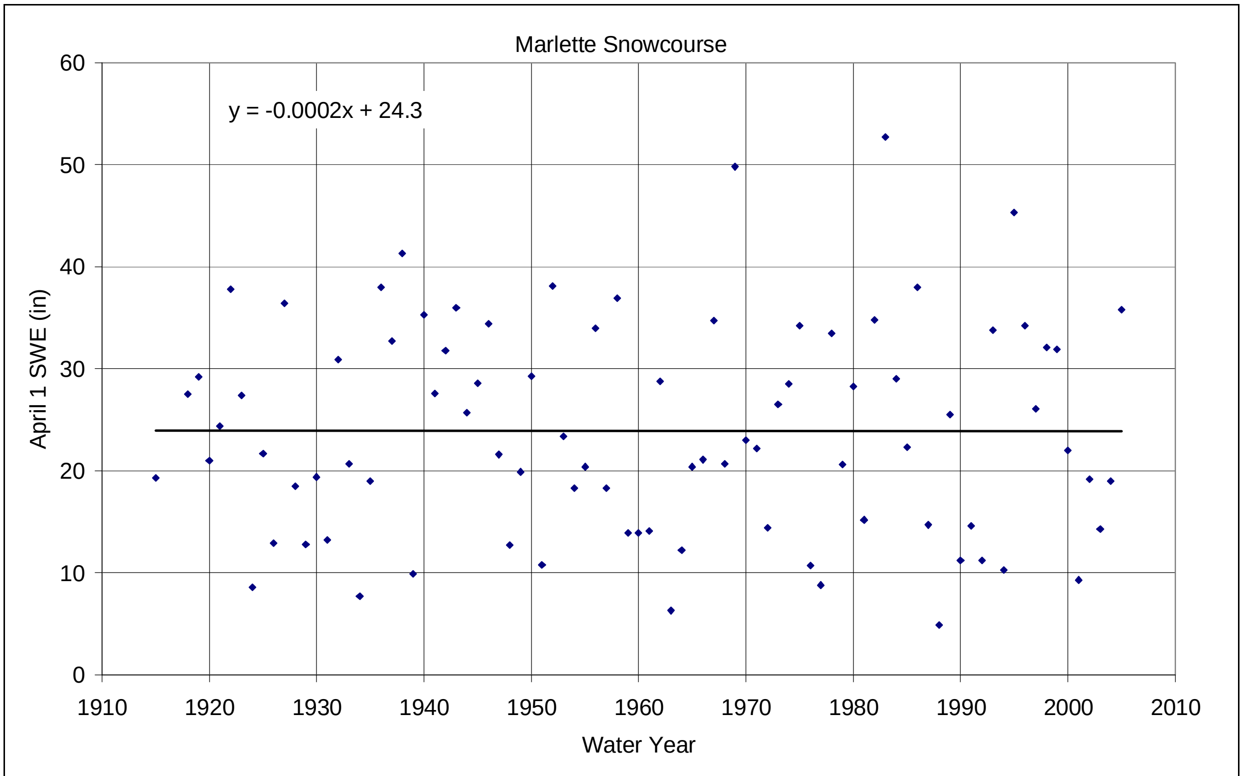


Figure C9. Marlette Lake snowcourse station April 1st SWE.

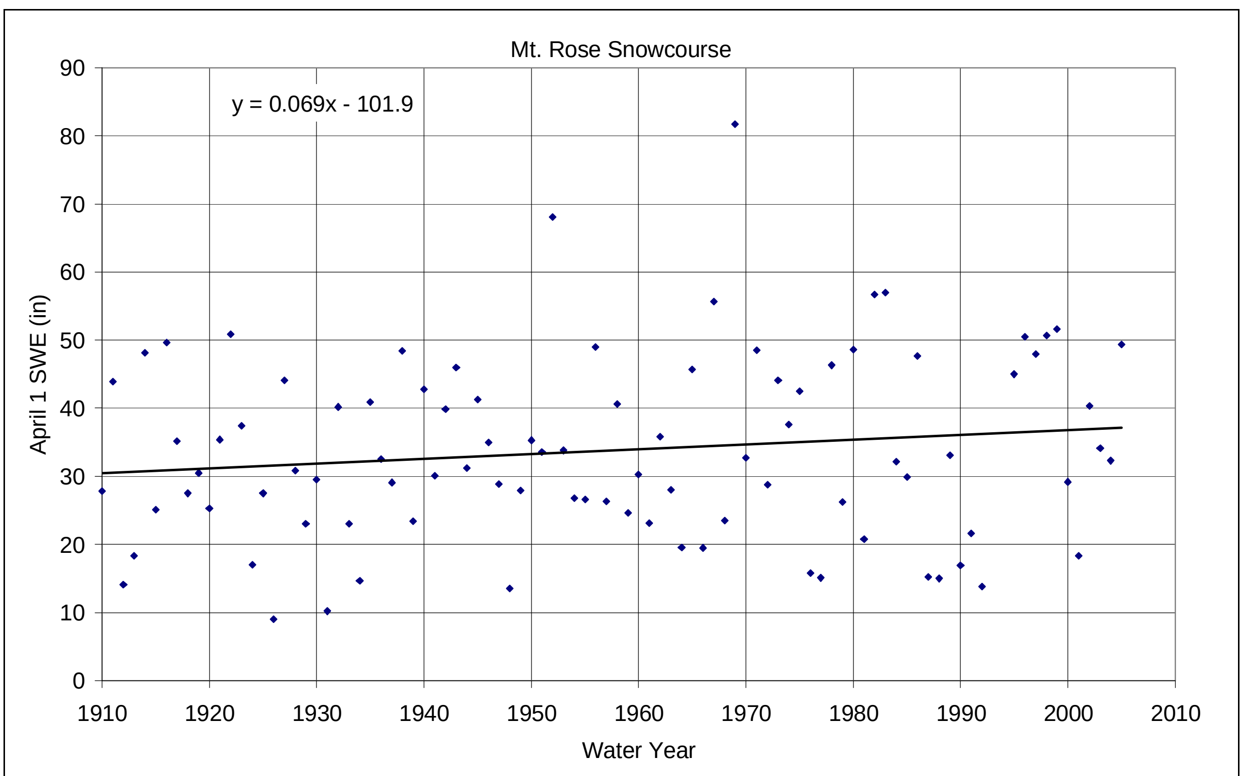


Figure C10. Mt Rose Ski Area snowcourse station April 1st SWE.

Appendix D

Streamflow

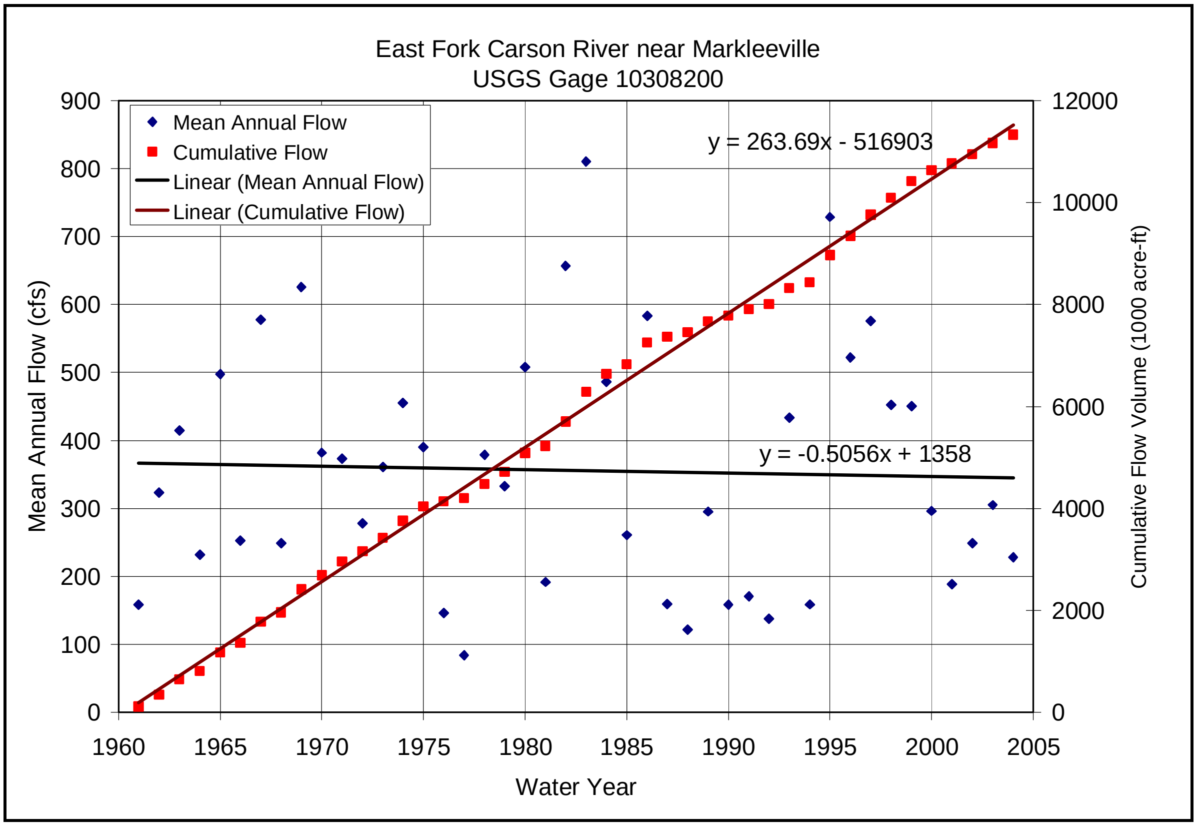


Figure D1. East Fork of the Carson River near Markleeville annual streamflow.

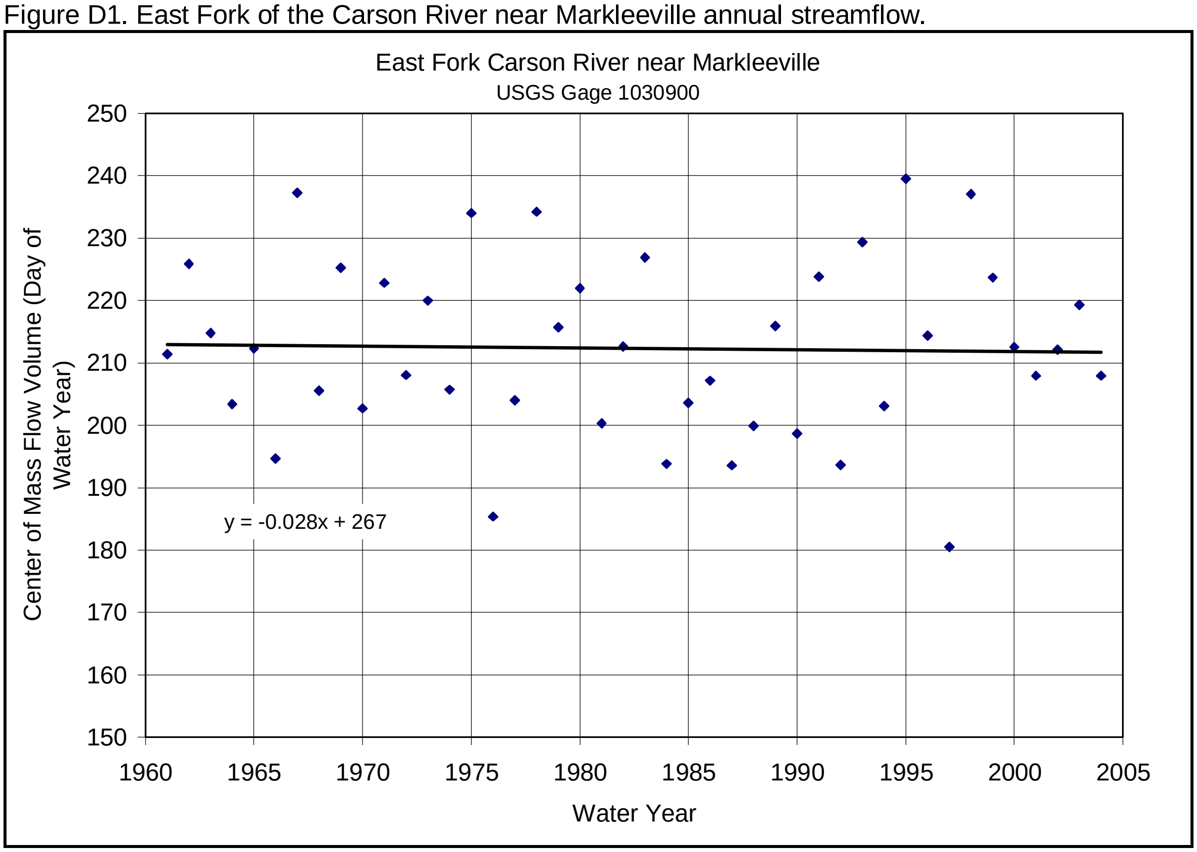


Figure D2. East Fork of the Carson River near Markleeville streamflow center of mass.

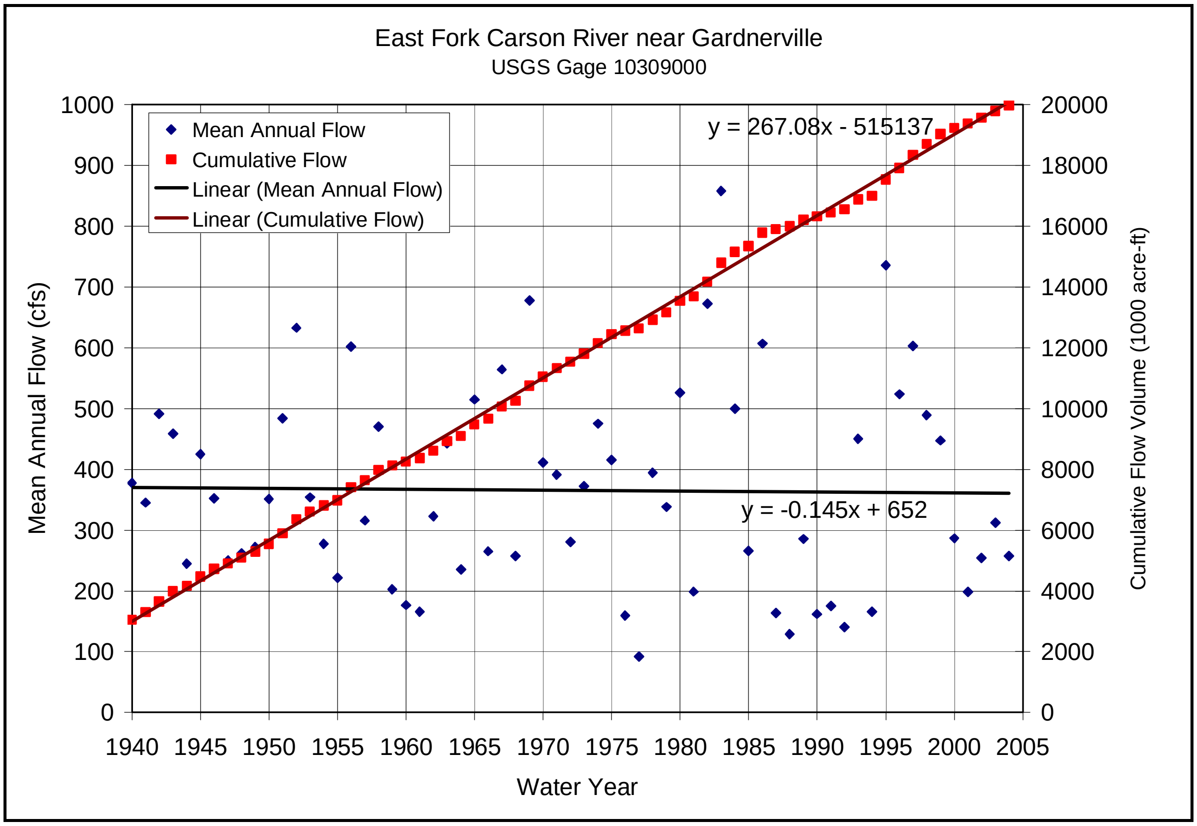


Figure D3. East Fork of the Carson River near Gardnerville annual streamflow.

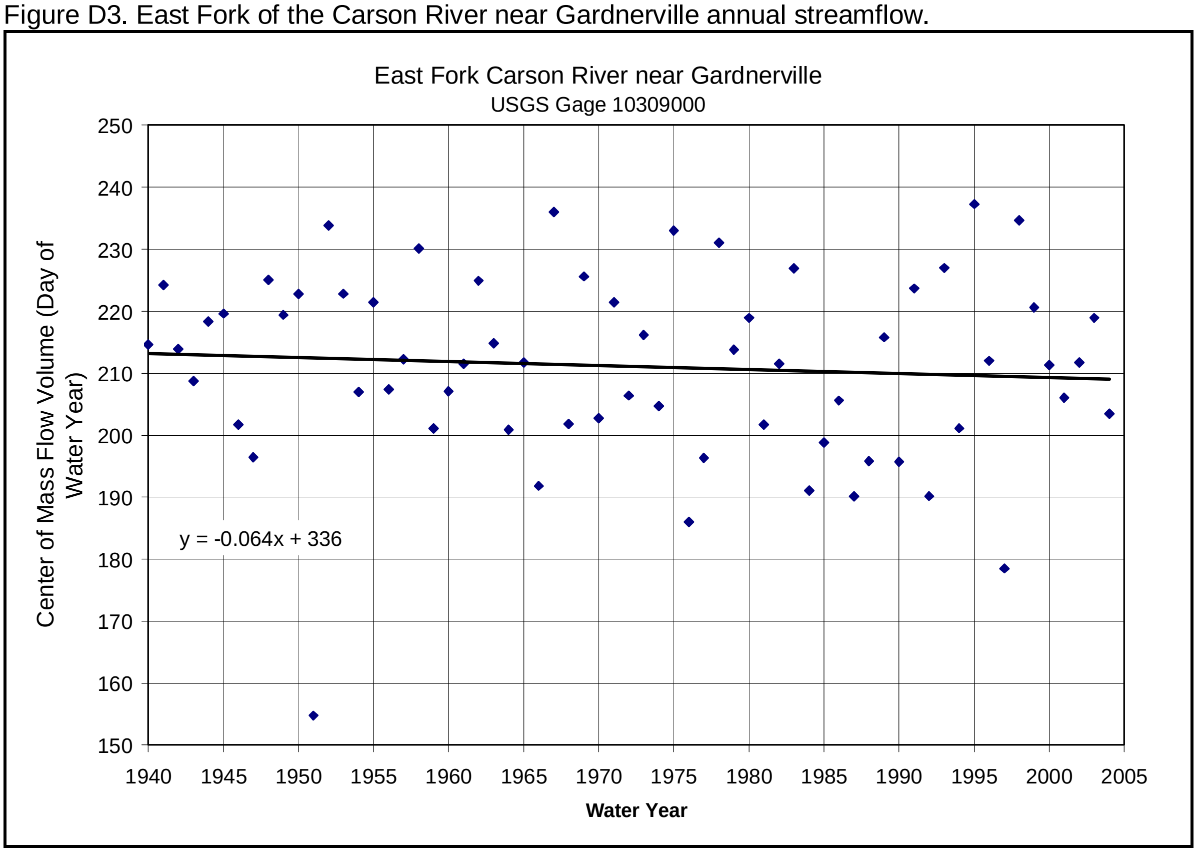


Figure D4. East Fork of the Carson River near Gardnerville streamflow center of mass.

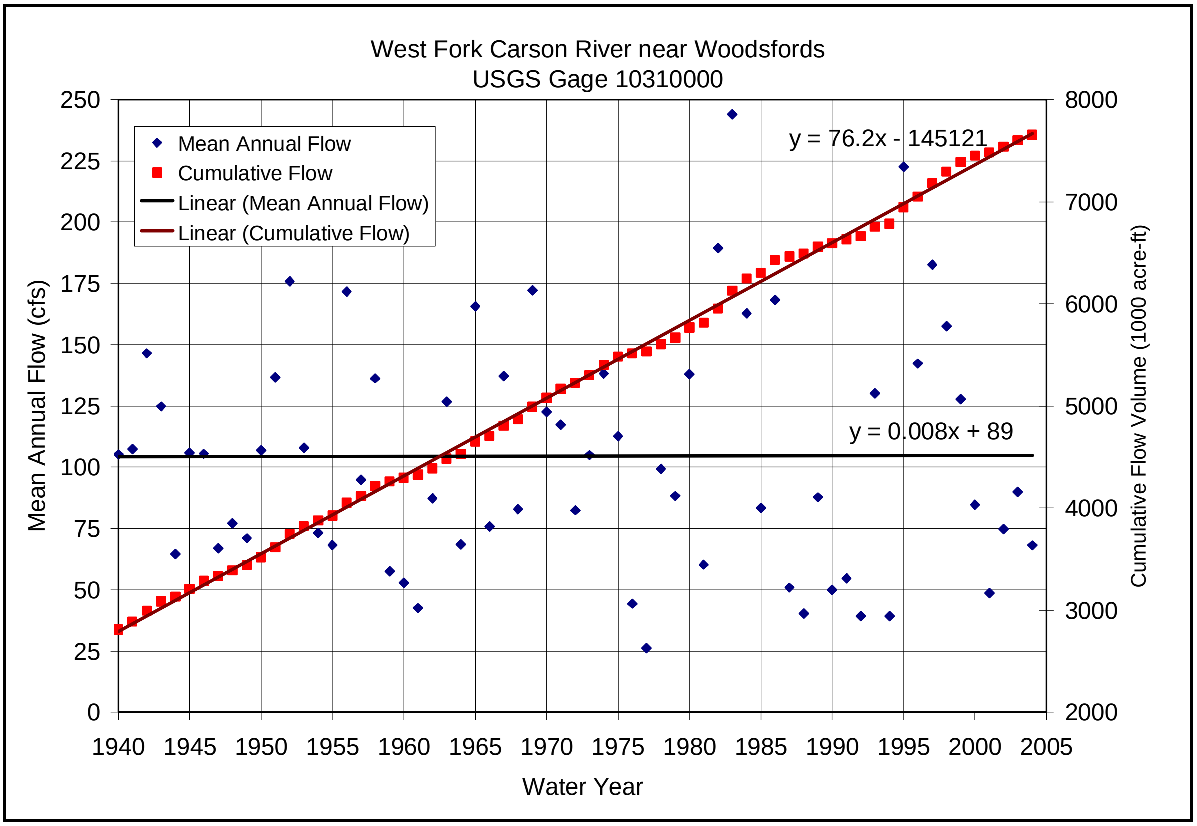


Figure D5. West Fork of the Carson River near Woodsford annual streamflow.

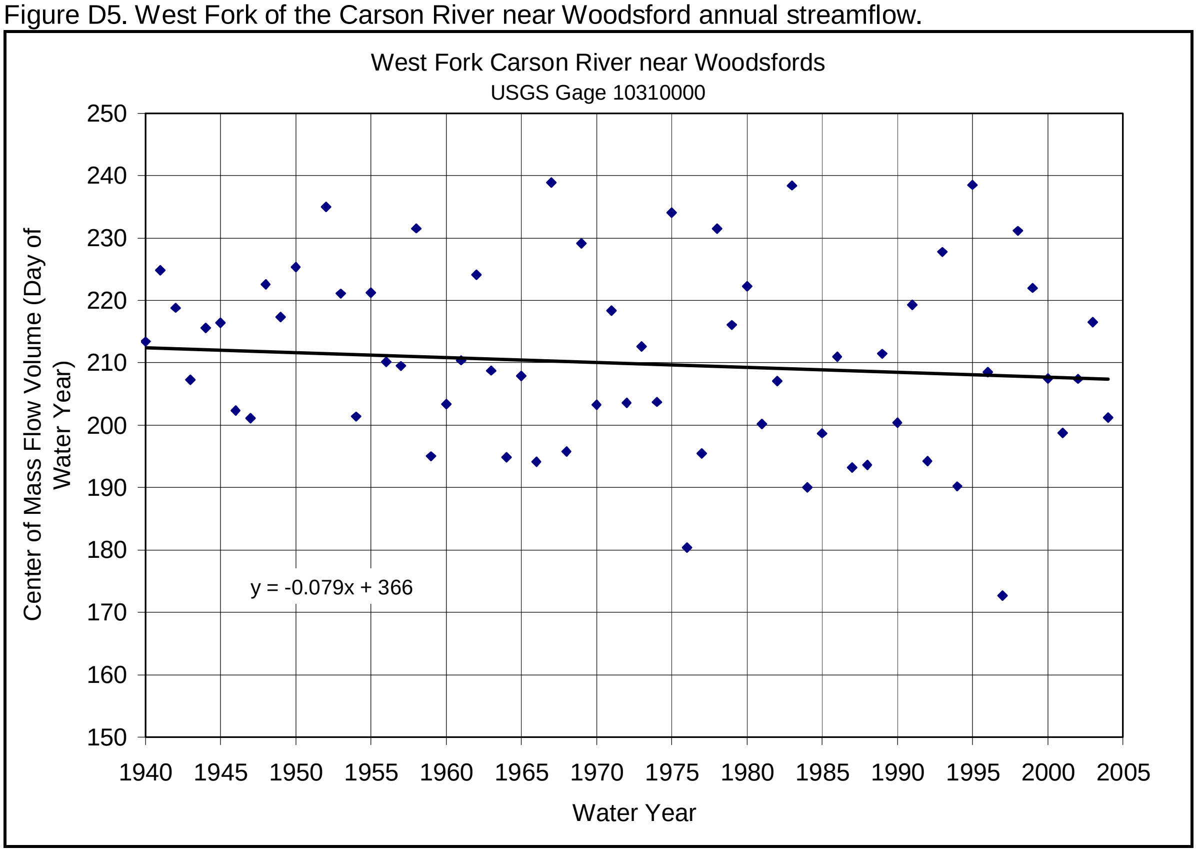


Figure D6. West Fork of the Carson River near Woodsford streamflow center of mass.

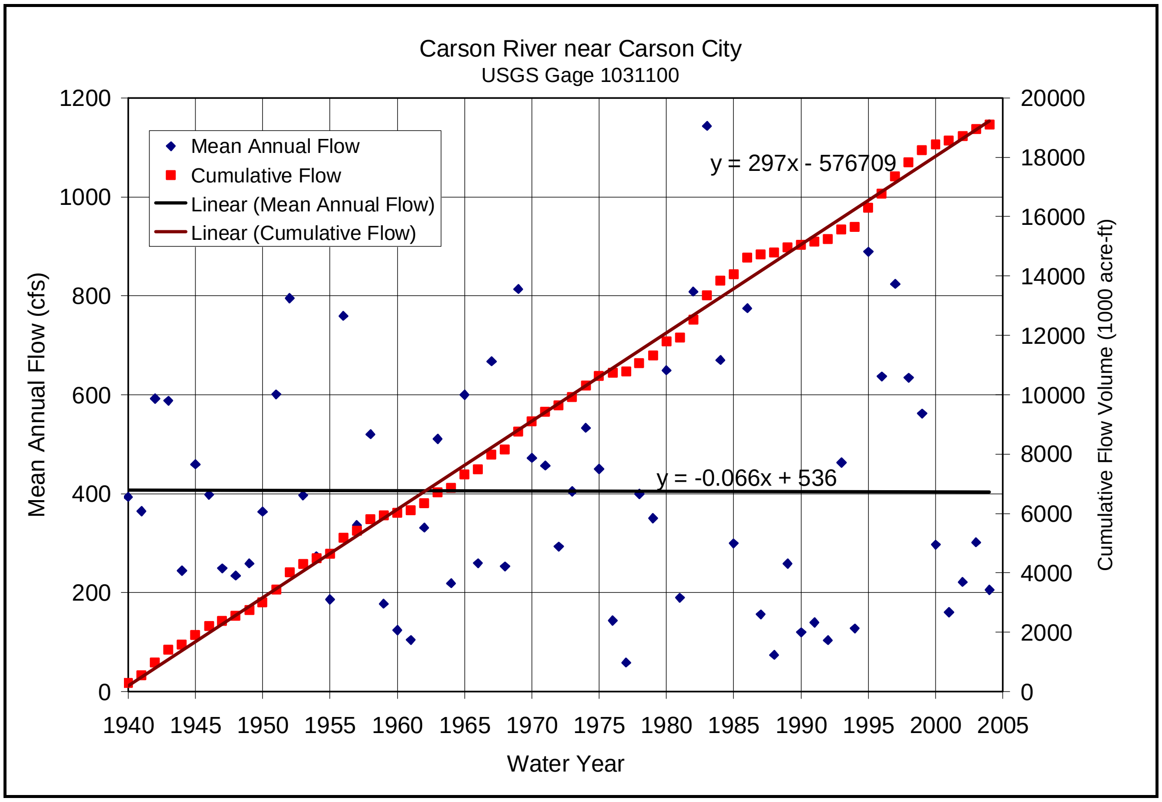


Figure D7. Carson River near Carson City annual streamflow.

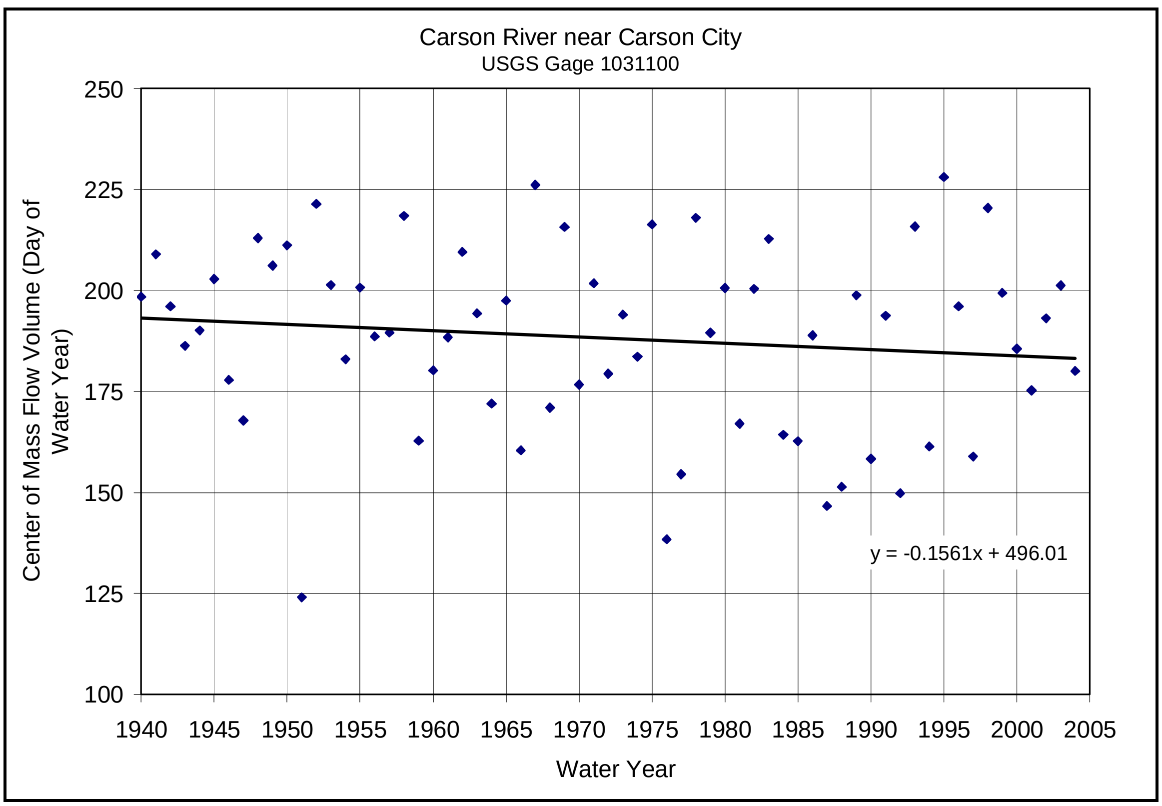


Figure D8. Carson River near Carson City streamflow center of mass.

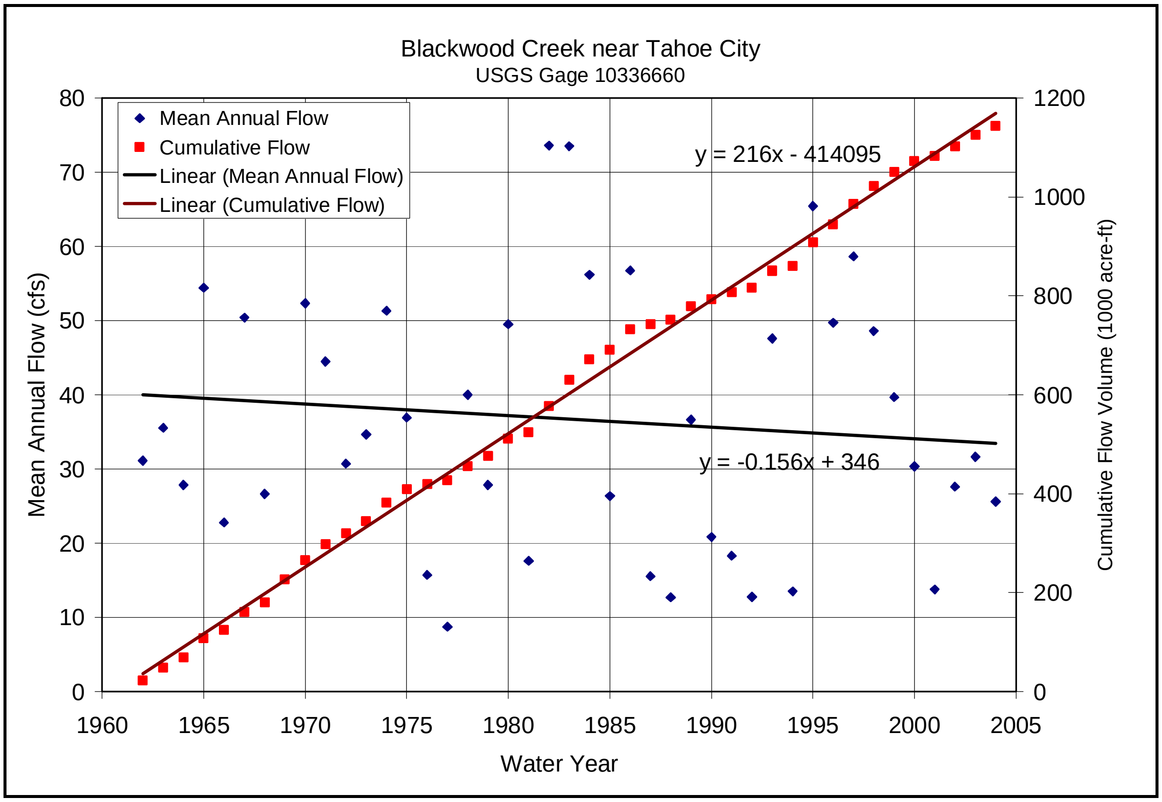


Figure D9. Blackwood Creek near Tahoe City annual streamflow.

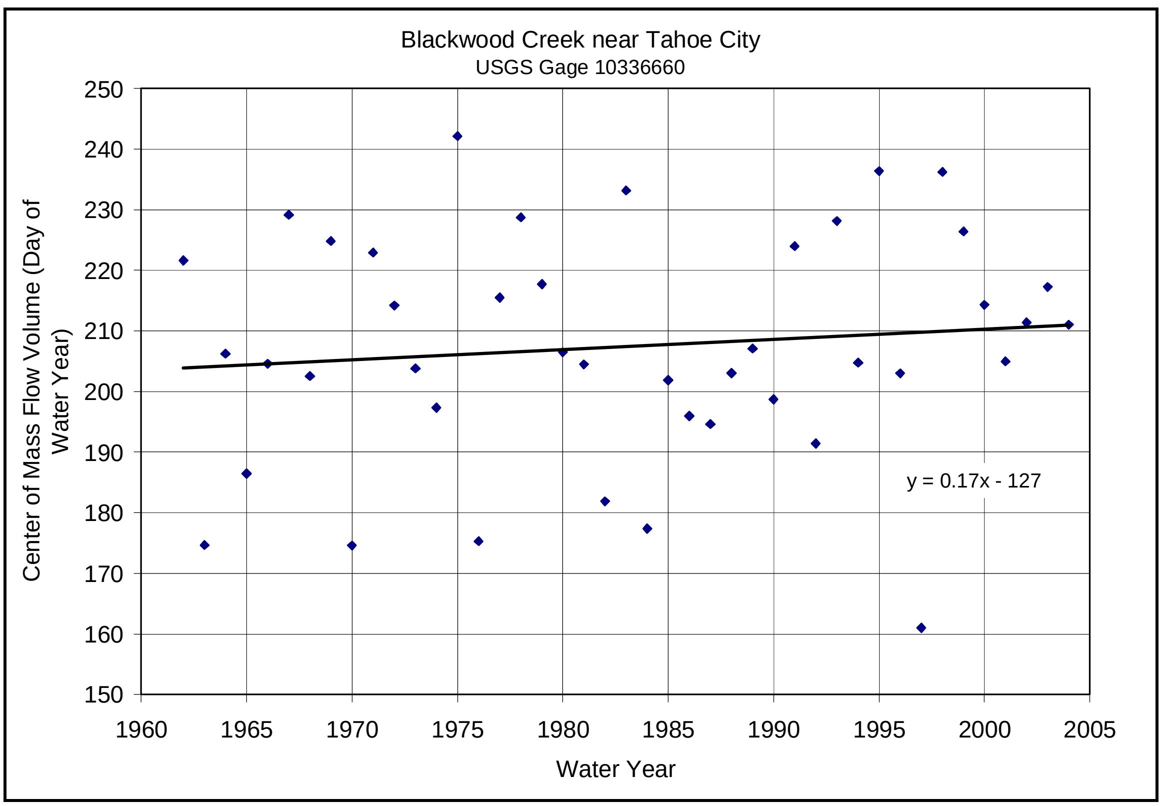


Figure D10. Blackwood Creek near Tahoe City streamflow center of mass.

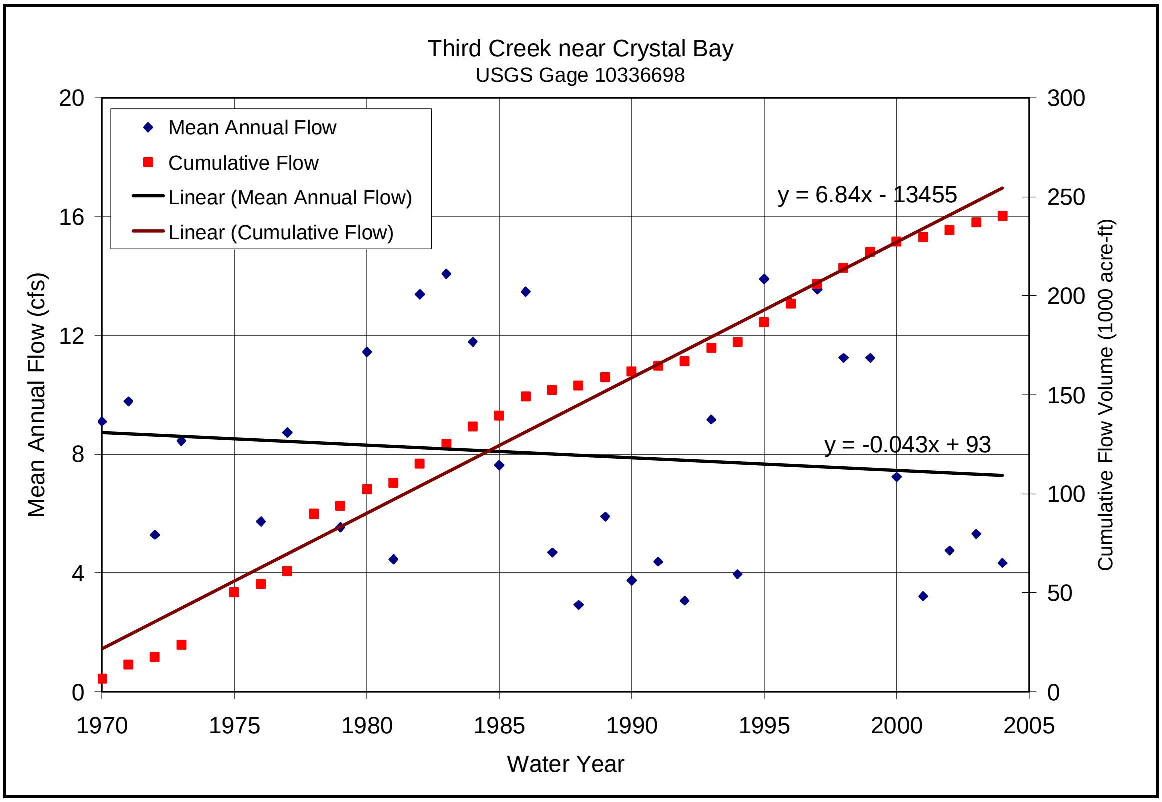


Figure D11. Third Creek near Crystal Bay annual streamflow.

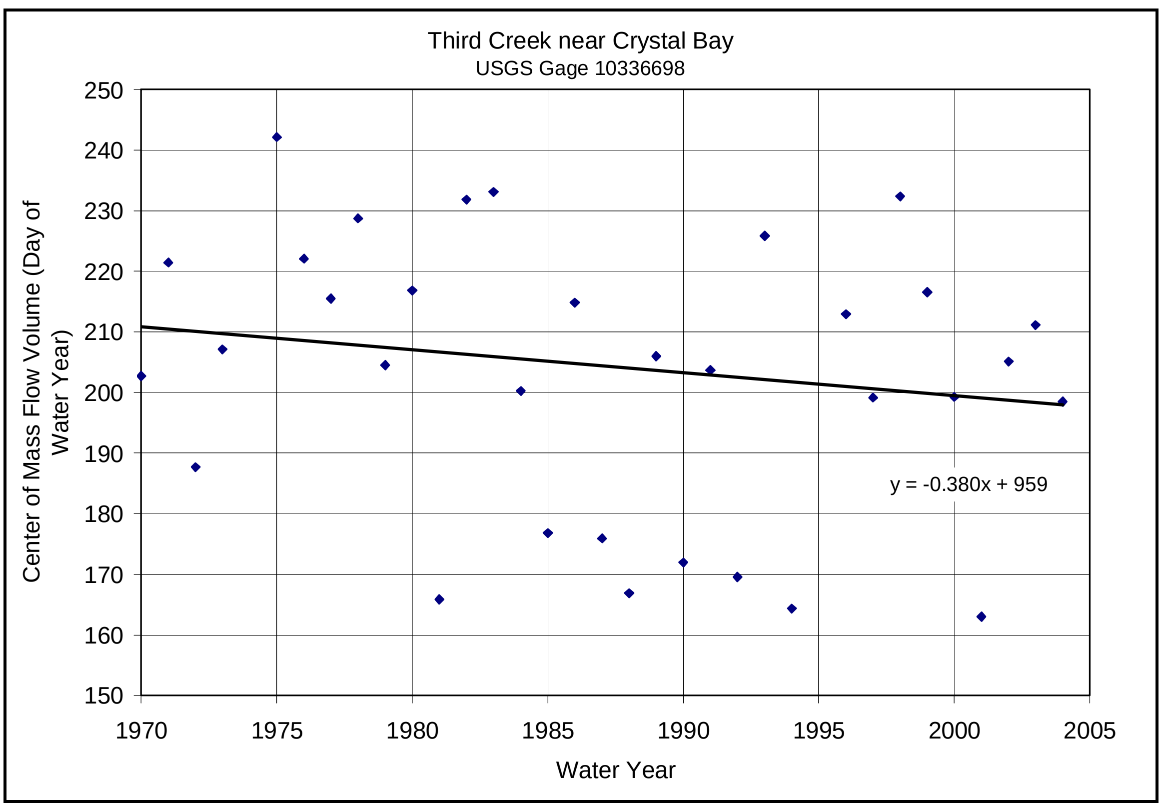


Figure D12. Third Creek near Crystal Bay streamflow center of mass.

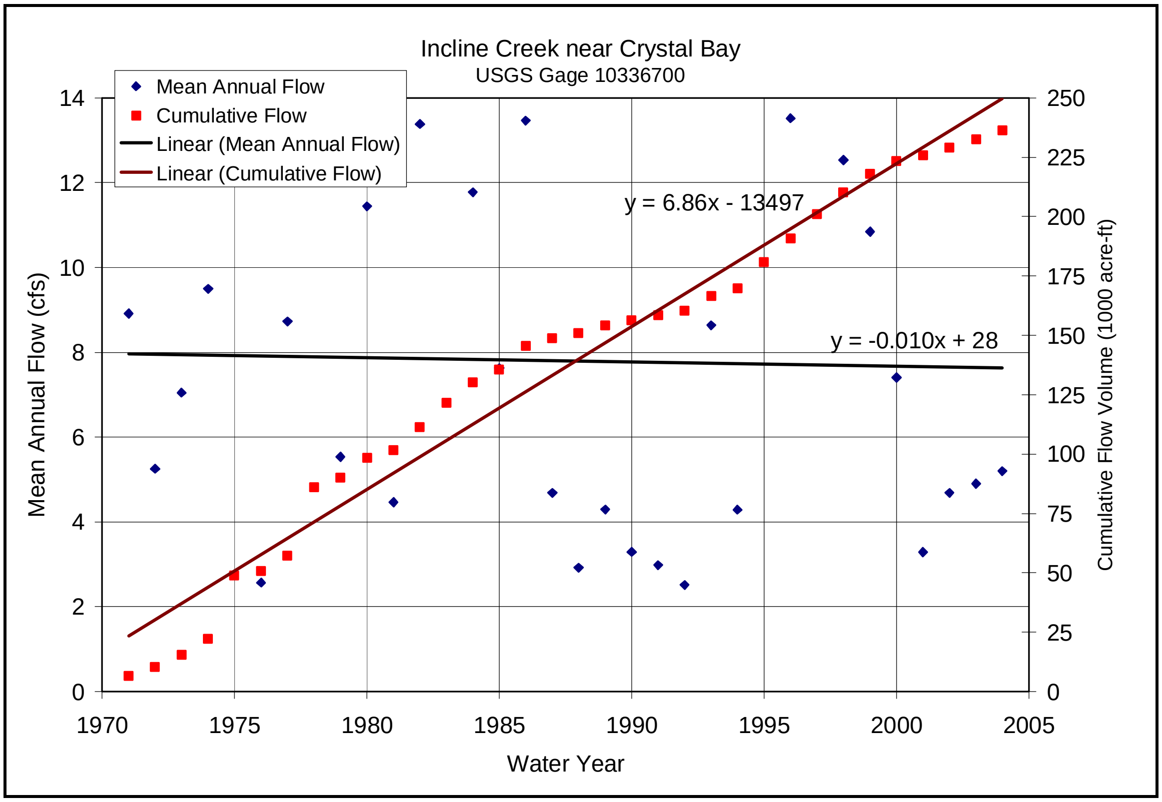


Figure D13. Incline Creek near Crystal Bay annual streamflow.

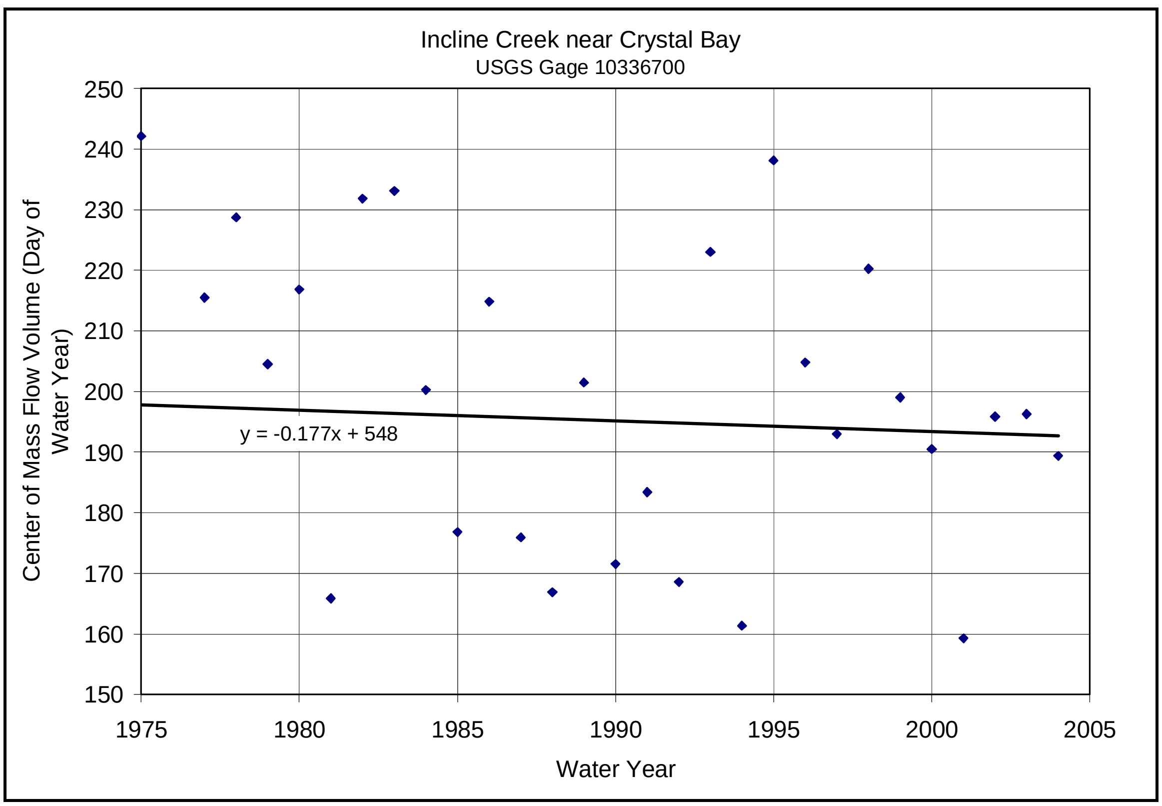


Figure D14. Incline Creek near Crystal Bay streamflow center of mass.

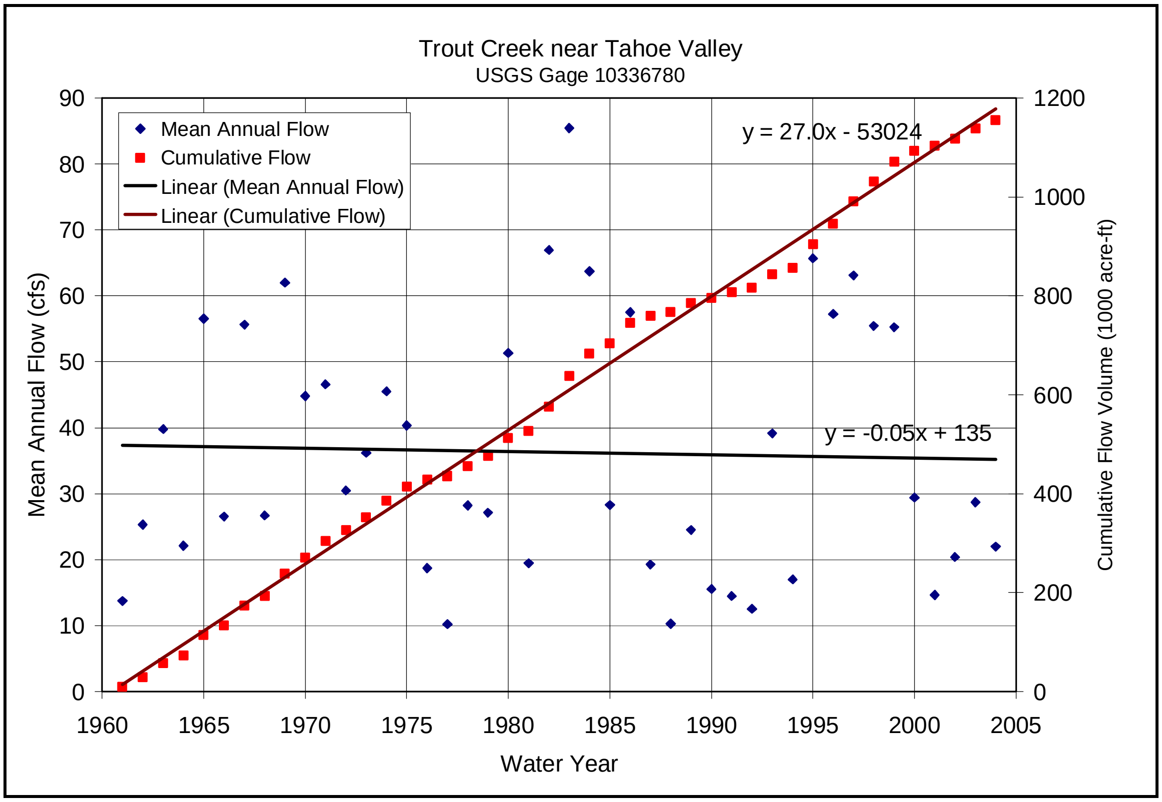


Figure D15. Trout Creek near Tahoe Valley annual streamflow.

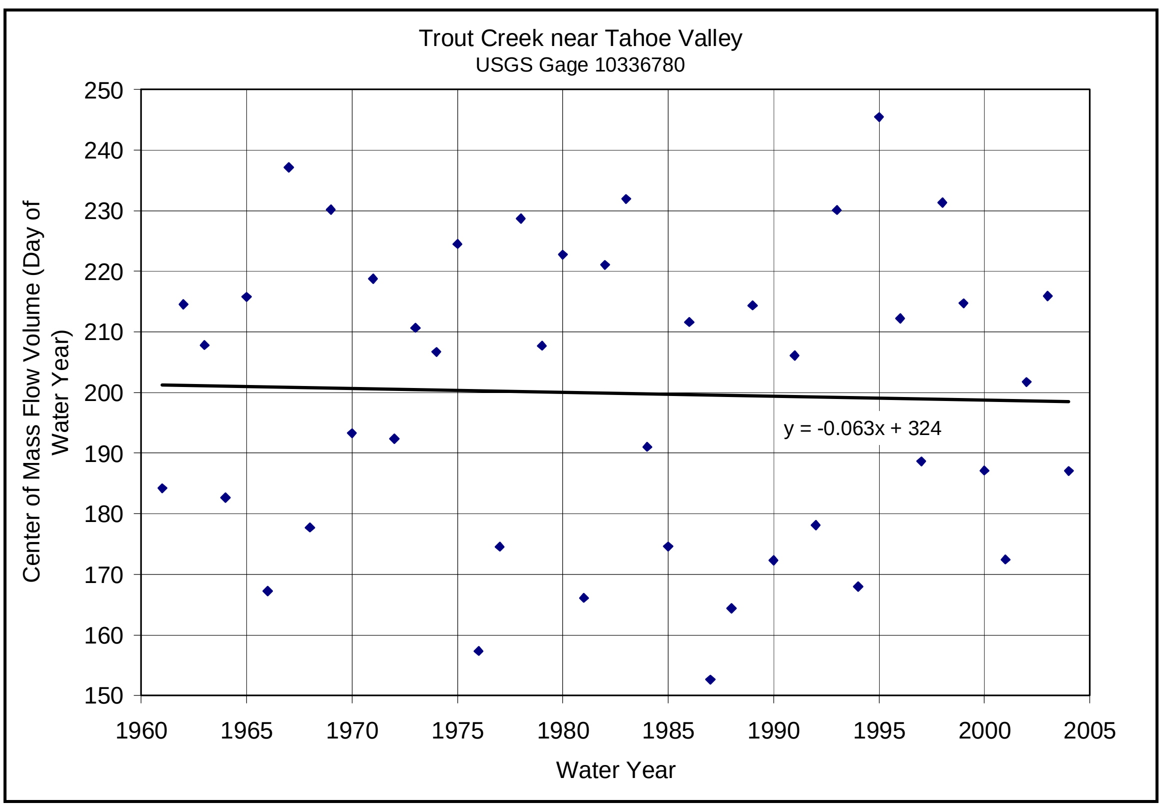


Figure D16. Trout Creek near Tahoe Valley streamflow center of mass.

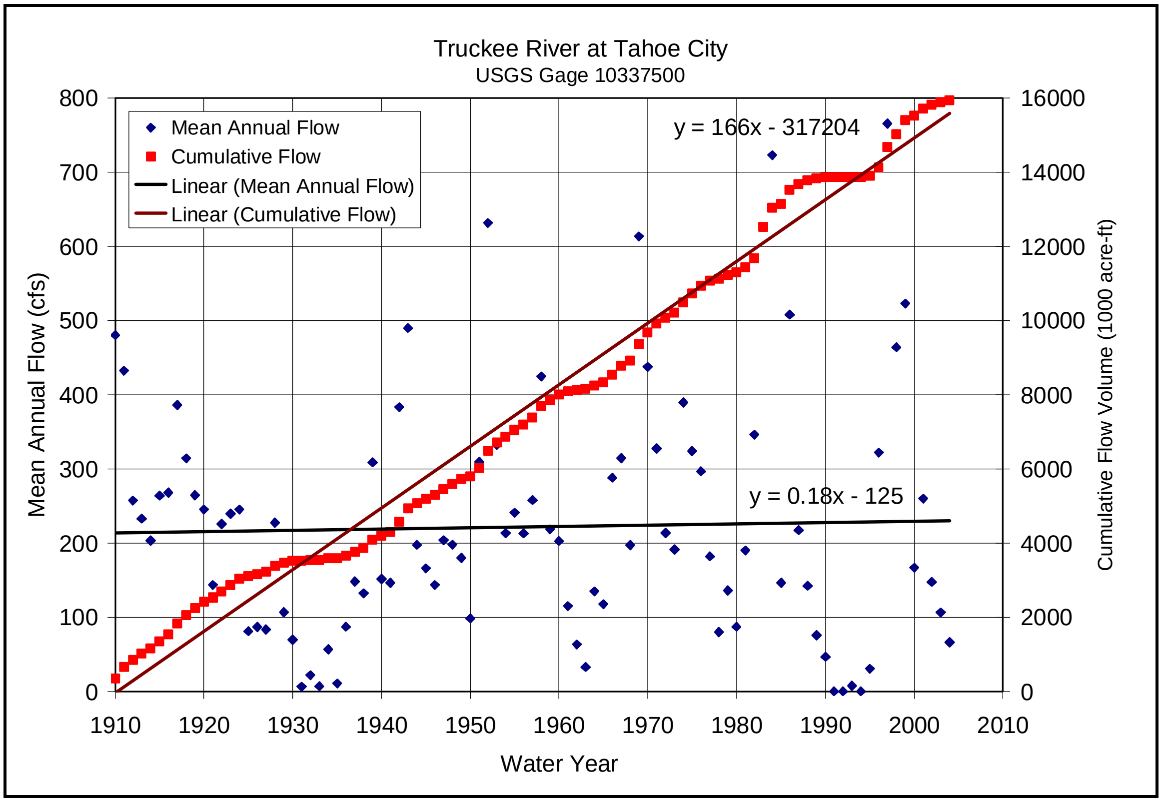


Figure D17. Truckee River at Tahoe City annual streamflow.

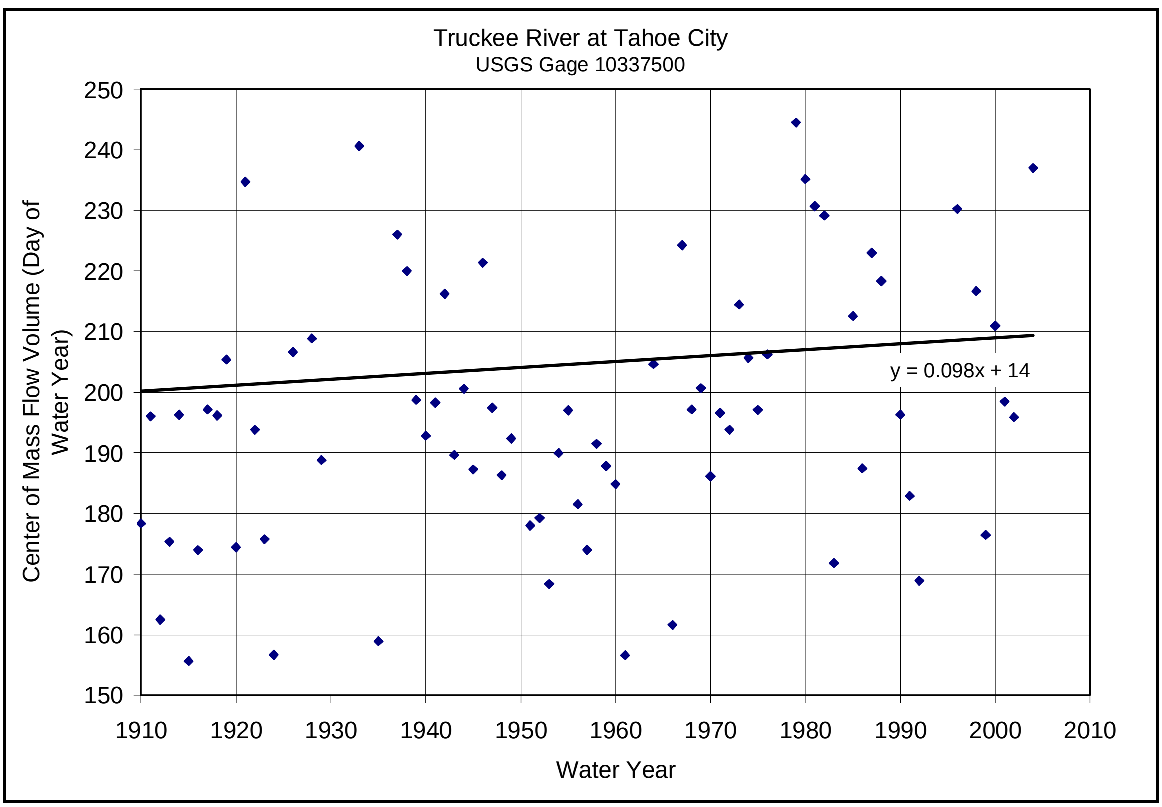


Figure D18. Truckee River at Tahoe City streamflow center of mass.

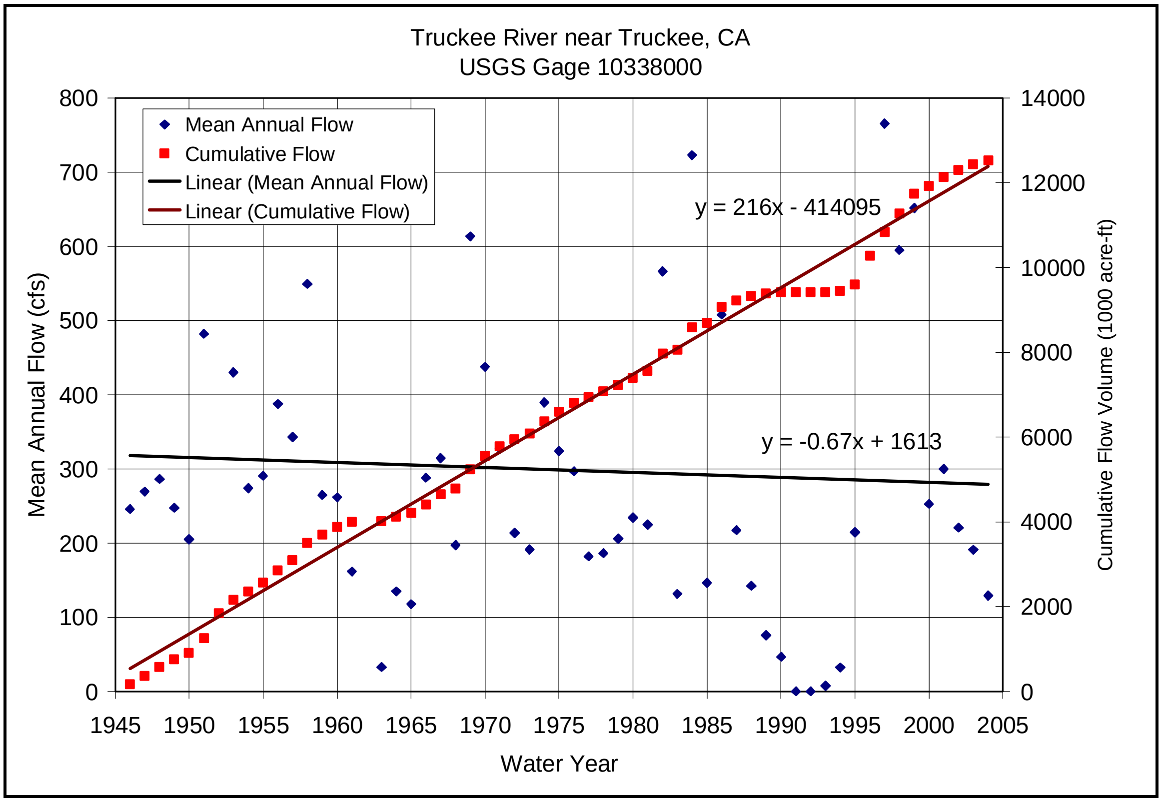


Figure D19. Truckee River near Truckee, CA annual streamflow.

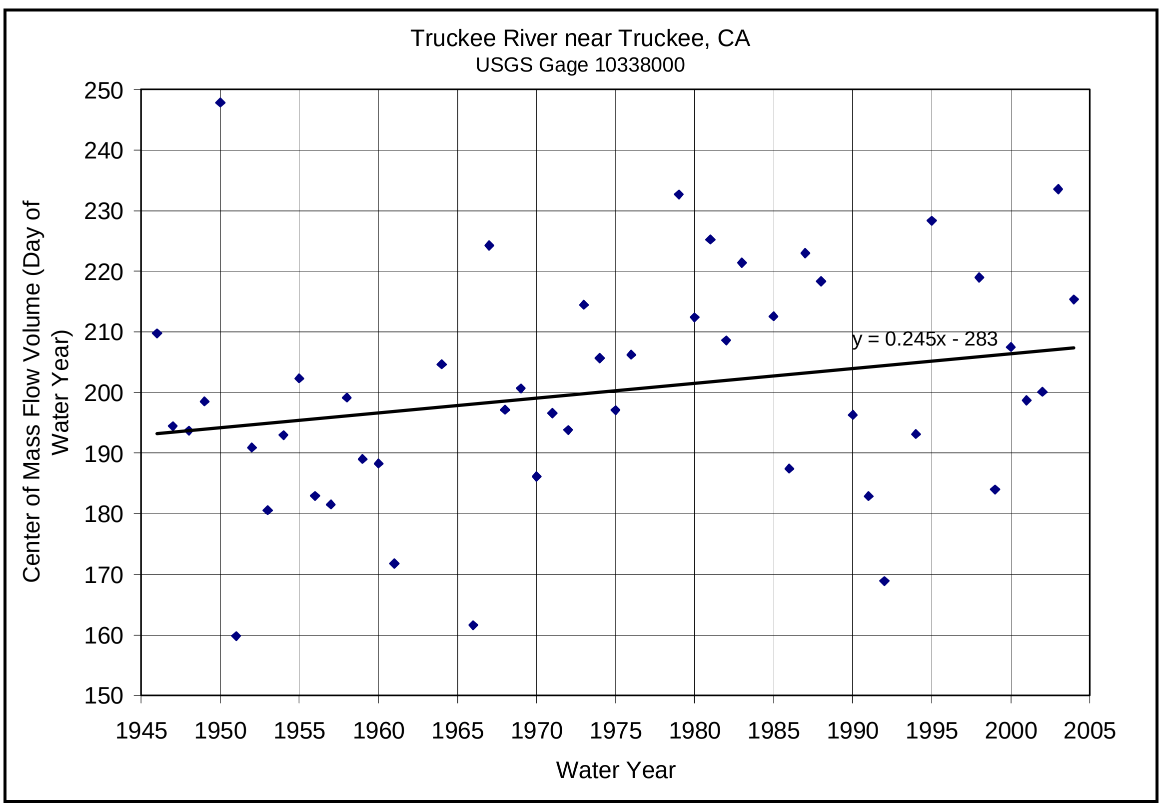


Figure D20. Truckee River near Truckee, CA streamflow center of mass.

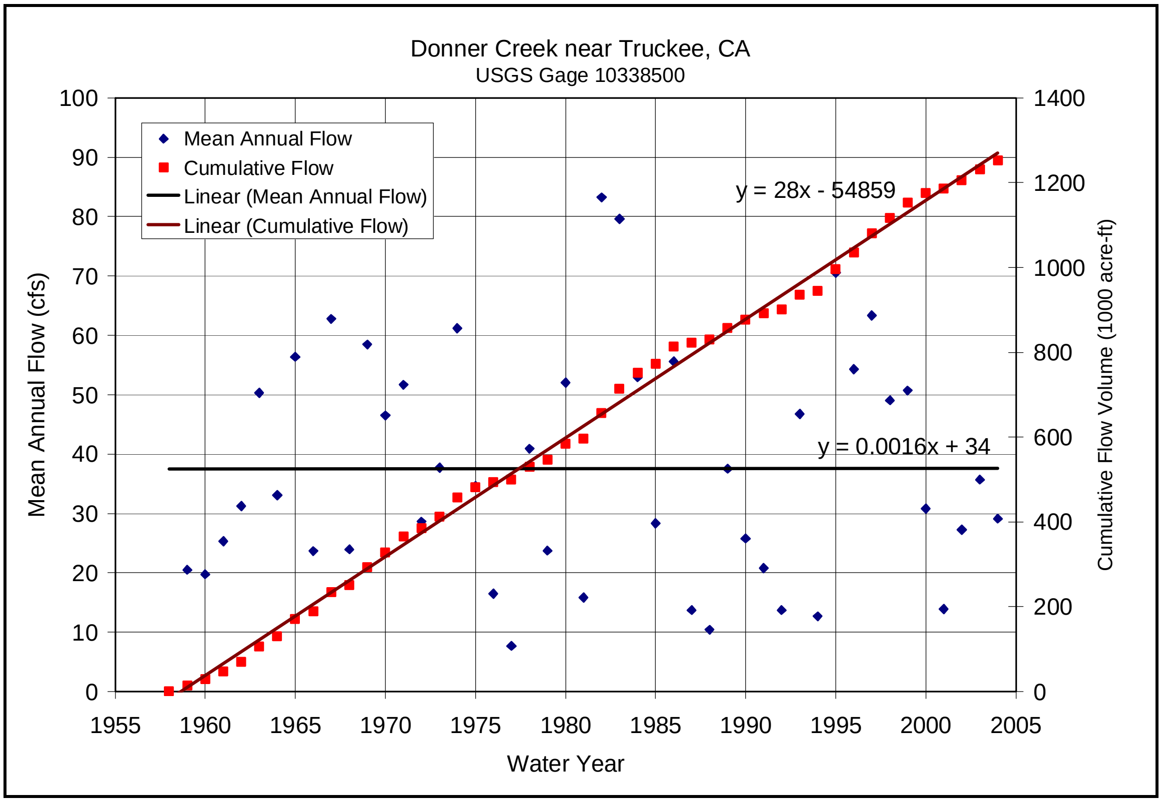


Figure D21. Donner Creek near Truckee, CA annual streamflow.

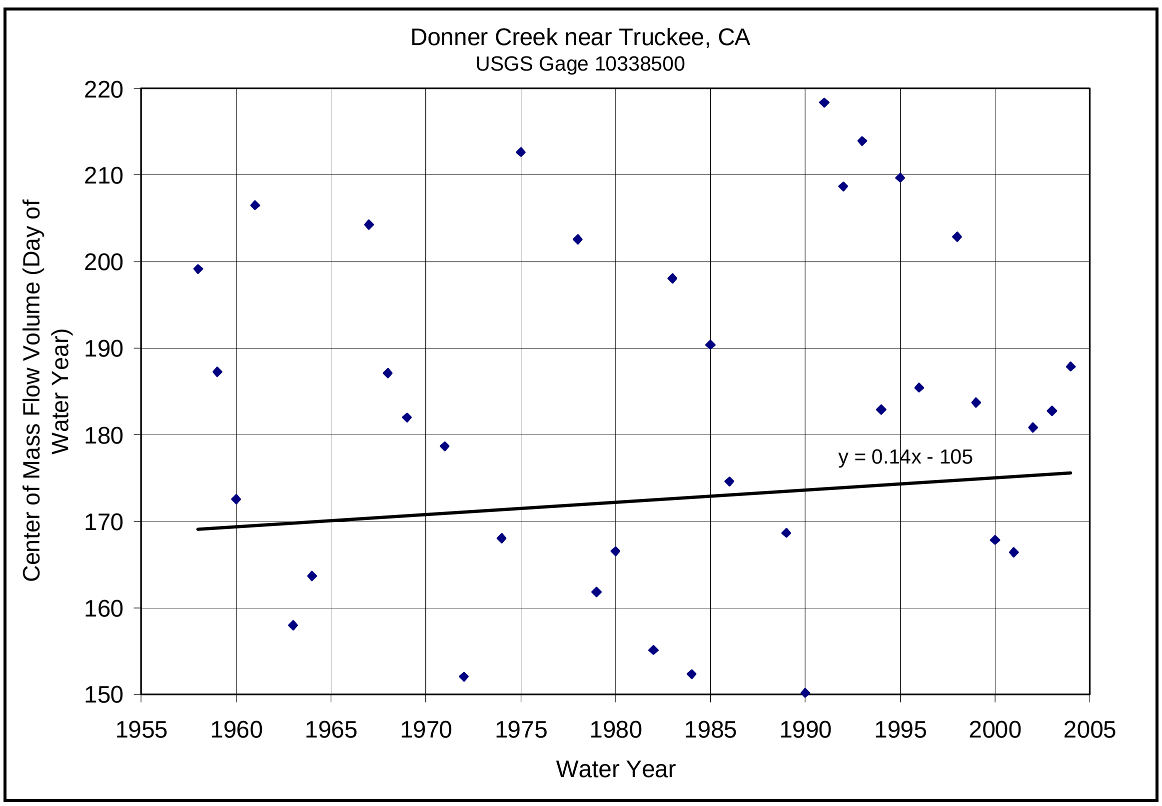


Figure D22. Donner Creek near Truckee, CA streamflow center of mass.

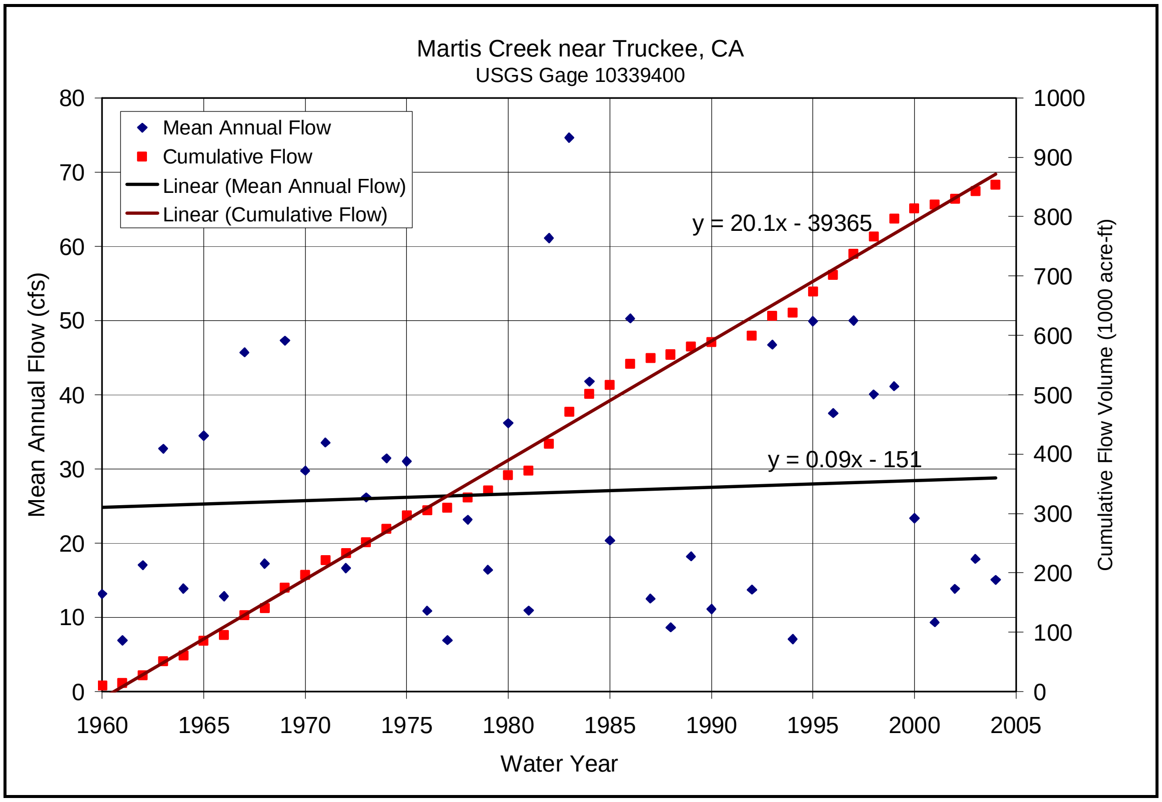


Figure D23. Martis Creek near Truckee, CA annual streamflow.

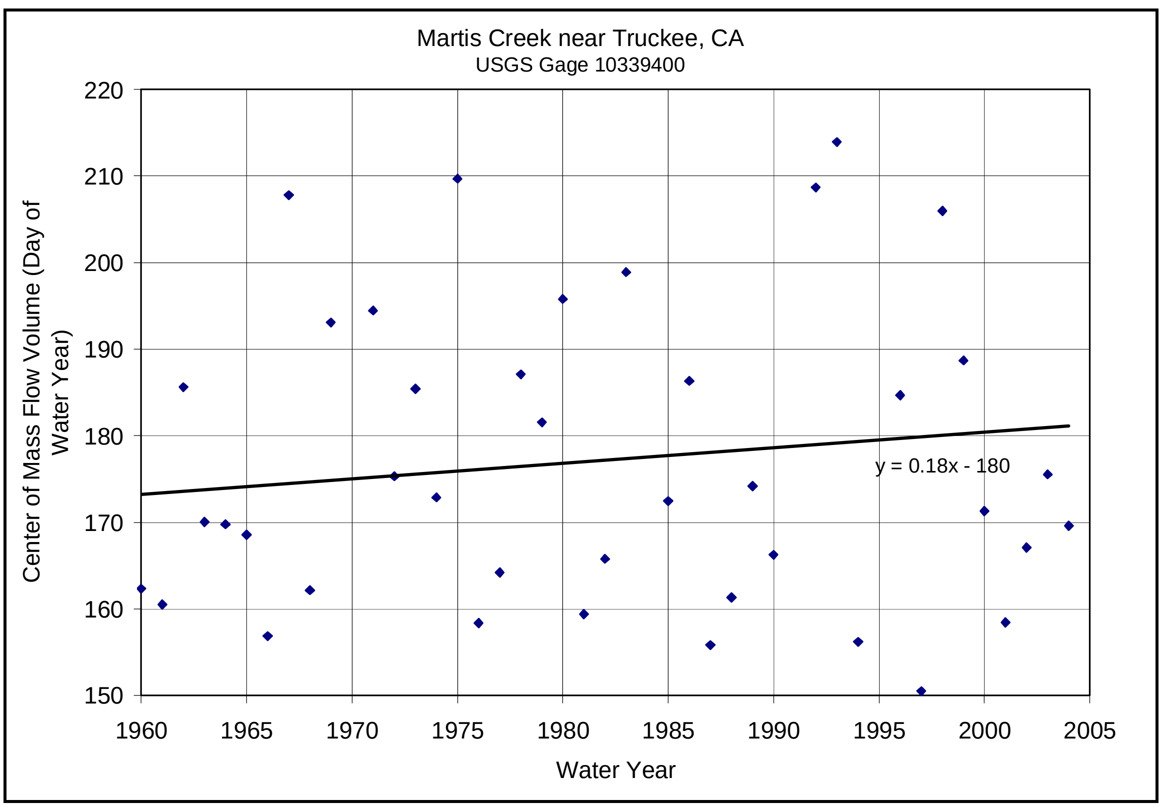


Figure D24. Martis Creek near Truckee, CA streamflow center of mass.

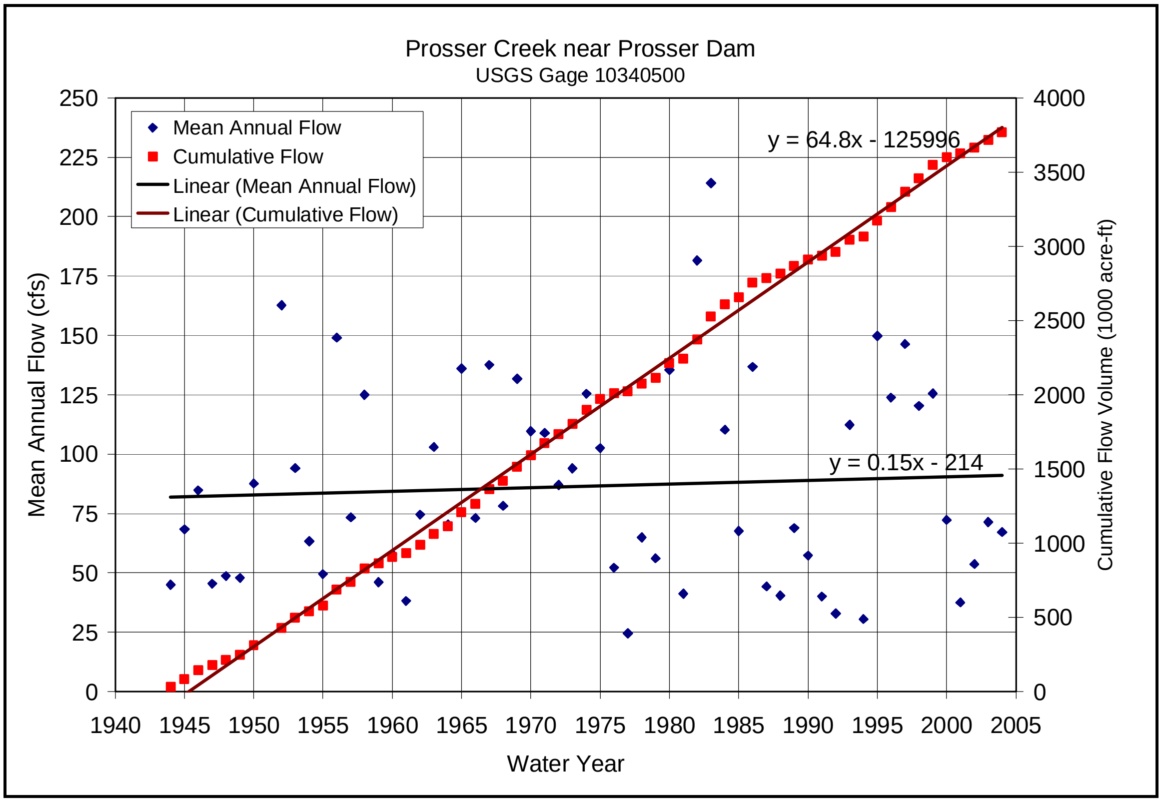


Figure D25. Prosser Creek near Prosser Dam annual streamflow.

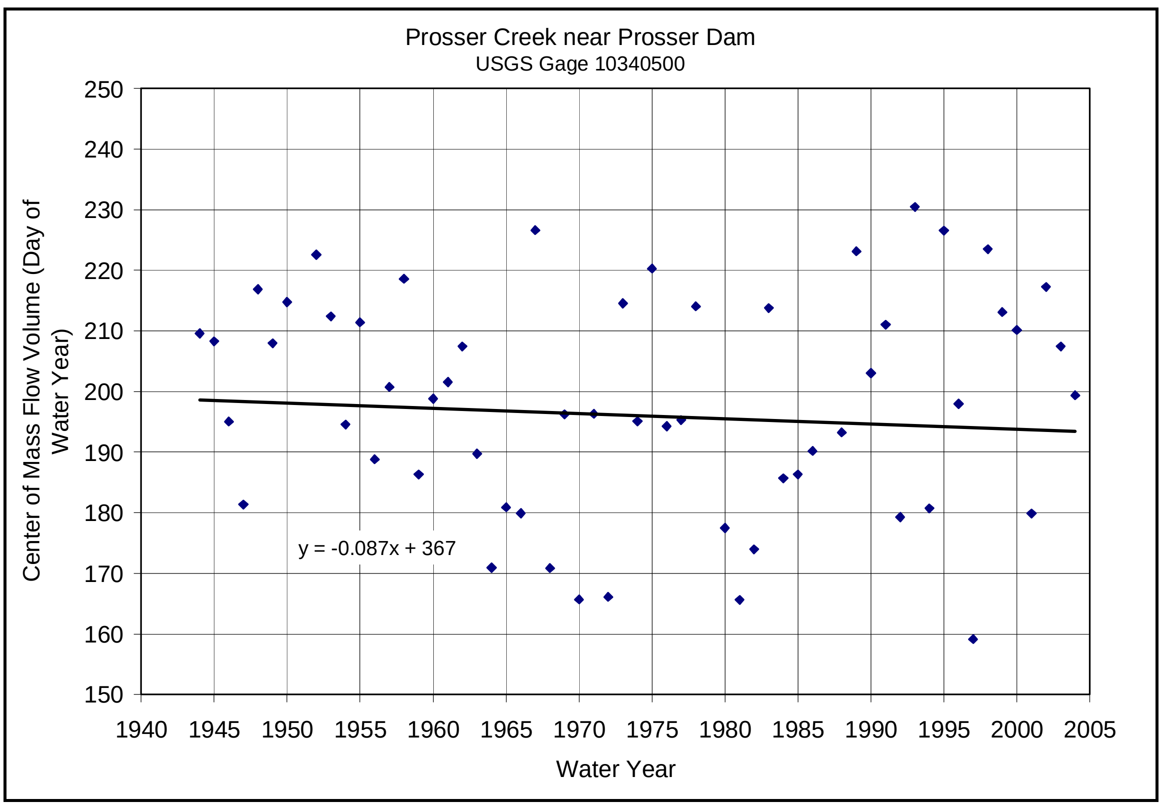


Figure D26. Prosser Creek near Prosser Dam streamflow center of mass.

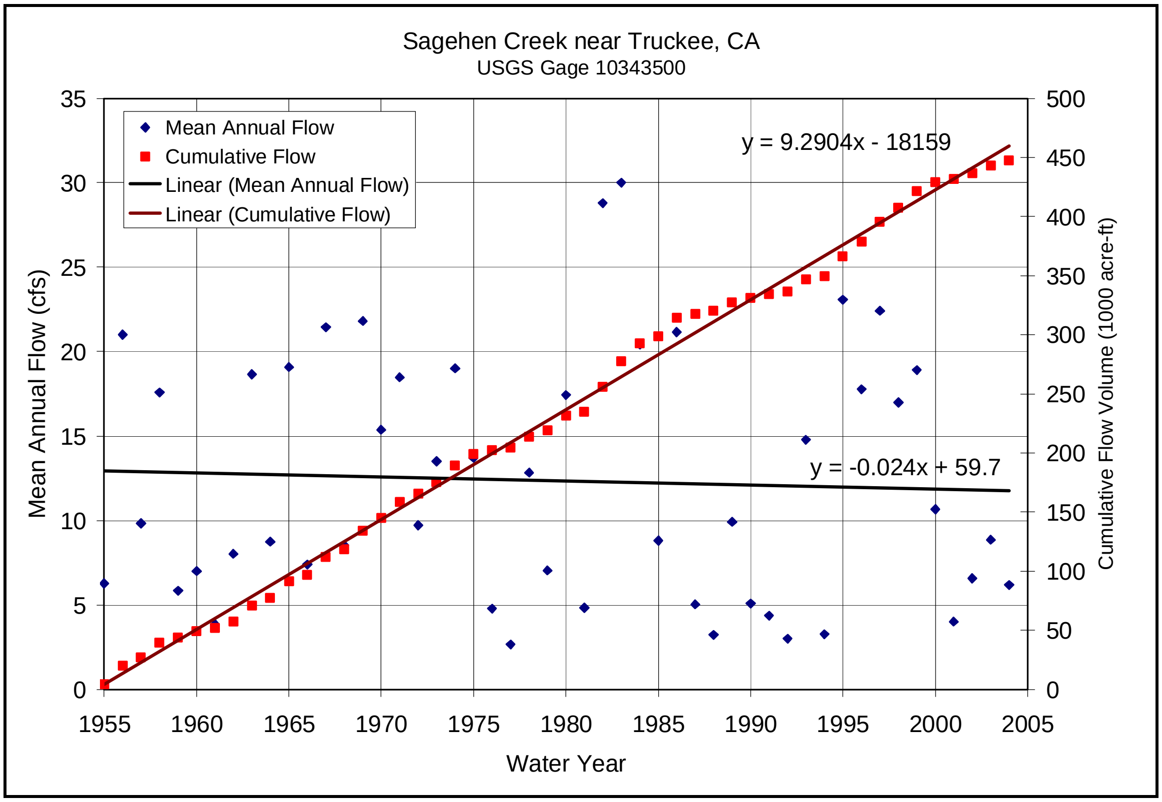


Figure D27. Sagehen Creek near Truckee, CA annual streamflow.

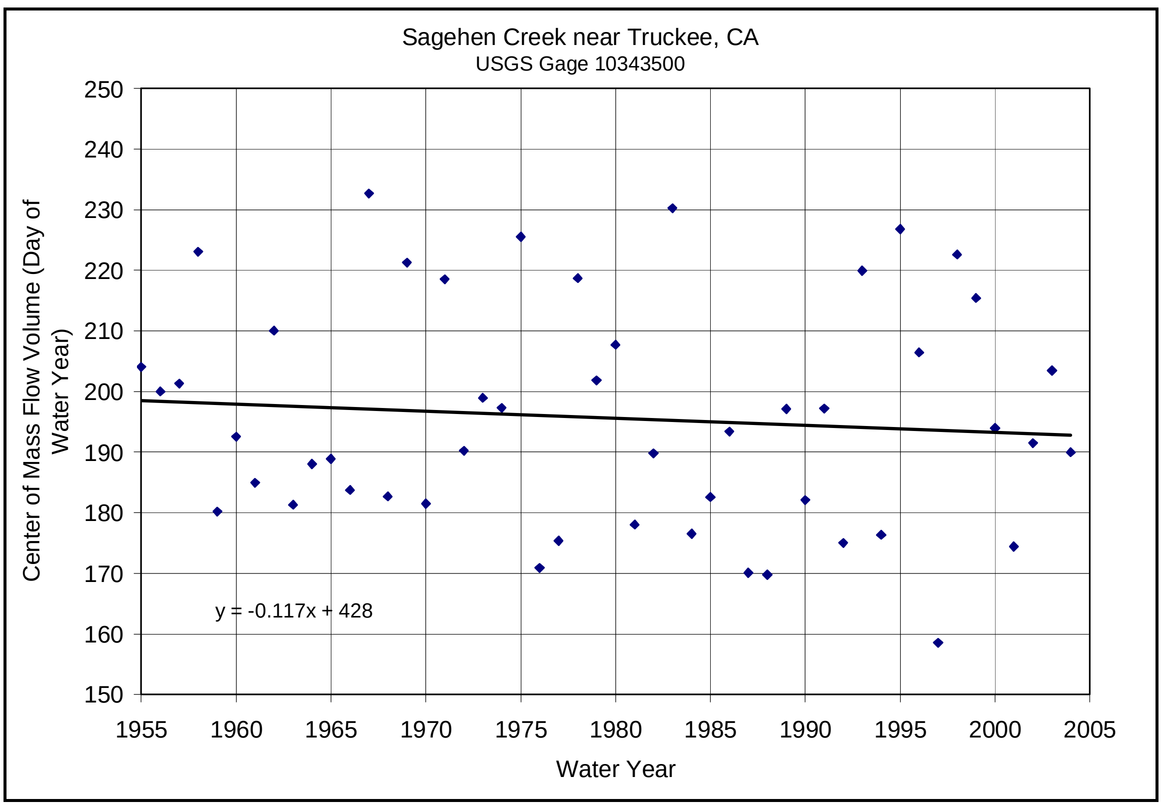


Figure D28. Sagehen Creek near Truckee, CA streamflow center of mass.

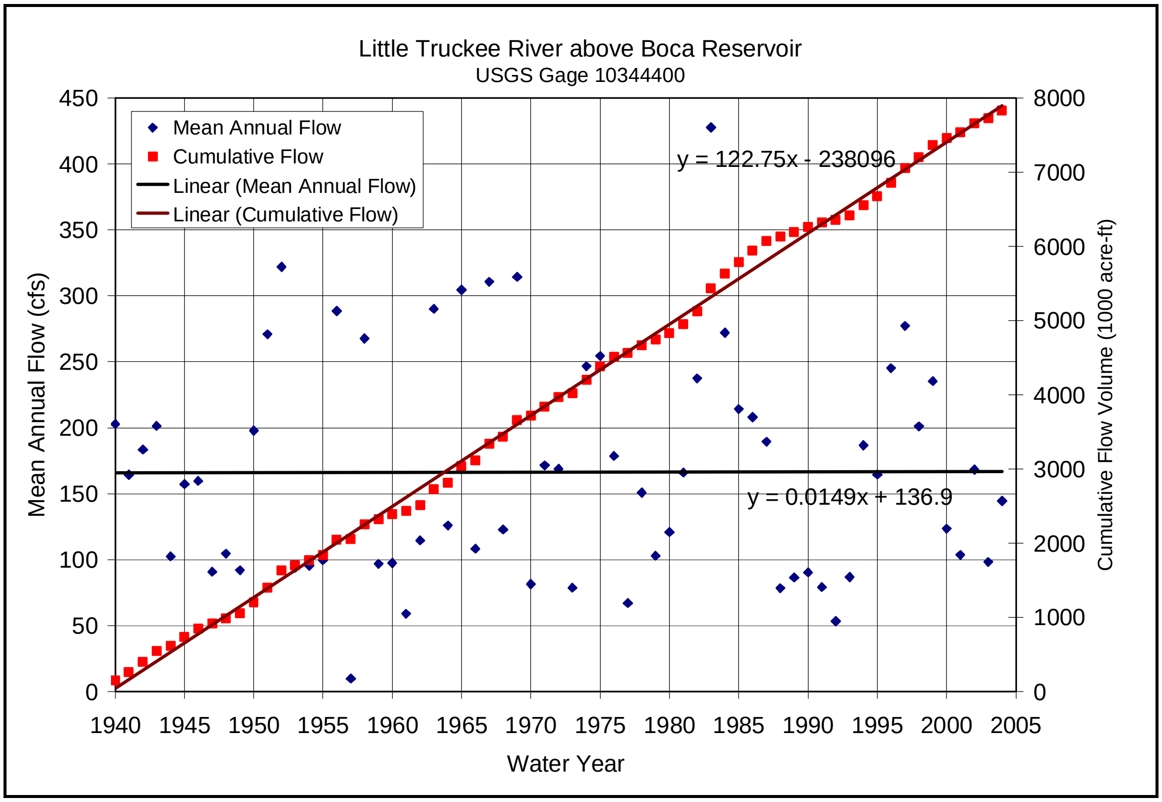


Figure D29. Little Truckee River above Boca Reservoir annual streamflow.

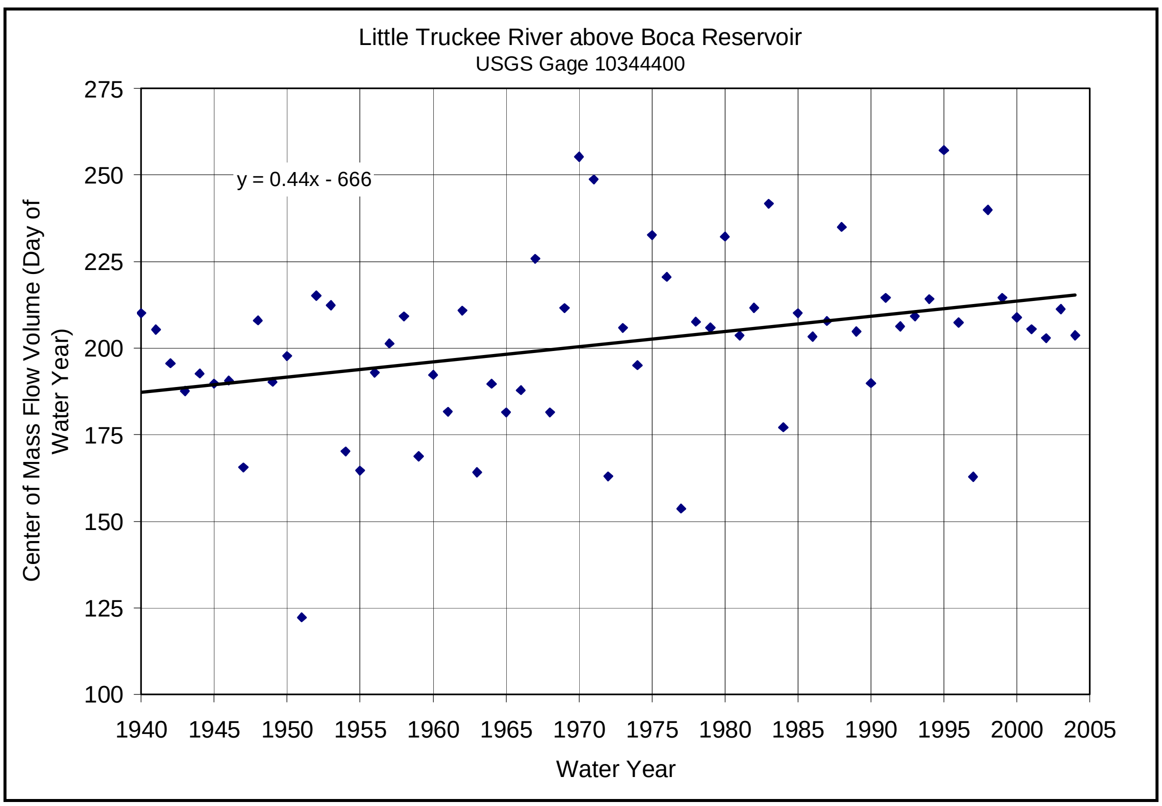


Figure D30. Little Truckee River above Boca Reservoir streamflow center of mass.

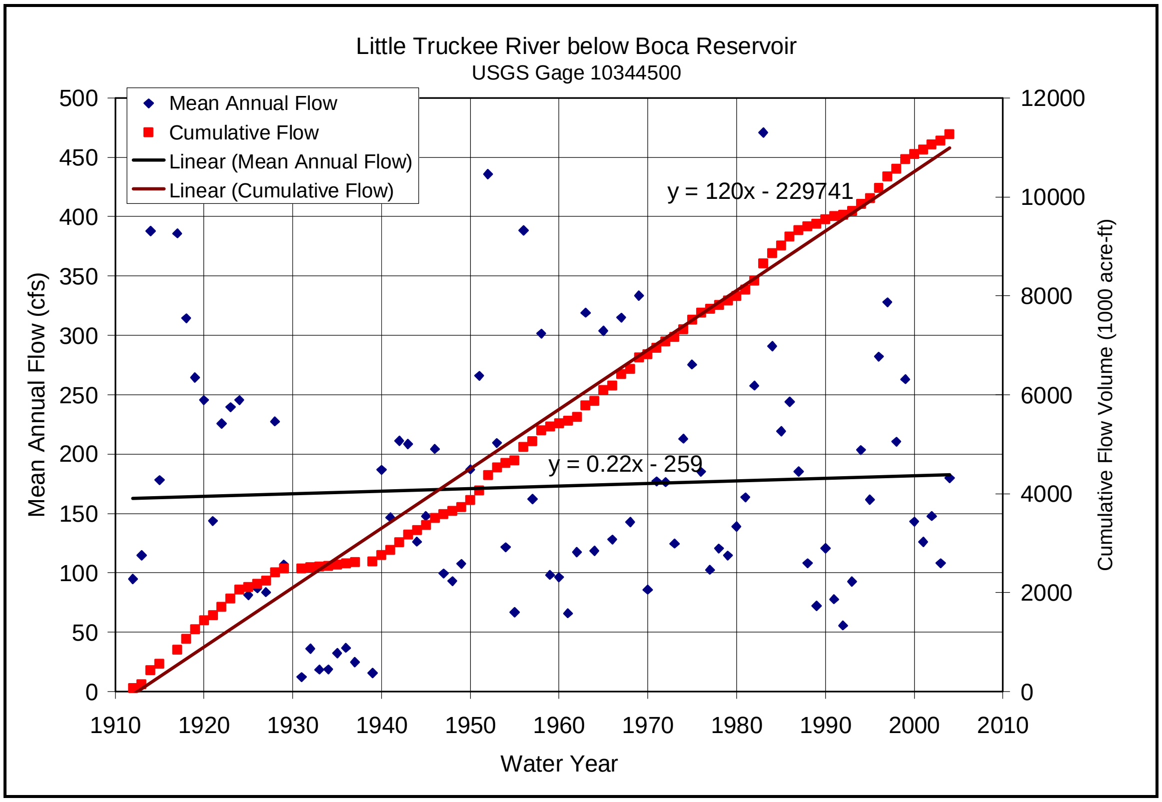


Figure D31. Little Truckee River below Boca Reservoir annual streamflow.

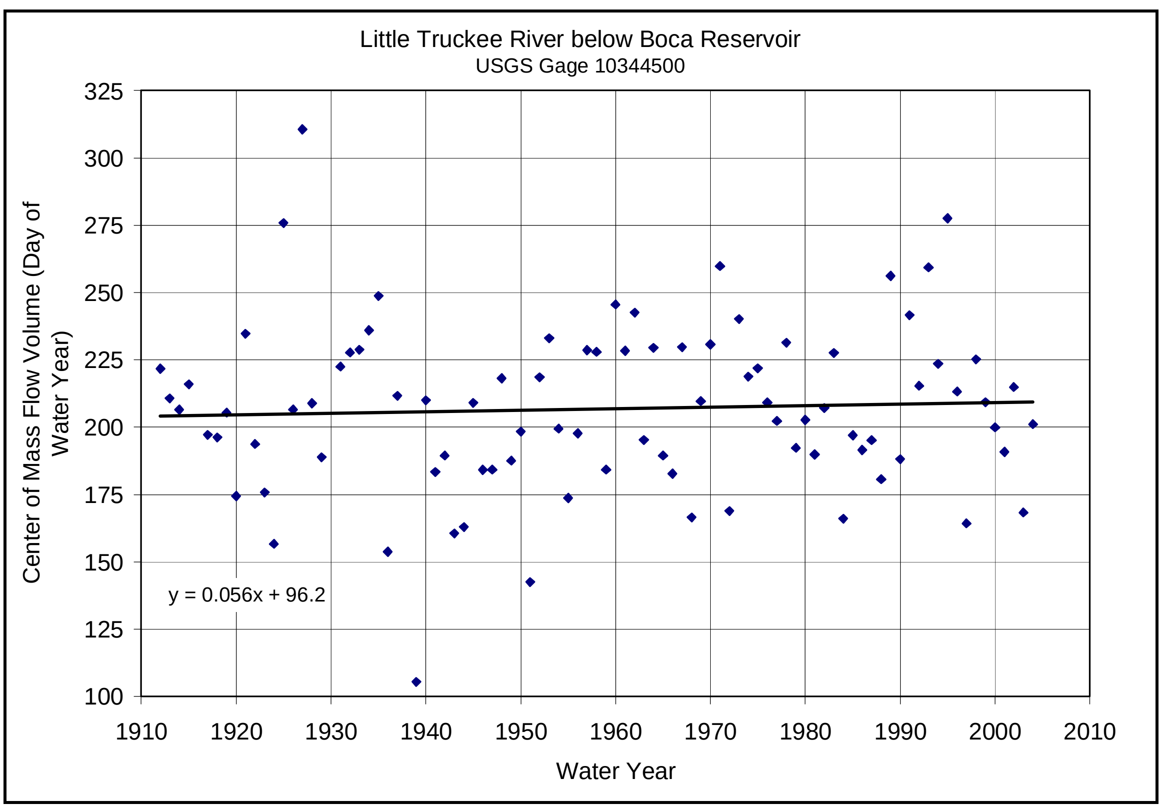


Figure D32. Little Truckee River below Boca Reservoir streamflow center of mass.

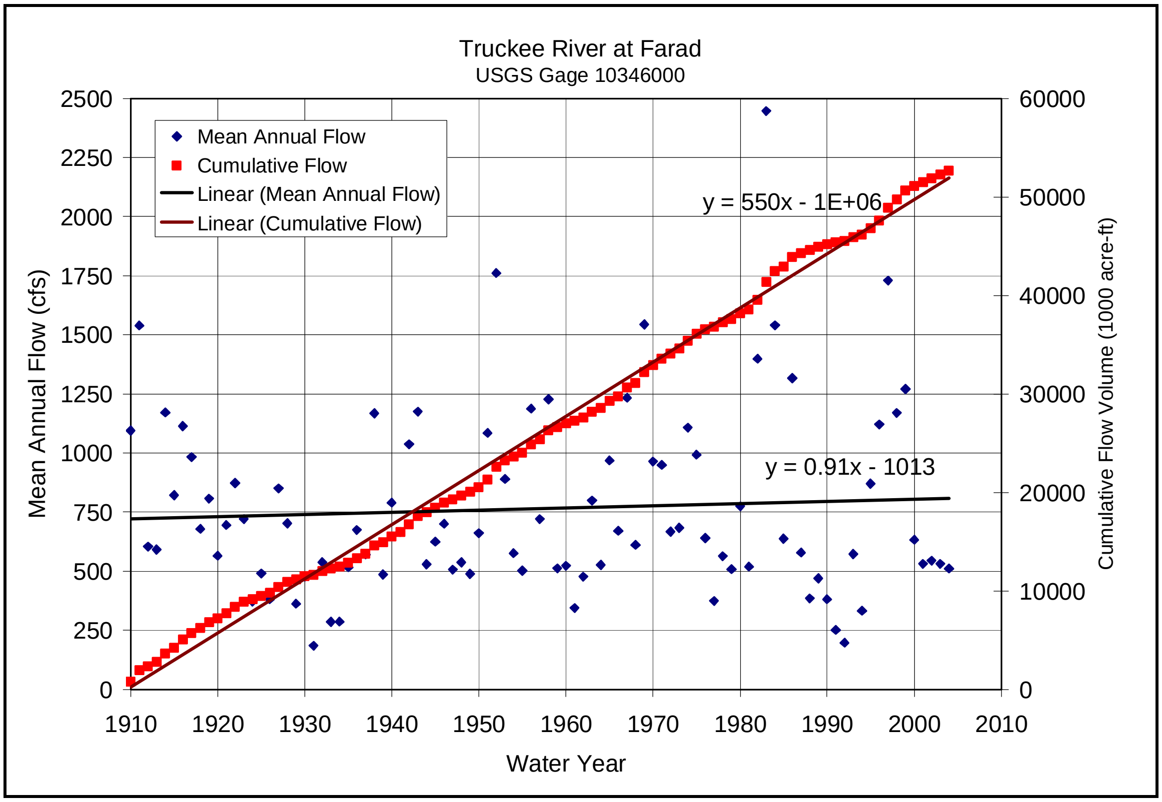


Figure D33. Truckee River at Farad annual streamflow.

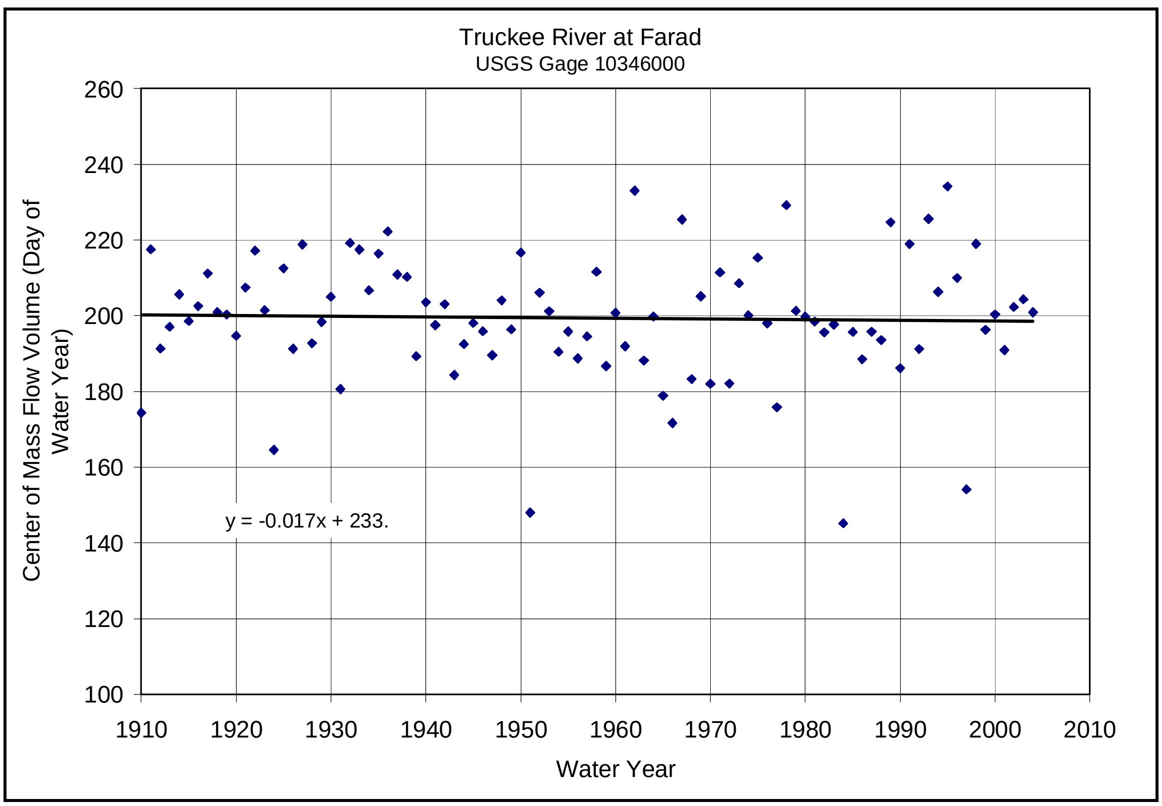


Figure D34. Truckee River at Farad streamflow center of mass.

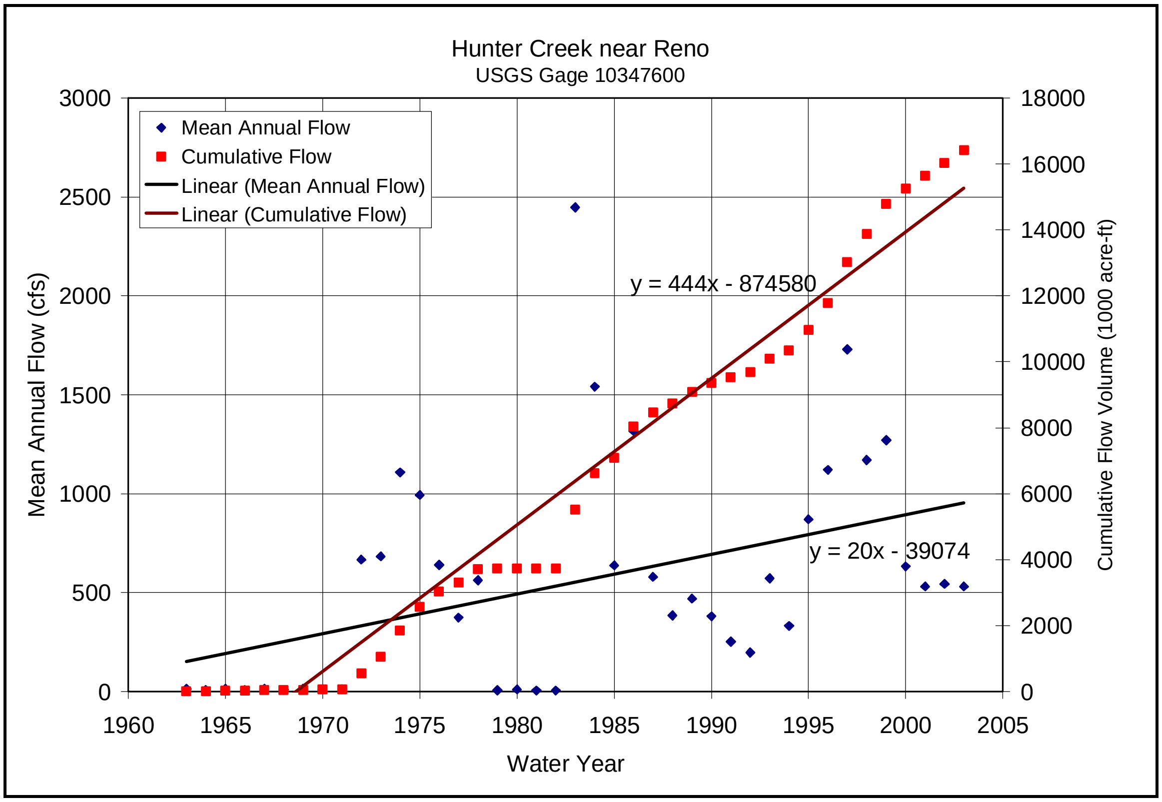


Figure D35. Hunter Creek near Reno annual streamflow.

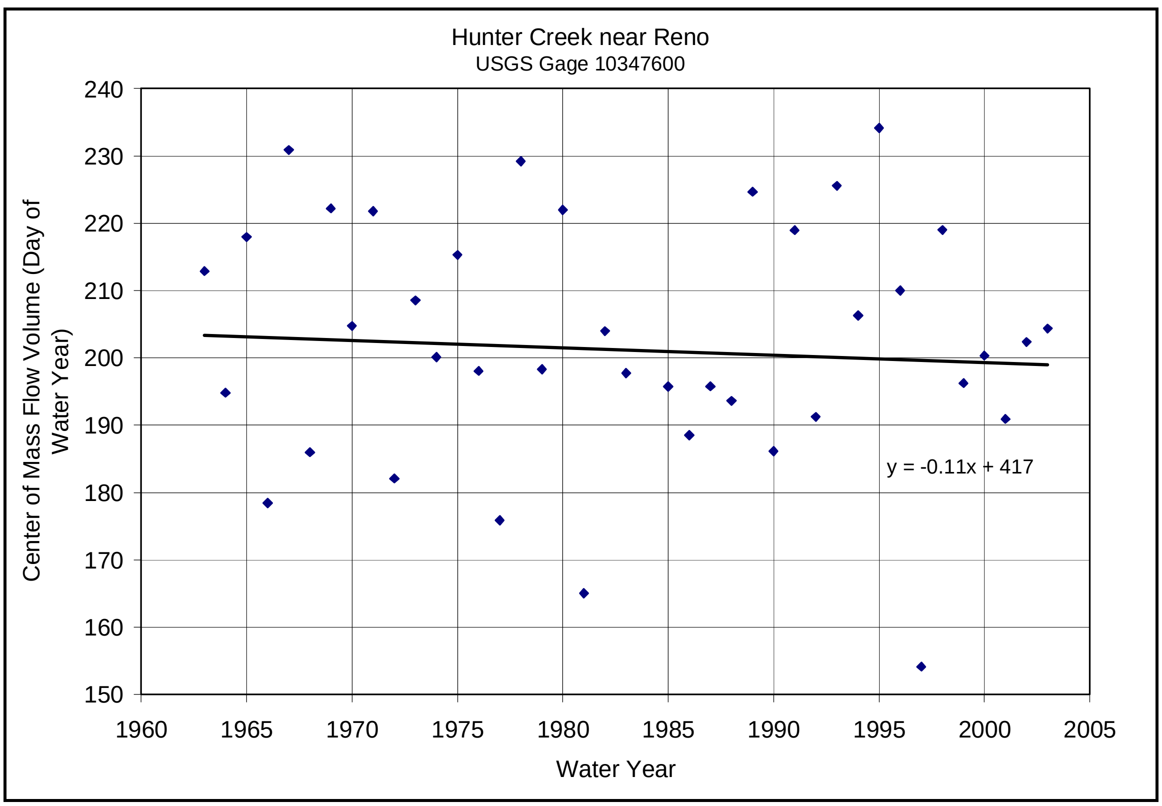


Figure D36. Hunter Creek near Reno streamflow center of mass.

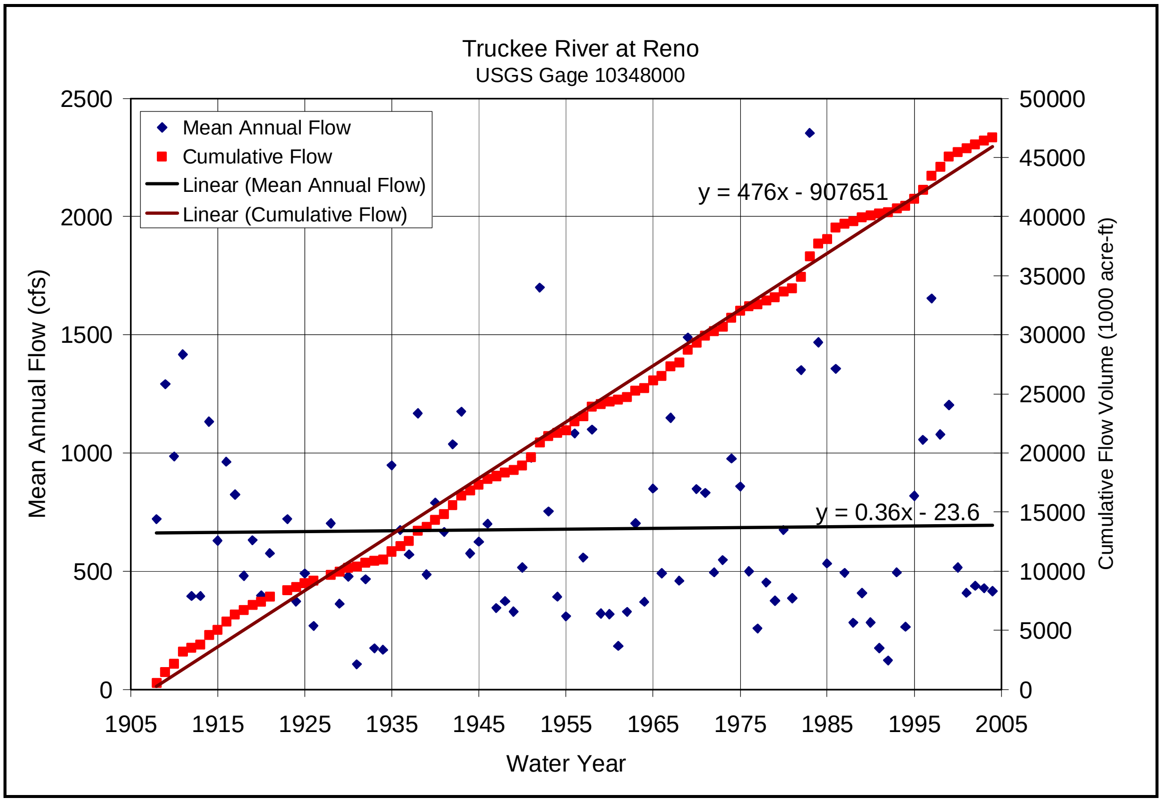


Figure D37. Truckee River at Reno annual streamflow.

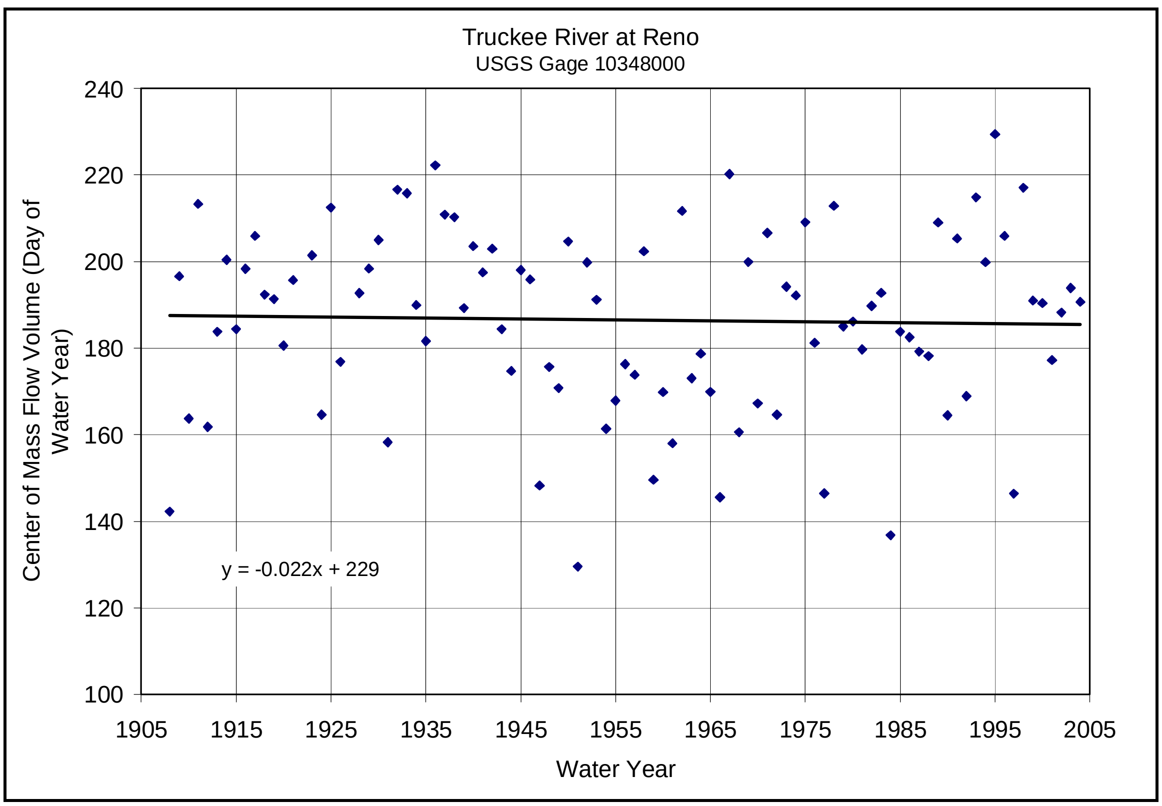


Figure D38. Truckee River at Reno streamflow center of mass.

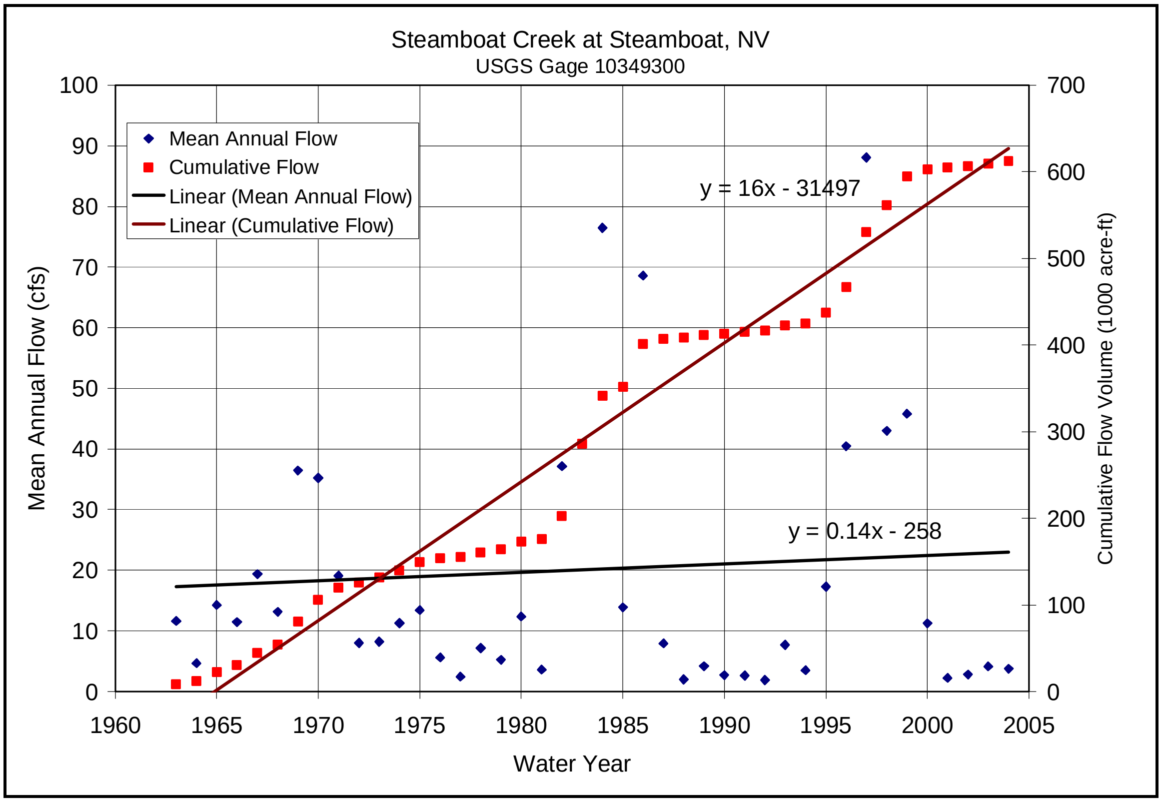


Figure D39. Steamboat Creek at Steamboat, NV annual streamflow.

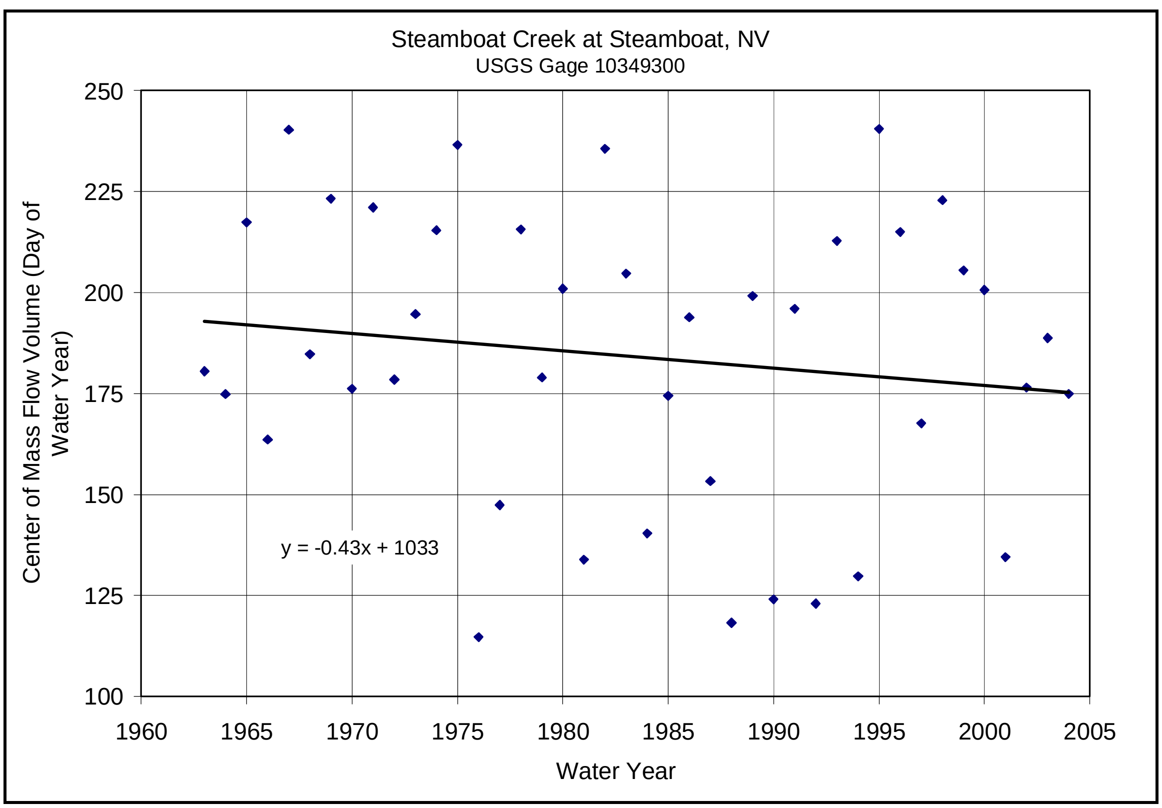


Figure D40. Steamboat Creek at Steamboat, NV streamflow center of mass.

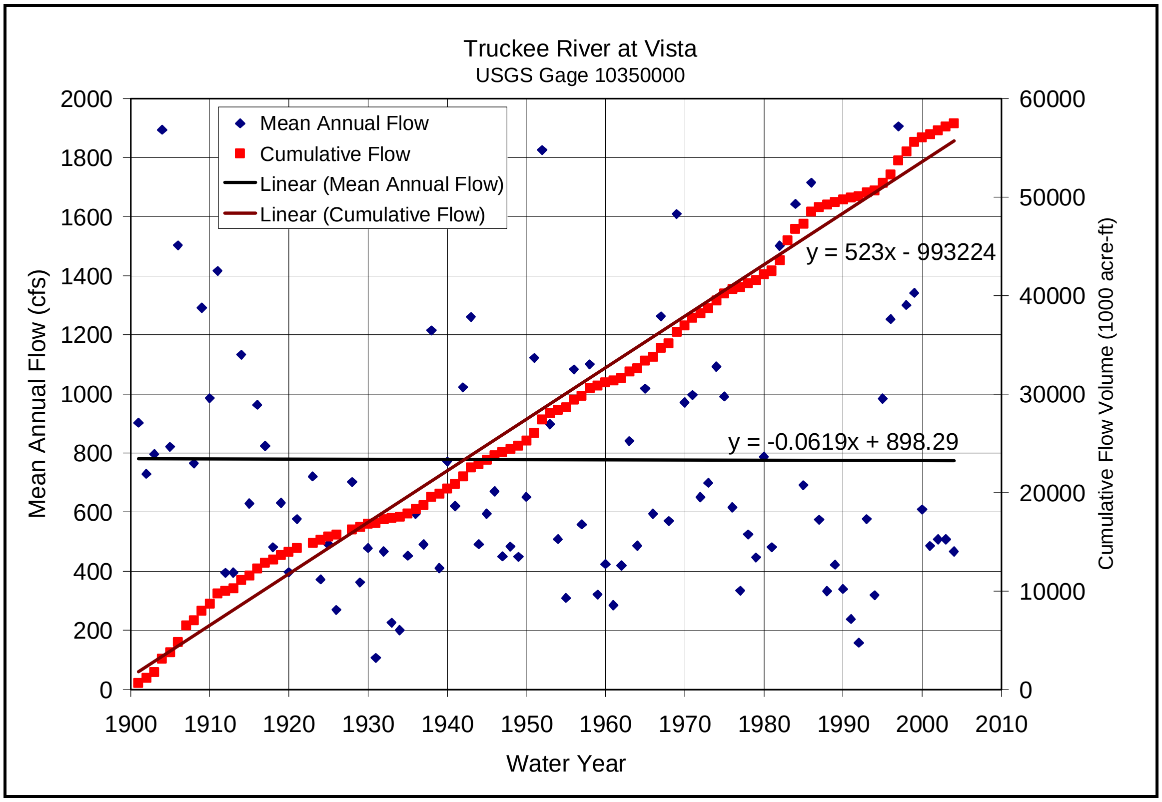


Figure D41. Truckee River at Vista annual streamflow.

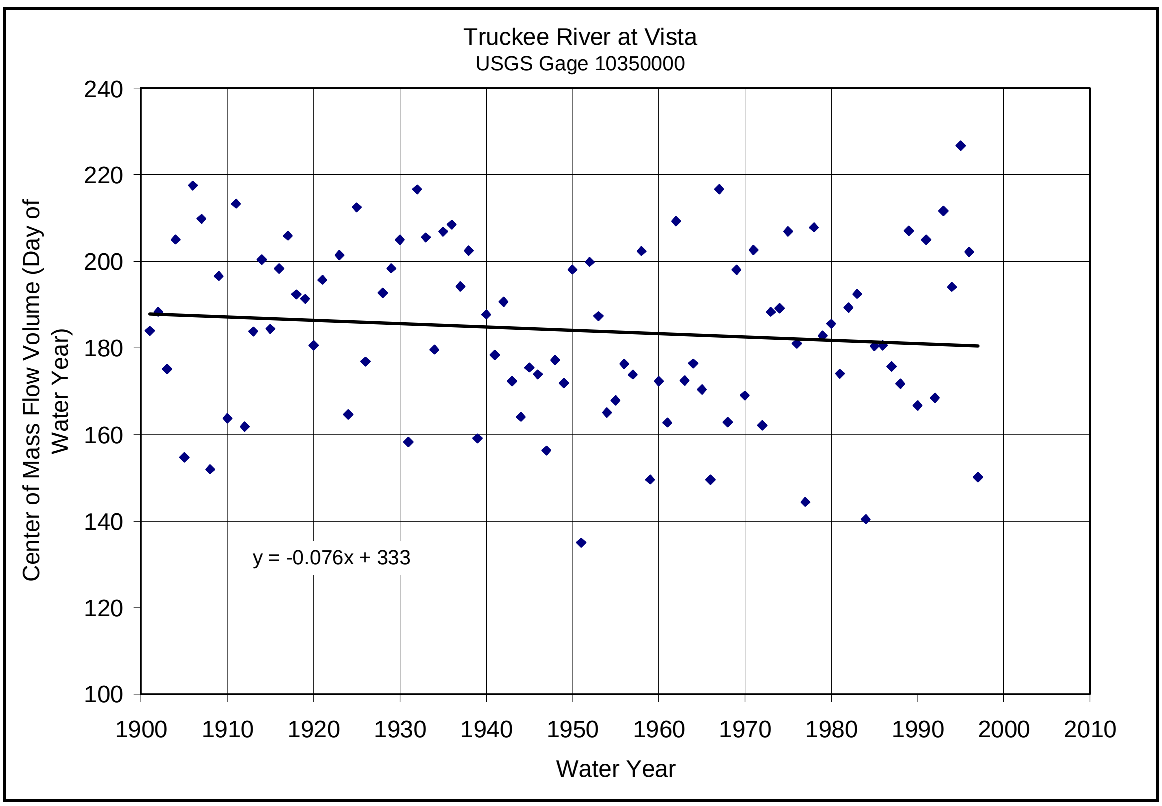


Figure D42. Truckee River at Vista streamflow center of mass.

Appendix E

Reservoir Volumes

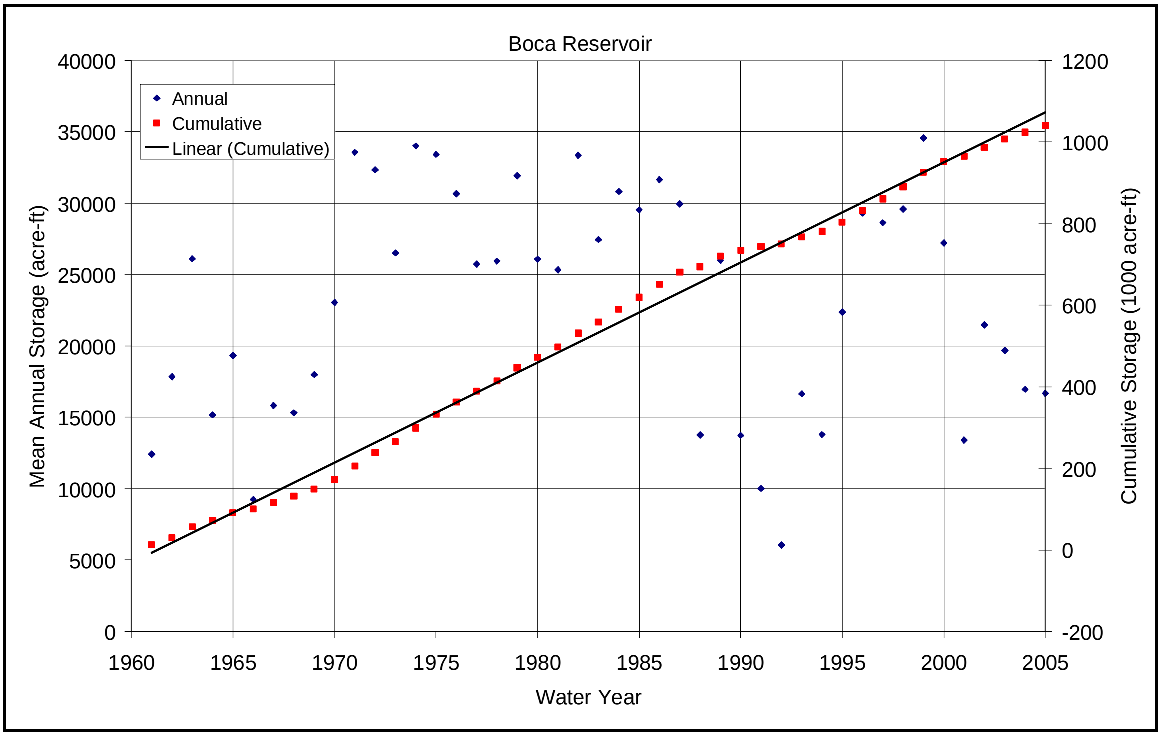


Figure E1. Mean annual storage and cumulative storage for Boca Reservoir.

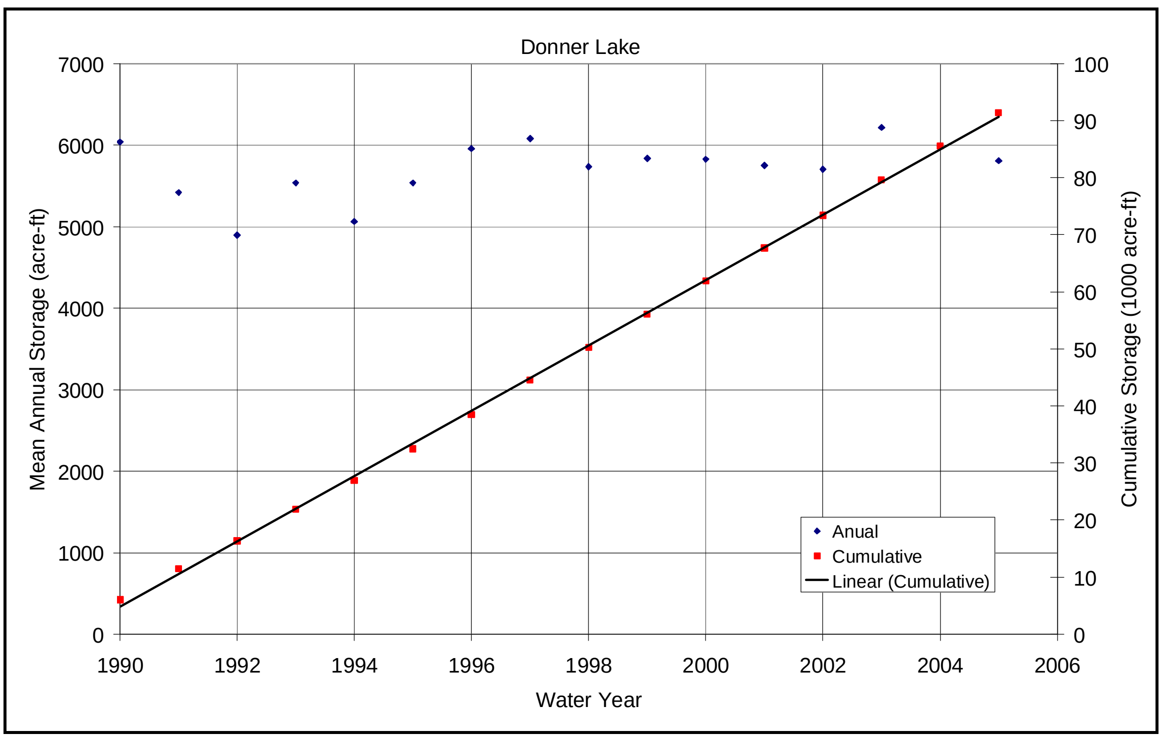


Figure E2. Mean annual storage and cumulative storage for Donner Lake.

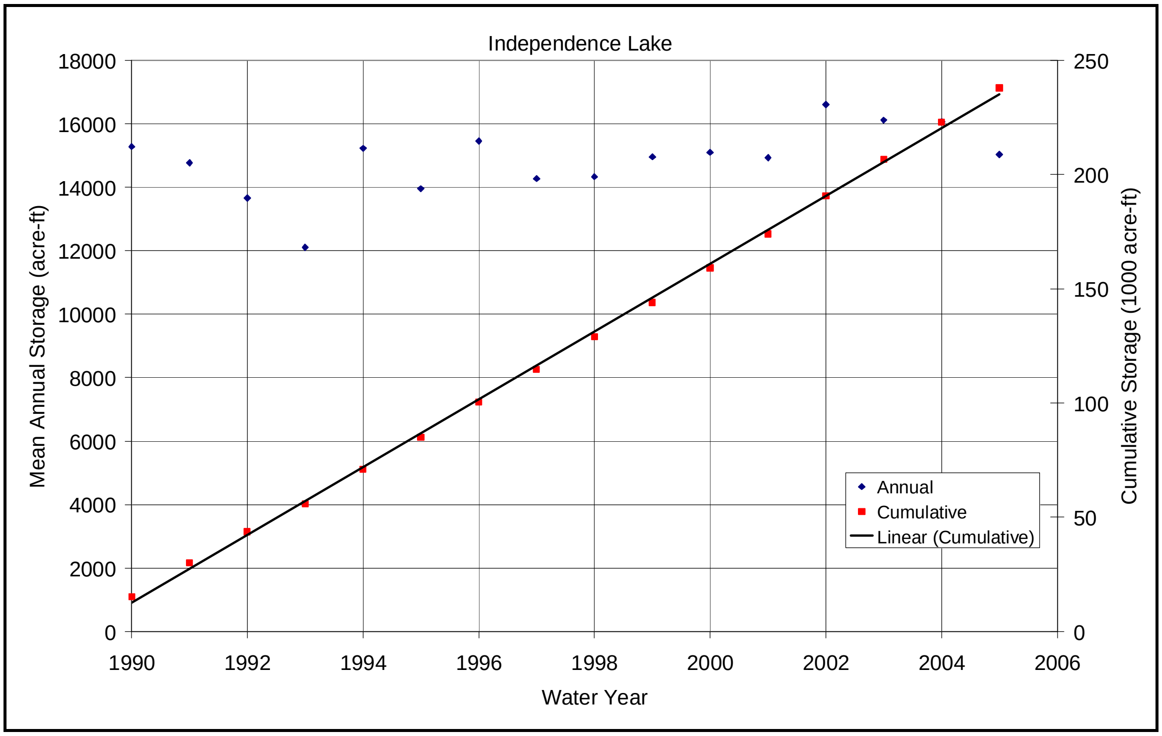


Figure E3. Mean annual storage and cumulative storage for Independence Lake.

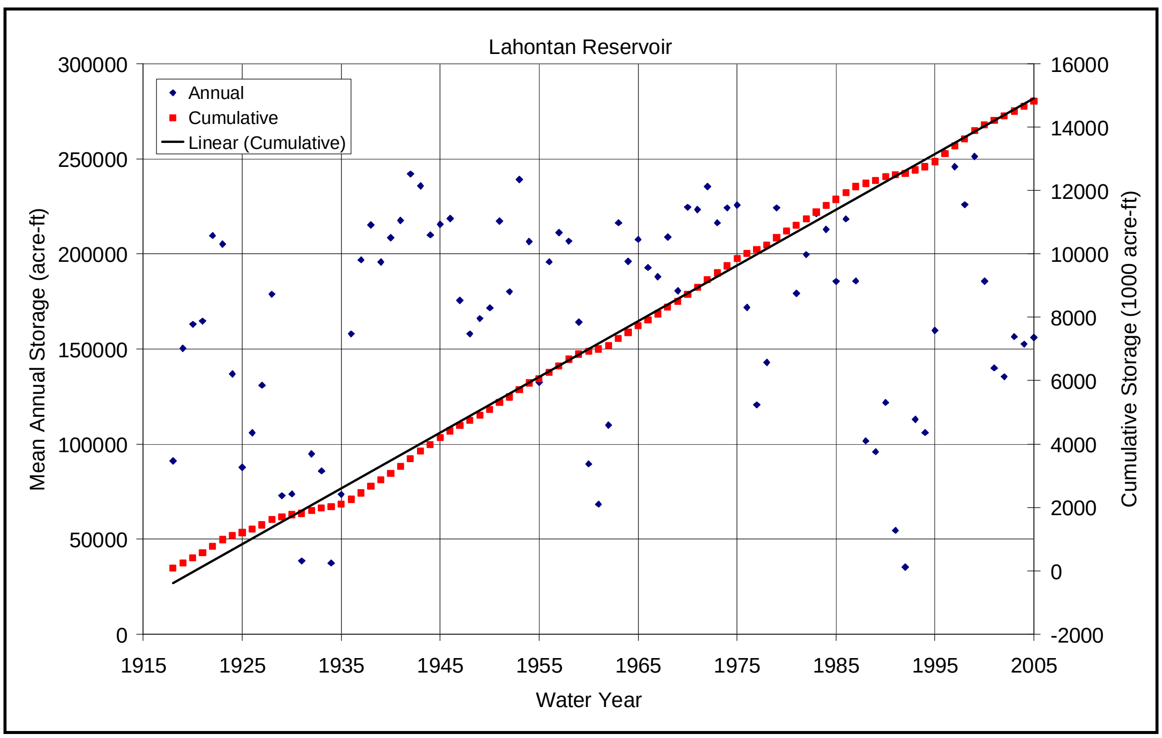


Figure E4. Mean annual storage and cumulative storage for Lahontan Reservoir.

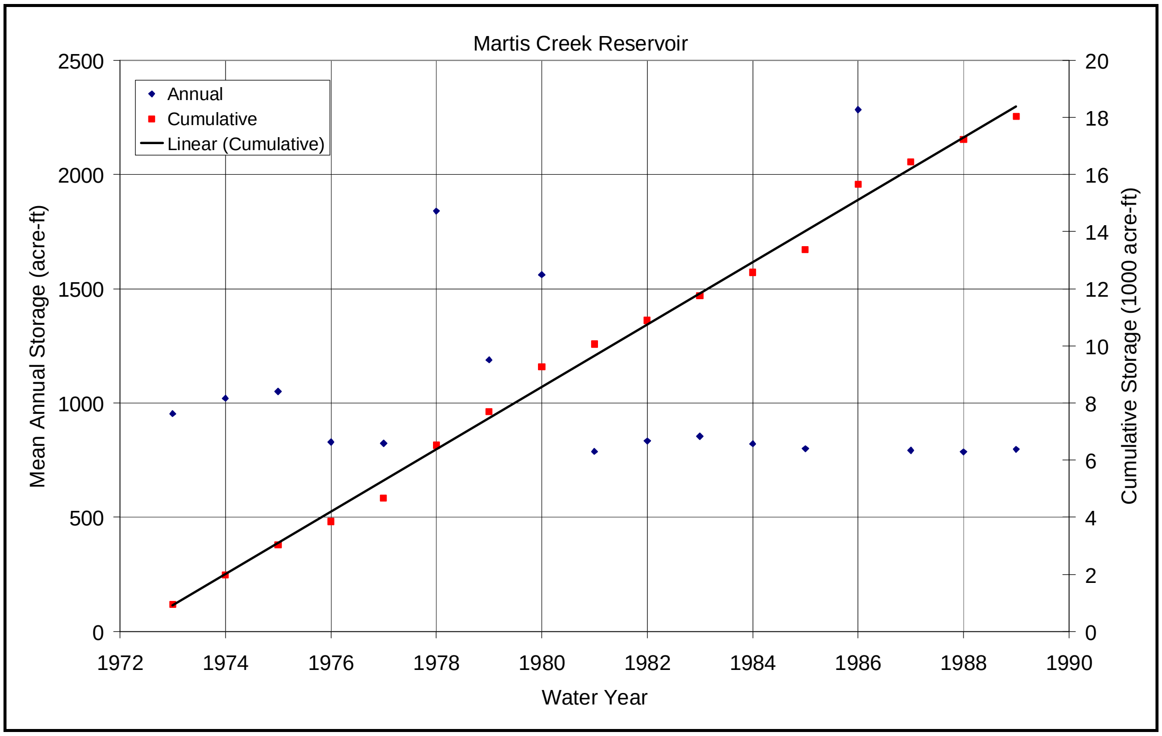


Figure E5. Mean annual storage and cumulative storage for Martis Creek Reservoir.

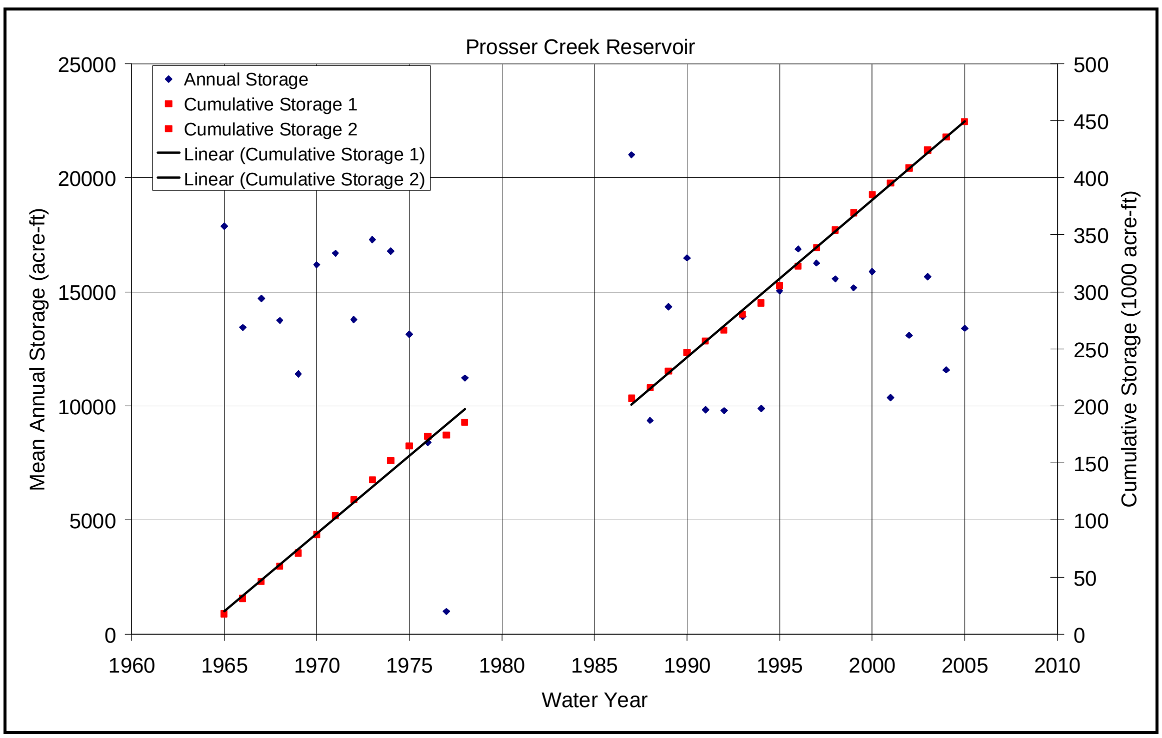


Figure E6. Mean annual storage and cumulative storage for Prosser Creek Reservoir.

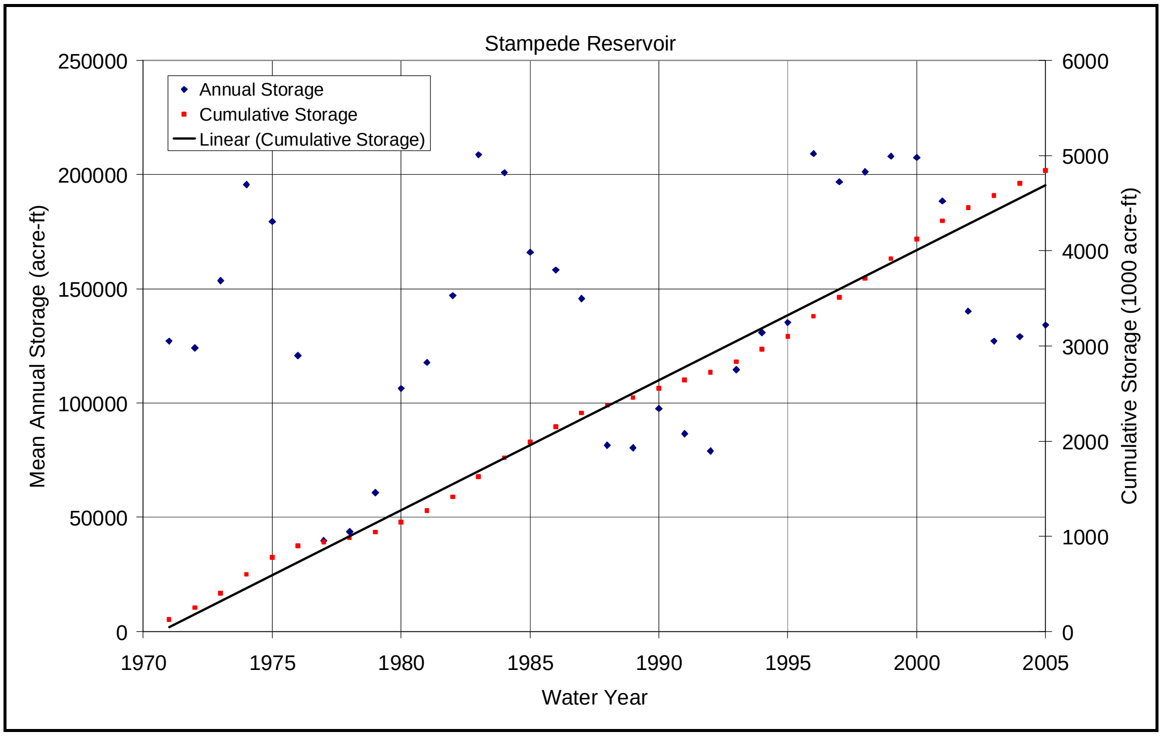


Figure E7. Mean annual storage and cumulative storage for Stampede Reservoir.

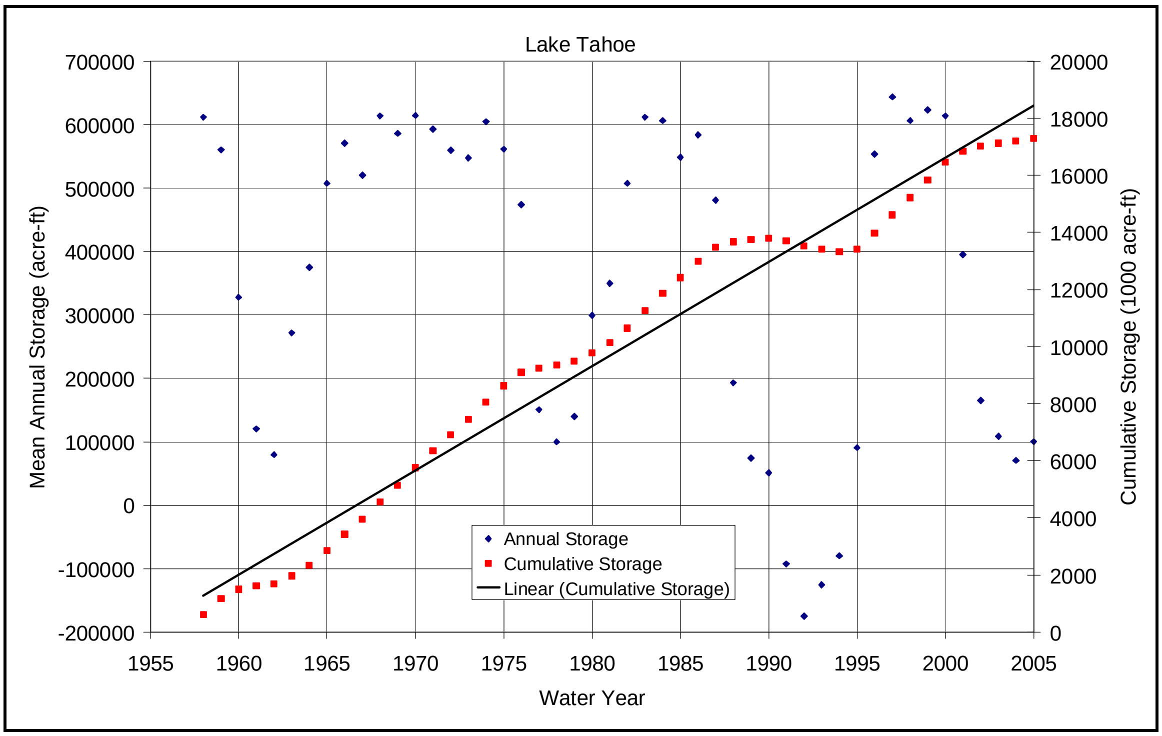


Figure E8. Mean annual storage and cumulative storage for Lake Tahoe.

Appendix F

Double Mass Curve Analysis
Precipitation and Snowpack

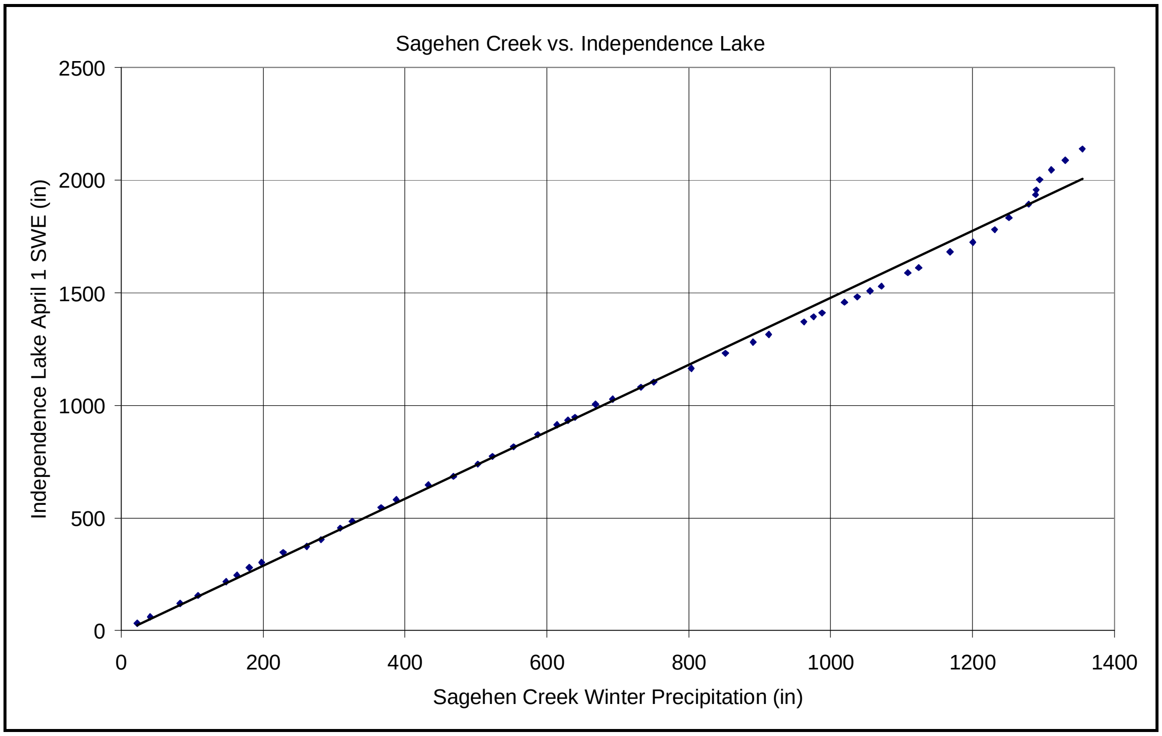


Figure F1. Double mass curve for Independence Lake snowcourse station April 1 SWE and Sagehen Creek winter precipitation.

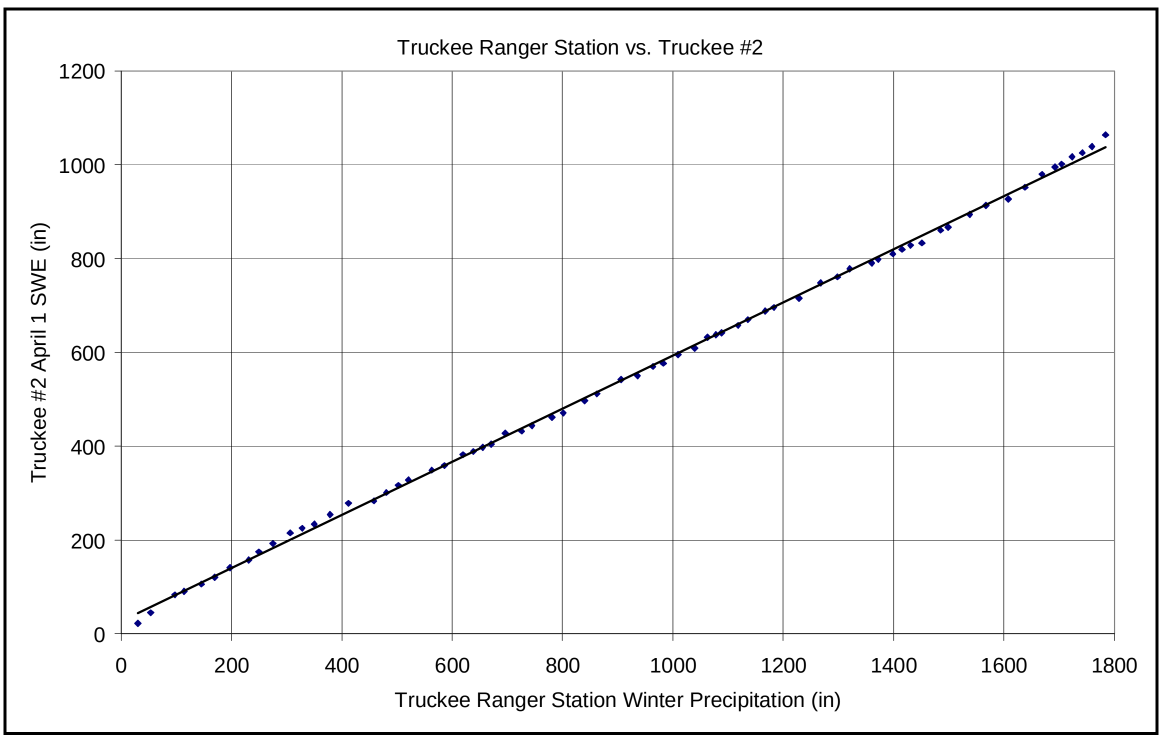


Figure F2. Double mass curve for Truckee #2 snowcourse station April 1 SWE and Truckee Ranger Station winter precipitation.

Appendix G

Double Mass Curve Analysis
Precipitation vs. Streamflow

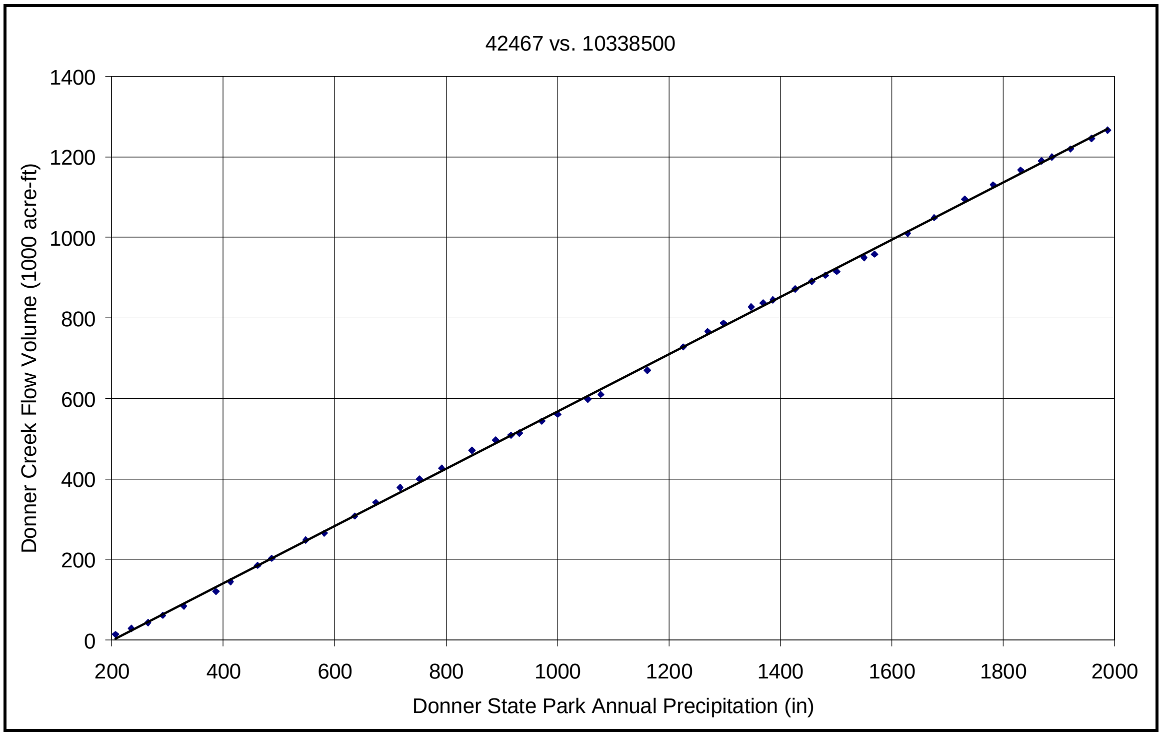


Figure G1. Double mass curve for streamflow volume for Donner Creek and annual precipitation at Donner State Park.

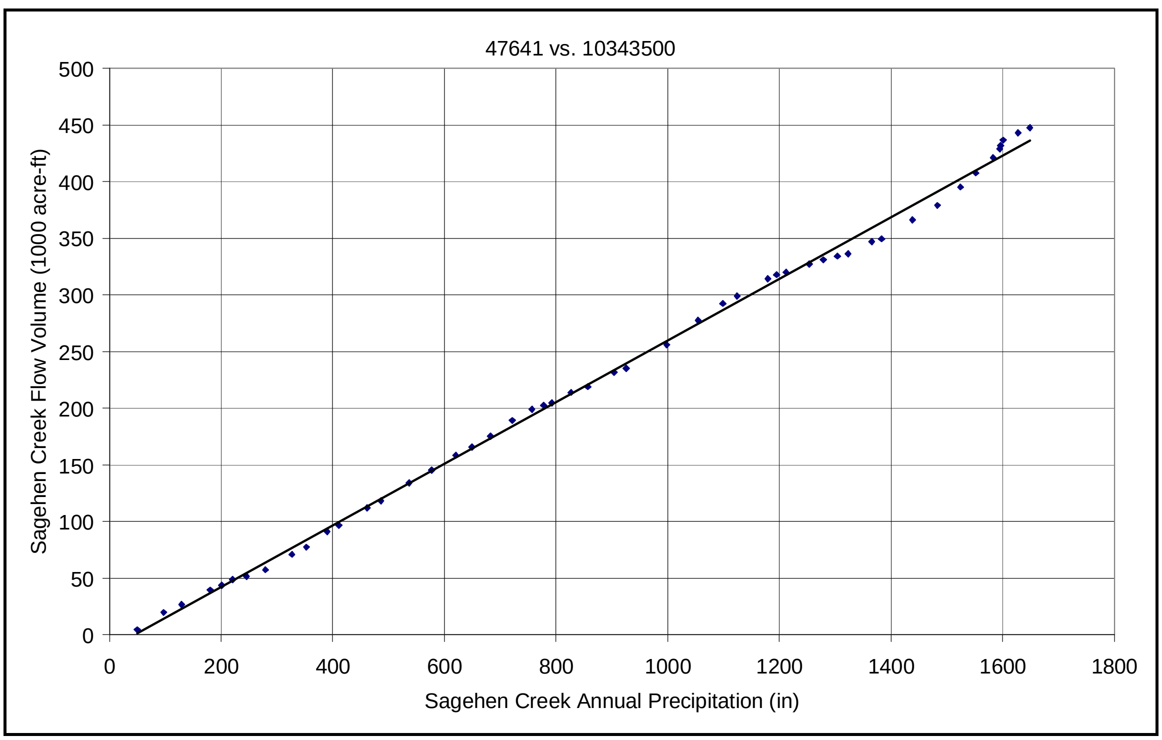


Figure G2. Double mass curve for Sagehen Creek streamflow volume and annual precipitation at the Sagehen weather station.

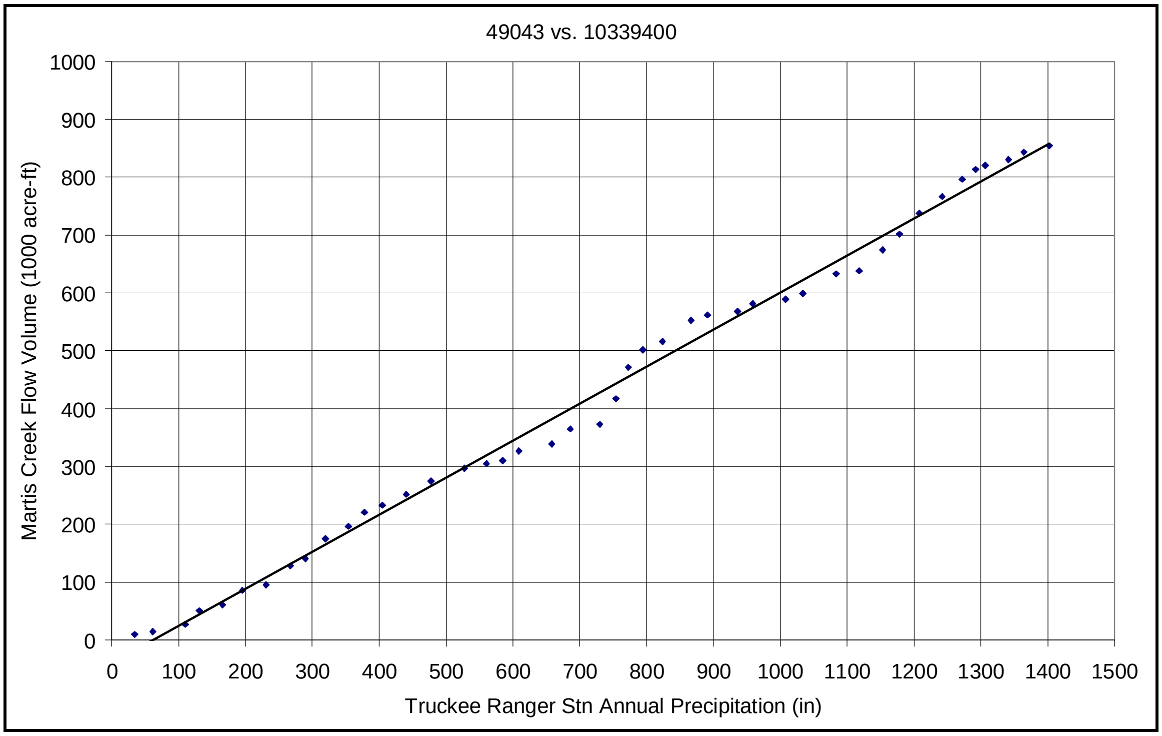


Figure G3. Double mass curve for Martis Creek streamflow volume and annual precipitation at the Truckee Ranger Station.

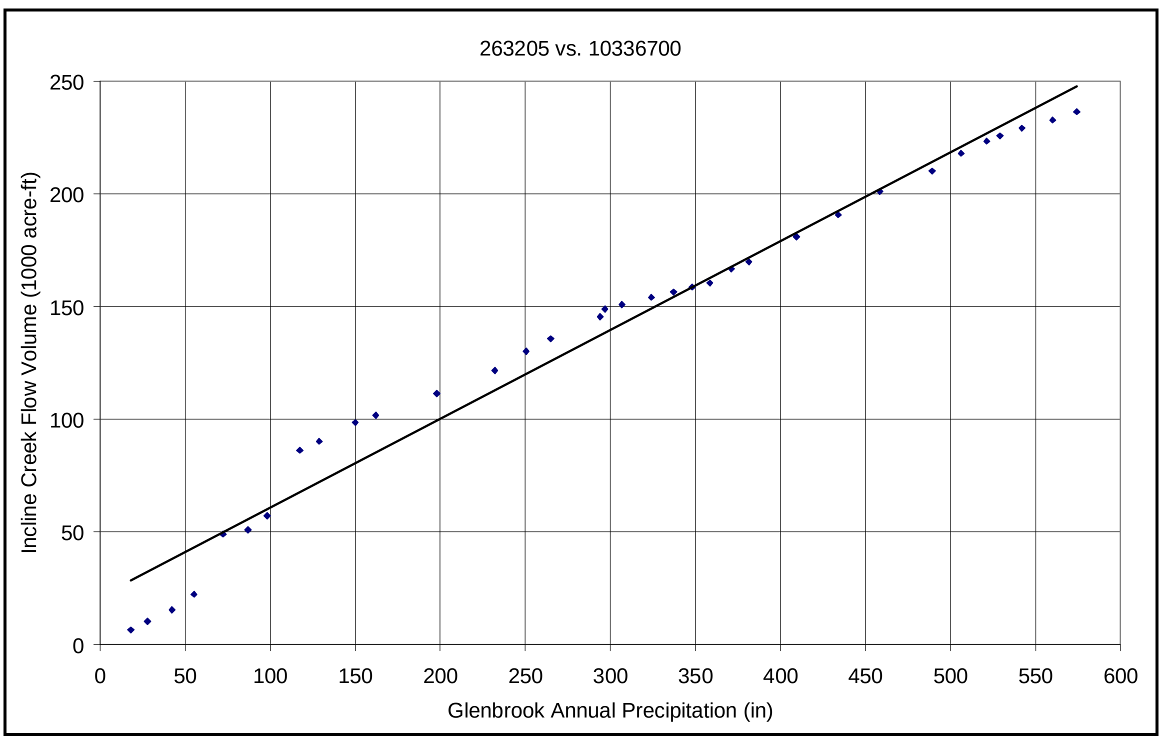


Figure G4. Double mass curve for Incline Creek streamflow volume and annual precipitation at the Glenbrook weather station.

Appendix H

Double Mass Curve Analysis
Precipitation vs. Reservoir Volumes

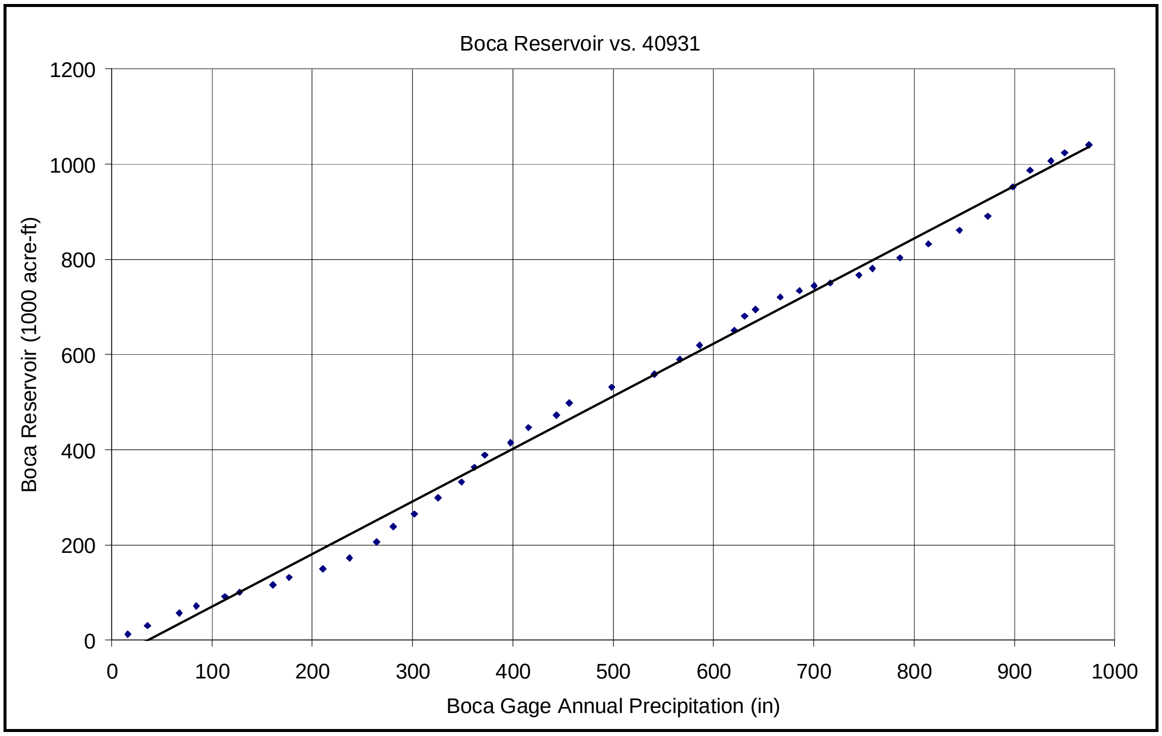


Figure H1. Double mass curve of Boca Reservoir storage and Boca annual precipitation.

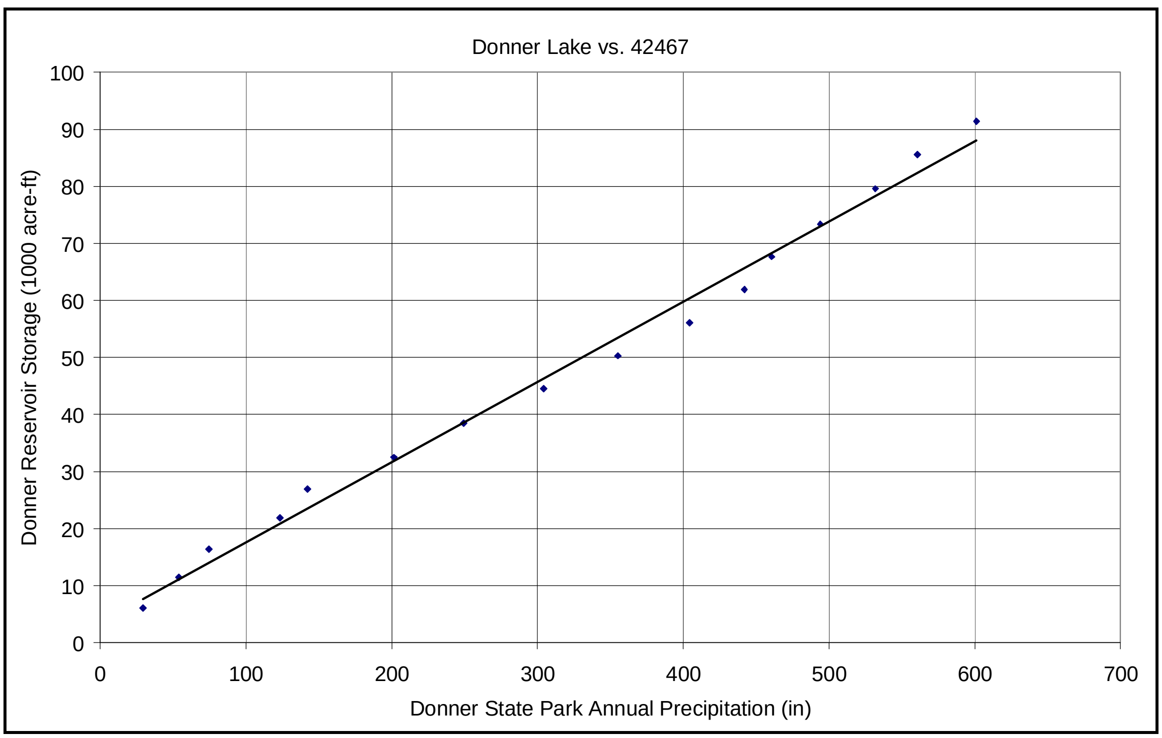


Figure H2. Double mass curve of Donner Lake storage and Donner State Park annual precipitation.

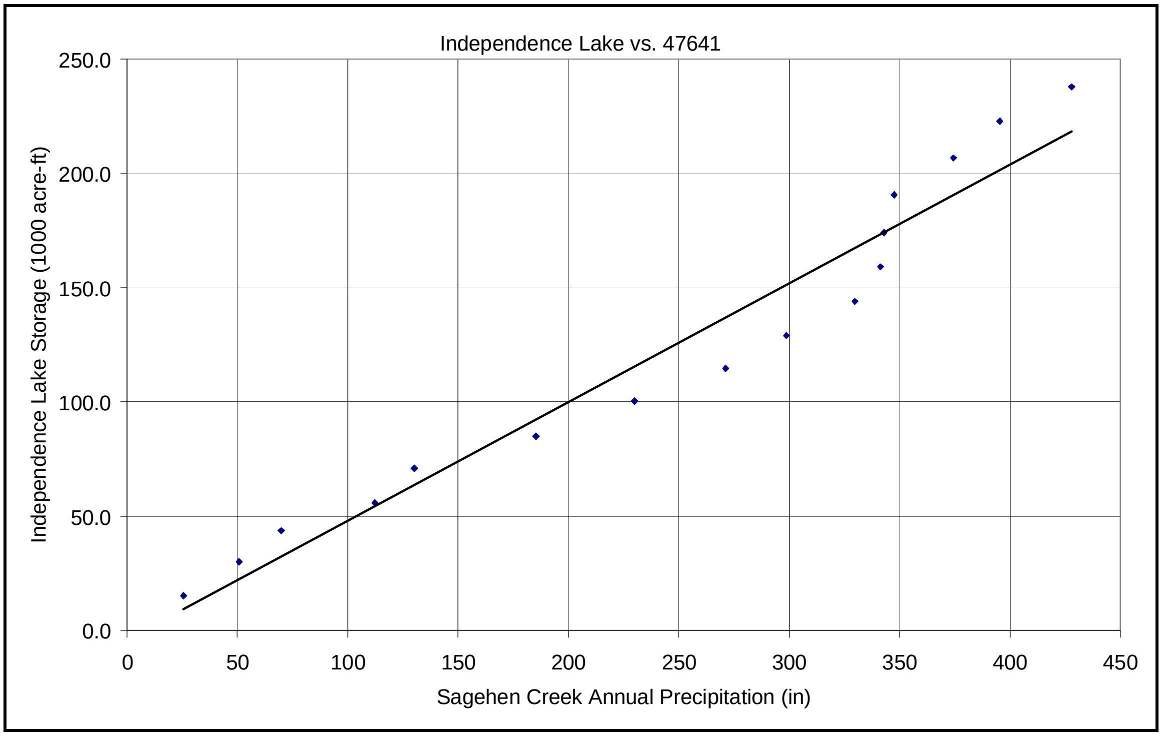


Figure H3. Double mass curve of Independence storage and Sagehen Creek annual precipitation.

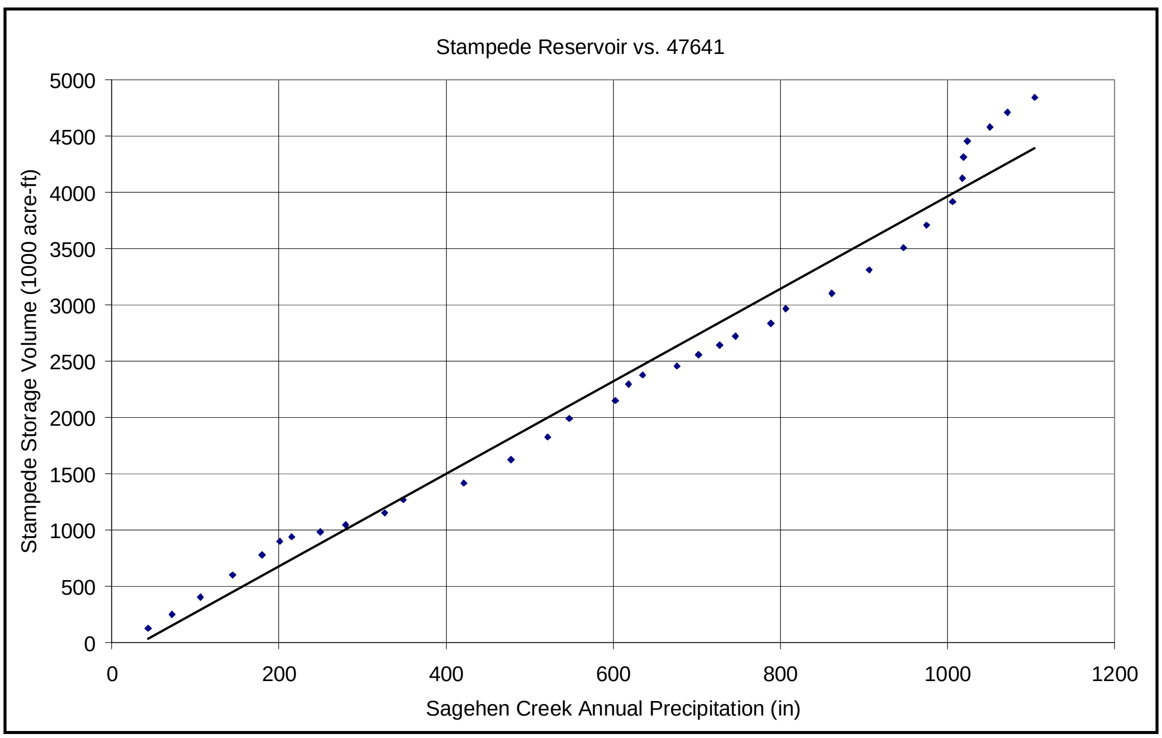


Figure H4. Double mass curve of Stampede Reservoir storage and Sagehen Creek annual precipitation.

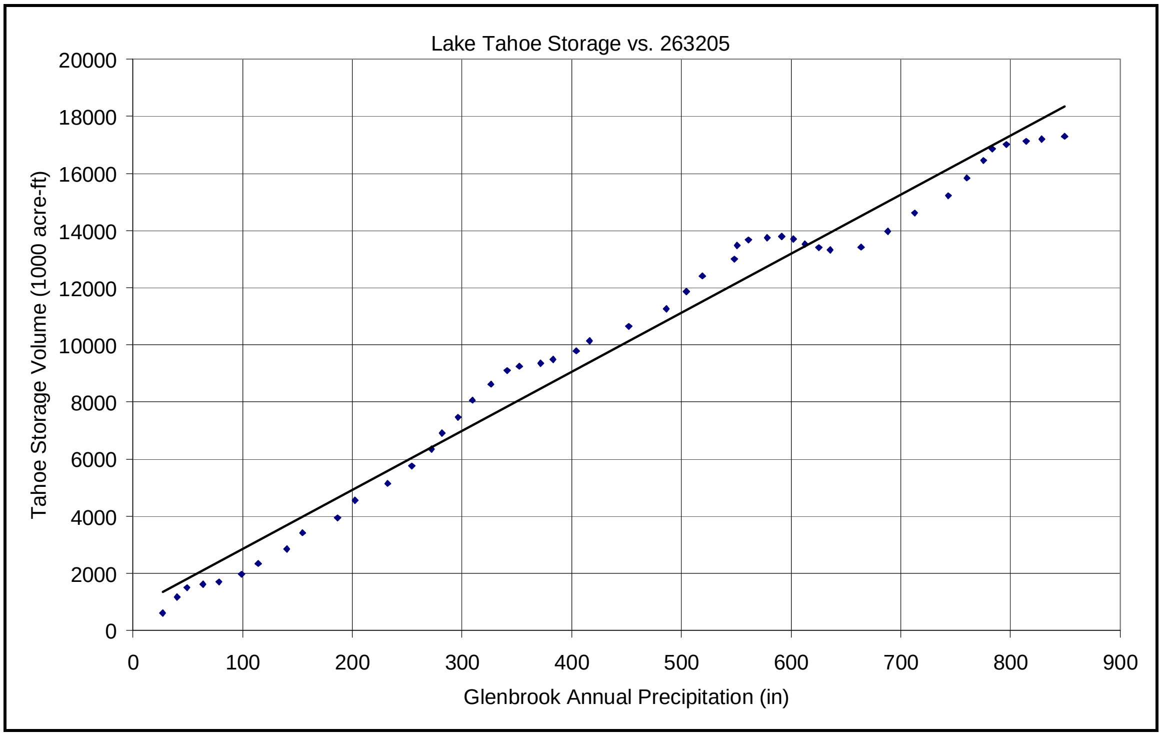


Figure H5. Double mass curve of Lake Tahoe storage and Glenbrook gage annual precipitation.

Appendix I

Double Mass Curve Analysis
Streamflow vs. Snowpack

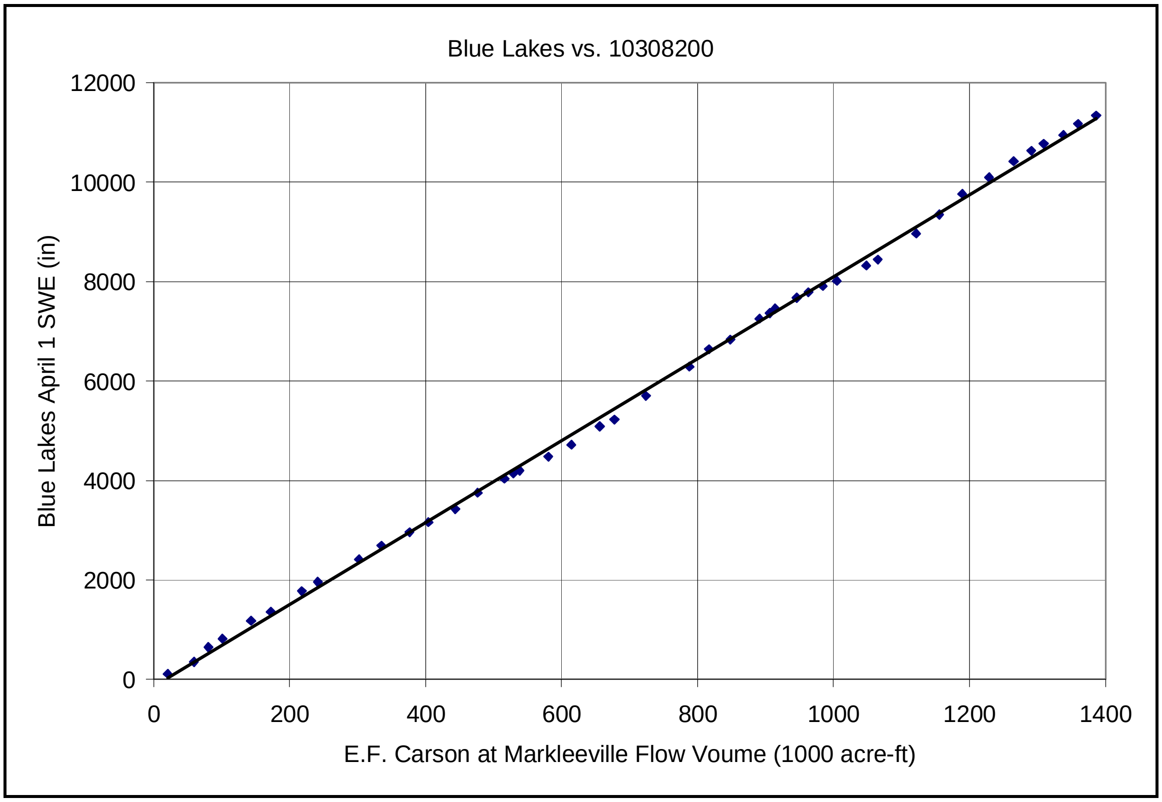


Figure I1. Blue Lakes SWE and streamflow in the E. Fork of the Carson at Markleevilles.

Figure I2. Hagan's Meadow SWE and Trout Creek streamflow volumes.

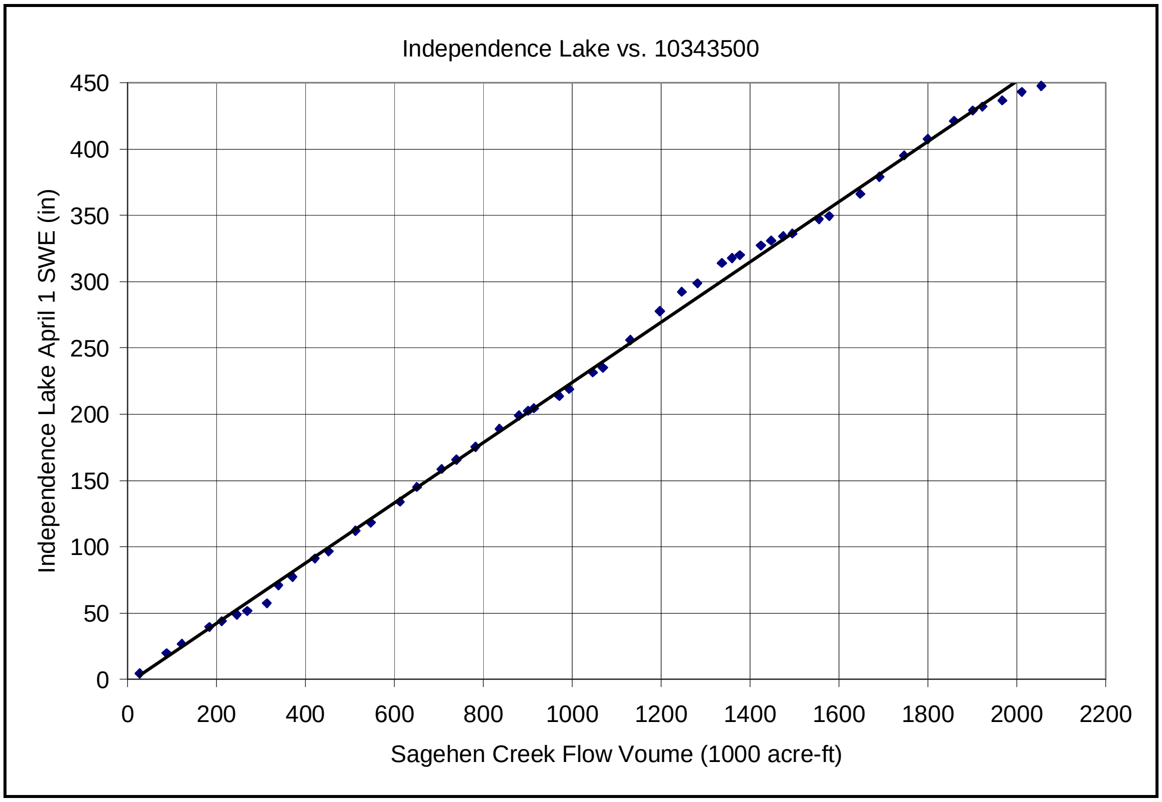


Figure I3. Independence Lake SWE and Sagehen Creek streamflow volumes.

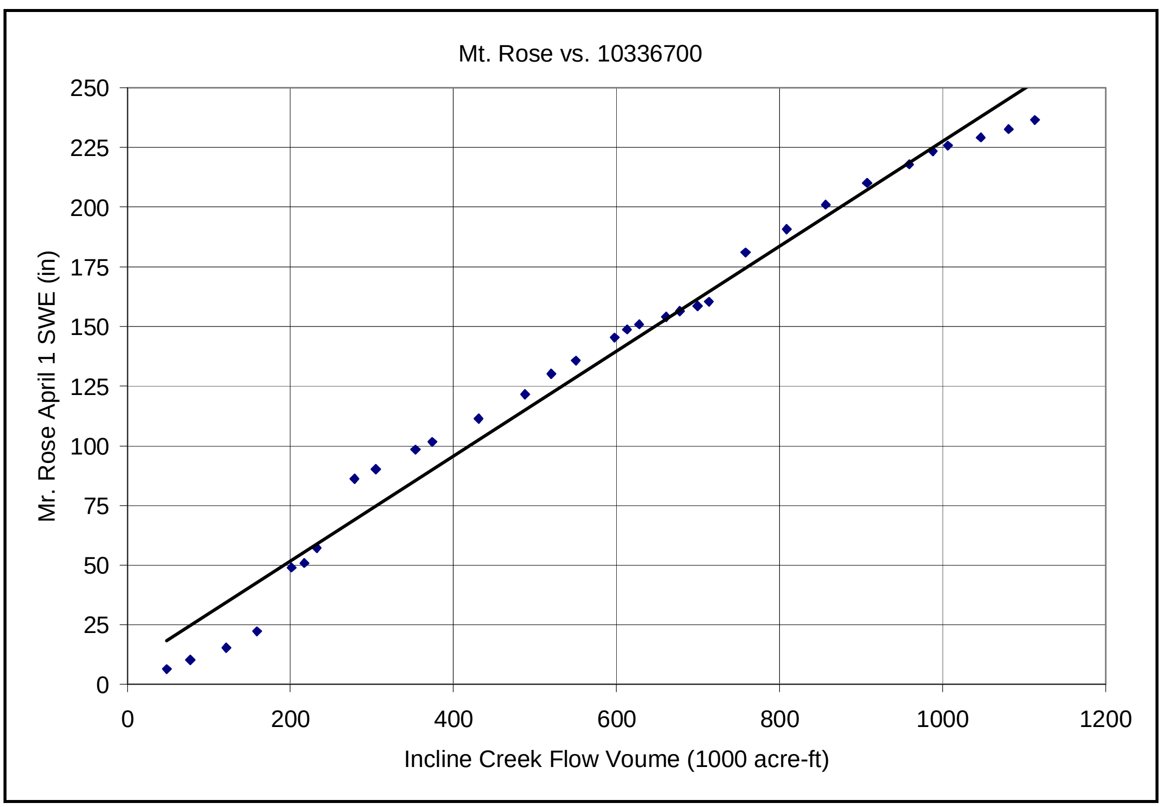


Figure I4. Mt. Rose SWE and Incline Creek streamflow volumes.

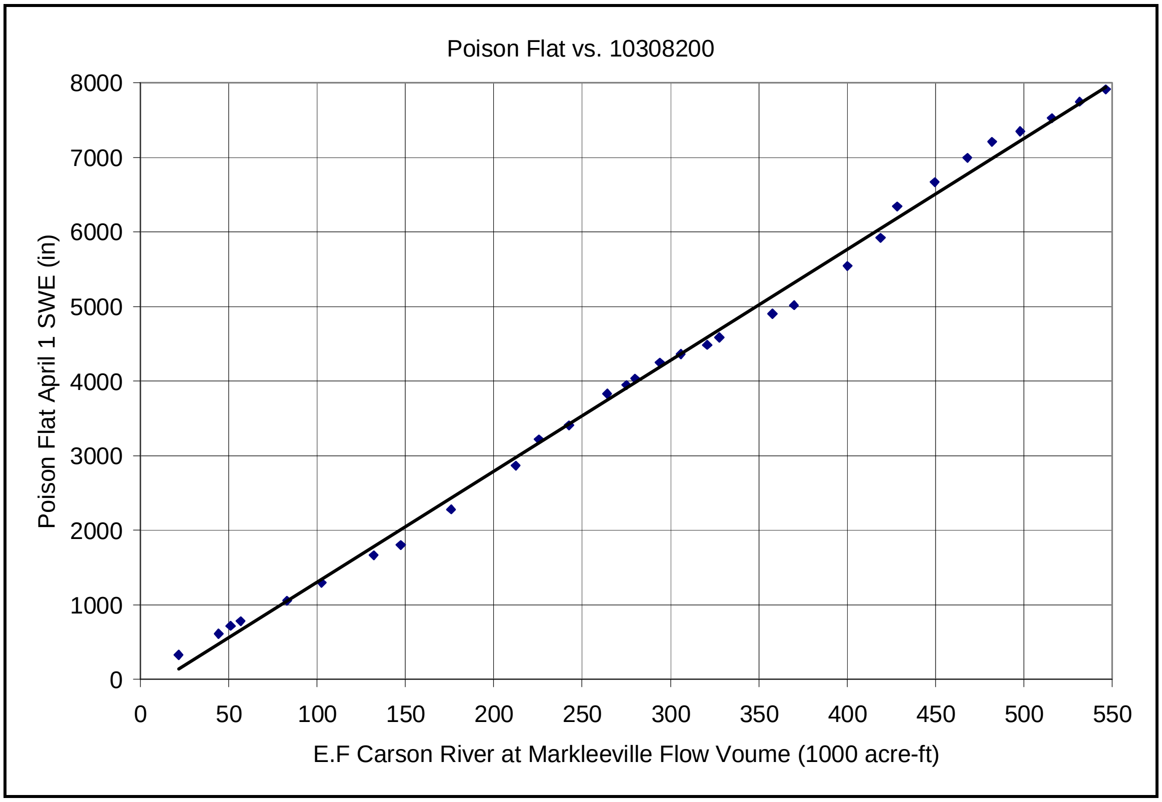


Figure I5. Poison Flat SWE and E.F Carson River at Markleeville streamflow volumes.

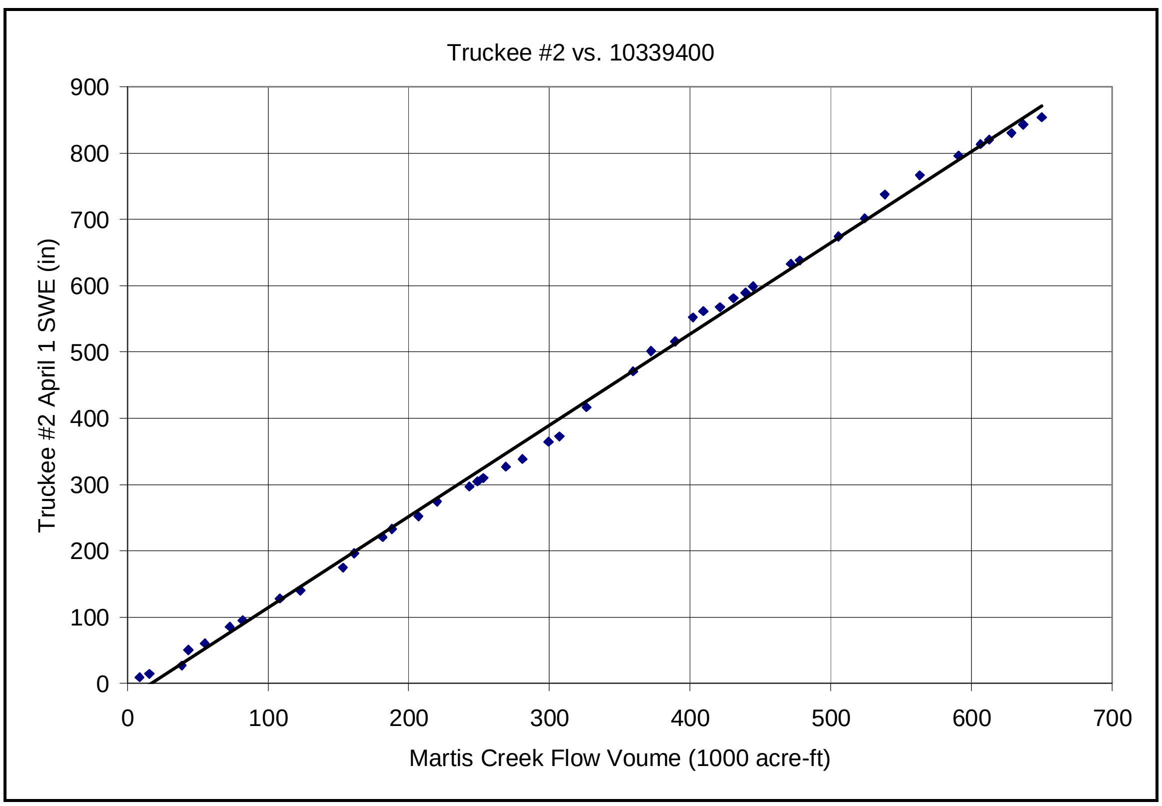


Figure I6. Truckee #2 SWE and Martis Creek streamflow volumes.

Appendix J

Double Mass Curve Analysis
Streamflow vs. Reservoir Volumes

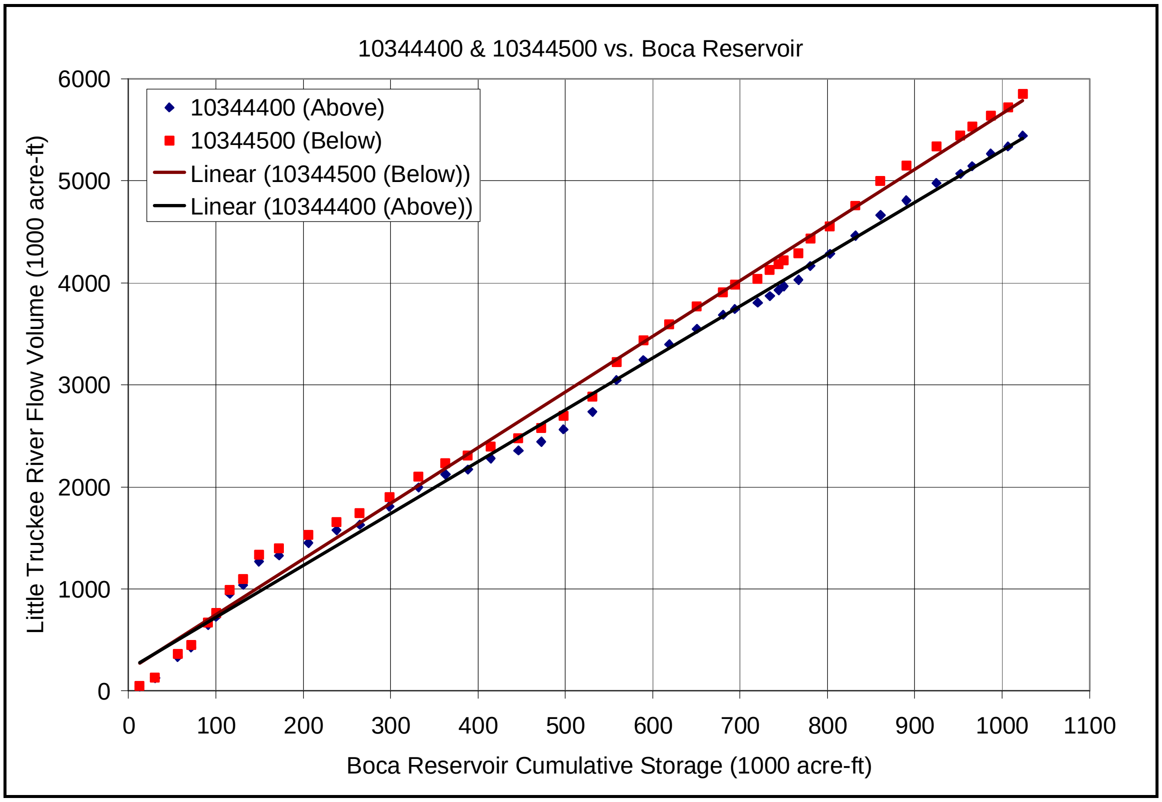


Figure J1. Little Truckee River streamflow volume and Boca Reservoir storage.

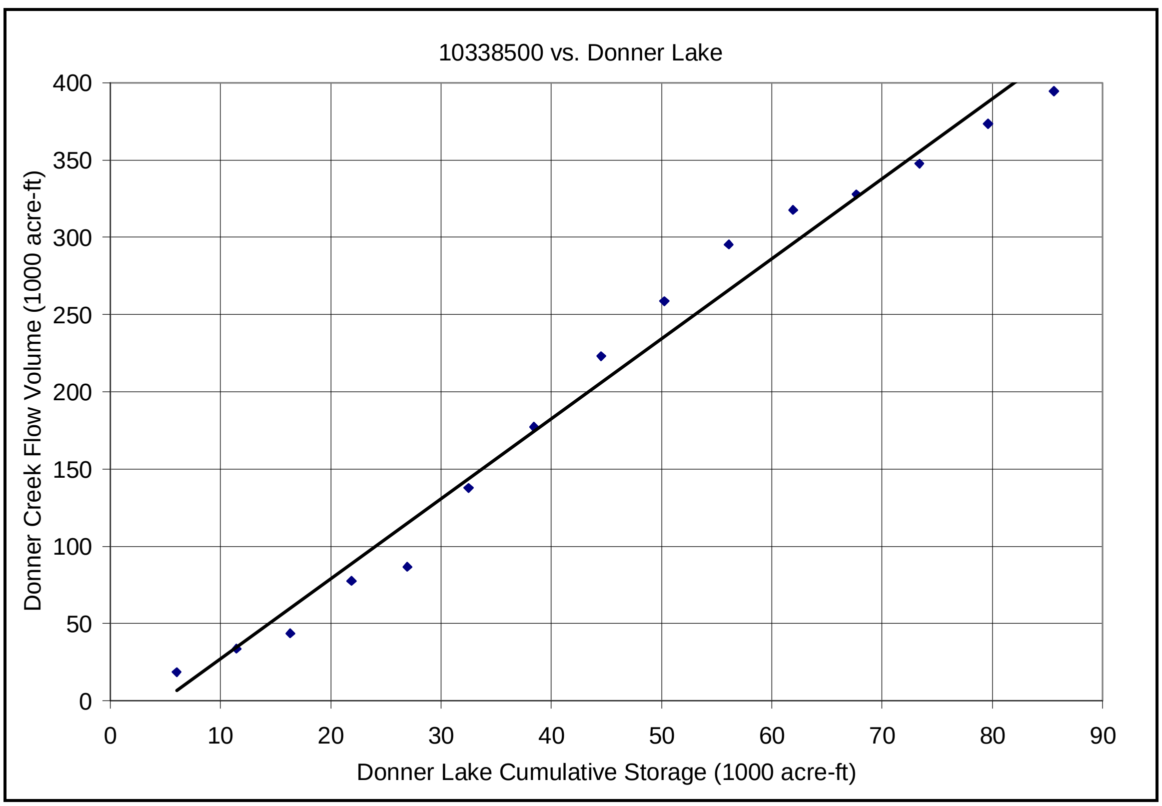


Figure J2. Donner Creek streamflow volume and Donner Lake storage.

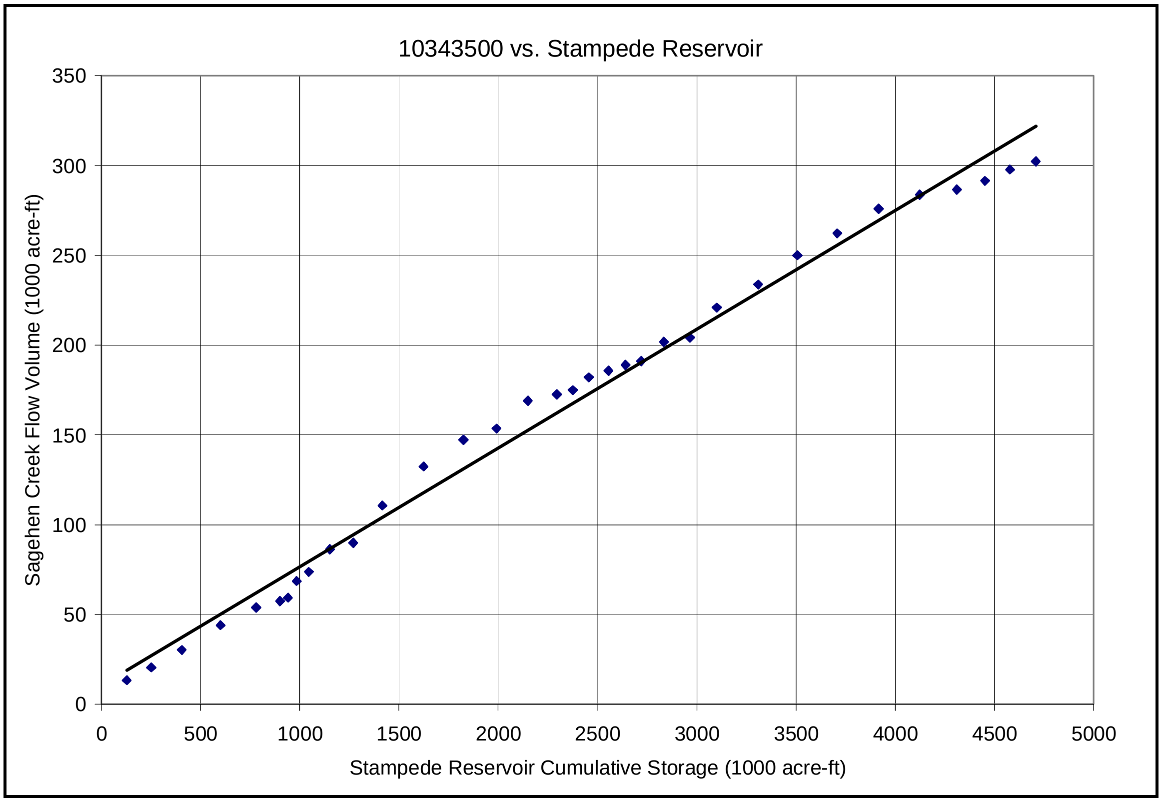


Figure J3. Sagehen Creek streamflow volume and Stampede Reservoir storage.

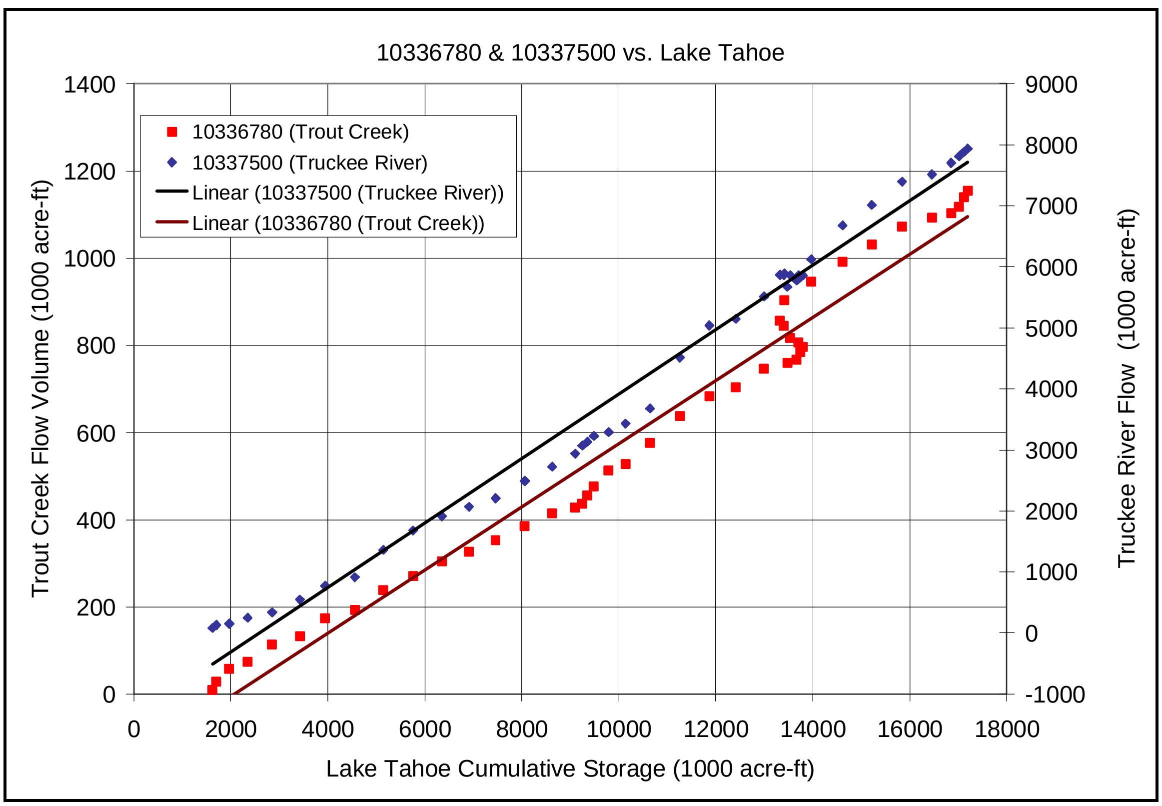


Figure J4. Trout Creek streamflow volume and Lake Tahoe storage.

Appendix K

Double Mass Analysis
Reservoir Volume vs. Snowpack

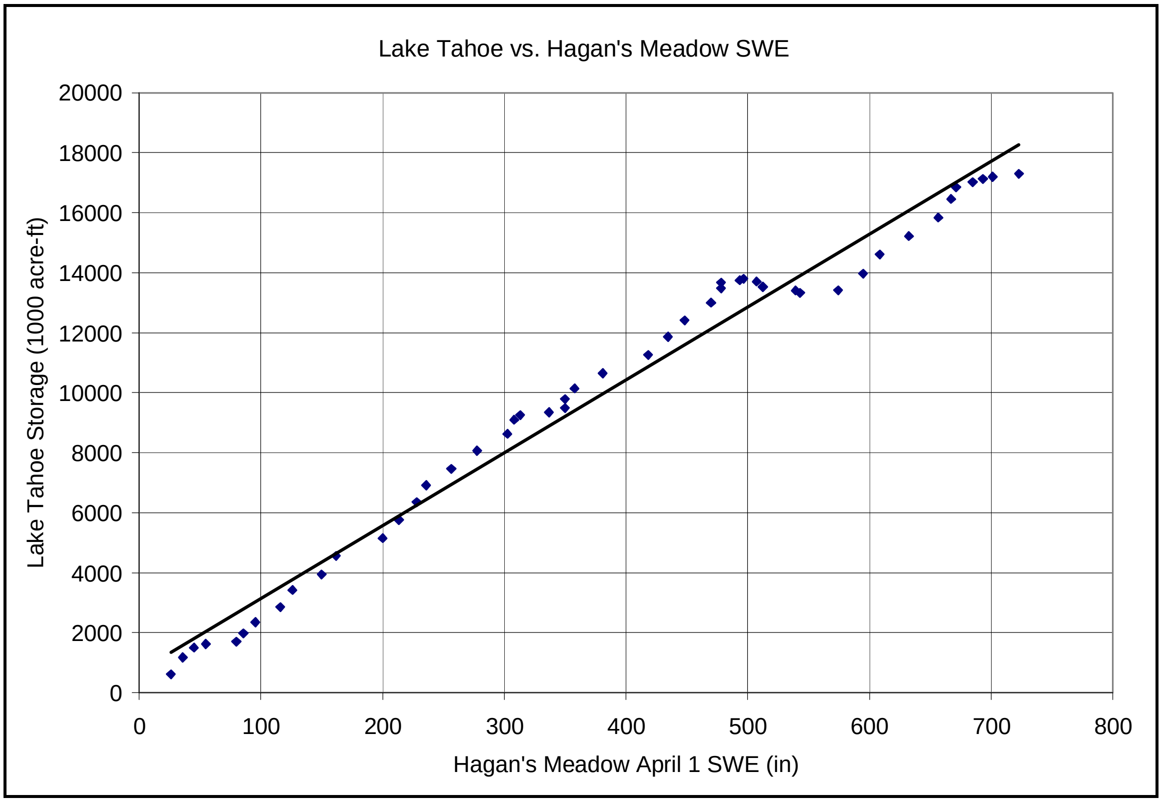


Figure K1. Lake Tahoe storage and April 1 SWE at Hagen's Meadow snowcourse station.

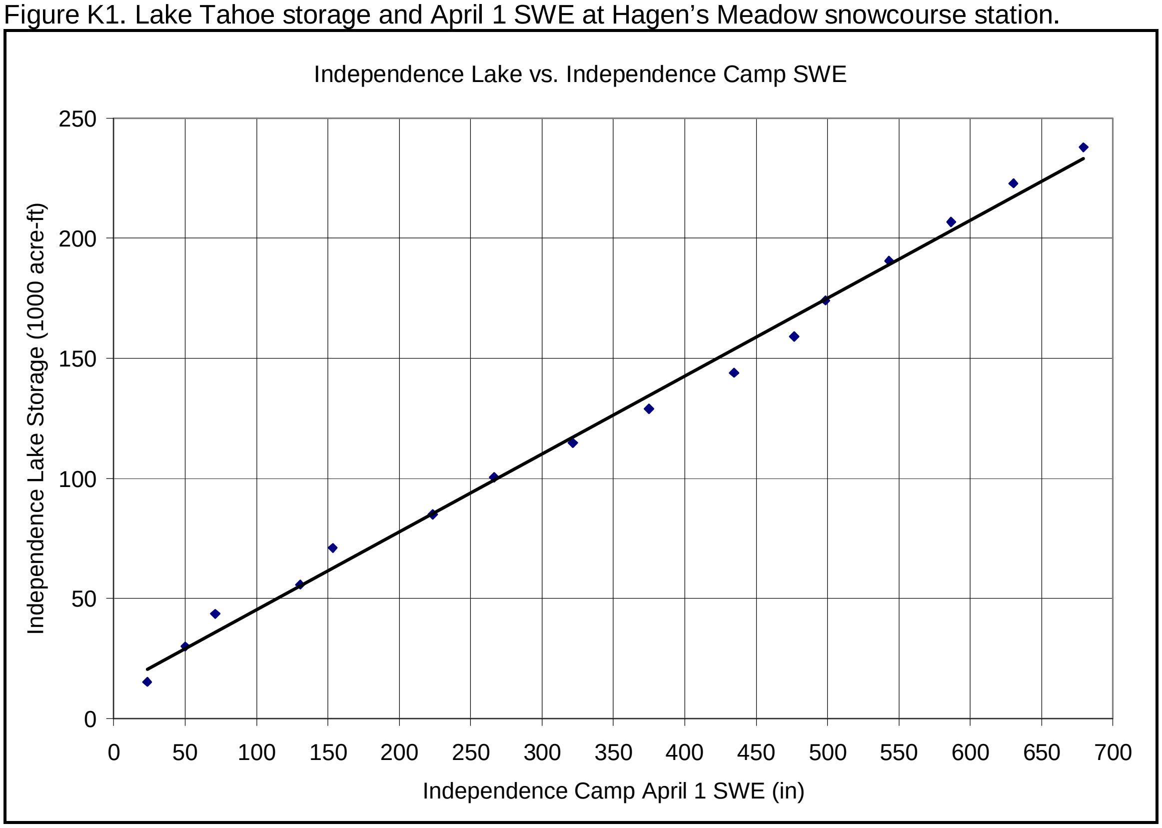


Figure K2. Independence Lake storage and April 1 SWE at Independence camp.

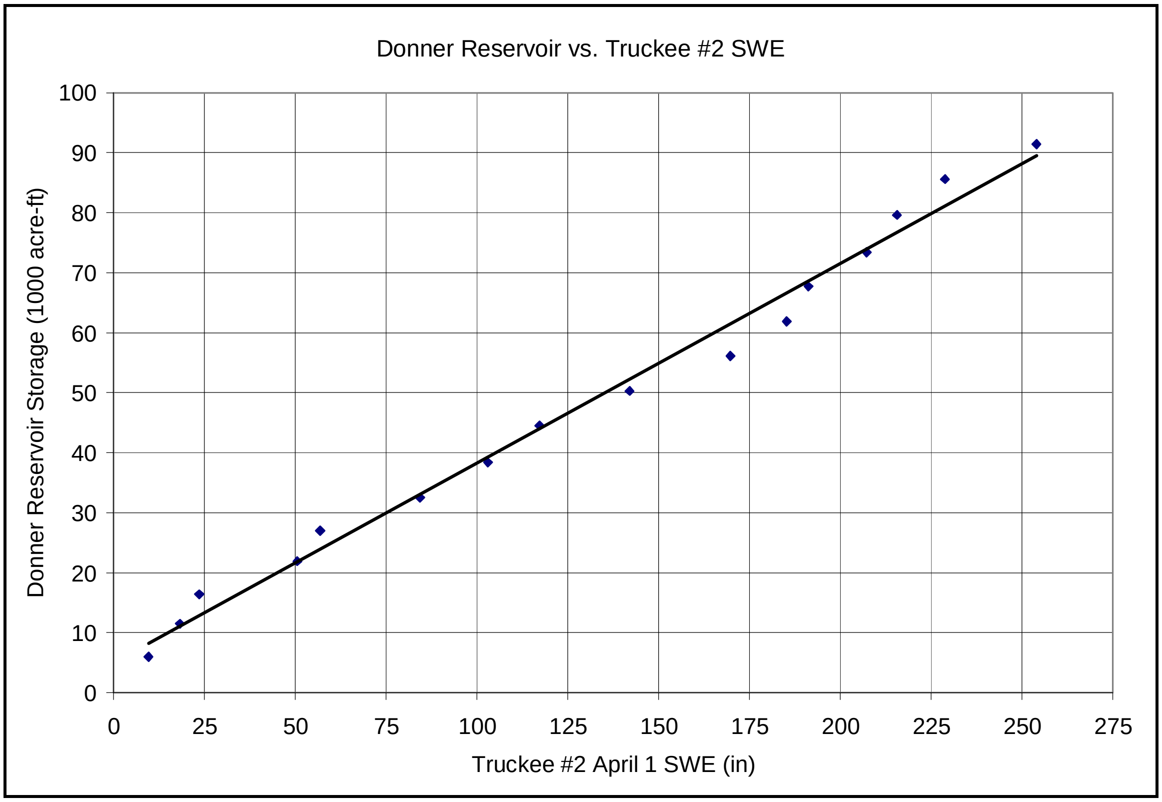


Figure K3. Donner Reservoir storage and April 1 SWE at Truckee #2 snowcourse station.

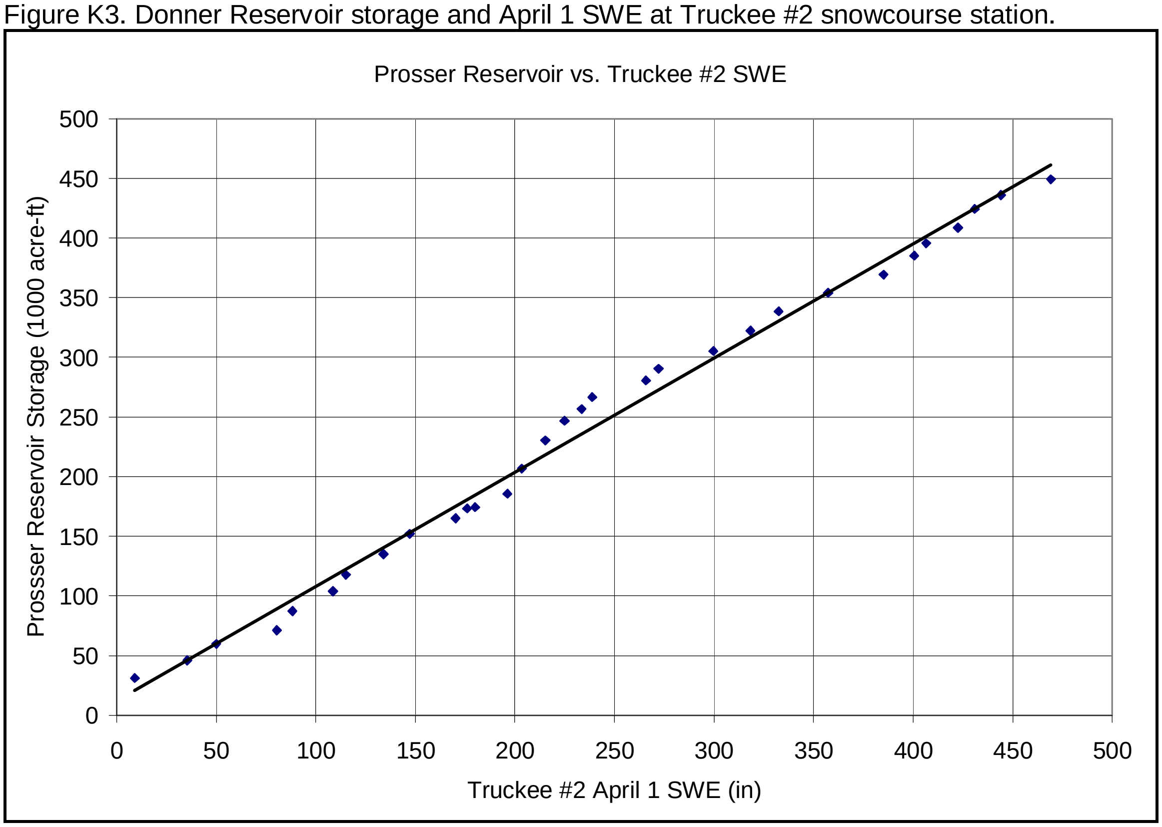


Figure K4. Prosser Reservoir storage and April 1 SWE at Truckee #2 snowcourse station.

Appendix L

Database Descriptions

Table L1. Snowcourse database information.

Name	*ID*	*Latitude*	*Longitude*	*Start*	*End*
Poison Flat	19l06s	38.5055	-119.6261	1942	2005
Blue Lakes	19l05s	38.6078	-119.9244	1918	2005
Hagen's Meadow	19l03s	38.8519	-119.9374	1916	2005
Independence Creek	20k03s	39.4902	-120.2813	1930	2005
Independence Camp	20k04s	39.4528	-120.2927	1941	2005
Independence Lake	20k05s	39.4275	-120.3134	1937	2005
Rubicon	20l02s	38.9992	-120.1303	1912	2005
Truckee	20k13s	39.3009	-120.1841	1931	2005
Marlette Lake	19k04s	39.1640	-119.8967	1915	2005
Mt. Rose Ski Area	19k07s	39.3157	-119.8947	1910	2005

Source: Natural Resources Conservation Service, National Water and Climate Center
http://www3.wcc.nrcs.usda.gov/snow/snowhist.html

Table L2. Streamgage database information.

Name	**ID**	**Latitude**	**Longitude**	**Start**	**End**
E.F. Carson R @ Markleeville	10308200	38.7146	-119.7649	1960	2005
E.F. Carson R @Gardnerville	10309000	38.8449	-119.7046	1900	2005
W.F. Carson R @Woodfords	10310000	38.7696	-119.8338	1900	2005
Clear Creek @ Carson City	10310500	39.1132	-119.7982	1948	2005
Carson R @ Cason City	10311000	39.1077	-119.7132	1939	2005
Carson R @ Fort Churchill	10312000	39.2917	-119.3111	1911	2005
Blackwood Cr. @ Tahoe City	10336660	39.1074	-120.1621	1960	2005
Third Cr. @ Crystal Bay	10336698	39.2405	-119.9466	1969	2005
Incline Cr. @ Crystal Bay	10336700	39.2402	-119.9449	1969	2005
Trout Cr. @ Tahoe Valley	10336780	38.9199	-119.9724	1960	2005
Truckee R @ Tahoe City	10337500	39.1663	-120.1444	1900	2005
Truckee R @ Truckee	10338000	39.2963	-120.2055	1944	2005
Donner Cr. @ Donner Lake	10338500	39.3235	-120.2344	1929	2005
Martis Cr. @ Truckee	10339400	39.3288	-120.1177	1958	2005
Prosser Cr. Bl. Prosser Dam	10340500	39.3732	-120.1316	1942	2005
Sagehen Cr. @ Truckee	10343500	39.4316	-120.2380	1953	2005
Little Truckee R. above Boca	10344400	39.4357	-120.0844	1939	2005
Little Truckee R. below Boca	10344500	39.3869	-120.0955	1911	2005
Truckee R. @ Farad	10346000	39.4280	-120.0341	1909	2005
Hunter Cr. @ Reno	10347600	39.4909	-119.8997	1961	2005
Truckee R. @ Reno	10348000	39.5302	-119.7955	1906	2005
Galena Cr. @ Streamboat	10348900	39.3619	-119.8267	1961	1994
Streamboat Cr. @ Steamboat	10349300	39.3771	-119.7437	1961	2005
Truckee R. @ Vista	10350000	39.5205	-119.7010	1900	2005

Source: U.S. Geological Survey, National Water Information System: Web Interface
http://water.usgs.gov

Table L3. COOP weather station database information.

Name	ID	Latitude	Longitude	Start	End
Boca	40931	39.3833	-120.1000	1936	2005
Donner Memorial St. Park	42467	39.3167	-120.2333	1953	2005
Markleeville	45356	38.7000	-119.7833	1931	2004
Sagehen Creek	47641	39.4333	-120.2333	1953	2005
Truckee Ranger Station	49043	39.3333	-120.1833	1935	2005
Carson City	261485	39.1500	-119.7667	1931	2005
Glenbrook	263205	39.0833	-119.9500	1945	2005
Lahontan Dam	264349	39.4667	-119.0667	1931	2005
Minden	265191	39.0000	-119.7500	1931	2005
Reno Airport	266779	39.5000	-119.7833	1937	2005
Virginia City	268761	39.3000	-119.6333	1951	2005

Source: National Weather Service, Cooperative Observer Program, via the Western Regional Climate Center
http://www.nws.noaa.gov/om/coop/
http://www.wrcc.dri.edu/

Table L4. Reservoir and Lake storage database information.

Name	ID	Latitude	Longitude	Start	End
Boca Reservoir	BOC	39.3830	-120.1000	1960	2005
Donner Lake	DNL	39.3240	-120.2330	1989	2005
Independence Lake	INL	39.4500	-120.2830	1988	2005
Lahontan Reservoir	10312100	39.2750	-119.0400	1917	2005
Martis Creek Reservoir	MRT	39.3270	-120.1130	1972	2005
Prosser Reservoir	PRS	39.3794	-120.1367	1964	2005
Stampede Lake	STP	39.4710	-120.1030	1970	2005
Lake Tahoe	TAH	39.1810	-120.1180	1957	2005

Source: California Department of Water Resources, Division of Flood Management, by request
http://cdec.water.ca.gov/misc/resinfo.html
Except for Lahontan Reservoir, which was from the USGS National Water Information System: Web Interface
http://waterdata.usgs.gov/nv/nwis/

PRELIMINARY EVALUATION OF CLIMATIC DATA
IN TRUCKEE MEADOWS REGION

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Our climate has always been in a state of change. Within the last 1000 years, the Sierra Nevada Mountains have undergone two warm, dry periods of 150 and 200 year duration during AD 900–1350, and a Little Ice Age, from AD 1400 to 1900 (Millar and Wolfenden, 1999). Any changes to the climate in the present times have the potential to severely disrupt the growth and survival of our civilization. Of all avenues which are affected by climate change, water availability is one of the most significant. The survival and growth of a number of our cities, agricultural areas, environmental reserves, natural resources, etc. will depend upon our preparedness for reacting towards changing climate and water availability.

Annual precipitation has increased for most of North America with large increases in northern Canada, but with decreases in the southwest U.S., the Canadian Prairies and the eastern Arctic (Trenberth et al., 2007; Shein, 2006). Heavy precipitation frequencies in the U.S. were at a minimum in the 1920s and 1930s, and increased to the 1990s (1895 to 2000) (Kunkel, 2003; Groisman et al., 2004). Streamflow in the eastern U.S. has increased 25% in the last 60 years (Groisman et al., 2004), but over the last century has decreased by about 2%/decade in the central Rocky Mountain region (Rood et al., 2005). Since 1950, stream discharge in both the Colorado and Columbia River basins has decreased, at the same time annual evapotranspiration (ET) from the conterminous U.S. increased by 55 mm (Walter et al., 2004). The fraction of annual precipitation falling as rain (rather than snow) increased at 74% of the weather stations studied in the western mountains of the U.S. from 1949 to 2004 (Knowles et al., 2006).

As is clear from the studies cited above, climate change has a multi-pronged effect on water resources. It not only changes the inflow of water into the water bodies, but also the outflow by changing withdrawals, evaporation from the water surface, and transpiration by plants. Several regions in the world are expected to face water shortages due to climatic changes but the situation is expected to be more severe in regions which are already arid or semi-arid. The US South West is one such region where water might be a limiting factor to further development. Several studies have been conducted to evaluate the impacts of climate change and their mitigation in river basins in the Western US (Payne et al, 2004; Hamlet and Lettenmaier, 1999; VanRheenen et al, 2004; Christensen et al, 2004).

Climate change projections for Southwestern United States remain uncertain about the magnitude of temperature and precipitation changes. Nonetheless, most climate change projections agree upon an increase in temperature and a reduction in precipitation in this region (IPCC, 2007; Seager et al., 2007). This will result in a greater portion of precipitation occurring as rainfall and an increased rate of snowmelt in the Sierra Nevada Mountains (Pupacko, 1993; Dettinger, 2005). Additionally this would cause an increase in streamflow during the spring season and drier conditions during summers, thus changing the entire hydrological cycle of the watershed by altering the flow hydrograph of streams and rivers (Knowles et al., 2006; Stewart et al., 2004; Stewart et al, 2005).

Historical records show that global runoff increases by 4% for every 1°C rise in temperature (Labat et al., 2004) but the changes may vary regionally and must be studied in greater detail for effective policy making.

Climate of the Western US has experienced large changes. It is estimated that since the 1940s the temperature in the western US has risen by 1-2°C with a more pronounced increase in winter and spring temperatures (Karl et al, 1993; Dettinger et al, 1995; Lettenmaier et al, 1994; Vincent et al, 1999). Spring in this region onsets earlier these days and spring snowmelt pulses in streams have shifted back (Cayan et al, 2001, Regonda et al, 2005). An analysis of certain climate change scenarios for California revealed a significant warming of the region and significant losses in snow cover in Northern and Central Sierra Nevada Mountains (Cayan et al, 2008; Pierce et al, 2008). April 1 snow water equivalent (SWE) has declined 15 to 30% since 1950 in the western mountains of North America, particularly at lower elevations and primarily due to warming rather than changes in precipitation (Mote, 2003; Mote et al., 2005; Lemke et al., 2007).

The changes in climate are expected to increase the intensity and frequency of major flood events in the river basins of Sierra Nevada Mountains (Kim 2005). Most existing modeling studies of increased atmospheric CO_2 point to increased precipitation variability (Giorgi et al., 1994; Maurer et al, 2006; Mearns et al., 1995a, b; Trenberth et al, 2003). Significant changes in patterns in streamflow through the year can be expected in the future due to climate change (Maurer 2007) with increases in winter streamflow and decreases in summer stream flows and a shift of flow towards the earlier part of the year (Maurer and Duffy, 2005). Climate change is also estimated to have major negative impacts on the reservoirs relying on the runoff from Sierra Nevada Mountains. This will severely limit the potential of such reservoirs in fulfilling their designated purposes of water supply, hydropower generation, environmental, and ecological functions (Vicuna et al, 2007).

The Truckee Meadows Water Authority (TMWA), which is the largest water purveyor in the Reno-Sparks region, in the western US, relies primarily on the snowmelt and runoff from the Sierra Nevada Mountains to provide 85% of the water it delivers to its customers via Truckee River diversions. The Truckee River which is a 140 miles long river originating at Lake Tahoe and draining into Lake Pyramid. Primary source of water for Lake Tahoe and consequently Truckee River is the snowpack on the Sierra Nevada Mountains. Therefore, it is one of those regions which can experience a significant change in the water availability in the future because of the changing climate.

One of the principal responsibilities of the Truckee Meadows Water Authority (TMWA) is to assure that the water resources are developed and managed to fulfill the present and future water needs of the greater Truckee Meadows community (Chapter 277, NRS). In order to achieve this objective, TMWA has a 20 year water resource plan that is updated every 3 to 5 years. Climate change, because of its uncertainty of magnitude, and implications on hydrology, poses a major challenge in the course of efficient planning.

Therefore, planners and decision makers must have access to the latest developments in the field of climate change science and the study of its impacts on water availability.

Another difficulty in planning for climate change arises due to a lack of spatial resolution suitable enough to be adopted for most watersheds (Giorgi and Mearns, 1991; Leung et al., 2003). Forecasts that may be applicable to a large region in general may not be applicable to smaller watersheds on a finer temporal resolution. Therefore, it is necessary to combine information from various sources to make the projections more adaptable to the Truckee Meadows region. This report compiles the knowledge from the latest studies, field data, experiments, and computer simulations and brings an integrated assessment of the climatic changes experienced by the Truckee Meadows and changes that it should prepare to expect in the future. It will be helpful to the decision makers while framing water management policies by providing them with an insight into the changes anticipated in the hydrological processes in the Truckee Meadows region due to climate change and to examine their policies so as to mitigate its potential effects.

Future climate changes have the potential to threaten the sustainability of water resources of Truckee Meadows by disturbing the hydrological processes and changing the water availability patterns. Scientific knowledge and the latest information on the developments in the field of climate change and hydrology is a very powerful tool in the hands of planners to develop well directed policies. In view of this, in 2006, Dr. Mark Stone of the Desert Research Institute prepared two reports for TMWA on climate change and its impacts on the hydrology of the region. The first document summarized the state of the science in climate change research with an emphasis on potential impacts on water resources. The second report contained an extensive analysis of the gauged weather, streamflow, and reservoir data in the Truckee River and Lake Tahoe basins to attempt to identify early signs of climate change impacts in the region. The purpose of these reports was to inform the TMWA management of how climate change could impact their ability to carry out their mission of water delivery to their customers. The present report updates those reports with current information and additional data sources which have become available over the past 3 years. This additional information is important to consider due to the recent proliferation of climate change research. Further, this report also includes the analysis of spatially explicit gridded datasets available from various sources to expand the analysis of station data carried out in previous reports.

This study will improve the understanding of the impact of potential climatic changes on the water resources of the Truckee Meadows region. The primary deliverables of the proposed research is this updated report on the state of the science of climate change impacts research and on the trends analysis which incorporates the gridded data described above.

1.1 Study Area

The study area is located in the north western part of Nevada on the Border with California. It contains the urban areas of Reno with a population of 214,853, Sparks with a population of 87,139, and Carson City with population of 54,939 (US Census Bureau). Figure 1 shows the relief of the study area. The western edge of the study area lies on the

Sierra Nevada Mountains and has an elevation of up to 3200 m above sea level. Carson Desert and Pyramid Winnemucca Lakes which are the lowest points in the study area lie on the floor of the Great Basin and have elevation of 1100 m. A significant portion of the snowcaps on the Sierra Nevada Mountains, which are the primary source of water to Lake Tahoe, Truckee River and Carson River, lie in California. However, a greater portion of the study area lies in the Great Basin in Nevada.

.

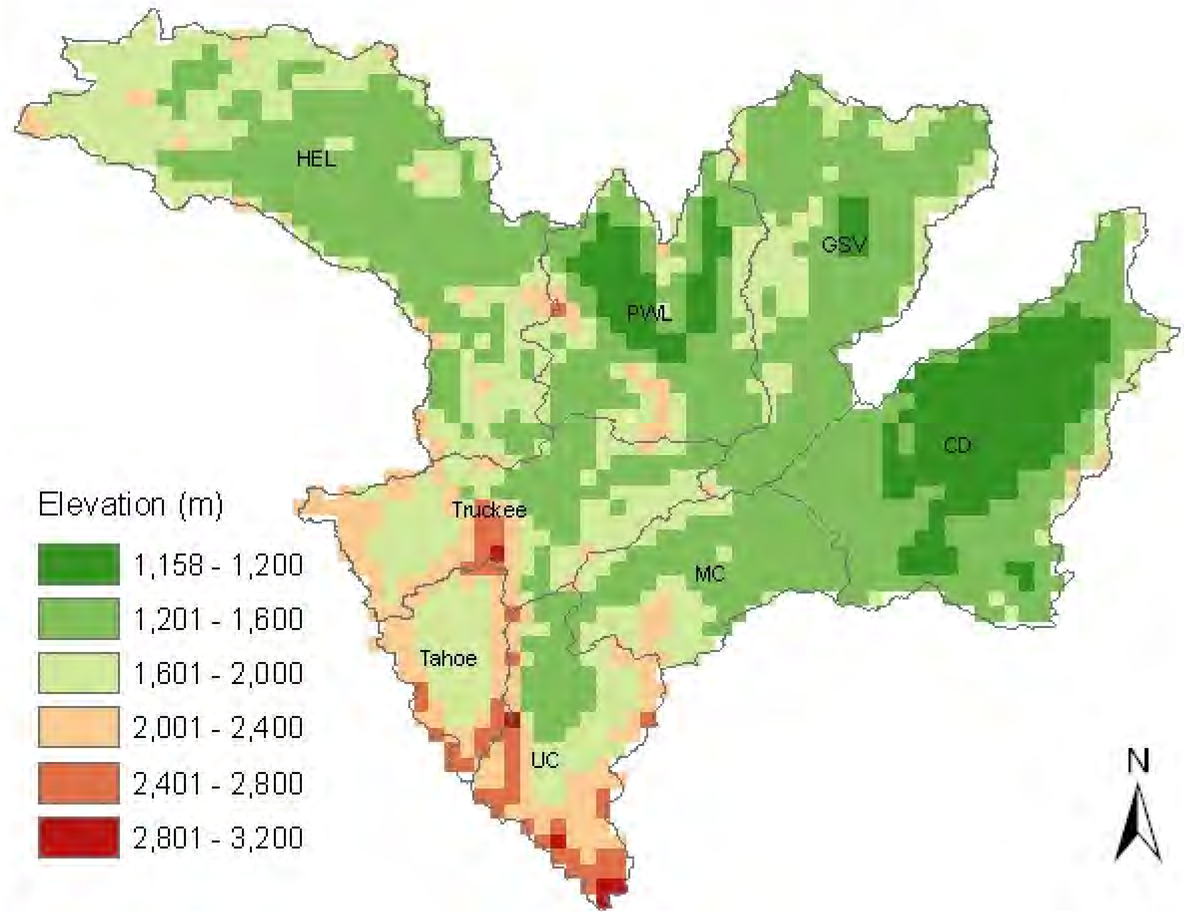


Figure 1 Elevation of the study area above MSL.

1.2 Objectives

Weather stations, stream gauges, and reservoir levels can all provide insights into long term trends in climate and hydrology. These sources include data from Natural Resources Conservation Service Snowpack Telemetry (SNOTEL), NWS Cooperative Network, Remote Automated Weather Stations, USGS High Altitude Precipitation, USGS streamflow gages, USGS groundwater monitoring wells, and Snow Course Stations. These stations were used in the 2006 report to study potential trends in the region. However, there are several limitations to gauged data which have led researchers to enhance the usefulness of the measured records by interpolating them over an extended area. Gauged data is collected at a single point and therefore has serious limitations in terms of studying spatial patterns in data. Further, inconsistencies in measuring techniques in both time and space often makes comparison studies quite complicated.

This limitation can be overcome through the use of gridded datasets which are based on a re-analysis of historical data using process based simulation models that ingest historic data. Precipitation-elevation Regressions on Independent Slopes Model (PRISM) and The Variable Infiltration Capacity (VIC) are examples of spatially gridded data that are used in this study to add to the data analysis task performed in the previous reports. Each of these is explained in brief in the following paragraphs.

PRISM, developed by the Spatial Climate Analysis Service and Oregon Climate Service, is an analytical model that uses station point data, a digital elevation model and additional spatial datasets to produce 4 km resolution grids of monthly temperature and precipitation across the continental US (Daly et al., 2002; Daly et al., 1994). As the model is also designed to incorporate high elevation data from mountainous regions and to accommodate difficult climate mapping situations in innovative ways, PRISM is well suited to capture the complex climatological conditions present in the western US (Nanus et al., 2003). PRISM is currently the primary dataset being used in WestMap, and is also implemented in the California Climate Tracker (CCT) to bolster climate information across sparsely monitored locations in the state of California. PRISM has also been adopted by NOAA's NWS for a number of products and projects. Monthly accumulated precipitation along with monthly averaged maximum and minimum temperatures will be used as inputs to derive a number of the drought indices of interest.

The VIC model (Liang et al., 1996) is a macroscale hydrologic model that is capable of distinguishing characteristics of subgrid heterogeneity in soils, vegetation, topography and precipitation. The VIC dataset is advantageous for examining hydrologic changes over the study area given its 1/8 degree or 10x12 km horizontal spatial and daily temporal resolution. VIC provides information of temperature, precipitation, snow water equivalent, soil moisture, runoff, and evapotranspiration for every pixel. One of the premier advantages of VIC is its simulation of the snow water and energy balance which is a key component of the hydrologic setting of the study area. VIC has been implemented in numerous research studies and operational products, and is well established for usage across the western US (Lettenmaier et al., 1999; VanRheenen et al., 2004; Christensen et al., 2004).

The broad objectives of this study can be summarized as follows.
Objective 1: Update the state of the science literature review, which was completed in 2006, with relevant publications and products released over the past 3 years.
Objective 2: Expand the data analysis task by evaluating spatial patterns and extended records available from the gridded datasets.
Objective 3: Perform a cursory analysis of existing climate change scenarios that have been downscaled for the Truckee basin to provide an overview of expected trends and related uncertainty.

2 PAST CLIMATE TRENDS

2.1 PRISM

It has been shown in a number of studies that topography plays a major role in the distribution of precipitation and temperature over an area especially in mountainous regions. The rate of precipitation as well as temperature varies considerably at different elevations and on the different faces of a relief. This feature, however, is not adequately represented by statistical or graphical methods of precipitation interpolation. Parameter-elevation Regressions on Independent Slopes Model (PRISM) is an analytical model that can be used to distribute point measurements of monthly, seasonal, and annual precipitation to a geographic grid. PRISM uses data from weather stations and digital elevation models to model annual, monthly and event based climate events that are gridded and GIS compatible.

The Lake Tahoe watershed primarily comprises of mountainous regions of the Sierra Nevada Mountains. In such topography, conventional interpolation methods are not sufficient to model climate parameters such as precipitation, temperature, etc. Therefore, this study utilizes the outputs from PRISM to evaluate the changes that have occurred to the climate of the region in the past decades. A collaborative effort between the Spatial Climate Analysis Service and the Oregon Climate Service has resulted in detailed, high-quality spatial climate datasets, referred to as PRISM maps (Daly et al., 2001). PRISM is an analytical model that distributes point measurements of monthly, seasonal, and annual precipitation to a geographic grid of four kilometers by four kilometers. By use of a resampling algorithm, two-kilometer by two-kilometer resolution grids can be estimated. These grids are produced in a GIS compatible latitude-longitude grid or a gridded map projection.

Digital elevation models (DEMs) are used in conjunction with observed precipitation values in the PRISM model to determine variation in precipitation as a function of elevation. DEMs contain information that describes the earth's topography, including slope, aspect, and elevation. Because the PRISM precipitation dataset is a function of the observed data and topography, orographic precipitation and rain shadows are uniquely and accurately modeled in PRISM (Daly et al., 2001).

Three existing climate datasets are used by PRISM to create maps: the National Climatic Data Center 1961-1990 normals dataset (CLIM-81) observed by the National Weather Service Cooperative Climate Network; the NRCS SNOTEL (SNOwpack TELemetry) network dataset, and supplemental datasets submitted by the individual State Climatologists or regional climate centers (Daly et al., 2001). The PRISM Evaluation Group (PEG), composed of State and Regional Climatologists, representatives of national agencies, NRCS representatives and other state and local government users, evaluated and endorsed the PRISM model for Idaho, Nevada, Oregon, and Utah data (Daly et al., 2001). An examination of average annual PRISM precipitation values in the Willamette River basin, northern Oregon, resulted in 0.1 cm (1.0 percent of observation) cross validation bias and 17 cm (10 percent of observation) mean absolute error (Daly et al., 1994).

PRISM is designed and updated to map climate parameters in varying terrains, including high mountains, rain shadows, coastal regions, and other complex climatic regimes. PRISM accounts for topographic facet (hill slope orientation) to handle rain shadows, and for elevation, a primary driver of climate patterns (Daly et al., 2001). Two main advantages of using PRISM data are that precipitation values are available on a regular grid size of four kilometers by four kilometers, and the data are available in digital form. These two factors allow PRISM data to be easily integrated with other water budget components and calculations within a Geographic Information System (GIS) environment.

To analyze the PRISM data, the study area was segmented into eight smaller sub basins. The sub basins used for this purpose were derived from the hydrologic units shapefile obtained from the National Atlas website last downloaded on August 7, 2009 (http://www.nationalatlas.gov/atlasftp.html#hucs00m). Table 1 shows the details of the watersheds studied using PRISM data.

Table 1 Division of the study area.

Sub-watershed	Denomination	Pixels	Area (Km^2)
Carson Desert	CD	335	5360
Granite Springs Valley	GSV	263	4208
Honey Eagle Lakes	HEL	437	6992
Middle Carson	MC	139	2224
Pyramid Winnemucca Lakes	PWL	215	3440
Lake Tahoe	Tahoe	79	1264
Truckee River	Truckee	191	3056
Upper Carson	UC	147	2352
Entire Watershed	Entire	1806	28896

Monthly precipitation, average monthly minimum and maximum temperature data were downloaded from the PRISM Group's ftp site for the years 1895 to 2008. These files stretch on a four kilometer by four kilometer grid scale covering the entire continental United States. Because a very small window of the entire United States dataset was needed, clipping of the data to the study area was completed as an initial step using the eight smaller subdivisions of the region. These clipped data were then used for determining the temperature and precipitation values over the watershed for the above mentioned time period on a monthly time scale. The end product of data processing resulted in precipitation data in millimeters, and monthly average maximum and minimum temperatures in ^oC. The monthly temperature and precipitation values were then tabulated and trends were generated. A detail of the data processing procedure is provided in the Appendix 6.1.

Figure 2 and Figure 3 show the average maximum and minimum monthly temperatures for the study area in 2007. Temperature variation within the study area shows an expected increase from west to east because of lowering of elevation. Similarly, Figure 4 shows the precipitation distribution over the study area. The south western edge of the study area, which has the maximum elevation, also receives the highest amount of precipitation. It decreases from west to east because of the rain shadow effect produced by the Sierra Nevada Mountains on the west portion of the study area.

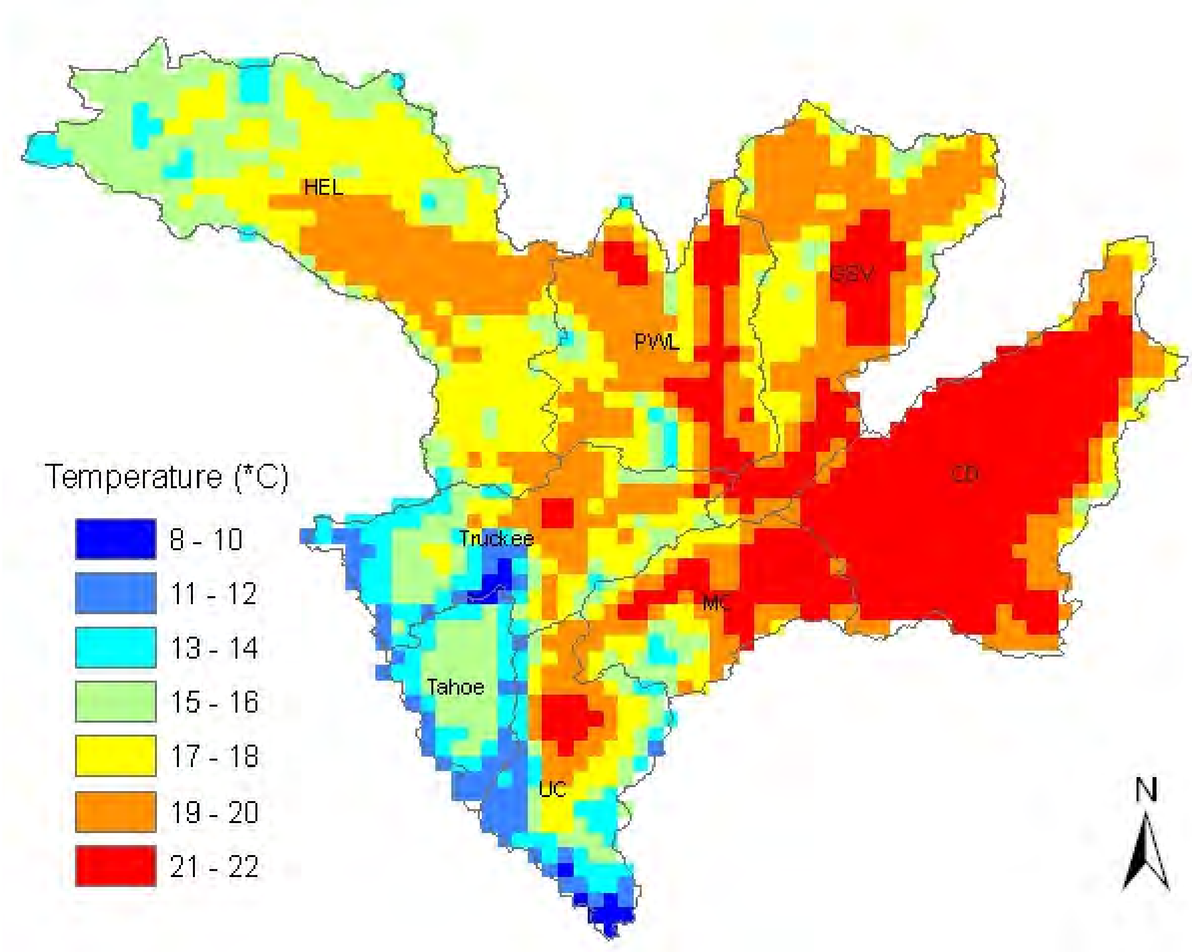


Figure 2 Average maximum monthly temperature for 2007.

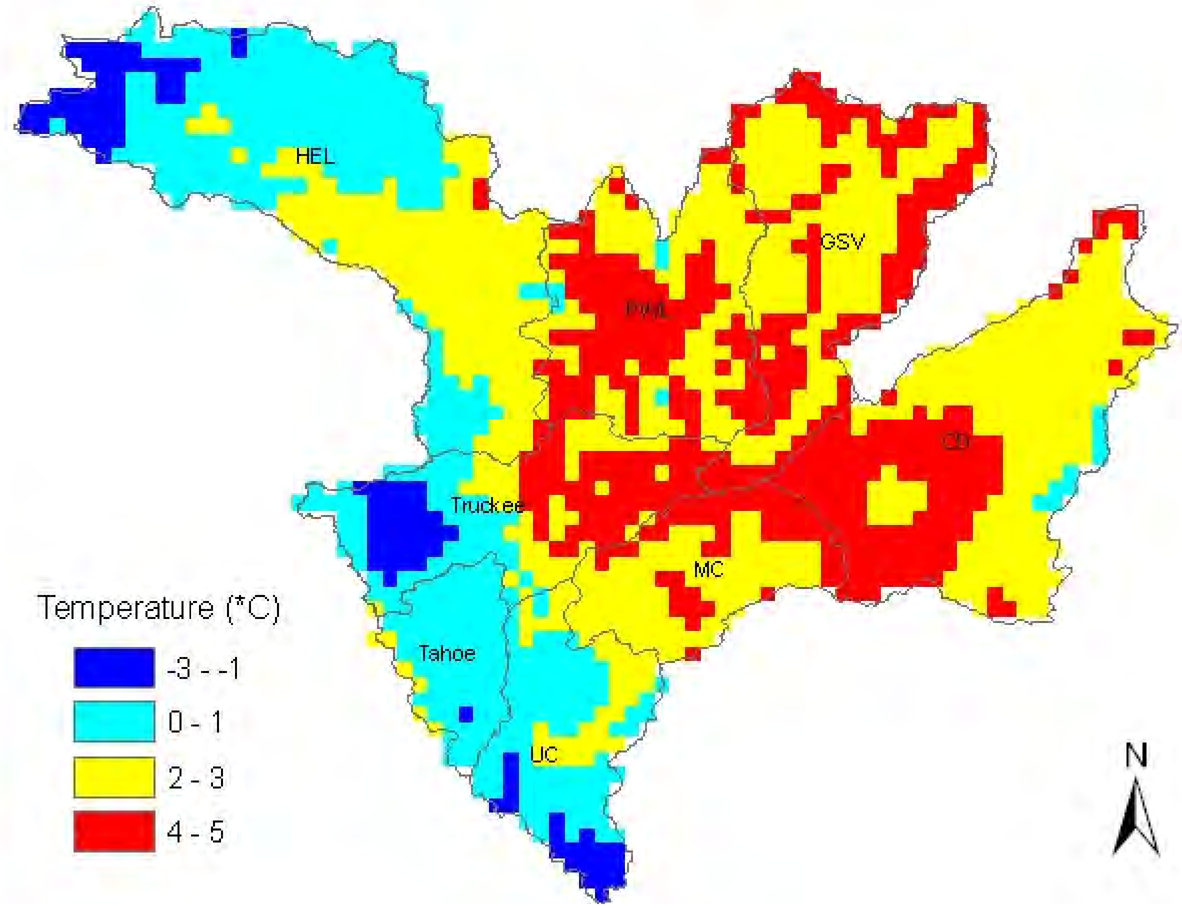


Figure 3 Average minimum monthly temperature for 2007.

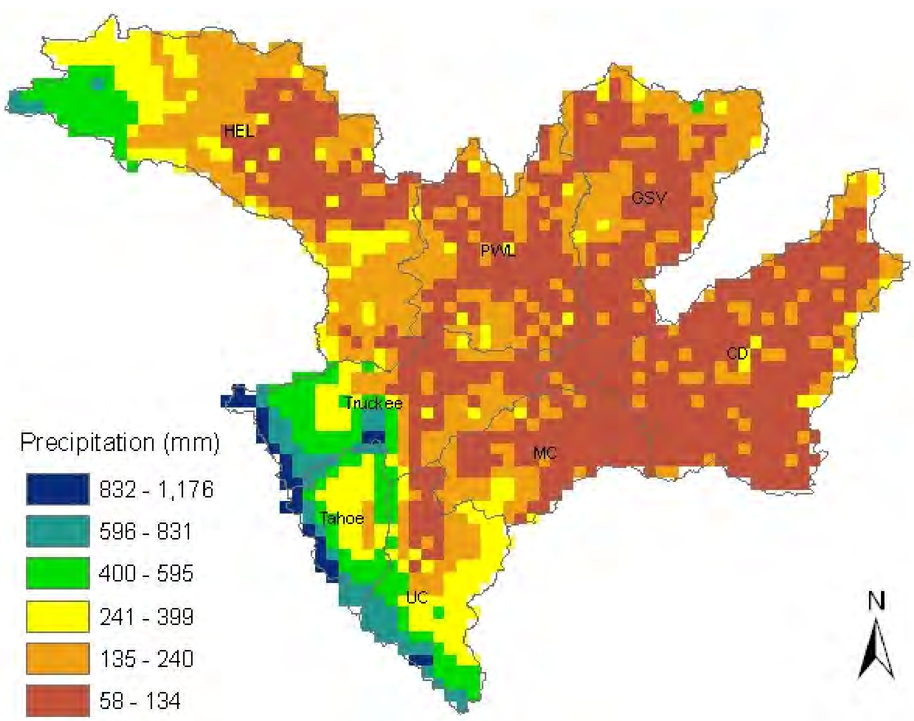


Figure 4 Total precipitation for 2007.

Analysis of precipitation data for the eight sub regions shows that annual precipitation has experienced an increasing trend in six of the sub regions excluding Honey Eagle Lakes and Upper Carson (Table 2). Figure 5 shows the variation in annual precipitation in the Lake Tahoe Basin. Breaking down the annual precipitation trends into the four seasons reveal that the increase is not uniform throughout the year. All but GSV show a decrease in winter precipitation with UC experiencing the largest rate of decrease. In case of spring season, all regions at lower altitudes experienced an increasing trend in precipitation during the study period and all the high altitude regions show a decline in spring precipitation. However, for the summer months, all regions show similar increasing trends. The high altitude regions which show a decreasing trend for spring precipitation show the greatest rates of increase in fall precipitation thus more than compensating for the decline experienced in winter and spring seasons. The lower regions also experience an increase in fall precipitation but at a smaller rate.

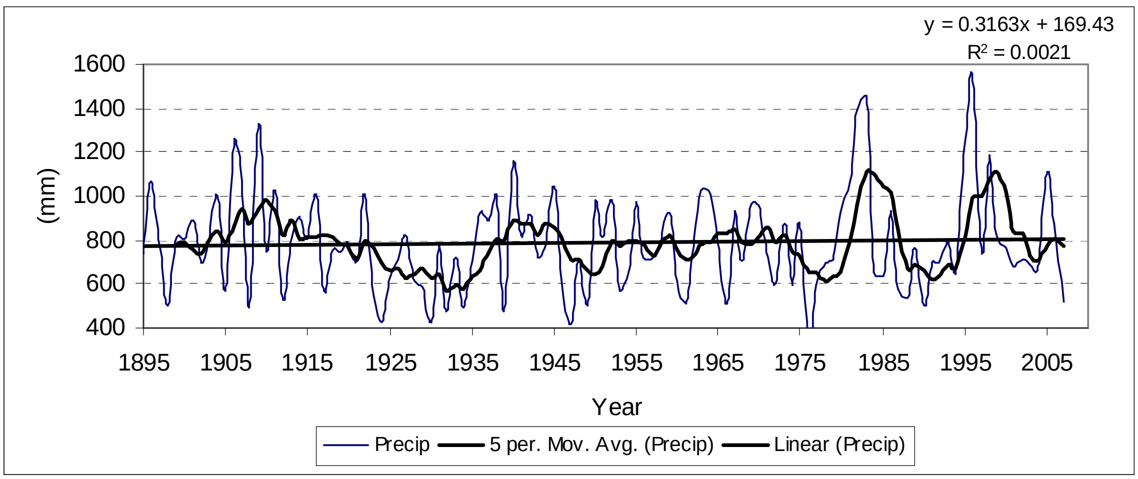


Figure 5 Annual precipitation for Lake Tahoe Basin.

Table 2 Annual average rate of change in precipitation.

Precipitation Trends		**Winter**	**Spring**	**Summer**	**Fall**	**Annual**
Carson Desert	CD	-0.0068	0.1335	0.1216	0.1006	0.3423
Granite Springs Valley	GSV	0.0007	0.1594	0.1471	0.1192	0.4283
Honey Eagle Lakes	HEL	-0.0432	-0.0679	0.114	-0.0022	-0.0198
Middle Carson	MC	-0.1408	0.0157	0.114	0.1052	0.0756
Pyramid Winnemucca Lakes	PWL	-0.1414	0.0165	0.1051	0.0579	0.0343
Lake Tahoe	Tahoe	-0.0797	-0.2516	0.1663	0.5514	0.3163
Truckee River	Truckee	-0.0086	-0.2608	0.1221	0.4065	0.214
Upper Carson	UC	-0.3452	-0.2393	0.1526	0.3977	-0.0823
Entire Study Area	Entire	-0.0718	-0.0233	0.1255	0.1500	0.1607

The monthly maximum and minimum temperatures for the Lake Tahoe basin have been rising as seen in Figure 6 and Figure 7. Temperature trends for all sub regions in the study area show consistent rising trends over the period of study (Table 3 & Table 4).

The analyses of average monthly minimum and maximum temperatures show that the rate of change was not uniform for the four seasons.
Maximum temperatures increased all over the study area for all seasons but average maximum temperature for winters displayed the highest rate of increase. Minimum temperatures on the other hand show a reversed trend for the winter season with the lowest rate of increase of all seasons.

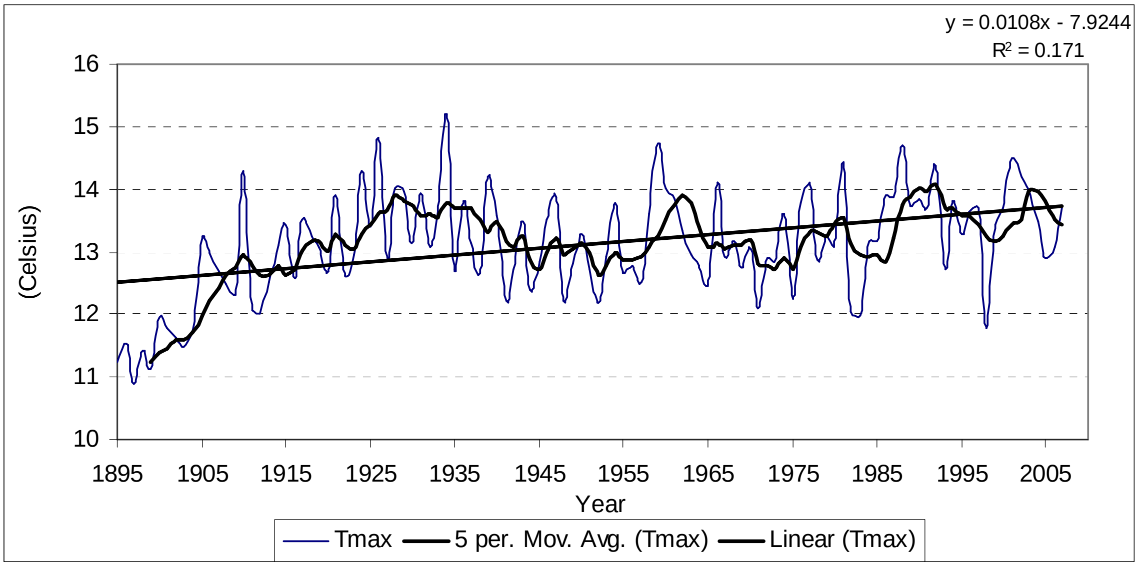


Figure 6 Annual average monthly maximum temperatures for Lake Tahoe Basin.

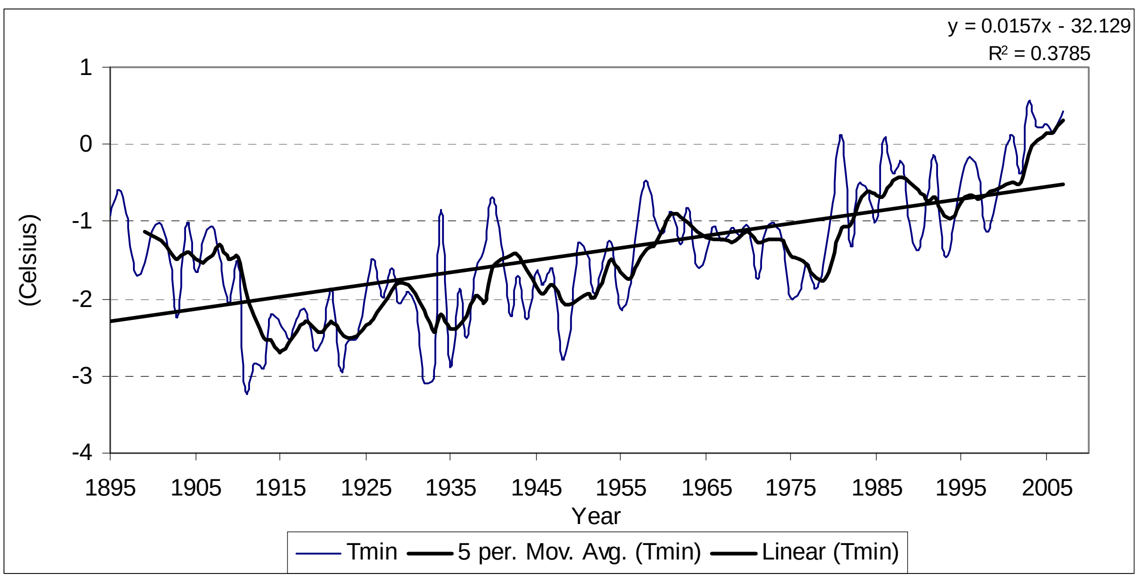


Figure 7 Annual average monthly minimum temperatures for Lake Tahoe Basin.

Table 3 Annual average rate of change in maximum temperatures.

Maximum Temperature		**Winter**	**Spring**	**Summer**	**Fall**	**Annual**
Carson Desert	CD	0.0234	0.0121	0.0109	0.0107	0.0143
Granite Springs Valley	GSV	0.017	0.0101	0.0102	0.0006	0.0095

Honey Eagle Lakes	HEL	0.0202	0.0103	0.0091	0.0004	0.01
Middle Carson	MC	0.015	0.0093	0.0108	0.0064	0.0104
Pyramid Winnemucca Lakes	PWL	0.0214	0.0123	0.0139	0.0032	0.0127
Lake Tahoe	Tahoe	0.0144	0.011	0.0101	0.0077	0.0108
Truckee River	Truckee	0.0172	0.0122	0.0201	0.0088	0.0146
Upper Carson	UC	0.0131	0.011	0.0088	0.009	0.0105
Entire Watershed	Entire	0.0189	0.011	0.0115	0.005	0.0116

Table 4 Annual average rate of change in minimum temperatures.

Minimum Temperature		**Winter**	**Spring**	**Summer**	**Fall**	**Annual**
Carson Desert	CD	0.0122	0.0142	0.0101	0.0093	0.0153
Granite Springs Valley	GSV	0.0095	0.0072	0.0133	0.0098	0.001
Honey Eagle Lakes	HEL	0.0064	0.0095	0.0164	0.0143	0.0117
Middle Carson	MC	0.012	0.0155	0.0171	0.0179	0.0155
Pyramid Winnemucca Lakes	PWL	0.0101	0.0119	0.0198	0.0166	0.0147
Lake Tahoe	Tahoe	0.0145	0.0144	0.017	0.0169	0.0157
Truckee River	Truckee	0.0067	0.01	0.0122	0.0136	0.011
Upper Carson	UC	0.0118	0.0116	0.0214	0.0167	0.0154
Entire Watershed	Entire	0.0096	0.0104	0.0153	0.0146	0.0125

2.2 VIC Hydrological Model

This study also uses the outputs of the Variable Infiltration Capacity (VIC) hydrological model to analyze the changes occurring to the snow water equivalent (SWE) in the region between 1915 and 2005. Daily gridded meteorological data obtained from the Surface Water Modeling group at the University of Washington from their web site at http://www.hydro.washington.edu/Lettenmaier/Data/gridded/, the development of which is described by Hamlet and Lettenmaier (2005) and Maurer et al., (2002). VIC is a macroscale hydrologic model that balances both surface energy and water over a grid mesh, typically at resolutions ranging from a fraction of a degree to several degrees latitude by longitude. The primary sources of meteorological data used in the data-processing sequence include NCDC Co-op data, monthly time step HCN and HCCD data, and PRISM data (Hamlet and Lettenmaier, 2005).

Most of the grid cells selected for the analysis lie along the periphery of Lake Tahoe. Figure 8 displays the grid cells from VIC model outputs which are used for the analysis of SWE changes. Each grid cell covers 1/8th of a degree grid cell (i.e. 13.8 km along the longitudes and approximately 10.1 km along the latitudes). To determine the changes in SWE over the time horizon afforded by VIC data, average SWE for January was calculated for each year. Figure 9 shows that the mean SWE for January has increased by almost 1mm per year. SWE calculations for April 1 were also carried out which showed a decline for all the grid cells. Therefore, to understand this inconsistency, March 1 and February 1 SWE were calculated for all the cells. The results show a rise in the SWE for January 1 and February 1 for all the grid cells whereas all the grid cells evaluated display a decline in April 1 SWE (Table 5). The average change in SWE per year ranges from 0.22 mm/yr to 1.07 mm/yr.

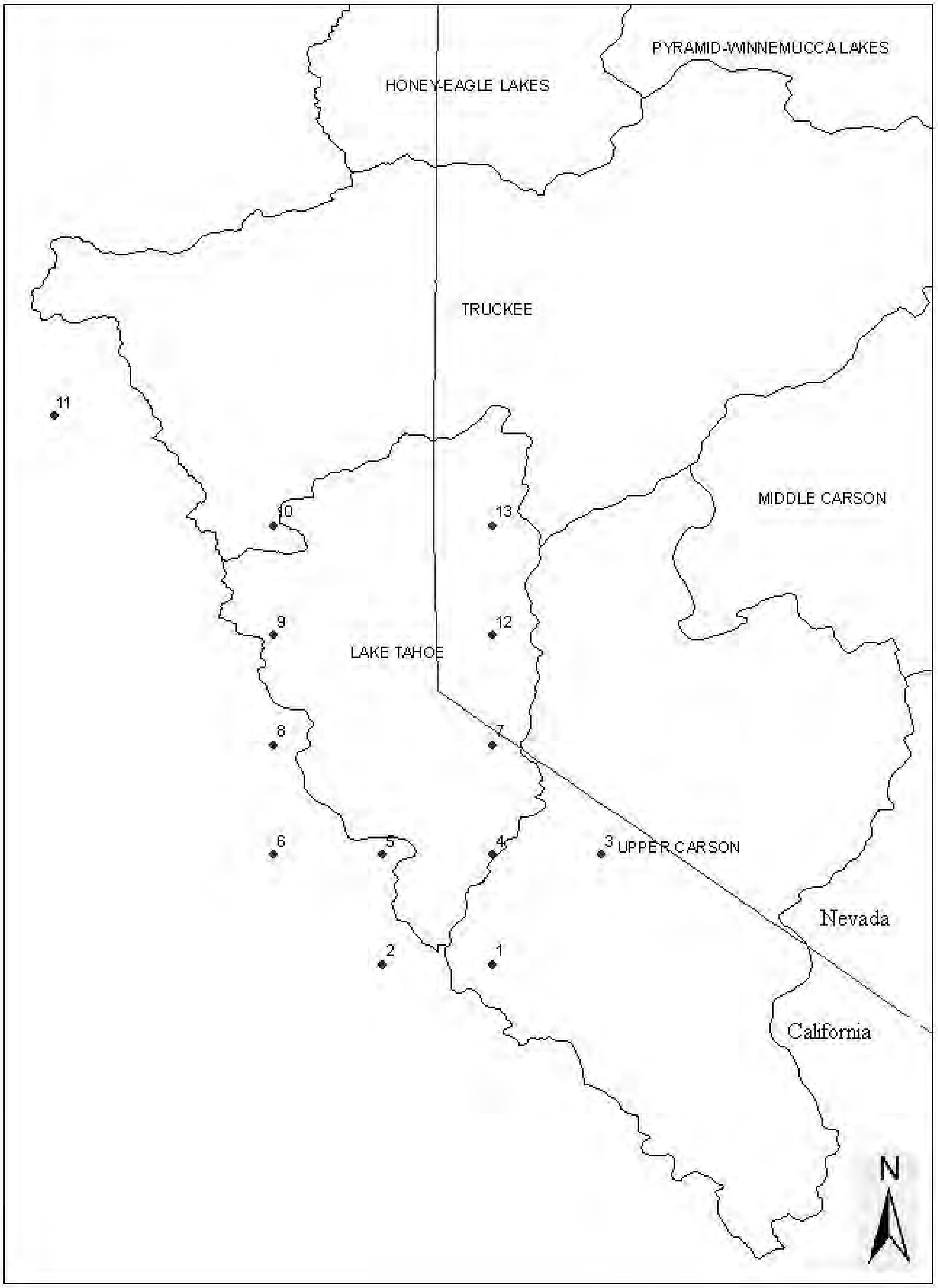


Figure 8 Location of VIC grid cells used for estimating SWE variations.

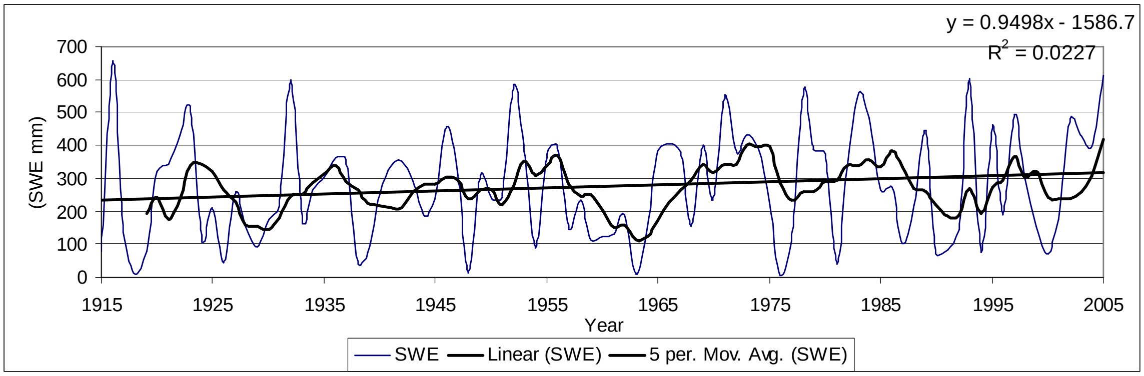


Figure 9 Mean January SWE variation for grid cell #1.

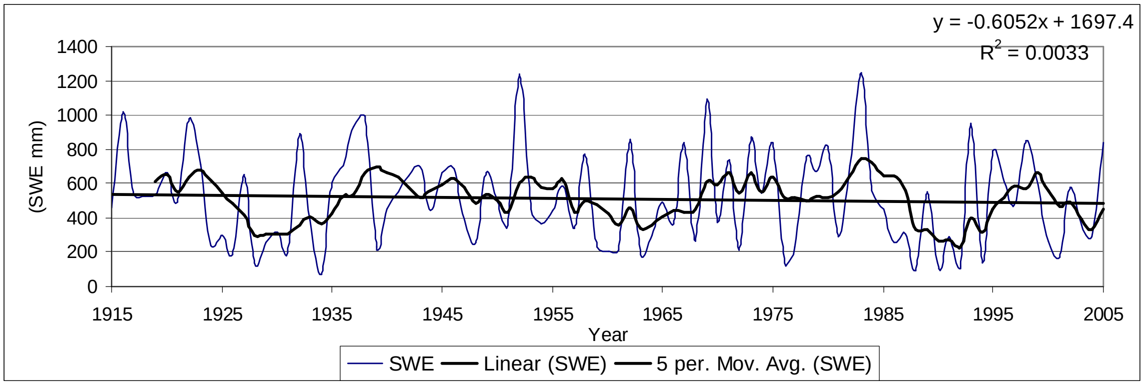


Figure 10 April 1 SWE for grid cell #2.

Table 5 VIC results for SWE variations.

Grid Cell	Latitude	Longitude	Average Change/Year (mm)				
			Mean Jan	1-Apr	1-Mar	1-Feb	1-Jan
1	38.6875	-119.938	1.079	-0.0413	0.3831	0.9179	1.1618
2	38.6875	-120.063	0.9498	-0.6052	0.0154	0.7107	1.1386
3	38.8125	-119.813	0.2191	-0.1405	-0.1725	0.0609	0.3279
4	38.8125	-119.938	1.0508	-0.0709	0.2505	0.8597	1.1997
5	38.8125	-120.063	1.0261	-0.3269	0.2751	0.8396	1.1811
6	38.8125	-120.188	0.4951	-0.5896	-0.2314	0.2683	0.7333
7	38.9375	-119.938	0.5468	-0.3521	-0.1536	0.363	0.7069
8	38.9375	-120.188	1.0262	-0.5268	0.1914	0.8565	1.1877
9	39.0625	-120.188	0.4471	-1.072	-0.4237	0.22	0.6665
10	39.1875	-120.188	0.7225	-0.101	0.1599	0.5842	0.8456
11	39.3125	-120.438	0.9876	-0.4272	0.1807	0.6736	1.1597
12	39.0625	-119.938	0.2212	-0.4176	-0.1687	0.0821	0.4019
13	39.1875	-119.938	0.3266	-0.5255	-0.2924	0.1996	0.5101

3 FUTURE CLIMATE CHANGE

3.1 Emission Scenarios

Green House Gas (GHG) emissions are dependent on a large number of factors which are interrelated in very complex and dynamic system. The emissions are driven by factors such as demographic development, socio-economic development, and technological change. Predicting the evolution of these factors is extremely difficult but a number of possible alternative paths, along which the future might unfold, can be postulated. These scenarios assist in analyzing the effects of changing climate on available resources and comparing available measures to mitigate its effects. Emission scenarios provide us with several alternative paths along which the world may progress and thus how GHG emissions might change over time. A number of such scenarios based on a wide array of driving forces have been developed by researchers all around the world.

Four different narrative storylines describing a range of possible alternative paths, excluding "surprise" or "disaster" scenarios have been generated by the IPCC based on literature. These were developed to describe consistently the relationships between emission driving forces and their evolution and add context for the scenario quantification. Each storyline represents different combination of demographic, social, economic, technological, and environmental developments. All scenarios based on the same storyline constitute a scenario "family". Each scenario represents a specific quantitative interpretation of one of four storylines described below.

Four qualitative storylines yield four sets of scenarios called "families": A1, A2, B1, and B2. All are equally valid with no assigned probabilities of occurrence. The set of scenarios consists of six scenario groups drawn from the four families described in Table 6: one group each in A2, B1, B2, and three groups within the A1 family, characterizing alternative developments of energy technologies: A1FI (fossil fuel intensive), A1B (balanced), and A1T (predominantly non-fossil fuel). Within each family and group of scenarios, some share "harmonized" assumptions on global population, gross world product, and final energy. These are marked as "HS" for harmonized scenarios. "OS" denotes scenarios that explore uncertainties in driving forces beyond those of the harmonized scenarios.

The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines.

The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

Table 6 Summary of four SRES storylines

	A1	**A2**
World	Market Oriented	Differentiated
Economy	Fastest Per Capita	Regionally oriented, lowest per capita growth
Population	2050 peak, then decline	Continuously increasing
Governance	Strong regional	Self reliance with preservation of local identities
Technology	Three groups: A1F1 (Fossil fuel), A1T (Non-fossil), & A1B Balanced)	Slowest and the most fragmented growth
	B1	**B2**
World	Convergent	Local solutions
Economy	Service and information based, lower growth than A1	Intermediate growth
Population	Same as A1	Continuously increasing at a rate lower than A2
Governance	Global solutions to economic, social and environmental sustainability	Regional solutions to environmental protection and social equity
Technology	Clean and resource efficient	More rapid than A2; less rapid and more diverse than A1/B1

The shortwave impact of changes in boundary-layer clouds, and to a lesser extent midlevel clouds, constitutes the largest contributor to inter-model differences in global cloud feedbacks.

3.2 Climate Models

Eighteen modeling groups performed a set of coordinated, standard experiments, and the resulting model output, analyzed by hundreds of researchers worldwide, forms the basis for much of the current IPCC assessment of model results. A total of 23 models by 18 groups are currently used by IPCC to generate the future climate change scenarios. (Randall et al., 2007). The modeling groups and models used for this purpose are mentioned in Table 7.

Table 7 AOGCMs featured in IPCC Reports.

Model	Sponsors/Country	References
CSIRO-MK3	Commonwealth Scientific and Industrial Research Organisation (CSIRO) Atmospheric Research, Australia	Gordon et al., 2002; O'Farrell, 1998.
MIROC3.2 (medres)	Center for Climate System Research (University of Tokyo), National Institute for Environmental Studies , and Frontier Research Center for Global Change (JAMSTEC), Japan	K-1 Developers, 2004; Oki and Sud, 1998.
UKMO-HadCM3	Hadley Centre for Climate Prediction and Research/Met Office, UK	Pope et al., 2000; Gordon et al., 2000; Cattle and Crossley,1995; Cox et al., 1999.

Figure 11 shows the continuation of the 20th-century simulations for warming trends. Lines show the multi-model means, shading denotes the ±1 standard deviation range of individual model annual means. Discontinuities between different periods have no physical meaning and are caused by the fact that the number of models that have run a given scenario is different for each period and scenario, as indicated by the coloured numbers given for each period and scenario at the bottom of the panel. For the same reason, uncertainty across scenarios should not be interpreted from this figure (see Section 10.5.4.6 for uncertainty estimates).

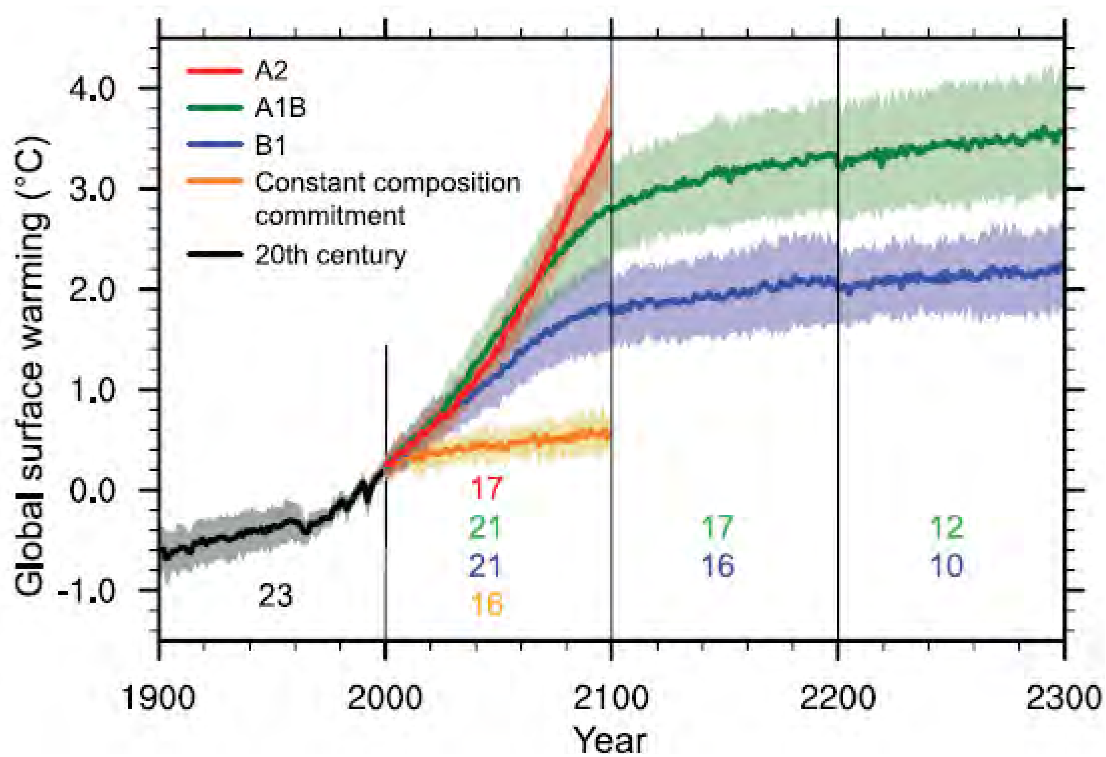


Figure 11: Multi-model means of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1. (Source: IPCC FAR)

3.3 Climate Change Projections

Accurate climate projections play a crucial role in determining the success of water management plans by providing an estimate of changes occurring to temperature and precipitation patterns which govern water availability. This section of the report compiles the climate change projections up to the end century obtained from three major coupled atmosphere-ocean general circulation models MIROC-M3, UKMO-HadCM3, and CSIRO-Mk3.0 for three emission scenarios namely A2, A1B, and B1.

Figure 12 shows the time series of globally averaged (left) surface warming (surface air temperature change, °C) and (right) precipitation change (%) from the various global coupled models for the scenarios A2 (top), A1B (middle) and B1 (bottom). Numbers in parentheses following the scenario name represent the number of simulations shown. Values are annual means, relative to the 1980 to 1999 average from the corresponding 20th-century simulations, with any linear trends in the corresponding control run simulations removed. A three-point smoothing was applied. Multi-model (ensemble) mean series are marked with black dots.

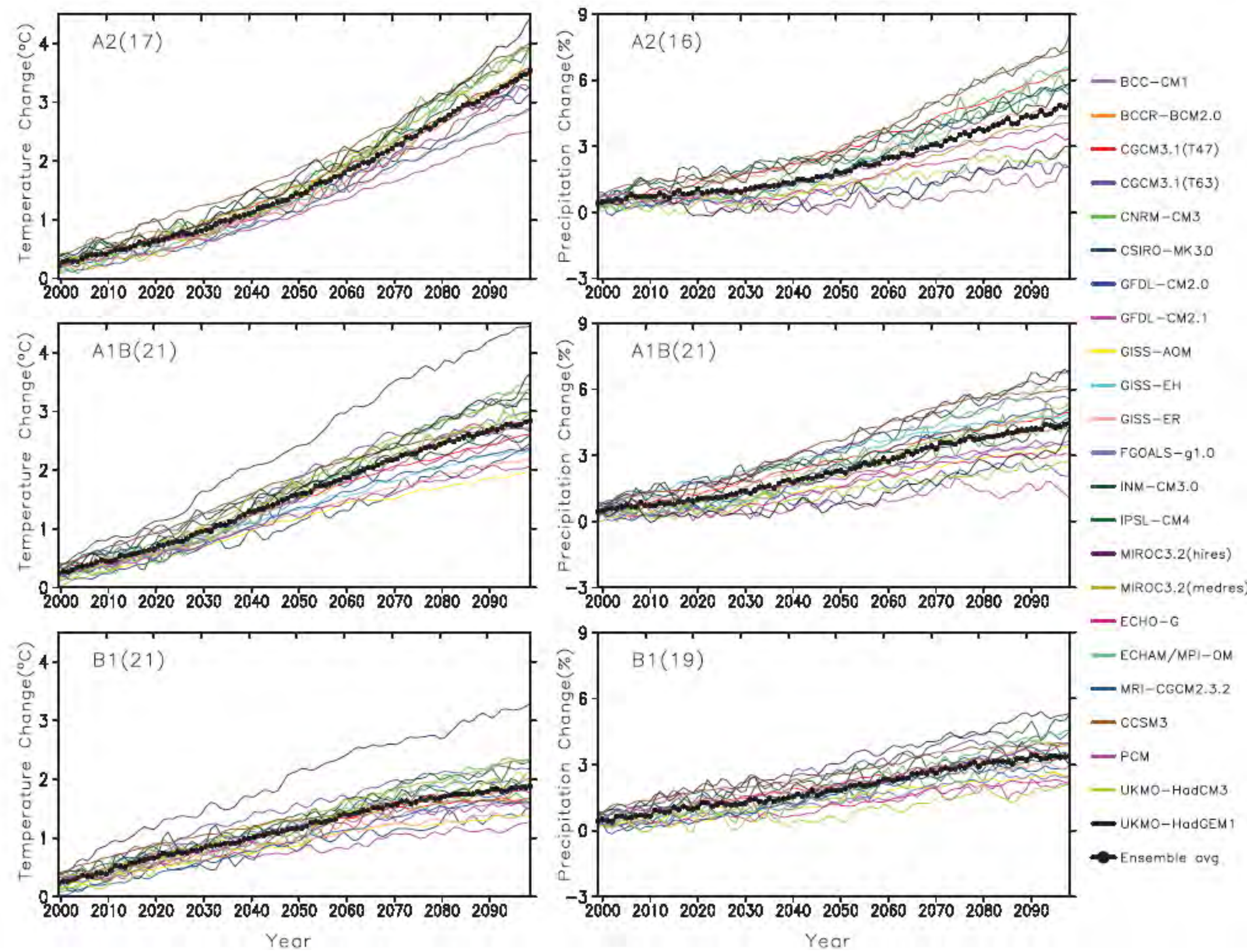


Figure 12: Time series of globally averaged surface air temperature and precipitation changes. (Source: IPCC FAR)

Confidence in climate models comes from the physical science behind their creation, and their skill at reproducing observed climate and past climate changes. Models have proven to be extremely important tools for simulating and understanding climate, and there is considerable confidence that they are able to provide credible quantitative estimates of future climate change, particularly at larger scales. Nonetheless, most models still suffer from a number of drawbacks which impose significant limitations on their results. Some of these drawbacks include their ability in representing clouds and man made aerosols etc which lead to uncertainties in the magnitude, timing, and spatial detail of predicted climate change. Nevertheless, over several decades of model development, they have consistently provided a robust and unambiguous picture of significant climate warming in response to increasing greenhouse gases at a global scale. However, since confidence in the changes projected by global models decreases at smaller scales, other techniques, such as the use of regional climate models, or downscaling methods, should be preferred for the study of regional and local scale climate change.

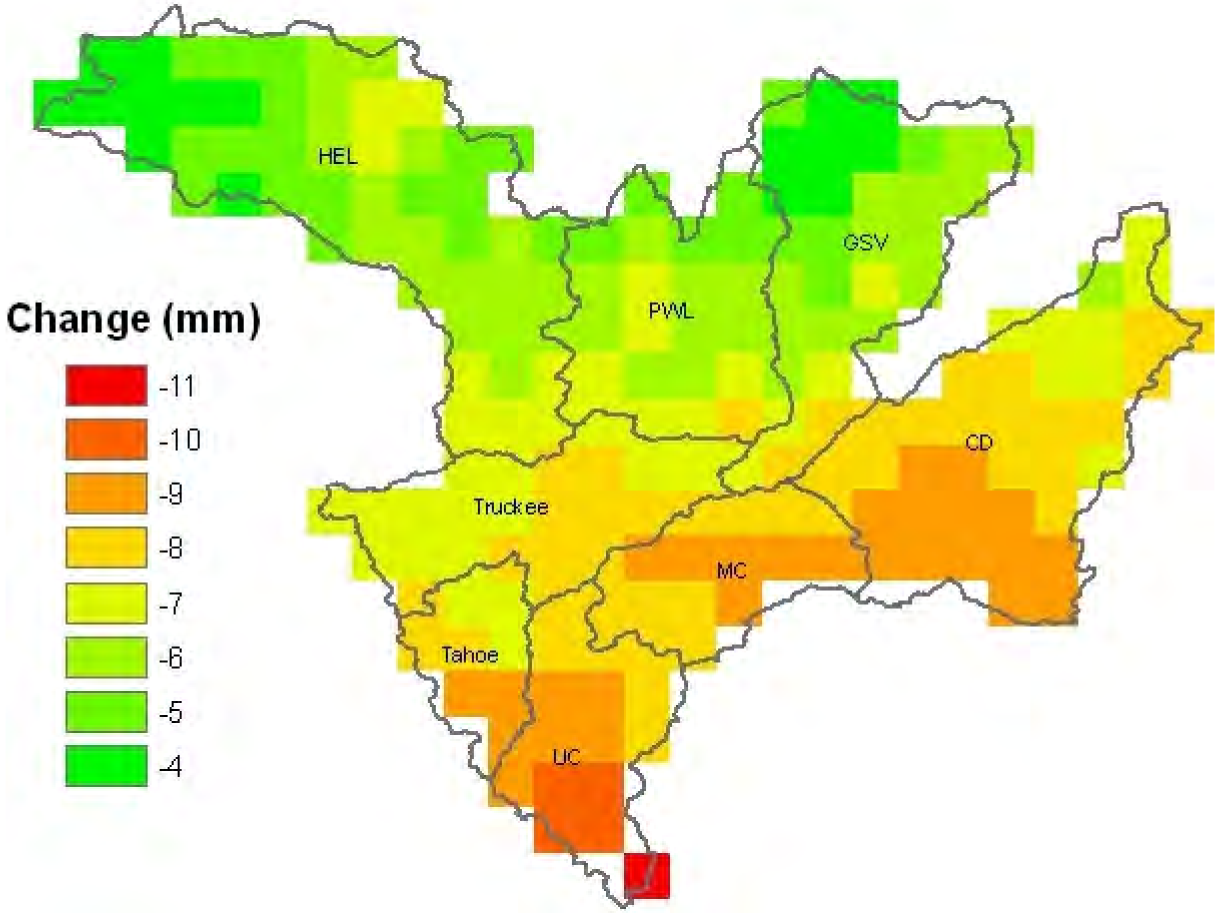


Figure 13 Precipitation change by mid 21st century as suggested by ensemble results from the three model outputs used in this study.

Figure 13 shows the anticipated mean precipitation departure by mid 21st century. The figure shows the estimated change in annual precipitation averaged over a period between 2040 and 2060. The change is compared to the mean historic data from 1961 to 1990. Figure 14 shows the reduction in precipitation by the end of 21st century. Both figures show significant decreases in annual precipitation in the high altitude regions of the study area. This region corresponds to the watershed of Lake Tahoe, Truckee River, and the Carson River and hence a decrease in precipitation in this area can significantly reduce the flow into these water bodies.

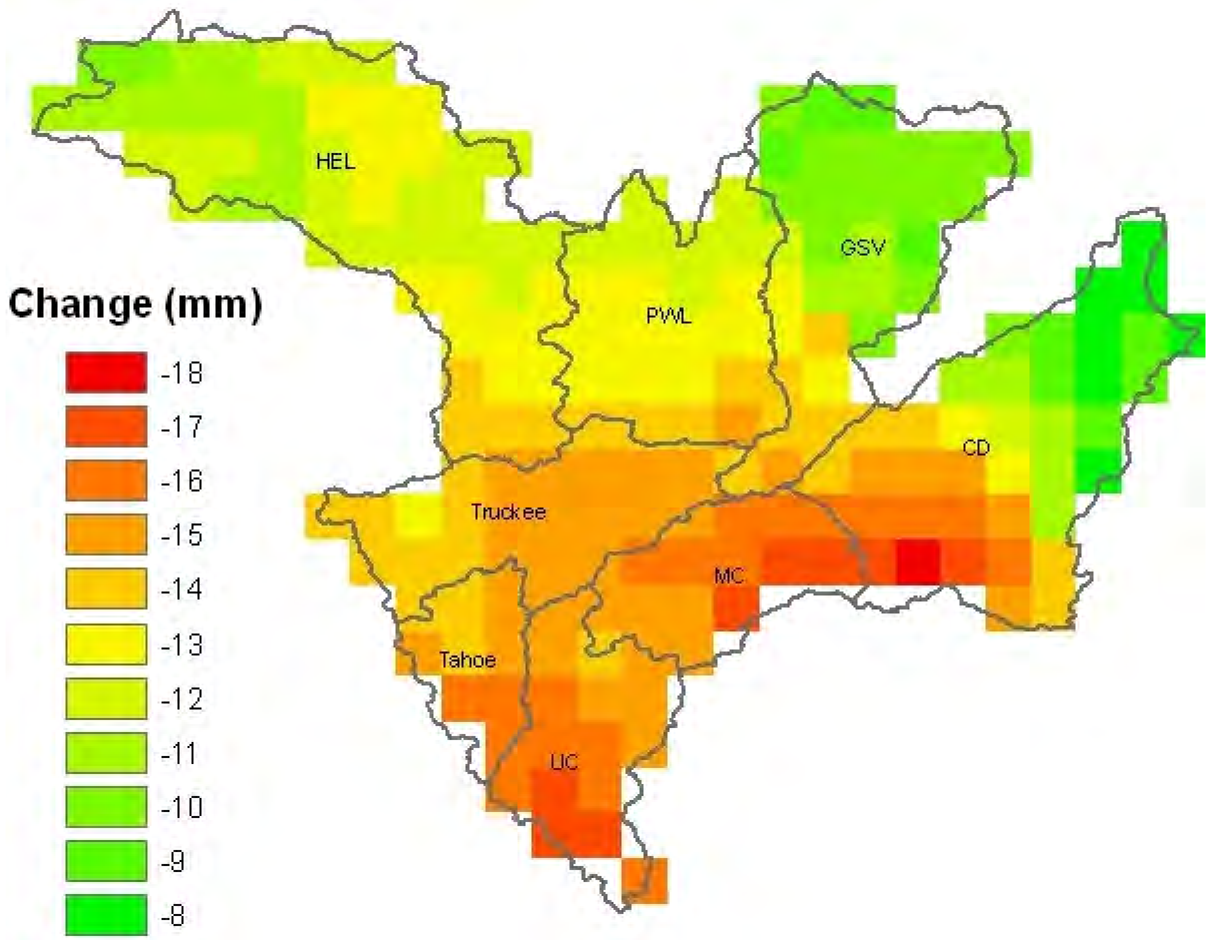


Figure 14 Precipitation change by the end of 21st century.

Table 8 and Table 9 provide a summary of the changes in precipitation and temperatures anticipated over the study area during the span of the 21st century. For all scenarios, an increase in average temperature and a decrease in annual precipitation are observed. The models predict an increase of 2.5 to 5.5 °F by 2050 and 4 to 11°F by 2100. The increase is expected to be more pronounced in the summer and fall as compared to winters and spring.

Table 8 (a-c) Ensemble average from MIROC-M3, UKMO-HadCM3, and CSIRO-Mk3.0 models Summary of anticipated changes in precipitation and temperature by mid 21st century under emission scenarios (a) A2, (b) A1B, and (c) B1.

Table 8(a)

Period	**Variable**	**Change**	**Units**
Dec-Feb	Temp	4.00	F
Mar-May		4.50	F
Jun-Aug		5.00	F
Sep-Nov		5.00	F
Annual		5.50	F
Dec-Feb	Precip	7.50	%
Mar-May		-18.50	%
Jun-Aug		-15.91	%
Sep-Nov		-7.00	%
Annual		-11.00	%

Table 8(b)

Period	**Variable**	**Change**	**Units**
Dec-Feb	Temp	4.50	F
Mar-May		3.50	F
Jun-Aug		5.50	F
Sep-Nov		5.50	F
Annual		5.50	F
Dec-Feb	Precip	-6.00	%
Mar-May		-15.00	%
Jun-Aug		-21.84	%
Sep-Nov		-14.92	%
Annual		-7.50	%

Table 8(c)

Period	**Variable**	**Change**	**Units**
Dec-Feb	Temp	3.50	F
Mar-May		2.50	F
Jun-Aug		4.50	F
Sep-Nov		4.00	F
Annual		4.00	F
Dec-Feb	Precip	-3.00	%
Mar-May		-7.00	%
Jun-Aug		-6.00	%
Sep-Nov		1.50	%
Annual		-4.50	%

Table 9 (a-c) Ensemble average from MIROC-M3, UKMO-HadCM3, and CSIRO-Mk3.0 models Summary of anticipated changes in precipitation and temperature by the end of 21st century under emission scenarios (a) A2, (b) A1B, and (c) B1.

Table 9(b)

Period	Variable	Change	Units
Dec-Feb	Temp	6.50	F
Mar-May		5.50	F
Jun-Aug		9.50	F
Sep-Nov		7.50	F
Annual		7.50	F
Dec-Feb	Precip	-11.00	%
Mar-May		-17.00	%
Jun-Aug		-16.50	%
Sep-Nov		-8.18	%
Annual		-13.00	%

Table 9 (a)

Period	Variable	Change	Units
Dec-Feb	Temp	6.50	F
Mar-May		6.50	F
Jun-Aug		11.00	F
Sep-Nov		8.50	F
Annual		8.50	F
Dec-Feb	Precip	-4.50	%
Mar-May		-29.33	%
Jun-Aug		-9.44	%
Sep-Nov		9.50	%
Annual		-7.00	%

Table 9(c)

Period	Variable	Change	Units
Dec-Feb	Temp	4.50	F
Mar-May		4.00	F
Jun-Aug		6.50	F
Sep-Nov		5.50	F
Annual		6.00	F
Dec-Feb	Precip	-12.50	%
Mar-May		-17.00	%
Jun-Aug		-17.00	%
Sep-Nov		-1.17	%
Annual		-10.50	%

4 CONCLUSIONS

Analysis of precipitation data shows that annual precipitation has increased during the last century. On dividing the trends into the four seasons, it was observed that the increase was not consistent for all the seasons. Winter precipitation has decreased over the last century whereas summer and fall precipitation has increased. Furthermore, the largest decrease in winter precipitation was experienced by the regions located at a high altitude in the Sierra Nevada Mountains. These regions are responsible for feeding Lake Tahoe, the Truckee River and the Carson River. Therefore, a decrease in winter precipitation in these regions means lesser snowpack and consequently lower inflows into the water bodies.

The results from VIC outputs show a rise in the SWE for January 1 and February 1 for all the grid cells whereas all the grid cells evaluated display a decline in April 1 SWE. These results obtained from VIC outputs are in agreement with the findings from PRISM data which suggest that precipitation during the fall season (Oct to Dec) has increased during the same period. The lowered SWE in the later half of winter months also corroborates the finding from PRISM data which shows that precipitation during the winter months has decreased.

Temperature trends for all sub regions in the study area show consistent rising trends over the last century. Increased temperatures in combination with changing precipitation patterns can change the hydrology of the study area. The results from this study cannot conclusively estimate the individual effects of temperature and precipitation changes on SWE but this combination is likely to be a major factor causing the shifting of SWE bulk towards the first half of the winters.

Future estimates from the climate models used in this study show decreases in annual precipitation throughout the study area. In addition the projections suggest a decrease in precipitation for all seasons throughout the watershed for all emission scenarios. The decreases are greater in magnitude in the high altitude regions of the study area. This region corresponds to the watershed of Lake Tahoe, the Truckee River, and the Carson River and hence a decrease in precipitation in this area can significantly reduce the flow into these water bodies. This finding however is inconsistent with the results obtained from PRISM and VIC outputs which show an increase in summer and fall precipitation in the study area over the last century. This inconsistency could be a result of the topography of the study area and the inability of climate models to generate accurate future trends for relatively small regions with abrupt changes in topography.

(notes: I have a general concern about the significance of the trend lines created in the Excel charts. The very low R^2 points one to conclude that the trend might not be statistically significant. If possible have Dinesh add 95% confidence interval to some of key statistics. I am going to try to do some time series test on some of the data to see if the trend lines are significant.

5 REFERENCES

Cattle, H., and J. Crossley (1995) *Modelling Arctic climate change*. Philos. Trans. R. Soc. London Ser. A, 352, 201–213.

Cayan, D. R., S. A. Kammerdiener, M. D. Dettinger, J. M. Caprio, and D. H. Peterson, (2001) *Changes in the onset of spring in the western United States*. Bull. Am. Meteor. Soc., 82, 399–415.

Cayan, D. R., E. P. Maurer, M. D. Dettinger, M. Tyree and K. Hayhoe (2008) *Climate Change Scenarios for the California Region*. Clim. Change 87, 21-42.

Christensen, N. S., A. W. Wood, D. P. Lettenmaier, and R. N. Palmer (2004) *Effects of Climate Change on the Hydrology and Water Resources of the Colorado River Basin*. Clim. Change 62, 337–363.

Cox, P.M., et al., (1999) *The impact of new land surface physics on the GCM simulation of climate and climate sensitivity*. Clim. Dyn., 15, 183–203.

Daly, C., R.P. Neilson, and D.L. Phillips (1994) *A Statistical-Topographic Model for Mapping Climatological Precipitation over Mountanious Terrain*. J. Appl. Meteor., 33, 140-158.

Daly C, G. H. Taylor, W. P. Gibson, T. W. Parzybok, G. L. Johnson, P. Pasteris (2001) *High-quality spatial climate data sets for the United States and beyond*. Trans. Am. Soc. Agric. Eng. 43:1957–1962

Daly, C., W. P. Gibson, G. H. Taylor, G. L. Johnson, P. Pasteris.(2002) *A knowledge-based approach to the statistical mapping of climate*. Clim. Res., 22, 99-113.

Dettinger, M. D. (2005) *From Climate Change Spaghetti to climate change distributions for 21st Century*, San Francisco Estuary and Watershed Science, 3(1).

Dettinger, M. D., and D. R. Cayan (1995) *Large-scale atmospheric forcing of recent trends toward early snowmelt runoff in California*. J. Clim., 8, 606–623.

Giorgi, F. and L. O. Mearns (1991) *Approaches to the simulation of regional climate change: A review*. Reviews in Geophysics, 29, 191-216.

Giorgi, F., C. S. Brodeur, and G. T. Bates (1994) *Regional climate change scenarios over the United States produced with a nested regional climate model: Spatial and seasonal characteristics.* J. Clim. 7, 375–399.

Gordon, C., et al., (2000): *The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments*. Clim. Dyn. 16, 147–168.

Gordon, H.B., et al., (2002) *The CSIRO Mk3 Climate System Model*. CSIRO Atmospheric Research Technical Paper No. 60, Commonwealth Scientific and Industrial Research Organisation Atmospheric Research, Aspendale, Victoria, Australia, 130 pp, http://www.cmar.csiro.au/e-print/open/gordon_2002a.pdf.

Groisman, P. Y., R. W. Knight, T. R. Karl, D. R. Easterling, B. Sun and J. H. Lawrimore (2004) *Contemporary changes of the hydrological cycle over the contiguous United States: trends derived from in situ observations*. J. Hydrometeorol., 5, 64-85.

Hamlet A. F., D. P. Lettenmaier (2005) *Production of Temporally Consistent Gridded Precipitation and Temperature Fields for the Continental U.S.* J of Hydrometeorol. 6 (3), 330-336.

Hamlet, A. F. and D. P. Lettenmaier (1999) *Effects of Climate Change on Hydrology and Water Resources in the Columbia River Basin*. J. of Am. Water Res Assn 35(6), 1597–1623.

Hengeveld, H., B. Whitewood and A. Fergusson (2005) *An Introduction to Climate Change: A Canadian Perspective*. Environment Canada, Downsview, Ontario, 55 pp.

IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Karl, T. R., P. Y. Groisman, R. W. Knight, and R. R. Heim (1993) *Recent variations of snow cover and snowfall in North America and their relations to precipitation and temperature variations*. J. of Clim. 6, 1327–1344.

Kim, J. (2005) *A projection of the effects of the climate change induced by increased CO2 on extreme hydrologic events in the western U.S.,* Clim. Change.

Knowles, N., M. D. Dettinger, and D. R. Cayan (2006) *Trends in snowfall versus rainfall in the Western United States*, J. Clim. 19, 4545– 4559.

Labat, D., Y. Godderis, J.L. Probst, J.L. Guyot, (2004) *Evidence for global runoff increase related to climate warming*. Adv. in Water Res. 27, 631–642.

K-1 Model Developers, (2004): *K-1 Coupled Model (MIROC) Description*. K-1 Technical Report 1 [Hasumi, H., and S. Emori (eds.)]. Center for Climate System Research, University of Tokyo, Tokyo, Japan, 34 pp. http://www.ccsr.u-tokyo.ac.jp/kyosei/hasumi/MIROC/tech-repo.pdf.

Kunkel, K. E. (2003)*Temporal variations of extreme precipitation events in the United States: 1895-2000*. Geophys. Res. Lett., 30.

Lemke, P., et al. (2007*) Observations: Changes in snow, ice and frozen ground, in Climate Change 2007: The Physical Science Basis*. edited by S. Solomon et al., pp. 337–383, Cambridge Univ. Press, New York.

Lettenmaier, D. P., E. F. Wood, and J. R. Wallis (1994) *Hydroclimatological trends in the continental United States, 1948–88*. J. Clim, 7, 586–607.

Leung, L. R., Y. Qian, and X. Bian (2003) *Hydroclimate of the western United States based on observations and regional climate simulation of 1981– 2000, part I: Seasonal statistics*, J. Clim., 16(12), 1892– 1911.

Maurer, E. P., A. W. Wood, J. C. Adam, D. P. Lettenmaier, and B. Nijssen (2002) *A Long-Term Hydrologically Based Dataset of Land Surface Fluxes and States for the Conterminous United States*. J. of Clim. 15, 3237-3251.

Maurer, E. P. (2007) *Uncertainty in hydrologic impacts of climate change in the Sierra Nevada, California under two emissions scenarios*. Clim. Change, 82, 309–325.

Maurer, E. P. and P. B. Duffy (2005) *Uncertainty in projections of streamflow changes due to climate change in California*. Geophys. Res. Lett., 32.

Mearns, L., F. Giorgi, L. McDaniel, and C. Shields (1995a) *Analysis of daily variability of precipitation in a nested regional climate model: Comparison with observation and doubled CO2 results.* Global Planet. Change 10, 55–78.

Mearns, L., F. Giorgi, L. McDaniel, and C. Shields (1995b) *Analysis of variability and diurnal range of daily temperature in nested regional climate model: Comparison with observation and doubled CO2 results*. Clim. Dyn. 10, 55–78.

Millar, C. I., W. B. Woolfenden (1999) *The Role of Climate Change in Interpreting Historical Variability*. Ecological Applications 9(4), 1207-1216.

Mote, P. W. (2003) *Trends in snow water equivalent in the Pacific Northwest and their climatic cause*s. Geophys. Res. Lett., 30, 1601, doi: 10.1029/2003GL017258.

Mote, P. W., A. F. Hamlet, M. P. Clark, and D. P. Lettenmaier (2005) *Declining mountain snowpack in western North America*. Bull. Amer. Meteor. Soc., 86, 39–49.

Nanus, L., D. H. Campbell, G. P. Ingersoll, D. W. Clow, and M. A. Mast, (2003) *Atmospheric deposition maps for the Rocky Mountains.* Atm. Env. 37, 4881–4892.

O’Farrell, S.P. (1998) *Investigation of the dynamic sea ice component of a coupled atmosphere sea-ice general circulation model*. J. Geophys. Res.,103, 15751–15782.

Oki, T., and Y. C. Sud (1998): *Design of total runoff integrating pathways (TRIP)—A global river channel network*. Earth Interactions 2, 1–37.

Payne, J. T., A. W. Wood, A. F. Hamlet, R. N. Palmer and D. P. Lettenmaier (2004). *Mitigating the effects of climate change on the water resources of the Columbia River basin*. Clim. Change 62, 233-256.

Pierce, D. W., T. P. Barnett, H. G. Hidalgo, T. Das, C. Bonfils, B. D. Santer, G. Bala, M. D. Dettinger, D. R. Cayan, A. Mirin, A. W. Wood and T. Nozawa (2008) *Attribution of Declining Western U.S. Snowpack to Human Effects*. J. Climate, 21, 6425-6444.

Pope, V.D., M.L. Gallani, P.R. Rowntree, and R.A. Stratton (2000) *The impact of new physical parametrizations in the Hadley Centre climate model: HadAM3*. Clim. Dyn., 16, 123–146.

Pupacko, A. (1993) *Variations in northern Sierra Nevada streamflow: Implications of climate change.* Water Resour. Bull. 29(2), 283-290.

Randall, D. A., R. A. Wood, S. Bony, R. Colman, T. Fichefet, J. Fyfe, V. Kattsov, A. Pitman, J. Shukla, J. Srinivasan, R. J. Stouffer, A. Sumi and K. E. Taylor (2007) *Cilmate Models and Their Evaluation. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Regonda, S. K., B. Rajagopalan, M. Clark, and J. Pitlick (2005) *Seasonal cycle shifts in hydroclimatology over the western United States*. J. Climate 18, 372–384.

Rood, S. B., G. M. Samuelson, J. K.Weber and K. A.Wywrot (2005) *Twentieth-century decline in streamflows fromthe hydrographic apex of NorthAmerica*. J. Hydrol. 306, 215-233

Shein, K. A. (2006) *State of the climate in 2005, including executive summary*. Bull. Amer. Meteorol. Soc., 87, 801-805,

Stewart, I. T., Cayan, D. R., Dettinger, M. D. (2004) *Changes in snowmelt runoff timing in western North America under a 'business as usual' climate change scenario.* Clim. Change, 62, 217-232.

Stewart, I.T., Cayan D. R., Dettinger, M. D. (2005) *Changes toward Earlier Streamflow Timing across Western North America*. J. Clim., 18(8), 1136–1155.

Seager R., Ting M., Held I., Kushnir Y., Lu J., Vecchi G., Huang H. P., Harnik N., Lau N. C., Li C. et al. (2007) *Model projections on an inminent transition to a more arid climate in southwestern North America*. Science 316: 1181– 1184.

Trenberth, K. E., A. Dai, R. M. Rasmussen, and D. B. Parsons (2003) *The changing character of precipitation*. Bull. Amer. Meteor. Soc., 84, 1205–1217.

Trenberth, K. E., L. Smith, T. Qian, A. Dai, and J. Fasullo (2007), *Estimates of the global water budget and its annual cycle using observational and model data*, J. Hydrometeorol. 8, 758-769.

US Census Bureau, Population Division. http://www.census.gov/popest/cities/SUB-EST2008-states.html Retrieved on July 18, 2009.

VanRheenen, N. T., A. W. Wood, R. N. Palmer and D. P. Lettenmaier (2004) *Potential Implications of PCM Climate Change Scenarios for California Hydrology and Water Resources*. Clim. Change 62, 257–281.

Vicuna S., E. P. Maurer, B. Joyce, J. A. Dracup, D. Purkey (2007) *The sensitivity of California water resources to climate change scenarios*. J Am Water Res Assoc 43(2): 482 –498

Vincent, L. A., X. Zhang, and W. D. Hogg (1999) *Maximum and minimum temperature trends in Canada for 1895–1995 and 1945–1995*. 10th Symp. on Global Change Studies, Dallas, TX, Amer. Meteor. Soc., 95–98.

Walter, M. T., D. S. Wilks, J.-Y. Parlange, and R. L. Schneider (2004*) Increasing evapotranspiration from the conterminous United States*, J. Hydrometeorol., 5, 405– 408.

6 APPENDICES

6.1 Processing steps for PRISM Dataset

Step 1.Downloading Data: PRISM data can either be downloaded interactively from (http://mole.nacse.org/prism/nn/index.phtml?vartype=ppt&year0=2003&year1=2003) or from the PRISM Group's ftp site (ftp://prism.oregonstate.edu/pub/prism/us/grids/)

Step 2.Unzipping: The files downloaded from the sources mentioned in Step 1 were unzipped and converted to ascii files by changing the extension to <*.asc>. Due to a large number of files, individual unzipping would have been impractical. Therefore, "7-zip" freeware was used for this process.

Step 3.Processing in ArcGIS: Resulting files from Step 2 were imported into ArcGIS and converted into raster format. "Modelbuilder" feature in ArcMap was used to automate the processing of files for this step and all other subsequent steps due to the large number of files.

Step 4.Raster files obtained from Step 3 were then clipped using the watershed shapefiles.

Step 5.Attributes tables were created for all the clipped raster files.

Step 6.Additional field ("precip" for precipitation files and "temp" for temperature files) was created in the attributes tables for the clipped raster files to hold the product of the fields "Value" and "Count".

Step 7."Summary Statistics" tool in ArcMap was used to obtain the mean of the field "precip/temp" and sum of the field "count". In addition,

Step 8.Summary statistics obtained as *.dbf files, for each corresponding raster file, were converted into *.xls files for processing in Matlab.

Step 9.A Matlab program was used to read the statistics of "precip/temp" and "Count" from the .xls files created in Step 8.

Step 10.The average temperature or depth of precipitation over the watershed were calculated using

$$\mathrm{X} = \mathrm{Y} \times C / P$$

Where
X =
Y = precip or temp read in Step 9
C = Count read in Step 9
P = Number of pixels the raster file for the corresponding watershed.

6.2 Notes:

ArcMap was unable to process all the files simultaneously using Modelbuilder. Therefore, files were processed one watershed at a time.

Due to naming protocols in ArcMap, files obtained after processing had complicated names. Renaming was found to be useful to prevent mixing up of files.

Theoretically it is possible to combine Steps 3 to 8 in one model but difficulties were encountered while running these processes in a single model. Modelbuilder failed to execute certain steps when multiple processes were combined in a single model.

The following Matlab code was used to execute the process described in Step 9.

```
xlsFiles = dir(‘Path\*.xls')
Matrix = zeros (length(xlsFiles),1)
for k = 1:length(xlsFiles);
  filename = xlsFiles(k).name
  data = xlsread(filename, 'a2:a2')
  Matrix(k) = data
end
xlswrite ('Path’\output_filename.xls', Matrix, 'Sheet1')
```

APPENDIX 2-2

Appendix Still Pending

APPENDIX 2-3

Cloud Seeding Report

2014

Annual Report

Cloud Seeding Project for Tahoe and Truckee Basins for WY2015:
Status Update for Oct 2014 -June 2015

Submitted to

Mr. Jeff Tissier
Truckee Meadows Water Authority
1355 Capital Blvd
Reno, NV 89502

By

Frank McDonough, Project Manager

Division of Atmospheric Sciences
Desert Research Institute

July 10, 2014

2215 Raggio Parkway, Reno, Nevada 89512-1095
Phone (775) 673-7300 Fax (775) 673-7397

1. Introduction

The goals of the DRI cloud seeding efforts in the Tahoe/Truckee Basin remain essentially the same from previous years: to enhance snowfall from winter storms and to increase the snowpack of the Tahoe and Truckee Basins through the application of wintertime cloud seeding technology. This report constitutes an update on project status for the first three quarters of the TMWA/WRWC grant period, covering 1 Oct 2014 -30 June 2015.

1.1. Brief Project Description

The project design and method of operation are the same as those used for the previous few seasons. Seeding is conducted from a line of five ground-based cloud seeding generators (CSGs) positioned on, or a few miles upwind of, the main Sierra Nevada crest to the west of Lake Tahoe (Fig. 1). The generators are positioned to take advantage of the generally westerly to southwesterly wind directions in winter storms in the Tahoe area, and are remotely activated by DRI staff when the proper weather and cloud conditions for seeding were verified. Forecasting for potential cloud seeding events during WY2015 began on November 1, 2014 and continued until May 28, 2015.

2. Summary of Phase 1 Activity

Activity under Phase 1 of the project was concluded during the first quarter and included preparation of the five seeding generators at the locations shown in Fig. 1. This work required several weeks, and included re-installation of the Barker generator as required by USFS permits for use of the site. Additional Phase 1 tasks included refilling the seeding solution tanks, refilling propane tanks, and testing all generator components and communications links.

3. Summary of Phase 2 Activity

Phase 2 of the project includes the actual cloud seeding operations and supporting work such as forecasting and real time monitoring of weather over the Tahoe target area. The project meteorologists monitor the weather and make forecasts for seeding events that are expected within one to five days. Throughout Phase 2 the cloud seeding field technicians and project meteorologists made at least weekly checks of cloud seeding equipment by logging into the data loggers, briefly activating the units and monitoring key operating parameters such as flame temperature and solution flow.

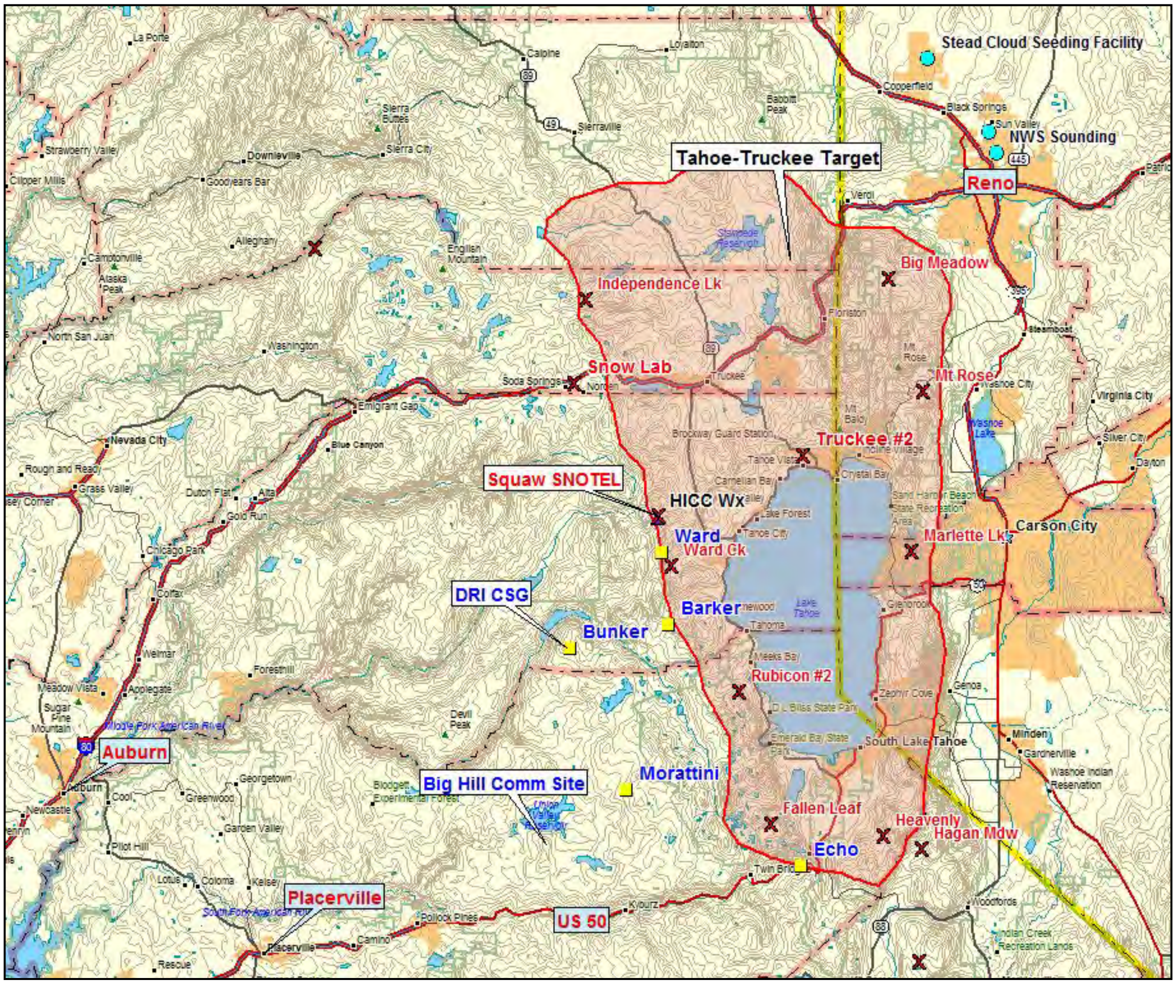


Figure 1. Map showing the Tahoe-Truckee cloud seeding target area (red shading) and instrument sites in and around the target area. NRCS SNOTEL sites, which measure precipitation and snow water equivalent (SWE) are indicated by red Xs. Ground seeding sites are shown as yellow squares. Reno facilities are shown in the upper right as cyan-colored circles. Weather data shown in Section 4 of this report were collected near the sites labeled Snow Lab, Squaw SNOTEL, and NWS Sounding.

3.1. Summary of Tahoe-Truckee Cloud Seeding Operations

The cloud seeding activity during Phase 2 that occurred through the winter season are presented in this report. By the end of May a total of 20 seeding operations had been conducted, with the final seeding operation of Phase 2 on 24-25 April 2015. Figure 2 shows the monthly totals for seeding hours and seeding events for all of WY2015. For the season there were a total of 681 seeding hours conducted over 20 separate events. The details of all operations are given in Appendix A. The record warm and dry winter led to lower total seeding hours than the previous seasons that the project has been funded by TMWA and WRWC. An analysis of generator operating efficiency (*ratio of actual seeding hours to total hours possible if all CSGs had operated correctly throughout all events*) for the season produced a value of 90%, which is significantly improved from last season. Poor communication to the Bunker Hill site caused the biggest loss of seeding hours. A few other problems, such as ignition failures, low flow, and depleted solution were also encountered, but were typically dealt with quickly and lead to fewer lost hours compared to the communication problem.

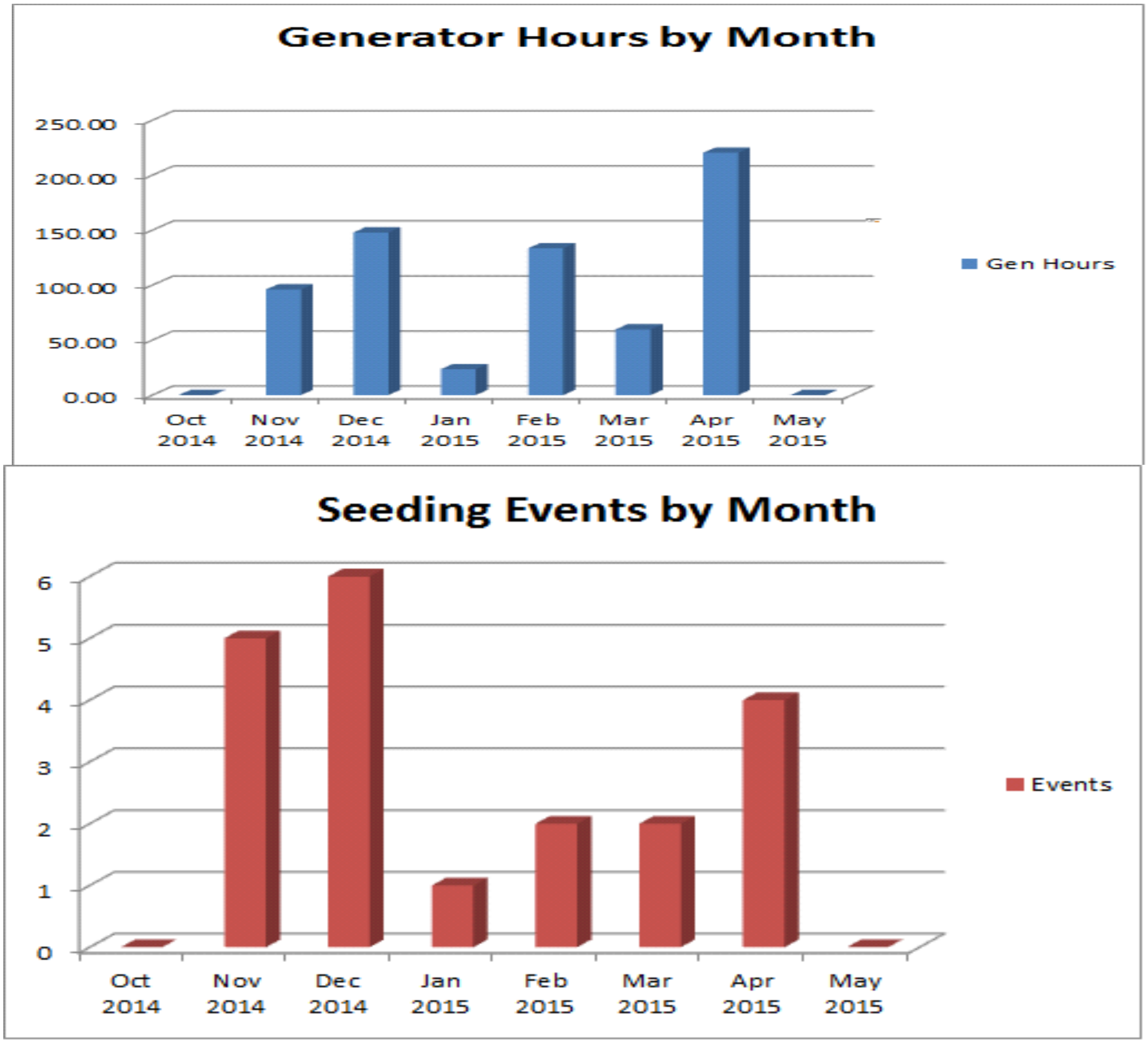


Figure 2. Monthly summaries for Tahoe-Truckee area cloud seeding operations in WY2015. Top panel shows CSG seeding hours by month and bottom panel shows the number of seeding events by month.

3.2. Water Year Summary

Figure 3 documents the history of snowwater liquid equivalent (SWE) accumulations (relative to 30-year median values) in the Tahoe and Lower Truckee Basins for WY2015. The winter season was again dry, with the snowpack's SWE only briefly reaching 50% of the median in late December.

Snowfall was minimal through much of the late fall. A set of warm storms in early December increased the snowpack somewhat, but SWE in both the Tahoe and the lower Truckee basins were at about 30% of the median values by the end of a very dry January. SWE remained exceptionally low as a set of very and wet warm rainstorms moved through area in early February. Storms in early February only increased the SWE in the highest elevations of the Tahoe Basin and lower Truckee Basin. Only a few additional storms occurred though the second half of the calendar winter and a very warm early spring in March allowed the low SWE values to go to near zero. A few spring storms added a bit of snow in April but only minimally added to the SWE.

The winter snowfall history at specific SNOTEL sites in the Truckee Basin is documented in Fig. 4. The sites shown vary in location (see Fig. 1) and altitude. The Central Sierra Snow Lab (CSSC) is the lowest site (6255 ft.) located upwind (west) of the main Sierra Nevada crest. Squaw is just above 8000 ft. and located slightly downwind (east) of the Sierra crest, and Big Meadow the highest site at 8250 ft. is in the Carson Range on the east side of Lake Tahoe. The warm early December storm seemed to only impact the Sierra Crest (Big Meadow showed no increase in SWE) is shown in Fig. 4, as is the extended dry period that encompassed most of January 2015. The second big warm storm occurred in early February, with Squaw SWE increasing by 5 inches. A storm in late February added slightly to the SWE at all three sites. By the end of March the snow was gone from both CSSL and Big Meadow, and less than 2-inches at Squaw. The 30-year median SWE at Squaw on March 31 is just under 50-inches. A late April storms briefly increased the snowpack at all three sites.

2215 Raggio Parkway, Reno, Nevada 89512-1095
Phone (775) 673-7300 Fax (775) 673-7397

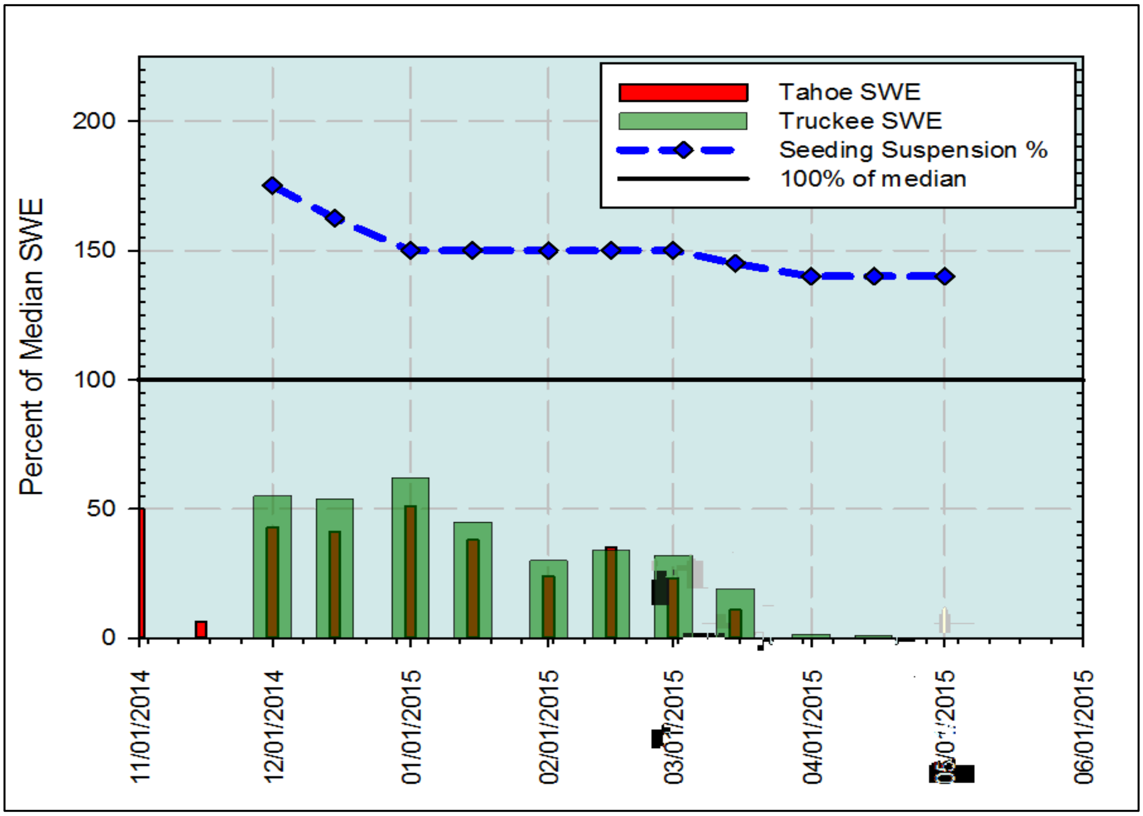


Figure 3. Snow water equivalent (SWE) percentages relative to 30-year median values for the Lower Truckee and Tahoe Basin for WY2015. Black line highlights 100% of the median. Blue dashed line shows SWE percentage thresholds at which cloud seeding is suspended due to above normal snowpack. Wide green bars show Truckee Basin SWE and thin red bars show Tahoe Basin

4. Summary of Phase 3 Activity

The phase 3 work typically begins in late May after the end of all seeding operations and includes the analysis of weather data during cloud seeding periods, an estimate of snow water augmentation from the season's seeding, and final postseason maintenance work on the CSG network. Maintenance includes removal of the Barker CSG because of its accessibility to the public during the summer. This was done in June this year. The ordering of expendable supplies for future operations also generally occurs as part of Phase 3, and this will be done during the final quarter of the contract period.

All of the significant storm systems in WY 2015 were warmer than normal and thus seeding conditions were not always optimal. In addition, some of these storms were characterized by relatively low atmospheric stability, such that the associated clouds were often more of a convective nature than the stratiform clouds observed in many wintertime storms in the Sierra Nevada range. With such convective clouds, updrafts of up to 10 m/s are possible, allowing seeding material to reach greater altitudes and colder temperature than is possible with stratiform cloud systems. Thus, it is quite possible that even when temperatures are warmer than -5°C at 700 mb (10,000'), the seeding material can be taken to somewhat higher altitudes within the clouds where supercooled liquid water at temperatures less than -5°C are present. Because of this, seeding strategies were modified somewhat for this period. The strategy allows seeding to commence for 700 mb. temperatures between 0°C and -5°C if it was determined that either convective clouds were already present over generator sites or that sufficient atmospheric instability (as determined from observed and model forecast temperature and moisture profiles) was present to promote convective cloud development.

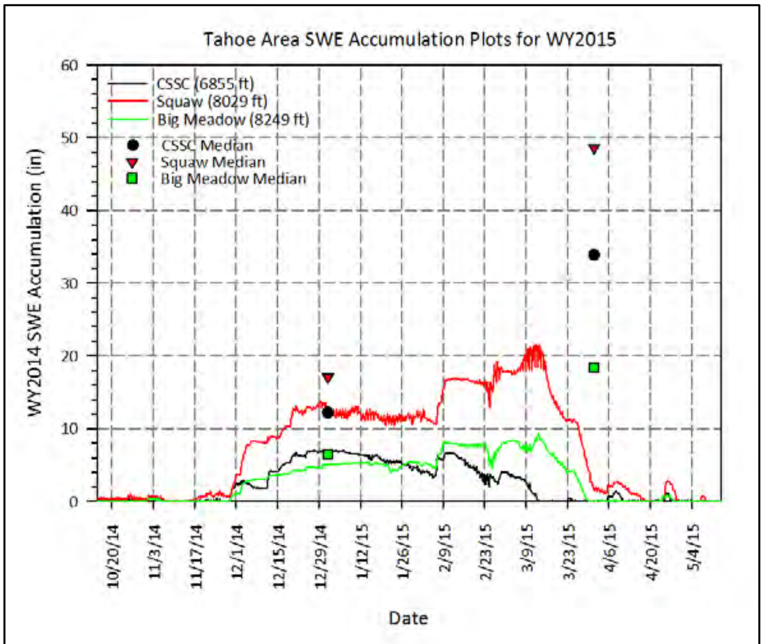


Figure 4. SWE accumulation plots for three SNOTEL sites in the Tahoe-Truckee River Basin. Note the locations in Fig. 1.

A complete assessment of weather conditions during seeding events is part of the Phase 3 analyses. The weather data and seeding periods for November 2014 are shown in Fig. 5. The season started quickly with a seeding event on November 1st. The next 3 weeks were too warm for operations. A complex set of storms moved through the area late in the month. These storms were not that cold, but the periods with 10,000' MSL temperatures colder than -5°C and the more unstable periods were seeded.

In early December (Fig. 6) a very wet but warm storm ('Pineapple Express') moved across the Sierra under southwesterly flow. This system was much to warm to seed. By December 12 at 10,000' MSL temperatures cooled below -5°C and several seeding events were conducted though the middle of the month. A cold storm ('Inside Slider') moved just east of the area on December 24-25 but winds were from the east throughout this event. January 2015 was quite dry and much warmer than the climatological normal (Fig. 7). There was only one seeding event in an unstable atmosphere at the end of the month with light precipitation.

At the end of first week of February 2015 (Fig. 8) a pair of warm and very wet 'Pineapple Express' storms moved across the area under southwesterly flow aloft. Most of the precipitation fell as rain, even across the highest elevations of the Sierra Crest. The end of the second event was seeded as the temperatures cooled and winds became more westerly. At the end of the month a colder Gulf of Alaska storm moved across the area. This entire event was seeded. March 2015 (Fig. 9) was also quite warm and dry. A brief event was seeded on March 2 and second stronger event on March 22. April 2015 (Fig. 10) was somewhat more active than earlier in the season with 4 events in the month. The first two storms of the month were cold with winds from the northwest and ideal cloud seeding conditions. A short event occurred as a cold front crossed the Sierra on April 14. Late in the month a cold front again crossed the area, which allowed an extended period of cloud seeding with 10,000' MSL temperatures colder than -5^{o}C, low clouds, and winds generally from the northwest.

The WY2015 seeding events are summarized in Fig. 11 where several weather variables are averaged or totaled over each seeding period. An hour was added to the end of each analysis period to account for any continued effects from seeding after CSGs were shut down. The data from the Tahoe City Snotel has replaced the Squaw Valley base data set, since that data set has been shown to be unavailable for extended periods of time in previous seasons. These two sites are close to each other and at about the same elevation. Figure 11 indicates that the 20 seeding events generally met all project seeding criteria. Exceptions were Events 4, 12 and 13, which had 700 mb. temperatures slightly higher than the -5^{o} C seeding threshold. The events 12 and 13 both were under unstable conditions where the seeding material would be expected to mix higher than the normal threshold and to colder levels of the clouds. Seventeen of the 20 events had measureable precipitation, although four events had less than 0.2 in. The differences in precipitation amounts between the observation stations were significant this winter. CSSL or the Squaw SNOTEL in the main Sierra Nevada range typically record the most precipitation, although Mt Rose in the Carson Range recorded more than Squaw during four events. The most precipitation (2.2 in) during any single seeding event was recorded at Squaw in late April.

There were several different 700 mb. wind direction regimes during seeding events in WY2015. Seven events had a more west to northwesterly flow pattern. All but one (event 12) of these 7 events had temperatures below the 5^{o} C seeding threshold. The remainder of the events had more typical south to southwesterly flow including all of the unseeded Pineapple Express storms.

In estimating the effect of seeding on snow water equivalent in the following section, the data in Figs. 11 and the data plots like Fig. 5 were first used to determine a seedability factor (SF) for each seeding period. The SF semi-quantitatively estimates how well the project seeding criteria were satisfied for each event. If cloud cover, wind and temperature criteria are all satisfied, then SF is one. If the wind criterion is only satisfied during half of an event then SF drops to 0.5. For the temperature criterion SF is reduced if the 700mb temperature is above -5^{o} C; from 0.9 for the first degree above -5^{o}, down to 0.2 at -1^{o}, and 0 at or above freezing. This reduction in SF was applied to stratiform atmospheric cloud structures. For convective cloud structures the temperature threshold (SF = .95) was increased to -3.5^{o}C with the SF linearly decreasing and set to 0 at the freezing level. To estimate snow water augmentation for the season an event duration-weighted value of SF was computed and found to be 0.92.

The 2 new TMWA/WRWC high-resolution snow gauges (one in Hope Valley and one above Incline Village) will help reassess the weather and resulting impacts from cloud seeding.

WY2015 Snow Water Augmentation Estimate

The analysis of weather events and seeding criteria in the previous section and from other analysis indicated that the project seeding criteria were identified in realtime a high percentage of the time during the winter of 2014-15. As noted in the previous section the estimate of snow water increase from seeding is factored according to the percent of time that criteria are met. As indicated above the seedability factor (SF) was computed to be 0.92. Our original proposal indicates that the expected benefit from cloud seeding is an increase in the precipitation rate of 0.25 mm per hour (~0.01 inch per hour). Past studies of seeding plume dispersion over mountainous target areas, and documentation of the fallout area (of snow) within a seeding plume, have shown that the area affected by one seeding generator is approximately 35 square miles. This area of effect will vary as cloud conditions and wind speed vary, and can also change as the dimension of the mountain barrier along the wind direction changes. For simplicity (and because all the parameters affecting area cannot be precisely evaluated) the area is taken as a constant.

Following previous years, the estimate of the amount of snow water produced by seeding (W_s) is provided by multiplying the total time of generator operation (T_s = 681.35 hours) by the precipitation rate increase (P_s = 0.25 mm per hour). This product is then multiplied by the area of effect (A_s = 35 sq. miles), and then by SF (0.92). To obtain the estimate in units of acre-feet the following conversions are also needed:

0.25 mm = 0.00328 ft.
1 sq. mile = 640 acres.

So, for the 2014-15 winter season the estimated snow water increase from seeding is:

W_s = 681.35 h x 0.25 mm/h x 0.00328 ft/mm x 35 sq mi x 640 acres/sq mi x 0.92

$W_s \approx$ 11,513 acre-feet.

A comparison of seeding operations in the current water year with those from 18 prior years is shown in Fig. 12. The comparison includes Nevada state-funded program water years 1998 to 2009, and the years of TRF and TMWA/WRWC sponsorship. The top panel also shows the number of seeding generators used in each season. Snow water augmentation estimates were computed using the same method for all seasons except the first three shown, when the seedability factor was not used. Seeding hours tend to reflect the frequency of storms in a given year, thus the lower number of hours during the drier years from 2007 through 2009. However, lower seeding hours can also occur in very wet years like 2000 when seeding was suspended during flooding events. WY2011 is also something of an anomaly since seeding hours were about 72% of the 16-year average (due to the snowpack suspension in April and May), but the storm frequency was well above average. The WY2015 snow water augmentation estimate was about 78% of the 16-year average of 14,643 acre-feet.

5. Budget and Expenditures

The project has gone as planned and is on budget. A final expenditures spreadsheet will be submitted to the sponsor in the fourth quarter of WY2015.

Reference

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang, and J. G. Powers, 2007: A description of the Advanced Research WRF Version 2. NCAR Tech. Note NCAR/TN-4681STR, 88 pp.

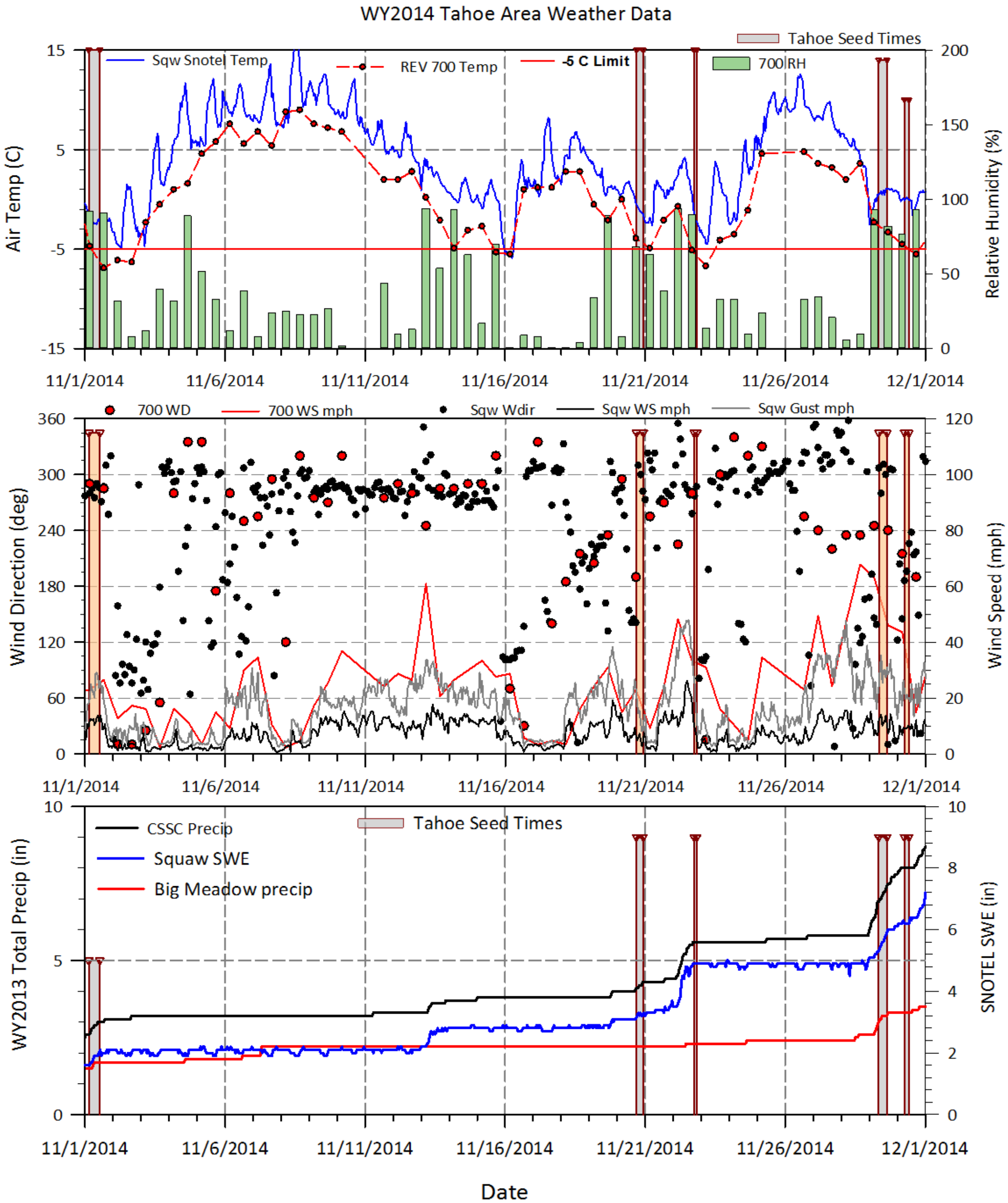


Figure 5. Tahoe area weather data and cloud seeding periods (shaded regions) for November 2014. Top panel shows 700 mb. temperature and relative humidity, and Squaw SNOTEL temperature. Middle panel shows wind data at 700 mb. and Squaw, and bottom panel presents precipitation or SWE accumulation at CSSL, and Squaw and Big Meadow SNOTEL sites.

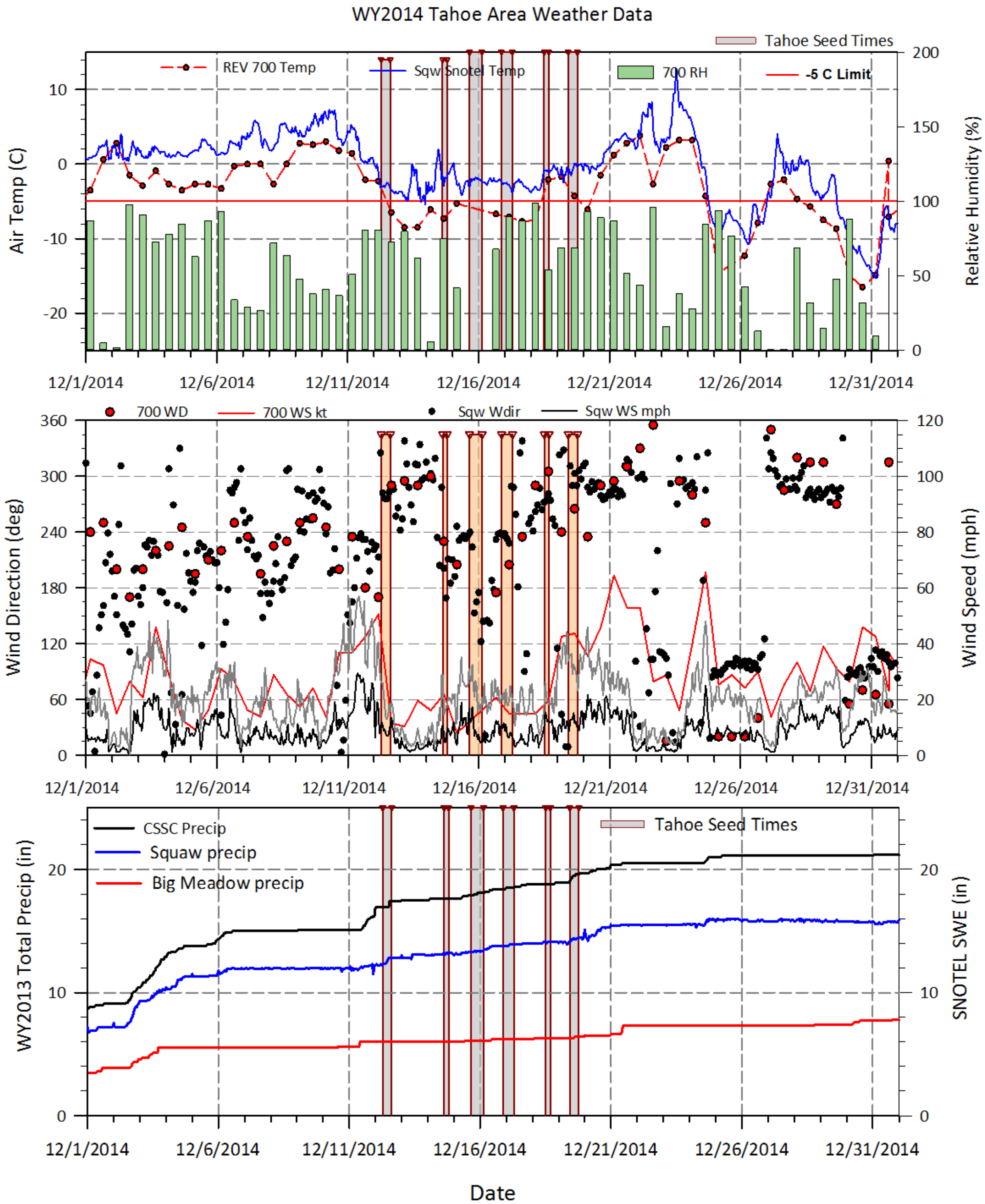


Figure 6. As in figure 5 but for the month of December 2014.

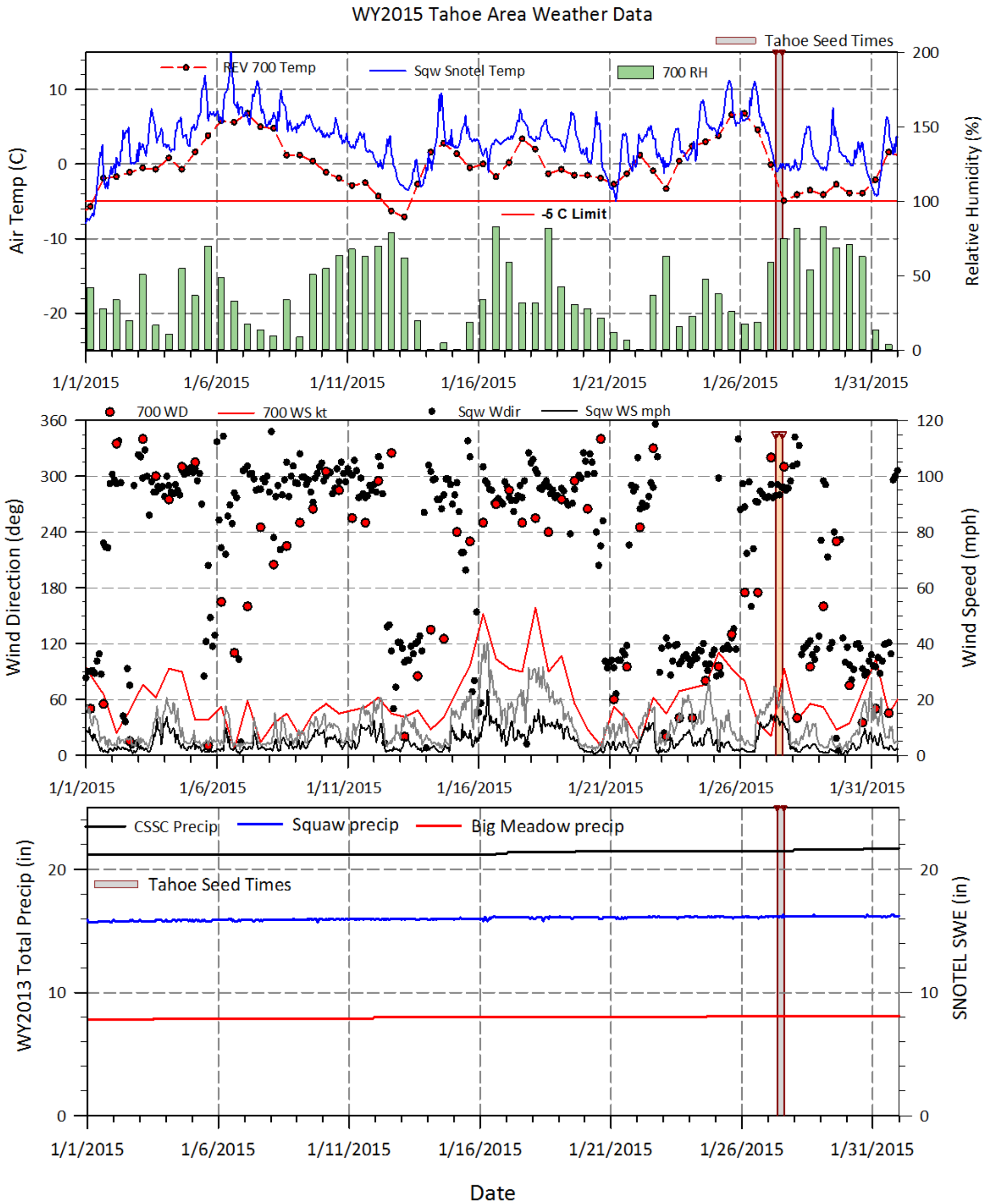


Figure 7. As in figure 5 but for the month of January 2015.

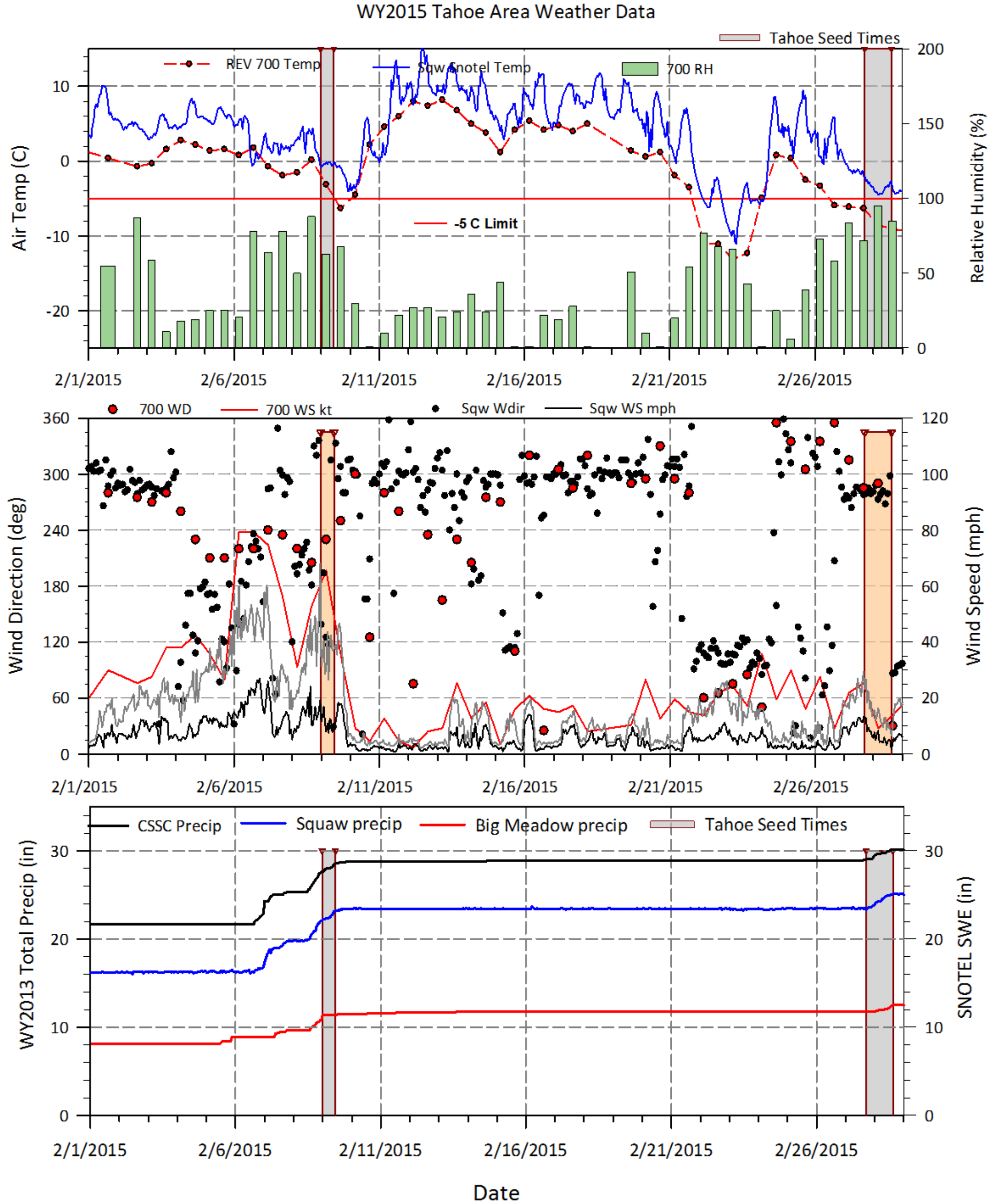


Figure 8. As in figure 5 but for the month of February 2015.

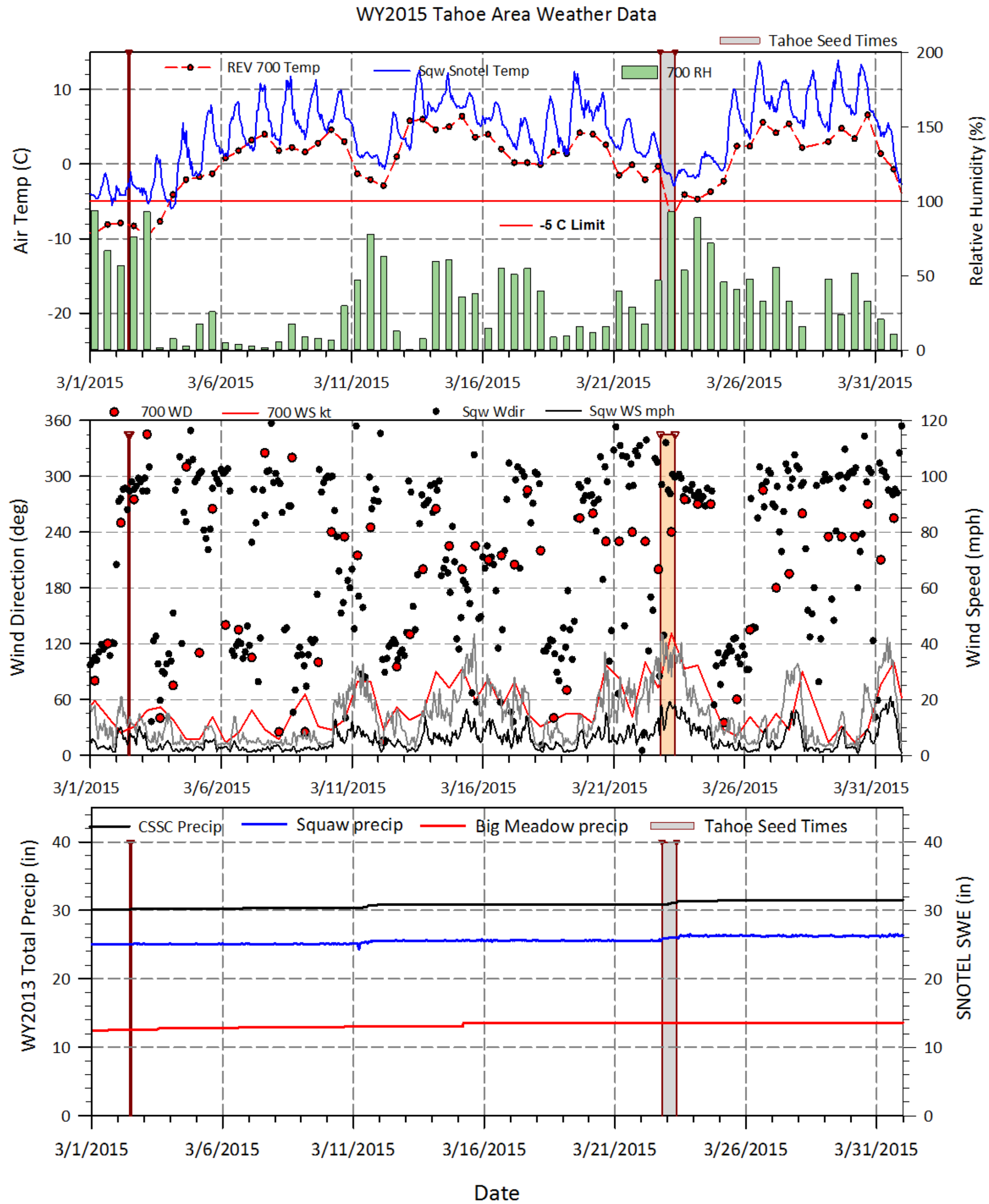


Figure 9. As in figure 5 but for the month of March 2015.

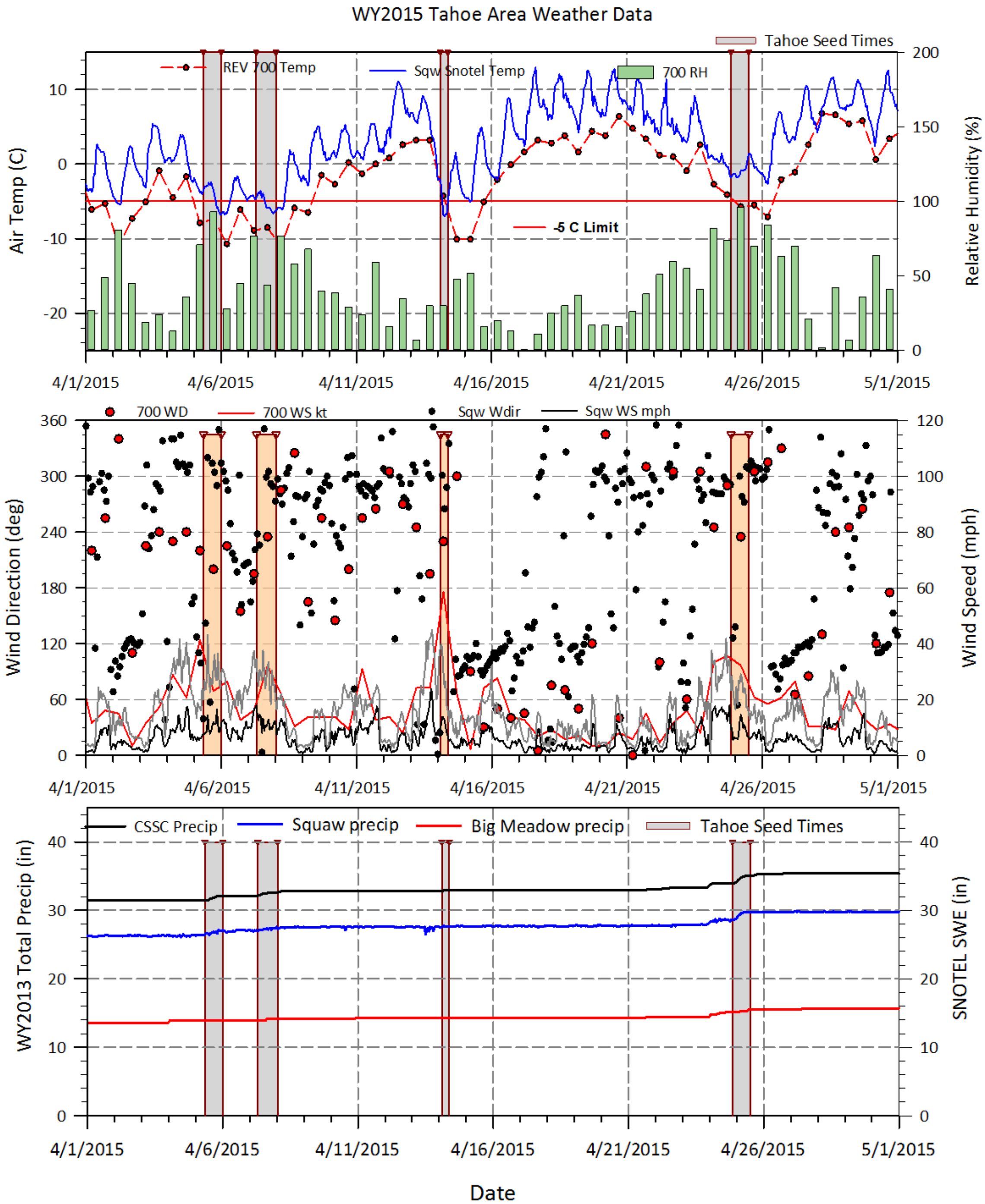


Figure 10. As in figure 5 but for the month of April 2015.

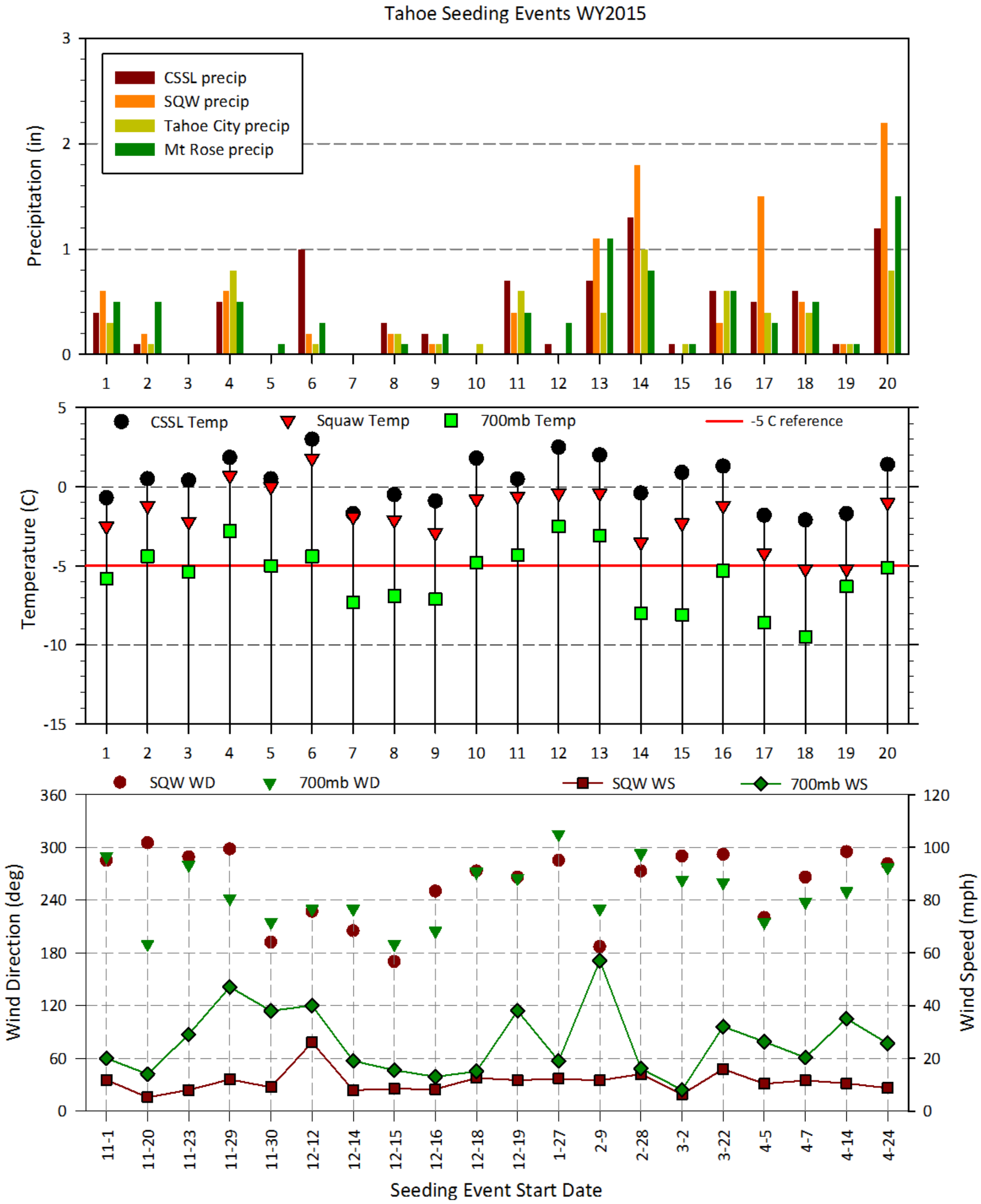


Figure 11. Weather variables for cloud seeding periods in the Tahoe area during November 2014 through May 2015. Top panel shows precipitation accumulation at the Central Sierra Snow Lab (CSSL), Squaw Valley (SQW), Tahoe City, and Mt. Rose SNOTEL sites. Middle panel presents the average temperature at CSSL and the Squaw SNOTEL, and the 700 mb. temperature interpolated to the midpoint of each seeding period. Bottom panel shows the average wind direction and speed at the Squaw SNOTEL, and the midpoint values at 700 mb. The bottom panel scale is annotated with the start date of each seeding period.

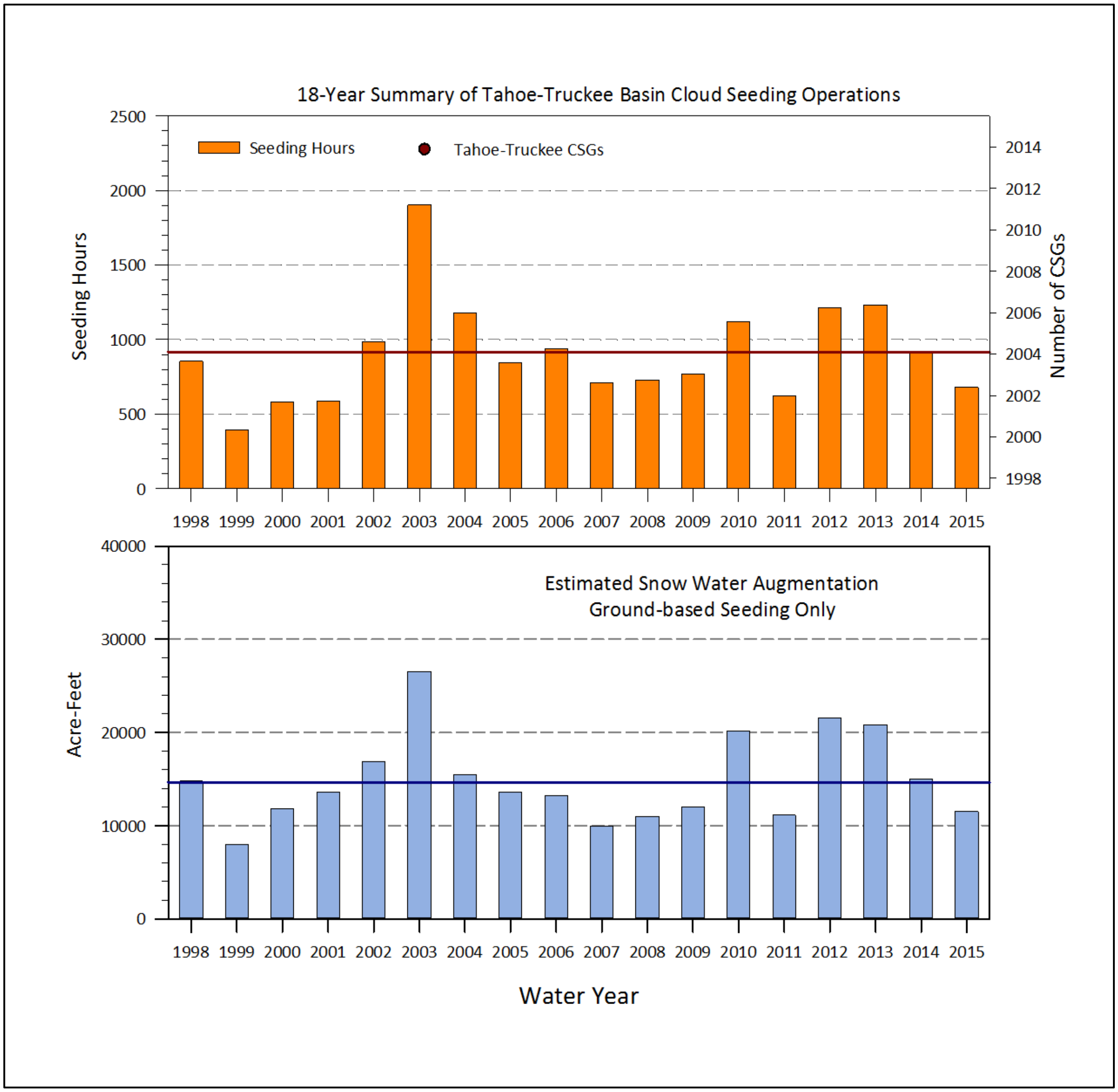


Figure 12. History of cloud seeding hours and snow water augmentation estimates in the Tahoe-Truckee Basin for Water Years 1998 to 2015. The Nevada state-funded project ran from 1998 to 2009. Solid line on each graph represents the 16-year average.

Appendix A. Tahoe Seeding Operations: 1 November 2014 to 14 December 2014

Operation #	Location	Generator	Start Date-Time	TC1	TC2	Flow at On (V)	End Date-Time	TC1	TC2	Flow at Off (V)	Generator Time (hh:mm)	Generator Hours	AgI Release (g)	Event Hours	Event AgI Release (g)	Season Total (hours)	Season Total AgI (g)
1	Barker Pass	6	11/1/14 3:10	890	891	4.070	11/1/14 12:40	821	860	4.050	9:30:00	9.50	295.06				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8	11/1/14 3:10	878	868	3.360	11/1/14 12:40	891	887	3.270	9:30:00	9.50	223.18				
	Bunker Hill	16									0:00:00	0.00	0.00				
	Ward Peak	31	11/1/14 3:19	621	770	3.580	11/1/14 12:40	672	709	3.830	9:21:00	9.35	268.90				
	Morattini	32	11/1/14 3:15	660	868	3.640	11/1/14 11:15	647	776	3.490	8:00:00	8.00	203.69				
	Echo	33	11/1/14 8:51	875	788	3.530	11/1/14 11:35			3.600	2:44:00	2.73	72.42				
													Total	39.08	1063.2	39.08	1063.2
2	Barker Pass	6	11/20/14 20:08	789	838	3.770	11/20/14 22:08	861	876	3.680	2:00:00	2.00	54.53				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16	11/20/14 15:35	822	855	3.600	11/20/14 20:08	265	467	3.610	4:33:00	4.55	120.98				
	Ward Peak	31	11/20/14 16:31	816	868	3.770	11/20/14 22:13	868	863	3.540	5:42:00	5.70	147.78				
	Morattini	32	11/20/14 16:33	856	847	3.410	11/20/14 20:17	816	858	3.400	3:44:00	3.73	91.99				
	Echo	33									0:00:00	0.00	0.00				
													Total	15.98	415.3	55.07	1478.5
3	Barker Pass	6	11/22/14 18:11	793	798	3.670	11/22/14 20:10	846	897	3.480	1:59:00	1.98	50.31				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16	11/22/14 17:44	471	484	3.500	11/22/14 19:23	842	824	3.480	1:39:00	1.65	41.86				
	Ward Peak	31									0:00:00	0.00	0.00				
	Morattini	32	11/22/14 17:47	622	681	3.410	11/22/14 19:23	842	862	3.360	1:36:00	1.60	38.85				
	Echo	33									0:00:00	0.00	0.00				
											0:00	0.00	Total	5.23	131.0	60.30	1609.6
4	Barker Pass	6	11/29/14 7:58	815	849	3.720	11/29/14 14:59	890	870	2.370	7:01:00	7.02	117.87				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16	11/29/14 7:58	680	680	3.450	11/29/14 15:04	879	861	3.460	7:06:00	7.10	178.81				
	Ward Peak	31	11/29/14 11:14	870	840	3.620	11/29/14 14:55	870	839	3.590	3:41:00	3.68	97.23				
	Morattini	32	11/29/14 8:06	765	857	3.400	11/29/14 15:06	835	860	3.490	7:00:00	7.00	178.23				
	Echo	33									0:00:00	0.00	0.00				
													Total	24.80	572.1	85.10	2181.7
5	Barker Pass	6									0:00:00	0.00	0.00				
	Barker Pass	22	11/30/14 5:53	870	850	3.000	11/30/14 8:52	870	850	3.000	2:59:00	2.98	63.41				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16	11/30/14 5:59	756	749	3.520	11/30/14 8:59	756	749	3.520	3:00:00	3.00	77.22				
	Ward Peak	31	11/30/14 6:12	729	657	3.480	11/30/14 8:12	729	657	3.480	2:00:00	2.00	50.74				
	Morattini	32									0:00:00	0.00	0.00				
	Echo	33	11/30/14 6:06	768	629	3.780	11/30/14 9:06	768	629	3.780	3:00:00	3.00	84.76				
													Total	10.98	276.1	96.08	2457.8
6	Barker Pass	6									0:00:00	0.00	0.00				
	Barker Pass	22	12/12/14 6:32	616	618	2.940	12/12/14 9:50	856	970	2.720	3:18:00	3.30	63.17				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16									0:00:00	0.00	0.00				
	Ward Peak	31									0:00:00	0.00	0.00				
	Morattini	32									0:00:00	0.00	0.00				
	Echo	33	12/12/14 7:07	882	852	3.710	12/12/14 15:21	879	717	3.740	8:14:00	8.23	229.35				
													Total	11.53	292.5	107.62	2750.3
7	Barker Pass	6	12/14/14 14:56	887	880	3.650	12/14/14 18:55	800	849	3.460	3:59:00	3.98	100.32				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16	12/14/14 14:51	788	736	3.650	12/14/14 18:58	873	824	3.880	4:07:00	4.12	120.50				
	Ward Peak	31									0:00:00	0.00	0.00				
	Morattini	32	12/14/14 14:59	705	846	3.650	12/14/14 18:57	799	800	3.610	3:58:00	3.97	105.47				
	Echo	33	12/14/14 14:54	849	718	3.740	12/14/14 18:52	813	868	3.610	3:58:00	3.97	105.47				
													Total	16.03	431.8	123.65	3182.1

Appendix A. Tahoe Seeding Operations: 15 December 2014 to 28 February 2015

Operation #	Location	Generator	Start Date-Time	TC1	TC2	Flow at On (V)	End Date-Time	TC1	TC2	Flow at Off (V)	Generator Time (hh:mm)	Generator Hours	AgI Release (g)	Event Hours	Event AgI Release (g)	Season Total (hours)	Season Total AgI (g)
8	Barker Pass	6	12/15/14 6:20	880	883	2.710	12/15/14 11:00	911	880	3.570	4:40:00	4.67	122.31				
	Barker Pass	6	12/15/14 15:35	900	907	2.870	12/16/14 3:00	899	889	2.760	11:25:00	11.42	221.84				
	Ward Peak	31	12/15/14 6:13	634	624	3.650	12/15/14 11:00	748	732	3.530	4:47:00	4.78	123.57				
	Ward Peak	31	12/15/14 15:30	769	787	3.510	12/16/14 3:00	737	699	3.440	11:30:00	11.50	287.52				
	Morattini	32									0:00:00	0.00	0.00				
	Echo	33	12/15/14 4:18	846	709	3.530	12/15/14 11:00	911	880	2.840	6:42:00	6.70	134.15				
	Echo	33	12/15/14 15:35	863	720	3.530	12/16/14 1:00	858	816	3.530	9:25:00	9.42	243.26				
													Total	48.48	1132.6	172.13	4314.7
9	Barker Pass	6	12/16/14 21:43	878	859	2.790	12/17/14 7:17	891	874	2.530	9:34:00	9.57	170.56				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16									0:00:00	0.00	0.00				
	Ward Peak	31	12/16/14 21:41	732	757	3.590	12/17/14 7:17	783	601	3.450	9:36:00	9.60	240.90				
	Morattini	32									0:00:00	0.00	0.00				
	Echo	33	12/16/14 21:43	871	786	3.530	12/17/14 7:18	879	744	3.530	9:35:00	9.58	247.56				
													Total	28.75	659.0	200.88	4973.8
10	Barker Pass	6	12/18/14 12:10	843	868	2.600	12/18/14 16:31	870	868	2.730	4:21:00	4.35	83.58				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16	12/18/14 12:08	814	822	3.780	12/18/14 15:08	814	822	3.780	3:00:00	3.00	84.76				
	Ward Peak	31	12/18/14 12:04	693	513	3.600	12/18/14 16:27	889	874	3.600	4:23:00	4.38	116.13				
	Morattini	32	12/18/14 12:06	607	813	3.470	12/18/14 15:06	607	813	3.470	3:00:00	3.00	75.83				
	Echo	33	12/18/14 12:02	780	561	3.360	12/18/14 15:06	780	561	3.360	3:04:00	3.07	74.46				
													Total	17.80	434.8	218.68	5408.53
11	Barker Pass	6	12/19/14 10:19	813	822	3.750	12/19/14 18:39	880	902	2.530	8:20:00	8.33	148.57				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16									0:00:00	0.00	0.00				
	Ward Peak	31	12/19/14 10:13	761	733	3.660	12/19/14 18:43	813	662	3.630	8:30:00	8.50	227.64				
	Morattini	32									0:00:00	0.00	0.00				
	Echo	33	12/19/14 10:15	772	682	3.580	12/19/14 18:42	871	715	3.680	8:27:00	8.45	230.39				
													Total	25.28	606.6	243.97	6015.1
12	Barker Pass	6	1/27/15 10:40	841	900	2.540	1/27/15 14:27	858	878	3.660	3:47:00	3.78	102.42				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8	1/27/15 8:20	840	839	3.400	1/27/15 14:28	791	870	2.290	6:08:00	6.13	100.03				
	Bunker Hill	16									0:00:00	0.00	0.00				
	Ward Peak	31	1/27/15 10:40	794	818	3.720	1/27/15 14:25	829	846	3.820	3:45:00	3.75	107.47				
	Morattini	32	1/27/15 8:20	843	883	3.580	1/27/15 14:26	898	887	3.850	6:06:00	6.10	176.67				
	Echo	33	1/27/15 10:40	768	689	3.100	1/27/15 14:29	799	689	3.100	3:49:00	3.82	84.20				
													Total	23.58	570.8	267.55	6585.9
13	Barker Pass	6	2/8/15 23:56				2/8/15 23:56				0:00:00	0.00					
	Barker Pass	22	2/8/15 23:56	865	835	3.800	2/9/15 5:34	811	821	3.600	5:38:00	5.63	149.25				
	Bunker Hill	8															
	Bunker Hill	16	2/8/15 23:37	741	778	3.680	2/9/15 5:30	786	827	3.670	5:53:00	5.88	159.84				
	Ward Peak	31	2/8/15 23:58	850	790	3.810	2/9/15 5:30	823	841	3.820	5:32:00	5.53	158.57				
	Morattini	32	2/8/15 23:30	730	856	3.500	2/9/15 5:30	710	872	3.500	6:00:00	6.00	153.32				
	Echo	33															
													Total	23.05	621.0	290.60	7206.9
14	Barker Pass	6	2/27/15 22:40	902	895	1.510	2/28/15 15:05	875	884	1.590	16:25:00	16.42	209.49				
	Barker Pass	22	2/27/15 16:56	893	890	3.390	2/27/15 22:36	893	890	3.390	5:40:00	5.67	139.12				
	Bunker Hill	8	2/27/15 16:59	805	778	2.950	2/28/15 15:05	847	840	3.160	22:06:00	22.10	498.52				
	Bunker Hill	16															
	Ward Peak	31	2/27/15 16:58	814	803	3.800	2/28/15 15:05	818	768	3.820	22:07:00	22.12	633.81				
	Morattini	32	2/27/15 16:52	833	849	3.580	2/28/15 15:05	824	848	3.580	22:13:00	22.22	584.38				
	Echo	33	2/27/15 17:02	833	849	3.510	2/28/15 15:05	779	691	3.840	22:03:00	22.05	636.38				
													Total	110.57	2701.7	401.17	9908.6

Appendix A. Tahoe Seeding Operations: 1 March to 25 May 2015

Operation #	Location	Generator	Start Date-Time	TC1	TC2	Flow at On (V)	End Date-Time	TC1	TC2	Flow at Off (V)	Generator Time (hh:mm)	Generator Hours	AgI Release (g)	Event Hours	Event AgI Release (g)	Season Total (hours)	Season Total AgI (g)
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8									0:00:00	0.00	0.00				
	Bunker Hill	16															
	Ward Peak	31	3/2/15 10:53	775	766	3.800	3/2/15 12:16	788	761	3.820	1:23:00	1.38	39.64				
	Morattini	32									0:00:00	0.00	0.00				
	Echo	33	3/2/15 10:55	632	393	3.410	3/2/15 12:16	771	674	3.810	1:21:00	1.35	38.55				
													Total	2.73	78.2	403.90	9986.8
16	Barker Pass	6									0:00:00	0.00	0.00				
	Barker Pass	22	3/22/15 22:26	884	867	3.760	3/23/15 8:27	692	824	3.770	10:01:00	10.02	282.01				
	Bunker Hill	8	3/22/15 19:00	817	753	1.240	3/23/15 8:29	810	746	1.220	13:29:00	13.48	153.97				
	Bunker Hill	16															
	Ward Peak	31	3/22/15 22:27	685	825	3.820	3/23/15 8:31	800	813	3.800	10:04:00	10.07	286.45				
	Morattini	32	3/22/15 19:05	800	867	3.480	3/23/15 8:31	775	836	3.310	13:26:00	13.43	320.26				
	Echo	33	3/22/15 22:28	767	638	3.820	3/23/15 8:31	777	677	3.770	10:03:00	10.05	282.95				
													Total	57.05	1325.6	460.95	11312.5
17	Barker Pass	6									0:00:00	0.00	0.00				
	Barker Pass	22	4/5/15 8:10	840	860	3.820	4/6/15 0:00	673	778	3.780	15:50:00	15.83	447.36				
	Bunker Hill	8	4/5/15 8:15	710	750	2.760	4/6/15 0:00	756	756	2.960	15:45:00	15.75	329.81				
	Bunker Hill	16															
	Ward Peak	31	4/5/15 8:10	679	738	3.820	4/6/15 0:00	697	805	3.800	15:50:00	15.83	450.55				
	Morattini	32	4/5/15 8:15	800	866	3.520	4/6/15 0:00	790	870	3.480	15:45:00	15.75	399.56				
	Echo	33	4/5/15 16:25	775	590	3.780	4/6/15 0:00	792	685	3.760	7:35:00	7.58	212.75				
													Total	70.75	1840.0	531.70	13152.5
18	Barker Pass	6									0:00:00	0.00	0.00				
	Barker Pass	22	4/7/15 7:07	673	824	3.820	4/7/15 19:51	673	778	3.780	12:44:00	12.73	359.78				
	Barker Pass	22	4/7/15 22:36	670	763	3.800	4/8/15 0:36	670	763	3.800	2:00:00	2.00	56.91				
	Bunker Hill	8										0.00	0.00				
	Bunker Hill	16	4/7/15 7:07	875	866	3.550	4/7/15 19:53	914	914	3.510	12:46:00	12.77	327.42				
	Bunker Hill	16	4/7/15 22:36	871	900	3.470	4/8/15 0:36	871	900	3.460	2:00:00	2.00	50.37				
	Ward Peak	31	4/7/15 7:07	679	738	3.820	4/7/15 19:54	620	660	3.800	12:47:00	12.78	363.76				
	Ward Peak	31	4/7/15 22:36	626	640	3.780	4/8/15 0:36	626	640	3.780	2:00:00	2.00	56.51				
	Morattini	32	4/7/15 7:10	822	852	3.540	4/7/15 19:54	752	786	3.480	12:44:00	12.73	323.03				
	Morattini	32	4/7/15 22:36	794	831	3.490	4/8/15 0:36	794	831	3.490	2:00:00	2.00	50.92				
	Echo	33	4/7/15 7:12	793	694	3.780	4/7/15 19:57	793	684	3.780	12:45:00	12.75	360.25				
	Echo	33	4/7/15 22:36	806	619	3.810	4/8/15 0:36	806	619	3.810	2:00:00	2.00	57.11				
													Total	73.77	1261.9	605.47	14414.4
19	Barker Pass	6	4/14/15 2:23	874	877	3.900	4/14/15 8:56	777	827	3.800	6:33:00	6.55	186.38				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8	4/14/15 2:27	774	716	2.540	4/14/15 8:56	710	721	3.160	6:29:00	6.48	146.25				
	Bunker Hill	16															
	Ward Peak	31	4/14/15 2:27	679	738	3.820	4/14/15 6:00	697	805	3.800	3:33:00	3.55	101.02				
	Morattini	32	4/14/15 2:29	775	850	3.490	4/14/15 9:00	754	820	3.460	6:31:00	6.52	164.12				
	Echo	33	4/14/15 2:29	800	651	3.820	4/14/15 9:02	818	672	3.800	6:33:00	6.55	186.38				
													Total	29.65	784.2	635.12	15198.6
20	Barker Pass	6	4/24/15 21:51	846	838	3.770	4/25/15 12:09	809	771	3.840	14:18:00	14.30	412.71				
	Barker Pass	22									0:00:00	0.00	0.00				
	Bunker Hill	8															
	Bunker Hill	16	4/24/15 20:19	766	742	3.660	4/25/15 12:08	878	879	3.510	15:49:00						
	Ward Peak	31	4/24/15 21:56	419	711	5.030	4/24/15 23:58	42	641	5.030	2:02:00	2.03	87.21				
	Morattini	32	4/24/15 20:19	842	858	3.580	4/25/15 12:07	823	846	3.620	15:48:00	15.80	421.63				
	Echo	33	4/24/15 21:59	737	630	3.860	4/25/15 12:05	809	771	3.840	14:06:00	14.10	406.94				
													Total	46.23	1328.5	681.35	16527.1

APPENDIX 2-4

2012 State of Nevada Drought Plan

STATE OF NEVADA
DROUGHT PLAN

Revised March 2012

Executive Summary

This State Drought Plan establishes an administrative coordinating and reporting system between agencies to appropriately respond and provide assistance to address drought and mitigate drought impacts. After outlining the significance of drought and types of drought encountered, this Plan identifies a system used in monitoring the magnitude, severity and extent of drought within the state on a county-by-county basis. It establishes a framework of actions based on three stages of drought response: Drought Watch (Stage #1), Drought Alert (Stage #2) and Drought Emergency (Stage #3).

The Drought Response Committee, comprised of representatives from the State Climate Office, Division of Water Resources and Division of Emergency Management, is involved throughout each of these stages and is responsible for monitoring drought conditions, collecting data associated with drought, overseeing intergovernmental coordination, disseminating information, reporting to the Governor and working with the State Emergency Operation Center on drought response (if applicable). The Drought Response Committee may establish *ad hoc* Task Force(s). Members of Task Force(s) will serve as experts in the drought affected region, serve as liaisons to local or federal government and collect needed information about the actual and/or projected impacts of the drought. If a drought reaches Stage #3 Drought Emergency, upon the decision of the Governor, the Division of Emergency Management may activate the State Emergency Operations Center. This Center will be advised by the Drought Response Committee, making drought response policy recommendations as needed, supporting local drought emergency response efforts and carrying out the Governor's policies.

Jason King, P.E. State Engineer Division of Water Resources	Christopher B. Smith, Chief Division of Emergency Management	Kate A. Berry, Director State Climate Office

1. Drought

Drought is a complex physical and social phenomenon of widespread significance. Drought is not usually a statewide phenomenon; differing situations in the state make drought local or regional in focus. Despite all the problems droughts have caused, drought has proven difficult to define. There is no universally accepted definition because drought, unlike flood, is not a distinct event and drought is often the result of many complex factors acting on and interacting within the environment. Complicating the problem of a drought definition is the fact that drought often has neither a distinct beginning nor end. It is recognizable only after a period of time and, because a drought may be interrupted by short spells of one or more wet months, its termination is difficult to recognize. The most commonly used drought definitions are based on: 1) meteorological and/or climatological conditions, 2) agricultural problems, 3) hydrological conditions, 4) economic considerations and 5) induced drought problems. Each type of drought will vary in severity, but all are closely related and caused by lack of precipitation.

1.1 Meteorological Drought

Meteorological drought is often defined by a period of well-below-normal precipitation. The commonly used definition of meteorological drought is an interval of time, generally of the order of months or years, during which the actual moisture supply at a given place consistently falls short of climatically appropriate moisture supply.

1.2 Agricultural Drought

Agricultural drought is typically defined as a period when soil moisture is inadequate to meet evapotranspirative demands so as to initiate and sustain crop growth. Another facet of agricultural drought is deficiency of water for livestock or other farming activities.

1.3 Hydrologic Drought

Hydrologic drought refers to periods of below-normal streamflow and/or depleted reservoir storage.

1.4 Economic Drought

Economic drought is a result of physical processes but concerns the areas of human activity affected by drought (e.g., municipal water supply shortages). The human effects, including the losses and benefits in the local and regional economy, are often a part of this definition.

1.5 Induced Drought

Induced drought is a condition of shortage which results from over-drafting of the normal water supply. The condition is aggravated by negative precipitation experience and below normal streamflow or aquifer recharge. An induced drought is brought about by introducing agricultural, recreational, industrial or residential consumptions into an area which cannot naturally support them.

2. Drought Monitoring System

While lower than normal precipitation is usually the cause of specific problems creating a drought situation, a drought condition is not simply a lack of rainfall or snow accumulation but can also be related to deficiencies in soil moisture and ground-water; lack of surface water in streams and rivers; and/or reduction of surface water stored in lakes and reservoirs. A number of factors are involved in determining if a drought exists and its severity for a given region: precipitation, snowpack, soil moisture, streamflow, surface water storage, and groundwater levels.

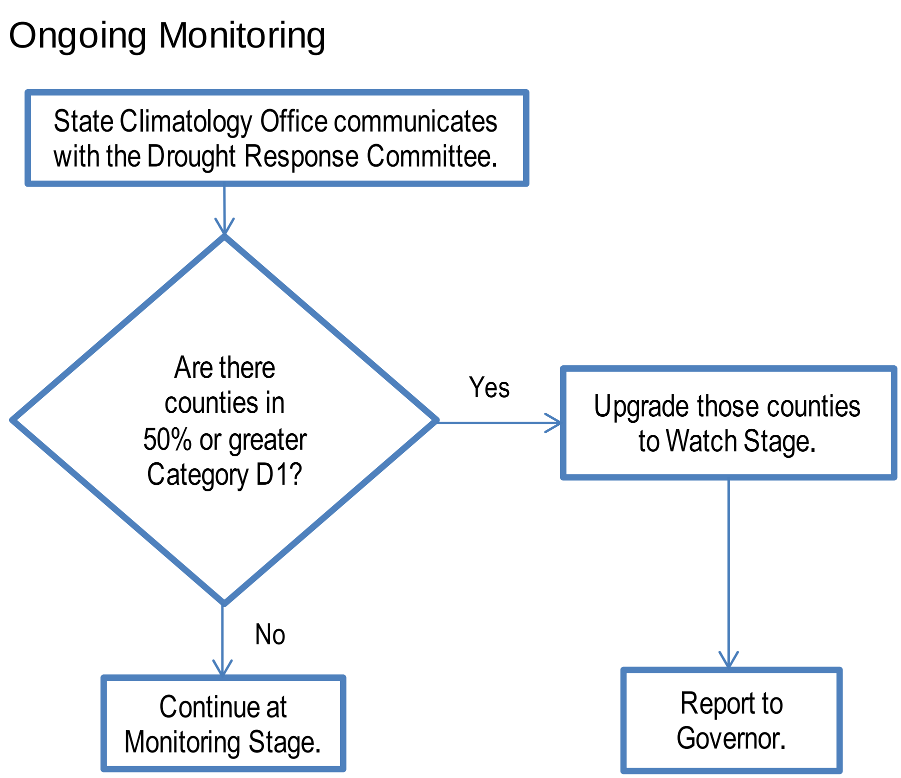
The US Drought Monitor is an independent and scientific approach that synthesizes multiple indices and impacts and is updated weekly. It integrates varies types of drought, with a particular emphasis on meteorological, agricultural, and hydrological drought. The US Drought Monitor is coordinated through the National Drought Mitigation Center at the University of Nebraska, Lincoln, with input and support from a number of federal, state, and local partners nationwide. To identify the initial stages of drought, the US Drought Monitor will be applied to counties in the State of Nevada. There are five drought intensity categories identified in the US Drought Monitor:

D0 Abnormally Dry
D1 Drought – Moderate
D2 Drought – Severe
D3 Drought – Extreme
D4 Drought – Exceptional

Issues posed by economic drought and induced drought will also be taken into account when moving into the third drought stage outlined in the following sections.

3. Measures Initiating Action

The Drought Response Committee is comprised of a representative from the Office of the State Climatologist, the Division of Water Resources, and the Division of Emergency Management. Drought Response Committee members remain in contact and, if it is determined that a Watch Stage exists for any counties, then the Nevada State Climatologist will call a meeting of the Drought Response Committee. Reports to the Governor are generated by the Drought Response Committee whenever there is a change in drought stage and throughout Drought Alert and Drought Emergencies stages.

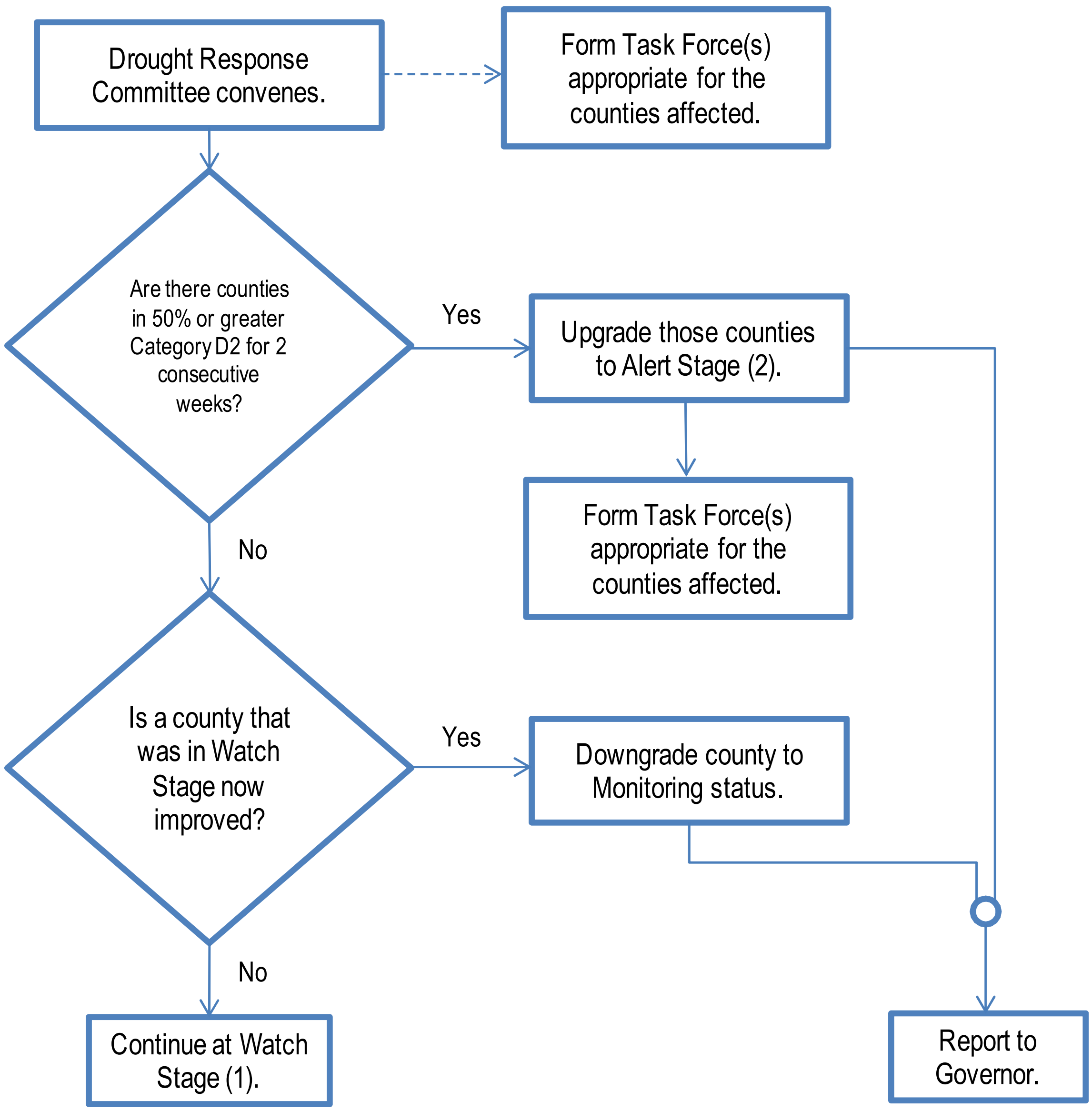


3.1 Drought Watch Stage

The Drought Watch Stage (Stage #1) begins when 50% or more of a county is classified as D1 (drought – moderate) in the Drought Monitor. During the Drought Watch Stage, the Drought Response Committee will assemble to monitor conditions within the area. The Drought Response Committee will monitor trends and serve as sources of technical information for state and local decision-makers, as well as for the public and media. The Drought Response Committee is composed of the directors (or their designees) of the State Climate Office, the Division of Water Resources, and the Division of Emergency Management. The chair of the Drought Response Committee will be the director of the State Climate Office.

Drought Impact Task Forces are *ad hoc* groups formed by the Drought Response Committee to act as experts in the drought affected region, serve as liaisons to local or federal government, and provide information needed for dissemination to decision-makers and stakeholders. Task Forces may be expanded or restricted as needed to suit the needs of the situation. Multiple small Task Forces (coordinated through the Drought Response Committee) may be more effective than a single large Task Force. This formation is optional at the Drought Watch stage, but is likely to be necessary at the Drought Alert Stage.

1. Drought Watch Stage

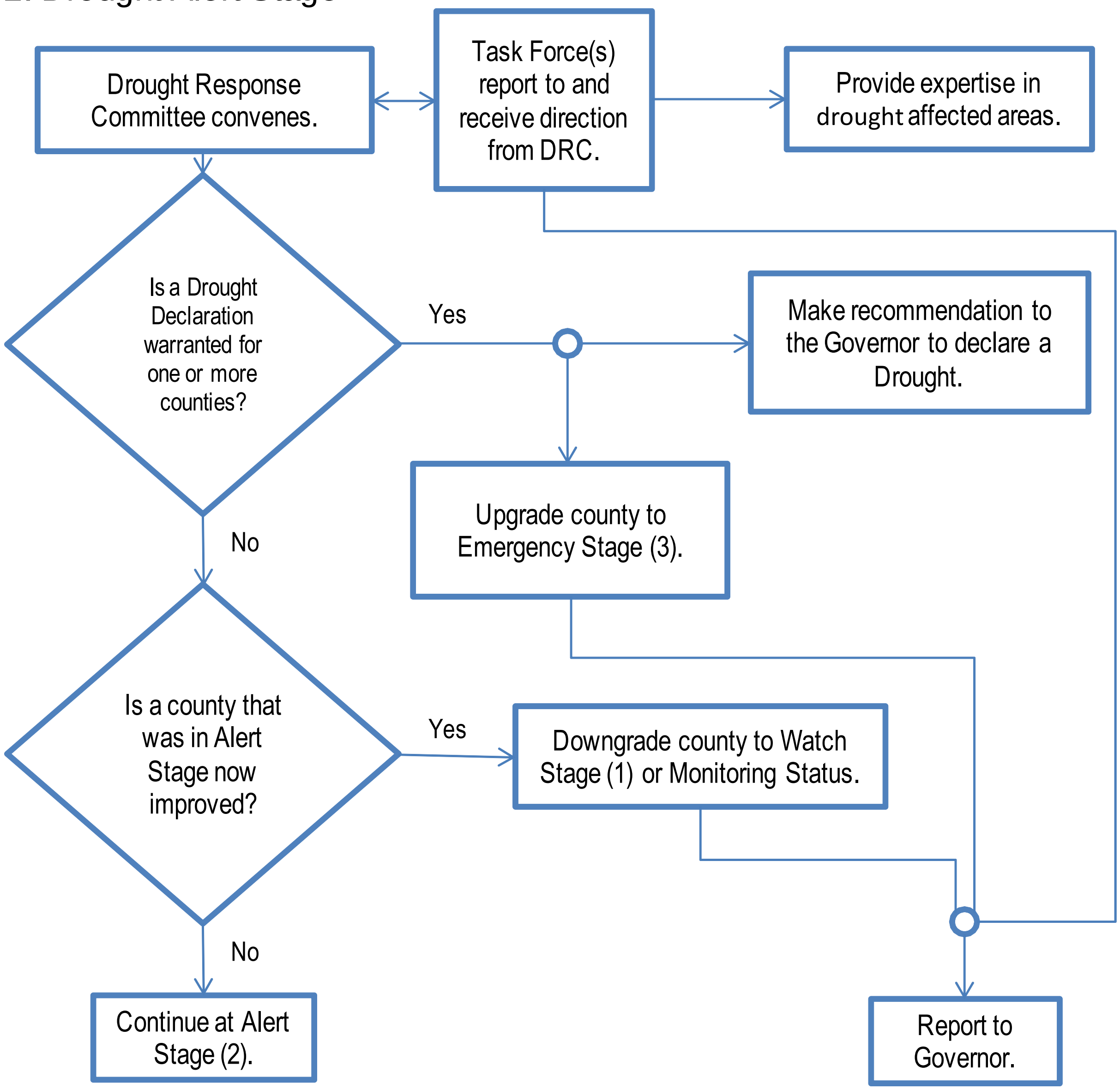


3.2 Drought Alert Stage

The Drought Alert Stage (Stage #2) occurs when 50% or more of a county is classified as D2 (drought – severe) or higher in the Drought Monitor for a minimum of two weeks. The Drought Response Committee will appoint the appropriate task force(s), on an *ad hoc* basis, in this stage. Task force members must be able to speak for their agencies or organizations and have authority to make reasonable commitments toward effective cooperation and coordination. A Task Force(s) may assess actual and projected impacts on the state's economy, agriculture, and/or fish and wildlife resources in the area impacted by the drought. The chair of a Task Force will report regularly to the Drought Response Committee with details concerning the drought extent, magnitude, and impacts and will provide information about drought mitigation measures being taken by public agencies or private individuals or organizations.

The Drought Response Committee will monitor the progress of Task Forces, and evaluate the adequacy of data collection, procedures, and reports. Further, the Drought Response Committee will collate information from individual Task Forces in order to develop its own assessments, projections, and trends. The Drought Response Committee will oversee intergovernmental coordination, including federal agency actions, and make timely reports on the status of the drought and response activities to the Governor, other state leaders, the media, and the public.

2. Drought Alert Stage



3.3 Drought Emergency Stage

The Drought Emergency Stage (Stage #3) begins after the Drought Alert Stage. This stage begins when the Drought Response Committee makes a recommendation, based on information from the Tasks Force(s) and other sources, that a drought should be formally declared for affected counties. The Drought Response Committee determines whether a critical situation exists or when it becomes obvious that existing state resources and strategies are insufficient to deal with the growing problems and needs. Upon making the recommendation, the Drought Response Committee alerts the Governor that identified portions of the state are experiencing a Drought Emergency.

The issue of whether to formally declare a drought is both controversial and important. The State of Nevada will approach formal declaration with caution. Formal designation may not substantially reduce economic impacts and may cause serious economic impacts on tourism, agriculture, finance, and other industries. Unless a drought situation is expected to be of extreme magnitude, the safest approach is to aid county and local governments in determining their own situations. In many cases existing networks and processes of public agencies, water system managers, and experts are available to assess and address particular needs. The criteria for such a recommendation is not as rigidly defined as it is for earlier stages, since the need is dictated by local and specific conditions and based on reporting and recommendations of the Drought Response Committee and Task Force(s). The declaration of a Drought Emergency signifies that conditions are present that may produce negative impacts in certain counties or regions. The Drought declaration may be a trigger point for federal resources. If the drought conditions persist to an extraordinary level, it may negatively impact a county to the point that it exhausts local resources available to respond to the emergency, the affected county may elect to execute a disaster declaration.

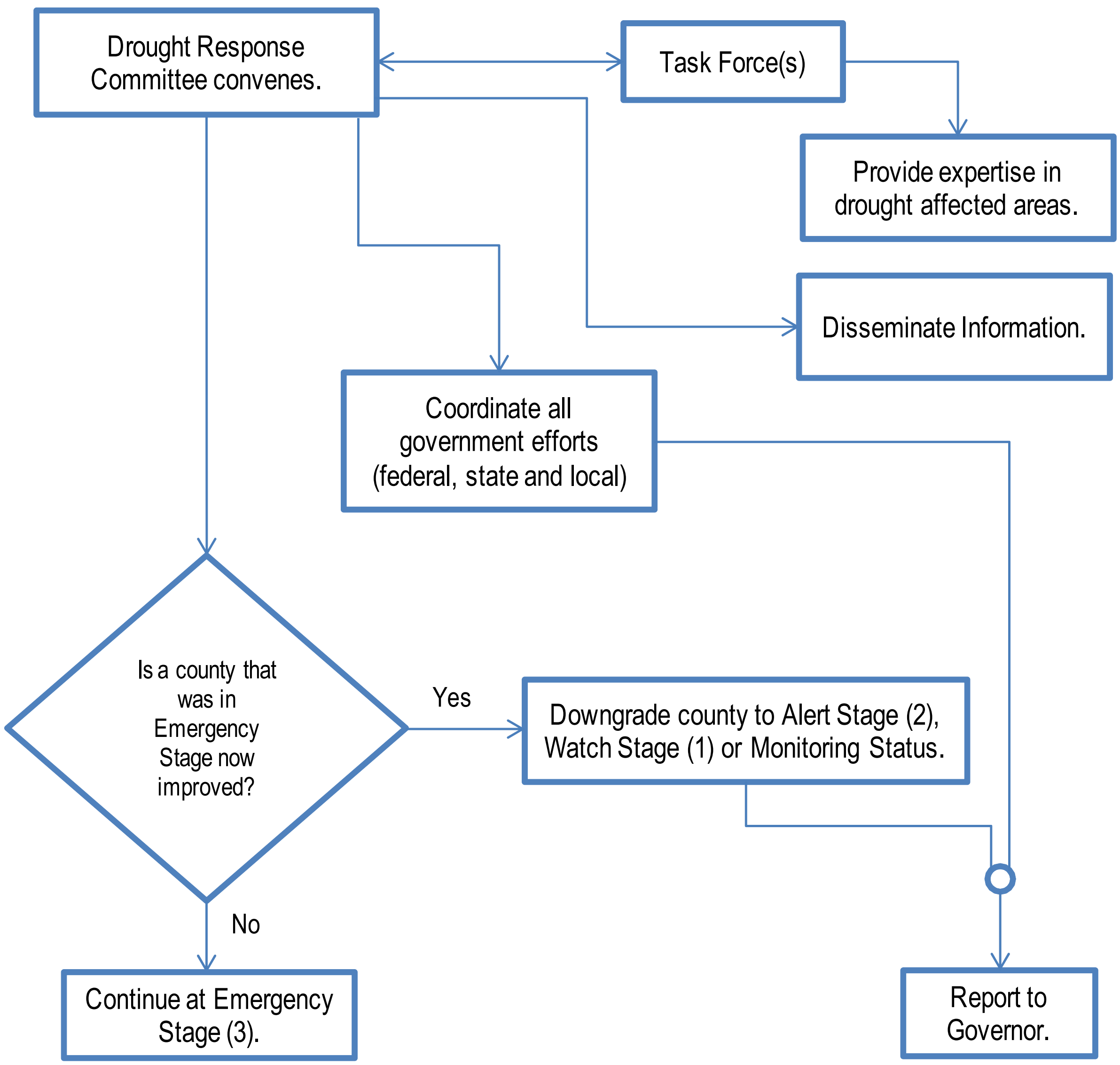
In the Drought Emergency Stage, the Drought Response Committee prepares a press release for the Governor. The Governor then may activate the State Emergency Operations Center (SEOC). The SEOC will be overseen by the director of the Division of Emergency Management (or designee) and will coordinate with directors (or their designees) of the Nevada State Climate Office and the Nevada Division of Water Resources as lead responsible agencies, so that continuity of response efforts is maintained.

Under a Drought Emergency declaration the Division of Emergency Management, acting in its authority in accordance with Nevada Revised Statute (NRS) 414 and the State Comprehensive Emergency Management Plan (SCEMP), will coordinate state response efforts and make mitigation, response and recovery recommendations to affected counties. The Division of Emergency Management coordinates the state's resources through the State Emergency Operations Center (SEOC) to support local drought emergency response efforts and to carry out the Governor's policies. The Division of Emergency Management may also request support and resources from federal agencies such as the U.S. Department of Agriculture, Bureau of Reclamation and Federal Emergency Management Agency and from non-governmental organizations such as the American Red Cross as needed based on the drought conditions and needs of the local jurisdictions.

Upon activation, the SEOC assumes a number of drought related responsibilities, including interagency and intergovernmental coordination and media relations. The SEOC reviews recommendations to address unmet needs from the Drought Response Committee and Task Forces and develops strategies to coordinate the delivery of resources through state mutual aid, state agencies, federal agencies, and non-governmental organizations. During the Drought Emergency stage, the SEOC directs the initiatives of the Drought Response Committee and Task Force(s). The Drought Response Committee will continue assessment activities and will provide advice and support to the SEOC, making drought response policy recommendations as needed through the duration of the drought. During the Drought Emergency stage, Tasks Force(s) will provide recommendations on possible mitigation solutions along with their assessments of the situation both to the Drought Response Committee and to the SEOC. Drought Response Committee duties take priority over the normal duties assigned to the Division of Water Resources.

The SEOC provides general policy direction and, as appropriate, makes policy recommendations to the Governor for his disposition (such as emergency funding requests and suggested legislative action). The SEOC may advise the Governor on the use of his emergency powers, including any requested data to support the Governor's request, if necessary, for a Secretarial or Presidential Disaster Declaration. The Governor will set the state's priorities, drought mitigation, response and recovery policy and resource allocation direction based on information and recommendations given to the Governor by the Drought Response Committee and the needs of the affected local jurisdiction, county or tribe. The Governor engages with the state legislature when new authority and funding are necessary. If needs exceed the resources of the State, the Governor may request Federal Disaster Assistance. Federal assistance that does not need state action should be implemented when necessary without going through the Center.

3. Drought Emergency Stage



3.4 End of Drought

As the drought subsides and the emergency passes, if continuing assistance requirements can be met within normal state administrative channels, the Center prepares a press release for the Governor to declare the end to the drought emergency. Prior to disbanding, the Center will prepare and issue a final report on its activities to the Governor. When the Center disbands, the Drought Response Committee again assumes primary responsibility for response activities and for interagency and intergovernmental coordination until all counties of the state are out of the drought alert and drought watch stages. Before disbanding, the Drought Response Committee will prepare and issue a final report to the Governor and appropriate agencies.

APPENDIX 2-5

Spill Risk Assessment

APPENDIX 2-5

Spill Risk Assessment

Probabilistic Hazardous Materials Contamination Model for a Municipal Water Source

JAMES R. CARR[1] AND SHAWN W. STODDARD[2]

[1]Department of Geological Sciences and Engineering, University of Nevada, Reno
[2]Truckee Meadows Water Authority, Reno, Nev.

In 1997 conditional probability was used to assess the frequency of contamination of the Truckee River by hazardous material (hazmat) released during a rail or highway accident. A Great Basin stream originating at Lake Tahoe, Calif., and terminating at Pyramid Lake, Nev., the Truckee River is the principal water source for the Reno–Sparks (Nev.) metropolitan region. The 1997 probabilistic assessment was based on sparse to nonexistent data for accident frequency and other factors. Assumptions made during the 1997 study were reassessed in 2007 using a significantly more comprehensive database for rail and highway accidents and hazmat incidents. The 2007 assessment confirmed that estimates of hazmat contamination probability (likelihood) were reasonable and even low. Consequently, the operational plan to be implemented, should a hazmat contamination occur, relies on estimates of arrival times coupled with the ability to shut down water treatment plants and rely on groundwater resources during such an emergency.

Keywords: *hazmat, hazardous material, probability, risk, safety*

This article serves two purposes: first, to describe the development of a model for evaluating the contamination risk to a river by the release of a hazardous material (hazmat) during a rail or highway accident and second, to detail the application of this model in an actual case study conducted over a decade-long period. The particular river on which the study is based is the Truckee River, a perennial stream that originates at Tahoe City, Lake Tahoe, Calif., flows northeastward through the communities of Reno and Sparks, Nev., and terminates at Pyramid Lake in northwestern Nevada (Figure 1).

BACKGROUND

Truckee River environs. The Truckee River is the principal source of raw surface water to be treated and delivered to the communities of Reno and Sparks. Additionally, 31 wells provide 16% of municipal water needs; moreover, should the Truckee River become contaminated, these wells can provide all of the indoor water demand during an emergency for an extended period of days or weeks. Upstream of the Reno–Sparks metropolitan region, the Truckee River flows through narrow, steep-sided canyons. Central Pacific Railroad Co. of California constructed the Transcontinental Railroad in 1869, following the river as it courses through these canyons. Since 2002, this rail route has been used and maintained by the Union Pacific Railroad. Additionally, a major interstate highway, Interstate 80 (I-80), was constructed through the same canyons between Truckee and Reno. As shown in the photograph on this page, the river, rail line, and highway are in close spatial proximity at several locations.

Risk model development. An accident during highway or rail transport of hazmat could potentially result in catastrophic contamination of the Truckee River, depending on the location of the accident. The motivation for risk-model development with application to the Truckee River was to aid in decision-making in

This screen capture from Google Earth (with elevation and distance added) shows the close spatial proximity of Interstate 80 (I-80), the rail route, and the Truckee River at 12 km upstream from the first Truckee Meadows Water Authority water treatment plant. Elevation (shown in white) drops by 21 m from the right edge of the I-80 pavement to the left edge of the rail line ballast. The total distance (shown in yellow) from the right edge of the I-80 pavement to the bank of the Truckee River is approximately 86 m.

planning for the response to such an occurrence (Høj & Kröger, 2002). The key question to be answered centered on the level of response planning warranted to plan for possible river contamination. How catastrophic the contamination would be depends on multiple factors, including the type of hazmat released, the time of year (which influences water demand), and the location where the contamination occurs (the distance upstream of treatment plant water intakes). Planning for a catastrophic contamination involves assessing the likely hazmat substances that may be released, the reaction time of emergency crews, the water demand, and the likelihood of such a contamination happening. The type of risk assessment that is used for decision-making depends on need. Route-selection optimization considers population density and all types of hazmat: gas, liquid, solid, explosive, and radioactive (Battelle, 2011; Erkut & Verter, 1998).

In the case of the current study, population density was not explicitly modeled. Only liquid and solid, nonradioactive hazmat was considered. Although explosiveness was not explicitly considered, explosive materials are taken into account as part of the solid hazmat volume transported via rail and highway. Of concern are the possible contamination of the major water source for a metropolitan area of moderate size and the resources, if any, that should be stockpiled at the water treatment plant in the event of water contamination. With these considerations in mind, a risk model was first developed in 1997 at a time when relatively few literature resources existed to provide examples of transportation risk analysis. One exception was a study that examined hazmat transportation risk based on accident frequency and release frequency (Harwood et al, 1993). These two fundamental components—accident frequency and release frequency—along with hazmat volume were included in the 1997 model. A conditional probability formulation enabled the quantification of risk based on individual event probabilities defined by actual data (although these data were limited at the time).

Increased availability of data and literature resources. A decade later, the database for accidents, hazmat volume, and release frequency was far more extensive, especially with respect to rail transport. Moreover, many more literature resources were available for both conceptual model development and database development. One study conceptualized risk theoretically, using expected values defined by selected data distributions (Fabiano et al, 2002). In this particular study, distributions of parameters important to the risk assessment (such as accident frequency) were modeled using known functions such as Gaussian (normal) and Poisson. Values of parameters used as input to the risk assessment calculation were selected using these models. This parametric approach was cross-validated using discrete distributions of actual accidents and traffic volume. The distribution function that yielded the best accuracy as determined through cross-validation was selected for further modeling. Another study (Gheorghea et al, 2005) focused on rail transport and describes the construction of a highly detailed risk-assessment model based on every factor that might contribute to derailing accidents. The four most likely factors causing derailing accidents are broken rails or welds, buckled track, train handling (excluding use of brakes), and broken wheels (Barkan et al, 2003). Derailing is the most likely rail accident to result in a container breach.

FIGURE 1 The Truckee River from its head at Lake Tahoe to its base at Pyramid Lake

The approximate location of the Chalk Bluff municipal water intake treatment plant is shown. This Chalk Bluff plant would be affected by any hazmat release into the river upstream (west). Map courtesy of the United States Geological Survey, www.usgs.gov.

Objective. What follows is a review of the 1997 model development when literature and data resources were limited to nonexistent. That presentation is followed by an assessment of the 1997 model conducted in 2007 with considerably improved databases for rail and highway transportation of hazmat. Data for this assessment were collected for the California counties of Nevada, Placer, and Sierra and the Nevada county of Washoe. One objective of this article is to demonstrate that a low data approach such as the 1997 model is nonetheless worth performing and can compare well with a model using a more detailed database.

RISK-ASSESSMENT MODEL

A quantitative risk assessment of Truckee River contamination was conducted in 1997 for the Sierra Pacific Power Co., a public utility that delivered electricity, natural gas, and water. At the time, the database on accidents was not accessible via the Internet. Some data for rail accident frequency were available for rail traffic between Truckee and Sparks. These data were supplied separately by the Federal Railroad Administration (FRA) for Nevada rail accident frequencies and the California Department of Transportation (Caltrans). The data consisted only of accident numbers with no other information available on such details as accident severity, the type (if any) of hazmat involved in the accident, the release (if any) of this hazmat, the weather conditions during the accident, and the time of year in which the accident occurred. The database for highway accident frequency was available for I-80 from the California–Nevada border eastward to Wadsworth, Nev. The data consisted of accident type, contributing factor, frequency of property damage accidents, frequency of injury accidents, and frequency of fatal accidents. Additionally, average vehicle miles traveled (AVMT) data were available for hazmat transport for 1994. These data were supplied by the Nevada Department of Transportation (NDOT).

An approach to risk assessment was developed that provided some bounds on actual risk because narrowly defining risk was not possible, given the limitations of the database circa 1997. Model development was approached as a conditional probability calculation. For example, if an event, A, happens, then the probability of an event, B, happening given that event A has already occurred is written as

$$P(B|A) \tag{1}$$

This probability is explicitly computed as $P(A) \times P(B)$, the product of the probabilities for each event. For example, with a fair coin toss, the probability of heads, given that heads occurred on the previous toss, is 1 in 4. The probability of each outcome is ½; therefore, the conditional probability of obtaining two heads in a row, P(heads|heads), is $P(\text{heads}) \times P(\text{heads}) = \frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$.

A similar calculation was used to determine the risk of a river contamination by hazmat released during a transportation accident. Many events were thought to have an influence on this contamination scenario, including accident frequency, hazmat type and volume, proximity of an accident to the river, and severity of the accident. Conditional probability provided a framework for characterizing risk. In the most general of terms, the model was written as

$$\text{Risk} = P(A|B|C|\ldots) = P(A) \times P(B) \times P(C) \times \ldots \tag{2}$$

This model is intentionally written as open-ended to show that any number of contributing events can be considered. Moreover, events A, B, C, and so on are presumed to be independent. If an accident occurs, a container of hazmat may or may not be involved. If the container itself did not cause the accident, then the two events—accident and hazmat involvement—are independent. In the case in which the hazmat is the cause of an accident, then the two events cannot be presumed independent events; a different model would be needed to assess the likelihood of this circumstance. In the current study, such a scenario was deemed too unlikely to warrant the development of a model just for this circumstance. Other events—such as accident severity, weather conditions, and time of year—are also independent of all other events unless weather conditions, for example, caused the accident. In general, most often the events used in the model are independent.

The initial focus was to define probabilities of individual events on the basis of actual data. Alternatively, probabilities could have been computed using theoretical probability functions. This alternative approach was rejected for two reasons. First, there was no way to justify a particular probability function for a particular event. Second, a realistic risk assessment based on actual data was sought in opposition to a theoretical characterization.

Because of the database limitations, however, a realistic risk assessment was at best an approximation. In light of this realization, several calculation scenarios were used that considered a differing number of events in the model to determine bounds (and an upper bound in particular) on risk. An upper bound on risk was thought to be provided by the model

$$\text{Risk, upper bound} = P(\text{hazmat}|\text{accident}) = P(\text{hazmat}) \times P(\text{accident}) \tag{3}$$

in which the probability of an accident is based on data for any and all accidents, regardless of severity. For this reason, this form of the model is considered to overestimate actual risk.

More realistic assessments of risk were envisioned by adding components to the upper-bound calculation. Accident severity was considered to be a significant additional component. Just because an accident occurs involving one or more railcars or vehicles carrying hazmat does not mean that the hazmat is released. An accident severe enough to breach the container of hazmat is necessary for release to occur. Other components to be considered for additions to the model include weather conditions, time of the year, proximity to the river, and type of hazmat (solid or liquid). Weather conditions and time of the year are considered to be separate components of the model because extreme weather conditions can result in accidents at any time of the year, and contamination of a river is more serious during the time of year when water demand is high. For northwestern Nevada, higher water demand exists from late spring to early fall. Applications of the risk model in the next section demonstrate that addition of just one more component—accident severity—to the upper-bound model significantly reduces the computed risk.

APPLICATION OF THE MODEL

Data supplied by FRA, Caltrans, and NDOT enabled the following calculations of probability of accident resulting in property damage:

$$P(\text{accident, rail}) = 0.0106 \text{ accidents per day} \tag{4}$$

$$P(\text{accident, highway, I-80}) = 1.14 \text{ accidents per day} \tag{5}$$

These values of probability characterized accident frequency in 1997 along sections of rail and highway that are in close proximity to the Truckee River, especially reaches upstream (west) of Reno to the city of Truckee.

Accidents within rail yards were excluded in computing the probability of rail accidents even though rail yards are associated with a relative high rate of hazmat incidents (Cozzani et al, 2007; Anderson & Barkan, 2004). The three rail yards closest to Reno and Sparks are located in Sparks and the California municipalities of Portola and Roseville and do not pose any threat to the Truckee River upstream of intakes for municipal water. Although the Sparks rail yard is in close proximity to the Truckee River, it is downstream of intakes for the municipal water supply. The rail yards in Portola and Roseville are not within the Truckee River watershed. For this reason, hazmat release incidents during loading and unloading, although noted as likely activities for hazmat release (Clark & Besterfield-Sacre, 2009), were excluded here.

In determining P(hazmat), highway hazmat transportation frequency was provided by AVMT data. For rail transport, the frequency and types of hazmat were obtained through the Reno Fire Department. At the time, the rail company that supplied this information to the city of Reno was the Southern Pacific Railroad. On the basis of the information supplied, the frequency of hazmat transport by rail was determined to be 0.10; in other words, data available in 1997 indicated that 10% of railcars traveling alongside the Truckee River were transporting hazmat. For highway transport, the probability of a vehicle carrying hazmat was computed from the AVMT data to be 0.0056 for I-80.

Maximum risk (upper-bound) of contaminating the Truckee River was computed on the basis of these values of probability with the following results:

$$\text{Rail: } P(\text{hazmat}|\text{accident}) = P(\text{hazmat}) \times P(\text{accident}) = 0.10 \times 0.0106 = 0.0011 \quad (6)$$

$$\text{Highway: } P(\text{hazmat}|\text{accident}) = P(\text{hazmat}) \times P(\text{accident}) = 0.0056 \times 1.14 = 0.0064 \quad (7)$$

These resulting probabilities represent frequency of contamination per day. For rail, 0.0011 contaminations per day translate to one contamination every 910 days (2.5 years), and for highway, 0.0064 contaminations per day translates to one contamination every 156.25 days (0.43 years). By this characterization, accidents on I-80 were approximately six times more likely to involve hazmat in 1997 compared with accidents on rail. This outcome demonstrates that even with a limited database, an assessment of relative risk is possible—in this case, a realization that highway transport is more likely to be associated with an accident that involves a vehicle carrying hazmat. Local history of the area indicates that contaminations on the order of one every 2.5 years (rail) or one every five months (highway) have not been experienced. In fact, no contamination of the Truckee River has occurred in recent memory. This historic knowledge suggests that the values of risk computed in the previous paragraph are conservative.

Incorporating an additional component in the risk model—in this case, the severity of an accident—yields a more realistic risk assessment. In 1997, however, the database was too limited to enable a direct count of accidents severe enough to have resulted in the release of hazmat. Therefore, accident severity had to be estimated. Because of the limited database for rail, the estimated severity was determined as the number of accidents (of total accidents) that involved two or more railcars. This estimated severity was 0.032; that is, 3.2% of the accidents in the database involved two or more railcars. For highway, the estimated severity was determined as the number of accidents out of total accidents that resulted in one or more fatalities. This estimated severity was 0.014, or 1.4% of accidents on the highway. Incorporating these values of probability into the foregoing maximum risk model yields the following:

$$\text{Rail: } P(\text{hazmat}) \times P(\text{accident}) \times P(\text{severity}) = 0.10 \times 0.0106 \times 0.032 = 0.000034 \quad (8)$$

$$\text{Highway: } P(\text{hazmat}) \times P(\text{accident}) \times P(\text{severity}) = 0.0056 \times 1.14 \times 0.014 = 0.000089 \quad (9)$$

These values of risk are in terms of contaminations per day and translate to one contamination every 29,412 days (80.5 years) for rail and one contamination every 11,236 days (30.75 years) for highway. As noted previously, water demand in northwestern Nevada is higher for about half of the year. Defining P(time of year) as 0.5 and incorporating this component into the risk model assesses the risk of hazmat contamination during higher water demand as one contamination every 161 years for rail and one contamination every 61.5 years for highway.

These estimates were also thought to be conservative, which emphasizes the imprecision of the database used in these computations. Equating the severity of rail accidents to the number of railcars involved is nonsensical in the presence of the high-quality data available today that include a description of each accident; however, such an estimate of severity was all that the 1997 database permitted. Similarly, the 1997 highway data did include frequency of fatalities, but fatal accidents are not necessarily severe enough to cause containers within vehicles to rupture. For these reasons, the 1997 estimates of hazmat contamination frequency of the Truckee River—one contamination every 80.5 years for rail transport and one contamination every 30.75 years for highway transport—were considered to be overestimates.

If the question, "What is the combined risk for contaminating the Truckee River by hazmat released during an accident on rail *or* highway?" is asked, then the risk values (probabilities) are summed. The word "or" is important and represents the union of the two events, an event on rail or an event on highway. The probability of the union of two events, A and B, is computed as

$$P(A) + P(B) - (\text{the probability of the intersection of these two events}) \quad (10)$$

The intersection of two events is written as P(A *and* B), with the word "and" being important. The intersection of two events is a situation in which the two events occur simultaneously. In the current study, the probability of accidents occurring simultaneously on rail and highway in which hazmat was released was deemed so small as to be neglected in the calculation of the union of the two events. The combined risk is consequently 0.000034 + 0.000089 = 0.000123 contaminations per day, or one contamination every 8,130 days (22.25 years; 44.5 years if the time of year is considered). Such an outcome must still be considered to be conservative (i.e., an overestimate), given that local history

TABLE 1 Rail accident data, 1975–2004

Accident Parameters	Number of Rail Hazmat Incidents per Year, 1975–1989														
	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
California Counties of Nevada, Placer, and Sierra															
Accidents (total)	19	21	23	29	26	30	19	11	32	7	13	1	7	6	7
Haz 1	0	1	4	3	0	3	1	0	0	0	1	0	1	1	2
Haz 2	0	0	1	2	0	2	1	0	0	0	1	0	1	1	1
Haz 3	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
Haz 4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Nevada, Washoe County															
Accidents (total)	4	4	8	12	8	0	4	4	1	6	1	2	2	0	1
Haz 1	0	0	1	1	0	0	1	0	0	0	0	0	1	0	0
Haz 2	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
Haz 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Haz 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Accident Parameters	Number of Rail Hazmat Incidents per Year, 1990–2004														
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
California Counties of Nevada, Placer, and Sierra															
Accidents (total)	9	10	2	5	14	15	8	3	8	5	4	11	12	18	9
Haz 1	0	3	1	1	3	1	1	0	2	2	0	4	3	0	2
Haz 2	0	3	1	0	1	1	0	0	1	2	0	0	0	0	1
Haz 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Haz 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nevada, Washoe County															
Accidents (total)	1	0	6	1	3	0	0	1	1	1	0	2	0	4	1
Haz 1	0	0	1	0	2	0	0	1	1	0	0	0	0	0	0
Haz 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Haz 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Haz 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

hazmat—hazardous material, haz 1—accidents in which hazmat was involved, haz 2—accidents in which railcars carrying hazmat were damaged, haz 3—accidents in which hazmat was released, haz 4—accidents that resulted in the evacuation of people

indicates that in 1997, contaminations of the Truckee River had not occurred with this frequency.

1997 MODEL VALIDATION USING 2007 DATA

In 2002, the Truckee Meadows Water Authority (TMWA) purchased the water distribution and water treatment system from Sierra Pacific Power Co. Because the database available for risk assessment in 1997 was limited, TMWA funded a study in 2006–2007 to reassess the risk of Truckee River hazmat contamination, this time making use of the vastly improved database that was readily accessible via the Internet.

Rail accident data are complete, comprehensive, and available through the FRA website (FRA, 2014), where users can conduct a detailed search for rail accidents in any portion of the United States. A search for accidents in which railcars carrying hazmat were involved yielded the data in Table 1.

Although highway accident data are still not as easily accessible as rail accident data, there is a comprehensive database for hazmat incidents. The Bureau of Transportation Statistics, a division of the US Department of Transportation (USDOT), maintains a website of incident data that can be searched via the Hazardous Materials Information Resource System (HMIRS), the central repository for Material Safety Data Sheets for US military services and civil agencies (USDOT, 2014). A hazmat incident is defined by USDOT as the leakage (release) of a hazardous substance from a container. An incident does not necessarily involve an accident; for example, an incident can, and often does, occur during loading and unloading of containers. However, any accident during hazmat transport that is so severe as to cause a leakage of hazmat from a container certainly constitutes an incident that would be documented in the incident database.

Hazmat incident reports are available for all 50 states but only within the period from 1995 to 2002. Nonetheless, these eight years of data are sufficient for the risk characterization necessary to the current study to reassess the risk of hazmat contamination to the Truckee River. Hazmat incident data are available for all modes of transportation. Because highway is one mode of transportation included in this database, the frequency of highway accidents that result in a hazmat leakage can be easily determined. Although this determination is less direct in comparison with what is possible using the rail safety data provided by the FRA, it is no less accurate. Search results for hazmat incidents are summarized in Table 2.

Table 3 is presented to enable the assessment of rail accident data during two equal time intervals: 1975–1989 and 1990–2004. A statistically significant decrease in the average total rail accident rate was identified for the three California counties for 1990–2004 compared with 1975–1989, which suggests improved rail operational safety. This result may indicate a decrease in future contamination risk for the Truckee River. The California result is based on 95% confidence (Table t, two-tailed test, is 2.05). For the more recent period, 1990–2004, a statistically significant decrease in accidents was seen in Washoe County, Nev., but the confidence is 90% (Table t, two-tailed test, is 1.70). Rail safety

TABLE 2 Hazmat incidents, 1995–2002

	Number of Hazmat Incidents per Year (All Modes of Transportation)							
Accident Parameters	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
California Counties of Nevada, Placer, and Sierra								
Incidents	8	3	7	7	5	11	10	4
Environmental damage	0	0	0	0	0	0	0	0
Nevada, Washoe County								
Incidents	25	12	23	18	19	19	49	20
Environmental damage	0	0	0	0	0	0	0	0

hazmat—hazardous material

TABLE 3 Summary table of California and Nevada rail hazmat incidents comparing 1975–1989 and 1990–2004

	Number of Hazmat Incidents									
	CA* Total	**NV† Total**	**CA, Haz 1**	**NV, Haz 1**	**CA, Haz 2**	**NV, Haz 2**	**CA, Haz 3**	**NV, Haz 3**	**CA, Haz 4**	**NV, Haz 4**
Totals, Table 1	384	78	40	10	20	2	2	0	1	0
Mean, 1975–2004	12.80	2.60	1.33	0.31	0.62	0.06	0.06	0	0.03	0
Mean, 1975–1989	16.25	3.62	1.06	0.25	0.62	0.12	0.12	0	0.06	0
Mean, 1990–2004	8.81	1.69	1.50	0.37	0.62	0.062	0	0	0	0
Variance, 1975–2004	71.163	8.555	1.628	0.286	0.629	0.087	0.060	0	0.03	0
Variance, 1975–1989	97.533	11.583	1.662	0.2	0.517	0.117	0.117	0	0.062	0
Variance, 1990–2004	20.029	4.094	1.600	0.383	0.783	0.062	0	0	0	0
t statistic	2.65	1.89	−0.94	−0.61	0	0.53	1.36	0	0.93	0
Table t (95% confidence)	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05
Reject null hypothesis	Yes	No	No	No	No	No	No	No	No	No

hazmat—hazardous material, haz 1—accidents in which hazmat was involved, haz 2—accidents in which railcars carrying hazmat were damaged, haz 3—accidents in which hazmat was released, haz 4—accidents that resulted in the evacuation of people

*CA indicates California counties of Nevada, Placer, and Sierra.
†NV indicates Washoe County, Nev.

Null hypothesis: H_0: $Mean_{75-89} = Mean_{90-04}$ and the alternative hypothesis, H_a, holds that the two means are not equal should the null hypothesis be rejected.

Computation of the *t* statistic: (Mean, A − Mean, B) / $(\sqrt{(Var(A)/NA) + (Var(B)/NB)}$, in which *NA* is the number of data values in group A and *NB* is the number of data values in group B. For example, comparing the mean total accidents for California for group A, 1975–1989, and group B, 1990–2004, the *t* statistic is equal to $(16.25 - 8.81)/((97.53/15) + (20.029/15))^{1/2} = 2.65$. In this case, the value of the *t* statistic is greater than the table value of 2.05, so the null hypothesis is rejected, and the alternative hypothesis is accepted, identifying a statistically significant decrease in total California accidents for the more recent period of 1990–2004.

also has improved within Washoe County since 1990, but this statement is not quite as certain as it is for the California counties.

Several additional conclusions can be drawn from Tables 1 through 3. For one, no accident on rail (Table 1) or, in fact, by any mode of transportation (Table 2), has resulted in a release of hazmat (identified by the columns headed "Haz 3" in Table 3) within the Truckee River watershed from 1975 to 2004. Within the same time frame, two accidents resulted in release of hazmat (haz 3) in Placer County, one of which was severe and forced the evacuation of citizens (identified by the columns headed "Haz 4" in Table 3) from Newcastle, Calif., in 1988. Both Placer County incidents occurred within the Sacramento River watershed. An additional conclusion that may be drawn from Table 3 is that rail accidents occurring in California are potentially more severe than those occurring in Nevada, with more hazmat substances likely to be involved and railcars carrying hazmat substances likely to be damaged severely enough to cause a hazmat release. No rail accident in California, however, has resulted in a release of a hazmat substance within the Truckee River watershed during the period of this study.

Table 3 mean values for the entire period from 1975 to 2004 suggest that the frequency of railcars carrying hazmat is approximately 10%. This is the value that was used in the first risk assessment study conducted in 1997. When mean values for the period from 1990 to 2004 are studied, however, the frequency appears to be closer to 20% (i.e., double the value used in the original 1997 risk assessment). This frequency is inferred from the notion that P(total accident) × P(hazmat) = P(hazmat is involved in an accident). In the total period from 1975 to 2004, P(total accidents, Calif.) is 12.53, and P(total accidents, Nev.) is 2.65. P(hazmat involved in accident, Calif.) is 1.28, and P(hazmat involved in accident, Nev.) is 0.31. Dividing P(hazmat involved in accident) by P(total accident) for each state yields P(hazmat, Calif.) = 1.28/12.53 = 0.10 (10%) and P(hazmat, Nev.) = 0.31/2.65 = 0.12 (12%).

For the period from 1990 to 2004, P(hazmat involved in accident) is 1.5 for California (mean haz 1) and 0.37 for Nevada. Total mean accidents within this time frame are 8.81 for California and 1.69 for Nevada. With the use of these values, P(hazmat, Calif.) = 1.5/8.81 = 0.17 (17%) and P(hazmat, Nev.) = 0.37/1.69 = 0.22 (22%). For the period from 1975 to 1989, these frequency values are 6.5% for California, obtained by dividing mean haz 1 for California with this timeframe, 1.06, by the mean total accidents, 16.25; frequency values are 6.9% for Nevada, found by dividing mean haz 1 for Nevada within this timeframe, 0.25, by the mean total accidents, 3.62. This outcome reveals a substantial increase in rail transport of hazmat.

Even though the frequency of hazmat transport by rail has increased significantly since 1990, no statistically significant difference was seen in the frequency of accidents involving hazmat, accidents severe enough to cause damage to railcars carrying hazmat, and accidents causing a release of hazmat between the two time intervals of 1975–1989 and 1990–2004. The null hypothesis used for this assessment (Table 3) is H_0: $Mean_{75-89} = Mean_{90-04}$; the alternative hypothesis, H_a, holds that the two means are not equal should the null hypothesis be rejected. With respect to the transport of hazmat, the fact that the null hypothesis was not rejected shows that despite the increase in hazmat transport since 1990, the average number of accidents, the average number of accidents involving railcars carrying hazmat, the average number of accidents causing damage to railcars carrying hazmat, and the average number of accidents severe enough to cause a release of hazmat are statistically indistinguishable from pre-1990 averages (Table 4).

Actual transportation statistics were used to test the probability-based risk calculations that developed in the 1997 study. The 1997 study relied heavily on conceptual calculations of risk, in large part because of the lack of accessible transportation data available.

As shown in Table 5, P(hazmat|accident) for rail transport of hazmat in California in actuality is three to four times higher than the incidence computed in the 1997 study (1.28 events per year versus 0.38 events per year). For Washoe County, Nev., the two values are more similar, with actual incidence at 0.31 per year and computed level of incidence at 0.29 per year. With respect to the portion of the Truckee River that flows through California, if Placer County rail accident data are discounted, then the actual P(hazmat|accident) risk changes from 1.28 incidents per year to one incident in 32 years, which took place in 1977 near Norden, Calif., within the Sacramento River watershed. Placer County includes only a small portion of the rail line within the Truckee River watershed; similarly, Sierra County includes only a small portion of the rail line near the Truckee River. Therefore, a rail accident severe enough to release hazmat into the river is most likely to occur in Nevada County, Calif. The rate of one accident in 32 years (0.03 per year) is more realistic for the California risk. Accordingly, risk of hazmat contamination to the Truckee River originating from a rail accident is considered negligible. This statement is bolstered by the fact that no accident on rail has caused a hazmat incident within the Truckee River watershed during the available database period beginning in 1975.

Highway data remain difficult to obtain for anything more detailed than a summary by state, a limitation that also affected the 1997 study. With the very detailed HMIRS database, however, hazmat incidents are accessible for individual counties for each state (USDOT, 2014). A hazmat incident is defined as a spill of a

TABLE 4 Frequency of rail accidents in general and involving hazmat for any given year

	Annual Frequency				
Region	Rail Accidents	Haz 1	Haz 2	Haz 3	Haz 4
California*	12.53	1.28	0.63	0.06	0.03†
Nevada‡	2.65	0.31	0.09	§	§

hazmat—hazardous material, haz 1—accidents in which hazmat was involved, haz 2—accidents in which railcars carrying hazmat were damaged, haz 3—accidents in which hazmat was released, haz 4—accidents that resulted in the evacuation of people

*California counties of Nevada, Placer, and Sierra
†The period 1975–2004 shows one incident, which occurred in 1988 in Newcastle, Calif., in the Sacramento River watershed.
‡Washoe County, Nev.
§No incidents occurred in the time frame 1975–2004, so frequency is not yet defined or known.

TABLE 5 Comparison of risk calculations from 1997 versus actual data through 2004

<table>
<tr><th rowspan="2">Risk Calculation</th><th colspan="4">Time Frame and Region</th></tr>
<tr><th>CA, 1997</th><th>NV, 1997</th><th>CA, 2004</th><th>NV, 2004</th></tr>
<tr><td>P(accident), rail</td><td>3.9 per year</td><td>0.9 per year</td><td>12.53 per year</td><td>2.66 per year</td></tr>
<tr><td>P(accident), highway</td><td>1.14 per day, I-80</td><td>1.14 per day, I-80</td><td>27.6 per day, entire state</td><td>1.65 per day, entire state</td></tr>
<tr><td>P(hazmat), rail</td><td>10% (0.1)</td><td>10% (0.1)</td><td>20% (0.20)</td><td>20% (0.20)</td></tr>
<tr><td>P(hazmat), highway</td><td>0.0056, I-80</td><td>0.0056, I-80</td><td>1.6% (0.016)</td><td>1.6% (0.016)</td></tr>
<tr><td>P(hazmat|accident), rail, computed</td><td>0.38 per year</td><td>0.29 per year</td><td></td><td></td></tr>
<tr><td>P(hazmat|accident), rail, actual (haz 1)</td><td>No data</td><td>No data</td><td>1.28 per year</td><td>0.31 per year</td></tr>
<tr><td>P(hazmat|accident), highway, computed</td><td>0.0064 per day, I-80</td><td>0.0064 per day, I-80</td><td></td><td></td></tr>
<tr><td>P(hazmat|accident), highway, actual</td><td>No data</td><td>No data</td><td>0.36 per day (131 per year) entire state</td><td>0.031 per day (11.3 per year), entire state</td></tr>
<tr><td>P(damage|hazmat|accident), rail, actual*</td><td>Not computed (no data)</td><td>Not computed (no data)</td><td>No event in TRW, 1975–2004</td><td>2 events in Washoe County, 1975–2004, both in Sparks rail yard</td></tr>
<tr><td>P(spill|hazmat|accident), rail, computed</td><td>0.0125 per year</td><td>0.0065 per year</td><td></td><td></td></tr>
<tr><td>P(spill|hazmat|accident), rail, actual</td><td>No data</td><td>No data</td><td>2 events, 1975–2004, both in Sacramento River watershed</td><td>No event, 1975–2004; P is undefined</td></tr>
<tr><td>P(spill|hazmat|accident), highway, computed</td><td>0.71 per year</td><td>0.35 per year</td><td></td><td></td></tr>
<tr><td>P(spill|hazmat|accident), highway, actual</td><td>No data</td><td>No data</td><td>No event, 1995–2002; P is undefined</td><td>No event, 1995–2002 P is undefined</td></tr>
<tr><td>P(TRW|spill|hazmat|accident), rail, actual</td><td>No data</td><td>No data</td><td>No event, 1975–2004; P is undefined</td><td>No event, 1975–2004; P is undefined</td></tr>
<tr><td>P(TRW|spill|hazmat|accident), rail, actual</td><td>No data</td><td>No data</td><td>No event, 1995–2002; P is undefined for Placer, Nevada, and Sierra Counties</td><td>No event, 1995–2002; P is undefined for Washoe County</td></tr>
</table>

CA—California, hazmat—hazardous material, I-80—Interstate 80, NV—Nevada, TRW—Truckee River watershed

*Damage includes derailment but does not include spillage.

Except where otherwise indicated, CA data pertain only to the California counties Nevada, Placer, and Sierra, and NV data pertain only to Washoe County, Nev.; I-80 data refer to those portions of the interstate passing through the California counties of Nevada, Placer, and Sierra and Washoe County, Nev.
P(accident), rail data were obtained from the Federal Railway Administration website (FRA, 2014).
P(accident), highway data were obtained from the Bureau of Transportation Statistics website (USDOT, 2014).
P(hazmat), rail and highway data for 1975–2004 were back-calculated as P(hazmat|accident) per P(accident).
P(hazmat|accident), rail data exclude accidents within rail yards.
P(spill|hazmat|accident), computed = P(spill) P(hazmat|accident); P(spill), rail, 1975–2004, CA & NV = [P(spill hazmat|accident), rail, actual, CA] which is equal to one event in 31 years (0.032); P(spill), highway = 0.125 per year
No accident on rail has resulted in a hazmat spill within the Truckee River watershed, 1975–2004.
No accident on the highway has resulted in a hazmat spill within the Truckee River watershed, 1995–2002.

hazardous material, regardless of the cause of the spill. Because incidents include a release of hazmat during an accident, the HMIRS database is valuable for inferring P(spill|hazmat|accident) for any mode of transportation. The values reported in Table 5 for highway are inferences based on the HMIRS database. On the basis of the HMIRS database, P(spill|hazmat|accident) for highway is no greater than 0.11 per year, given the fact that no hazmat incident is associated with a highway accident within the Truckee River watershed during the period 1995–2002. The HMIRS database, although comprehensive for individual counties, comprises only data within the timeframe 1995–2002.

DISCUSSION

Results of this hazard/risk assessment are not adequate for use in complying with the Public Health Security and Bioterrorism Preparedness and Response Act of 2002, better known as the Bioterrorism Act (US Public Law 107–188, 2002). This act requires community drinking water systems serving populations of more than 3,300 to conduct assessments of their vulnerabilities to terrorist attacks or other intentional acts and to defend against adversarial actions that might substantially disrupt the ability of the system to provide a safe and reliable supply of drinking water. The assessment necessary for compliance with this act does not involve the collection of data for characterizing accident frequency or severity. Terrorist acts are deliberate, not accidental. Moreover, design details of the water treatment system are important input to this assessment process; such details were not relevant to, and therefore not included in, the assessment of hazmat contamination risk.

Source water–protection goals and a source water–protection action plan are two of the six primary elements of the ANSI/AWWA G300 Water Protection Standard (ANSI/AWWA, 2007). Source water requires protection from contamination by hazmat release. In November 2009, the Preparedness, Emergency

Response, and Recovery Critical Infrastructure Partnership Advisory Council Working Group issued the report *All-Hazard Consequence Management Planning for Water Sector* (CIPAC, 2009). According to Section II of this report, "When thinking about emergency preparedness, response, and recovery, it is important that utilities consider high probability hazards that they may face and all the potential consequences that flow from them." The key phrase here is "high probability hazards."

Given the assessment that risk of Truckee River contamination by hazmat released during an accident is small, TMWA decided not to stockpile chemicals or institute any other operational changes at or to water treatment plants. Given that TMWA has an alternate water supply (i.e., wells), it was decided to focus on response times and creation of a plan to adjust operations. To this end, TMWA developed a contaminant spill model (Rivord et al, 2014) to provide estimates of how long it would take for a spill to reach one of the treatment plant inlets and how long the plants might have to remain offline. If such an incident were to occur in summer, TMWA could limit outdoor watering and switch production over to the 31 production wells. If the incident were to occur during winter, the production wells could replace surface water, and the plants could be taken offline until the spill had been cleaned up or had passed the plants.

SUMMARY

As shown in this study, when a database is limited, working with conditional probability estimates to develop upper and lower bounds for risk yields a reasonable characterization of actual risk. Given a comprehensive database, the conditional probability model is more precise. This study found that the 2007 calculations represented better estimates of risk, yet the 1997 estimates were reasonable when compared with the 2007 calculations.

A cost analysis (Verma, 2009) was not part of this study. The cost of a hazmat contamination of the Truckee River is difficult or impossible to estimate. The cost could in fact be zero, depending on the location of the accident and the type of hazmat involved. At the opposite extreme, the cost could be in the millions of dollars if an accident were to occur in the summer, disrupting water delivery for irrigation.

Since the conclusion of the 2007 study, additional work (Qiao et al, 2009) has been devoted to estimating accident frequency for the transport of hazmat by highway. This accident frequency remains difficult to calculate with confidence. As shown in this article, data for rail accidents are highly detailed, and calculations of accident frequency have a high confidence. Access to highway transport incidents, on the other hand, is more difficult. Qiao and colleagues (2009) proposed methods that included fuzzy logic for estimating highway hazmat accident frequency for which error is quantifiable. Still, the estimates of highway hazmat-transportation risk reported here are intentionally conservative, given the lower confidence in the database.

ACKNOWLEDGMENT

The research that provided the basis of this article began in 1995 with a grant from Sierra Pacific Power Co. to John Warwick, then hydrological sciences director at the University of Nevada in Reno. The authors thank John Irwin, now with the Truckee Meadows Water Authority (TMWA) in Reno, Nev., for this grant. Further research was conducted in 2006 and 2007 through a grant to the first author funded by TMWA. This second phase of research was guided by the second author with input from John Irwin. Both authors are grateful to the three reviewers of the original manuscript.

ABOUT THE AUTHORS

***James R. Carr** (to whom correspondence should be addressed) is a professor of geological sciences and engineering at the University of Nevada, Reno, Mail Stop 172, Reno, NV 89557-0172 USA; carr@unr.edu. He has served on the faculty of the University of Nevada at Reno from 1986 to the present and previously taught at the University of Missouri–Rolla (now the Missouri University of Science and Technology). He has several areas of specialization, including data analysis, and is the author of the textbook* Data Visualization in the Geosciences. *Carr holds a BS degree from the University of Nevada at Reno and MS and PhD degrees from the University of Arizona at Tucson.* ***Shawn W. Stoddard** is a senior planner/senior research economist at Truckee Meadows Water Authority in Reno.*

PEER REVIEW

Date of submission: 12/01/2013
Date of acceptance: 09/24/2014

REFERENCES

Anderson, R. & Barkan, C., 2004. Railroad Accident Rates for Use in Transportation Risk Analysis. Transportation Research Record: *Journal of the Transportation Research Board,* 1863:88. http://dx.doi.org/10.3141/1863-12.

ANSI/AWWA (American National Standards Institute/AWWA), 2007. G300-07. Standard for Source Water Protection. AWWA, Denver.

Barkan, C.; Dick, C.; & Anderson, R., 2003. Railroad Derailment Factors Affecting Hazardous Materials Transportation Risk. *Transportation Research Record: Journal of the Transportation Research Board,* 1825:64. http://dx.doi.org/10.3141/1825-09.

Battelle, 2011. City of Boston Hazmat Route Evaluation. Report prepared for the City of Boston, Department of Transportation. Batelle, Columbus, Ohio.

CIPAC (Critical Infrastructure Partnership Advisory Council), 2009. All-Hazard Consequence Management Planning for Water Sector. Preparedness, Emergency Response, and Recovery CIPAC Workgroup, US Department of Homeland Security, Washington.

Clark, R. & Besterfield-Sacre, M., 2009. A New Approach to Hazardous Materials Transportation Risk Analysis: Decision Modeling to Define Critical Variables. *Risk Analysis,* 29:3:344. http://dx.doi.org/10.1111/j.1539-6924.2008.01163.x.

Cozzani, V.; Bonvicini, S.; Spadoni, G.; & Zanelli, S., 2007. Hazmat Transport: A Methodological Framework for the Risk Analysis of Marshalling Yards. *Journal of Hazardous Materials,* 147:1–2:412. http://dx.doi.org/10.1016/j.jhazmat.2007.01.065.

Erkut, E. & Verter, V., 1998. Modeling of Transport Risk for Hazardous Materials. *Operations Research,* 46:5:625. http://dx.doi.org/10.1287/opre.46.5.625.

Fabiano, B.; Currò, F.; Palazzi, E.; & Pastorino, R., 2002. A Framework for Risk Assessment and Decision-Making Strategies in Dangerous Goods Transportation. *Journal of Hazardous Materials*, 93:1:1. http://dx.doi.org/10.1016/S0304-3894(02)00034-1.

FRA (Federal Railroad Administration), 2014. Office of Safety Analysis, Washington. http://safetydata.fra.dot.gov/OfficeofSafety/ (accessed Nov. 23, 2014).

Gheorghea, A.; Birchmeiera, J.; Vamanub, D.; Papazoglouc, I.; & Kröger, W., 2005. Comprehensive Risk Assessment for Rail Transportation of Dangerous Goods: A Validated Platform for Decision Support. *Reliability Engineering and System Safety*, 88:3:247. http://dx.doi.org/10.1016/j.ress.2004.07.017.

Harwood, D.; Viner, J.; & Russell, E., 1993. Procedure for Developing Truck Accident and Release Rates for Hazmat Routing. *Journal of Transportation Engineering*, 119:2:189. http://dx.doi.org/10.1061/(ASCE)0733-947X(1993)119:2(189).

Høj, N. & Kröger, W., 2002. Risk Analysis of Transportation on Road and Railway From a European Perspective. *Safety Science*, 40:1:337. http://dx.doi.org/10.1016/S0925-7535(01)00053-4.

Qiao, Y.; Keren, N.; & Mannan, M., 2009. Utilization of Accident Databases and Fuzzy Sets to Estimate Frequency of Hazmat Transport Accidents. *Journal of Hazardous Materials*, 167:1–3:374. http://dx.doi.org/10.1016/j.jhazmat.2009.01.097.

Rivord, J.; Saito, L.; Miller, G.; & Stoddard, S., 2014. Modeling Contaminant Spills in the Truckee River in the Western United States. *Journal of Water Resources Planning and Management*, 140:3:343.

USDOT (US Department of Transportation), 2014. *HMIRS Incident Report*. Research and Information Technology Administration, Bureau of Transportation Statistics, Washington. www.transtats.bts.gov/DL_SelectFields.asp?Table_ID=508&DB_Short_Name=HMIRS (accessed Nov. 23, 2014).

US Public Law 107–188, 2002. Public Health Security and Bioterrorism Preparedness and Response Act of 2002. 107th US Congress, June 2002, Washington.

Verma, M., 2009. A Cost and Expected Consequence Approach to Planning and Managing Railroad Transportation of Hazardous Materials. *Transportation Research Part D*, 14:5:300. http://dx.doi.org/10.1016/j.trd.2009.03.002.

APPENDIX 2-6

Modeling Contaminant Spills in the Truckee River

Modeling Contaminant Spills in the Truckee River in the Western United States

Jeremy Rivord[1]; Laurel Saito, P.E., M.ASCE[2]; Glenn Miller[3]; and Shawn S. Stoddard[4]

Abstract: Originating at Lake Tahoe, the Truckee River provides 85% of drinking water for the Reno/Sparks metropolitan area. Major highways and a railroad run adjacent to the river, which increases risk of a contaminant spill into the river that could have detrimental effects on drinking water supplies. A one-dimensional solute transport model (OTIS) was applied to the Truckee River. Data from dye studies on the river were used to determine a relationship to estimate dispersion coefficients for the Truckee River and calibrate the model. Two sizes of hypothetical contaminant spills from 9 locations under 13 flow scenarios were simulated. Travel times to the first water intake for a train spill of 130,000 L ranged from 3 to 46 h and maximum simulated concentrations of a conservative water soluble contaminant at the intake ranged from 340 to 4,800 mg/L. Model output was influenced by uncertainties in the equation for longitudinal dispersion, so model runs were executed with estimated dispersion values that were a factor of 1.5 greater and less than the equation-estimated value of dispersion.
DOI: 10.1061/(ASCE)WR.1943-5452.0000338.

Author keywords: Modeling; Transport and fate; Rivers/streams; OTIS.

Introduction

Large contaminant spills from transportation accidents have impacted aquatic ecosystems and water quality of municipal drinking waters [Government Accountability Office (GAO) 2006]. On August 5, 2005, nine Canadian National rail cars fell off a bridge into the Cheakamus River north of Vancouver, British Columbia, releasing 41,000 L of sodium hydroxide that killed more than 500,000 fish in an 18-km section of the river (Canadian Broadcasting Corporation 2006). Similarly in 1991, 70,000 L of metam sodium, a commonly used agricultural fumigant, was spilled into the Sacramento River when several rail cars overturned near Dunsmuir, California. The spill degraded into several products toxic to humans and aquatic life. Metam sodium-derived analytes were detected in sites downstream from the spill 23 days after the spill (del Rosario et al. 1994) and the spill impacted the aquatic ecosystem at monitoring sites up to 55 km downstream for 26 days (Brett et al. 1995). However, the quick response in monitoring solute concentrations assisted officials in managing the accident and verifying when water was safe to drink (del Rosario et al. 1994).

Solute transport models that can predict travel times and contaminant concentrations due to spills are useful for municipalities that rely on nearby rivers for drinking water supplies. This paper describes the application of the one-dimensional transport with inflow and storage (OTIS) model (Runkel 1998) to the Truckee River in California and Nevada. OTIS has been used to model in-channel solute mixing and transport, nutrient uptake, and trace metal chemical reactions for both steady and unsteady state scenarios for streams and rivers (Runkel 2000).

The Truckee River and its tributaries provide approximately 85% of total water supplies to the cities of Reno and Sparks, Nevada (TMWA 2012). Originating at Lake Tahoe at Tahoe City, California, the river flows in close proximity to California Highway 89, U.S. Interstate 80 (I-80), and the Union Pacific Railroad (UPRR) into the Reno-Sparks area (Fig. 1). Regular traffic on the highway and rail line and harsh winter conditions present the potential for a contaminant spill. While there is an emergency response plan for spills in the Truckee River corridor [Truckee River Area Committee (TRAC) 2005], it does not address spill travel times. Truckee Meadows Water Authority (TMWA), the area's drinking water purveyor, has a need for predicting the timing, duration, and concentration of spills that might occur on the Truckee River and contaminate drinking water of the Reno-Sparks area. The objective of this paper is to present methods for modeling this highly regulated river, including development of new dispersion equations for the Truckee River based on dye study data from 1999, 2006, and 2007.

Methods

Study Area

From its origins in California, the Truckee River flows 190 km through the Tahoe National Forest, past the town of Truckee, California, into the Truckee Meadows with the cities of Reno and Sparks, Nevada, and to its terminus at Pyramid Lake (Fig. 1). The Truckee River watershed drains approximately 8,000 km^2 and contains five major reservoirs with headwater altitudes in excess of 3,000 m around Lake Tahoe. The elevation of the river from its outlet to its terminus decreases more than 700 m. Higher altitudes around Lake Tahoe experience an average annual precipitation of 81 cm, mostly in the form of winter snow and occasional summer thunderstorms, whereas Truckee Meadows

[1]Hydrologist, Waters Division, Minnesota Dept. of Natural Resources, St. Paul, MN 55155-4040.

[2]Associate Professor, Dept. of Natural Resources and Environmental Science, Graduate Program of Hydrologic Sciences, Univ. of Nevada, Reno, NV 89557 (corresponding author). E-mail: lsaito@cabnr.unr.edu

[3]Professor, Dept. of Natural Resources and Environmental Science, Univ. of Nevada, Reno, NV 89557.

[4]Senior Resource Economist, Dept. of Natural Resources Planning and Management, Truckee Meadows Water Authority, Reno, NV 89520-3013.

Note. This manuscript was submitted on February 20, 2012; approved on November 30, 2012; published online on December 3, 2012. Discussion period open until August 1, 2014; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Water Resources Planning and Management***, Vol. 140, No. 3, March 1, 2014. © ASCE, ISSN 0733-9496/2014/3-343-354/$25.00.

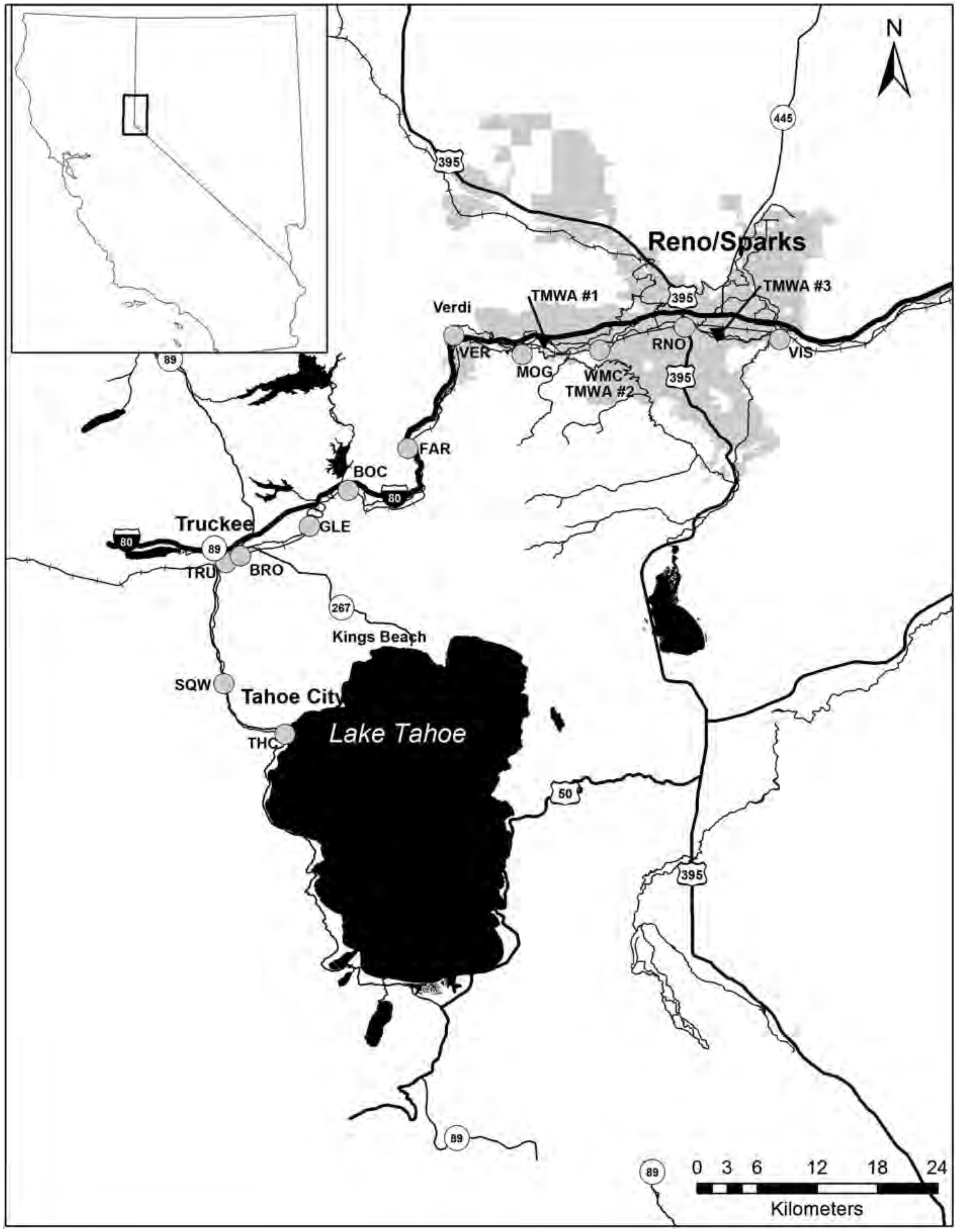


Fig. 1. Site map showing sites used in the study (see Table 1 for definitions of the site abbreviations)

and Pyramid Lake average only about 18 cm of precipitation each year. Spring snowmelt in the Sierra Nevada creates the highest river flows of the year with lower discharges typically occurring in late July and August.

Only 103 km of the river [from Lake Tahoe to U.S. Geological Survey's (USGS) Vista gauge just east of Sparks, Nevada] was included in this study. The river was divided into three portions as defined by dye studies conducted by the USGS in 1999, 2006, and 2007 (Crompton 2008; Crompton and Bohman 2000). The upper portion of the river begins at the California State Route 89 Bridge in Tahoe City, California (THC, USGS Station No. 10337500, Table 1) and is composed of five downstream sites over 32 river km (Fig. 1, Table 1). From THC, the Truckee River flows north alongside California State Route 89, passing

Table 1. Site Abbreviations, Site Descriptions, and Distances of Sites from Lake Tahoe that were Included in Dye Studies, Surveying, and OTIS Model

Site abbreviation	Site description	Distance from Lake Tahoe (km)	Included in dye studies?	Cross-section survey?	Included in OTIS?
Upper portion					
THC	Truckee River below Tahoe City Dam	0.03	Y	Y	Y
SQW	Truckee River below confluence with Squaw Creek	10	Y	Y	Y
DEE	Deep Creek off of Hwy 89	—	N	Y	N
TRU	Truckee River near Truckee	20	Y	Y	Y
DC	Donner Creek tributary	—	N	N	Y
BRO	Truckee River at Brockway Bridge	25	Y	Y	Y
MC	Martis Creek tributary	—	N	N	Y
GLE	Truckee River at Glenshire Drive Bridge	32	Y	Y	Y
Middle portion					
GLE	Truckee River at Glenshire Drive Bridge	32	Y	Y	Y
PC	Prosser Creek tributary	—	N	N	Y
LTR	Little Truckee River tributary	—	N	N	Y
BOC	Truckee River at Boca Bridge	40	Y	Y	Y
FAR	Truckee River near Farad	55	Y	Y	Y
VER	Truckee River at Bridge Street Bridge (site not included in model domain)	69	Y	Y	N
TMWA#1	Highland Ditch (TMWA diversion)	73	Y	Y	Y
MOG	Truckee River near Mogul	77	Y	Y	Y
Lower portion					
MOG	Truckee River near Mogul	77	Y	Y	Y
WMC	Truckee River at West McCarran Bridge	84	Y	Y	Y
TMWA#2	Orr Ditch (TMWA diversion)	84	Y	N	Y
REN	Truckee River near Reno	92	Y	Y	Y
TMWA#3	Glendale Intake (TMWA diversion)	92	Y	Y	Y
VIS	Truckee River at Vista (site not included in model extent)	103	Y	Y	N

confluences with Squaw Creek (SQW) and Donner Creek. East of the town of Truckee, the river, I-80, and the Union Pacific Railroad descend into the Truckee Meadows. Tributaries Martis Creek, Prosser Creek, and the Little Truckee River join the river, all of which are controlled by reservoirs. The portion of the Truckee River from the Boca Bridge (BOC, USGS Station No. 10344505) to the Glenshire Bridge (GLE) has unconsolidated sedimentary rocks that lead to accretion from groundwater (Fox 1982; McKenna 1990).

The middle portion of the spill model covered 44 river km with four downstream dye study sample locations (Crompton 2008; Crompton and Bohman 2000). The last sample site in the upper portion (GLE) was the middle portion injection site for dye studies in 1999 and 2006. From GLE, the Truckee River enters a steep canyon (average slope of 0.0066) with I-80 adjacent to the river for the next 35 km. Between Farad, California (FAR, USGS Station No. 10346000), and Verdi, Nevada (VER, USGS Station No. 10347320), there are three hydropower diversions and returns that regularly divert 10–13 m^3/s along this section of river (David Wathen, personal communication, 2008). East of VER, the river exits the mountains and enters the flatter alluvial valley of the Truckee Meadows. The first of three TMWA municipal diversions—the Highland ditch diversion (TMWA#1), which feeds the Chalk Bluff Treatment Plant, occurs about 1 km upstream of the Mogul site (MOG, USGS Station No. 10347460), which was also the final dye study sample location of the middle portion.

The lower portion of the spill model began at MOG with two downstream sample locations and 25 km of river. Three separate dye studies on this reach occurred on May 4, 1999; August 25, 1999; and June 27, 2006. The gradient is relatively flat (about 0.0003) and there are numerous agricultural diversions throughout this reach that divert water on a seasonal basis at flows less than 0.5 m^3/s (David Wathen, personal communication, 2008). It is also in this reach where the final two TMWA treatment diversions are located. A diversion at Orr Ditch (TMWA#2) occurs about 6 km downstream of MOG and routes water to the Chalk Bluff Treatment Plant. The river passes the West McCarran Bridge (WMC) and then encounters the Glendale Treatment Plant diversion (TMWA#3), which is less than 1 km downstream from the dye study sample location at the USGS Reno gauge (REN, USGS Station No. 10348000). The final sampling location for the dye studies was at Vista (VIS, USGS Station No. 10350000).

Dye Studies

Field procedures for conducting travel time dye studies as described in Kilpatrick and Wilson (1989) were followed for both the 1999 and 2006–2007 studies (Crompton 2008; Crompton and Bohman 2000). An instantaneous slug injection of Rhodamine WT (RWT) dye was made near the center of active flow at each injection site. The amount of dye, time and location of injection, and observed streamflow were recorded for each injection. Peak concentrations did not exceed 10 $\mu g/L$ at sampling sites. Background readings were determined on-site using a Turner Designs Model 10 fluorometer (Turner Designs, Sunnyvale, California). When readings at the sample site increased from background levels, samples were collected at approximately 5-min intervals until concentrations returned to background levels. Samples were stored in a cooler and transported to the USGS Laboratory in Carson City, Nevada, for analysis with the same fluorometer at a controlled temperature. Concentrations determined in the USGS Lab were used in model calibration.

J. Water Resour. Plann. Manage. 2014.140:343-354.

Cross-Sectional Surveys and Sediment Sampling

In October 2006, 15 cross sections along the Truckee River were surveyed (Table 1). These measured cross sections provided physical characteristics such as channel geometry, water elevation, and average slope of the sampling sites that were used in calibrating the model. Sediment samples were also collected from 13 sites and analyzed for organic matter and particle size distribution. Results of the sediment samples provided sorption and porosity information and indicated the RWT dye was unlikely to sorb. According to USDA soil classification, 10 of the 13 sites had a very gravelly and sand substrate, and the other sites had loamy sand substrates. With the exception of five sites (THC, FAR, VER, MOG, and TMWA#1), organic matter in sediment samples was less than 1%, which would limit sorption of organic compounds.

Modeling Approach

To develop predictive plans that address accidental or intentional spills in rivers, it is important to understand the movement and transport of contaminants in a particular water body. Tracer studies have commonly been used to determine mixing characteristics of stream systems for solute transport (Stream Solute Workshop 1990). RWT dye is a commonly used tracer measured with a fluorometer, but other tracers such as chloride and dissolved iron from mine tailings have been successfully used as conservative and nonconservative tracers (Broshears et al. 1993; Kilpatrick and Wilson 1989; Knust and Warwick 2009; Stream Solute Workshop 1990).

Tracer studies provide valuable data for development of water quality and hydraulic models that can be used to model potential contaminant spills. The one-dimensional advection-dispersion equation (ADE) (Fischer et al. 1979) has been extensively used in solute transport and hydraulic studies of streams and rivers. However, response curves from the one-dimensional ADE model have been inconsistent with response curves in numerous tracer studies, especially in predicting the tail of the response (Bencala and Walters 1983; Knust and Warwick 2009). It has been hypothesized that this phenomenon was due to a temporary storage mechanism referred to as *dead zones* or transient storage (Bencala and Walters 1983; Fischer et al. 1979) that occur as eddies, pools, or subsurface flows paths, and lengthen the duration of a spilled contaminant's presence in the channel.

The transient storage model uses the one-dimensional ADE modified to account for transport delays from dead zones by simulating storage zones that exhibit a first-order mass transfer relationship with the main channel (Bencala and Walters 1983). The equations are defined as (Bencala and Walters 1983; Runkel 1998)

$$\frac{\partial C}{\partial t} = -\frac{Q}{A}\frac{\partial C}{\partial x} + \frac{1}{A}\frac{\partial}{\partial x}\left(AK\frac{\partial C}{\partial x}\right) + \frac{q_L}{A}(C_L - C) + \alpha(C_S - C) - \lambda C \tag{1}$$

$$\frac{dC_s}{dt} = -\alpha\frac{A}{A_S}(C_S - C) - \lambda_S C_S \tag{2}$$

where α = stream storage zone coefficient [1/T]; A = stream cross-sectional area [L^2]; A_S = cross-sectional area of the storage zone [L^2]; C = solute concentration in control volume [M/L^3]; C_L = solute concentration in lateral inflow [M/L^3]; C_S = solute concentration in the storage zone [M/L^3]; K = dispersion coefficient [L^2/T]; λ = main channel first-order decay coefficient [/T]; λ_S = storage zone first-order decay coefficient [/T]; Q = volumetric flow rate [L^3/T]; q_L = lateral volumetric flow rate [L^3/T]; t = time [T]; and x = downstream distance [L].

OTIS is a FORTRAN-based computer model developed by the USGS with Eqs. (1) and (2) as the governing equations for simulation of one-dimensional surface water transport. Within OTIS is a parameter estimation algorithm called OTIS-P. OTIS-P uses the adaptive nonlinear least squares technique (residual sum of squares) for instream concentrations as described by Dennis et al. (1981).

For the Truckee River OTIS model, reaches were bounded both upstream and downstream by locations where tracer samples were collected. Reaches had many 30-m segments (or control volumes), but it was assumed that cross-sectional areas of the main channel (A) and the storage zone (A_s), dispersion (K), storage zone exchange coefficient (α), and first-order decay coefficients of the main channel (λ) and the storage zone (λ_s) were constant for an entire reach.

Model Setup and Calibration

Data from the seven tracer tests conducted on the Truckee River in 1999 and 2006/2007 were used to calibrate dispersion and decay coefficients and cross-sectional areas for the Truckee River spill model. One tracer study from 1999 for the lower portion and the 2006 tracer studies for the middle and lower portions were used in model calibration for high flows (flows between 36 and 75 m^3/s). All other tracer studies were used in model calibration for moderate flows (flows between 4 and 18 m^3/s). Reach lengths and output locations were calculated using river distances from the Lake Tahoe Dam in Tahoe City, California, as documented by Crompton and Bohman (2000) and Crompton (2008). Additional river locations such as tributaries, diversions, and TMWA intakes are obtained from TMWA's River Recreation map [Truckee Meadows Water Authority (TMWA) 2007].

Two different types of upstream boundary conditions were needed for model calibration. A continuous concentration boundary condition was used for reaches that had an observation time series at the upstream boundary. For the three reaches that had a tracer injection as an upstream boundary, a step concentration was used as the boundary condition. In this case, the volume of dye injected was converted into a constant concentration sustained over one integration time step. The modeled flow regime was assumed to be steady, nonuniform flow, with steady uniform flow within a reach, but nonuniform flow for the model extent.

A water balance for each reach was set up using streamflows from the tracer studies along with tributary or diversion data. There are four large tributaries to the Truckee River as well as three run-of-river hydropower diversions and returns that divert up to 80% of instream flow. If a tributary had a considerable year-round contribution to the Truckee River, then the change in streamflow due to that tributary was simulated to occur over a distance of one 30-m segment. Tributaries modeled in this way were Donner Creek, Martis Creek, Prosser Creek, and the Little Truckee River. Change in flow for smaller tributaries like Squaw Creek and Bronco Creek was averaged over the entire reach rather than a 30-m segment.

The integration time step (Δt) used in the Truckee River spill model was set to 0.02 h (1.2 min) to account for variability in sample frequencies. When an injection served as a step concentration boundary condition, the time step was set at 0.001 h (3.6 s) to simulate the brevity and magnitude of injected tracer.

Tracer data from each dye study was analyzed using the method of moments to provide initial estimates of main channel cross-sectional area and longitudinal dispersion for OTIS-P calibration. After OTIS-P was calibrated for area, dispersion, and decay, the model was again calibrated with OTIS-P with transient storage. For each reach, initial values of the storage zone exchange coefficient were defined to be 1.0×10^{-6} L/s (Fernald et al. 2001). Initial values of A_s were set such that the ratio of storage zone

J. Water Resour. Plann. Manage. 2014.140:343-354.

cross-sectional area to main channel cross-sectional area (A_s/A) was 0.2, which was the mean ratio found for rivers in the Willamette Basin, Oregon (Laenen and Bencala 2001). Statistics for model fits with OTIS-P were calculated using r^2, root mean squared error (RMSE) and percent bias between modeled and observed concentrations.

Spill Scenario Simulations

Because of the Truckee River emergency response plan (TRAC 2005), a major spill on the river has a good chance of being attended to in an expeditious manner. It was therefore assumed that a train tanker spill would occur over the course of 90 min, and a semitruck spill occurred over 60 min. It was also assumed that both would be best simulated by a simple step function (i.e., concentration was constant over spill duration). The volume of a rail car spill was simulated at 130,000 L and the volume of a dual tanker rig spill from a semitruck was simulated at 75,000 L, which are maximum allowable volumes described in the Code of Federal Regulations (49CFR179.13) (Holtzman 1997). It was assumed that the contaminant spilled was a conservative constituent that did not decay or degrade, and that the density of the spilled contaminant was similar to that of water (i.e., 1,000 kg/m^3), which allowed for the fastest transport downstream. The assumed density and spill duration were used to estimate the injection rate. The mass per unit time was then divided by the simulated streamflow in liters to define the upstream boundary condition for a spill.

Thirteen streamflow scenarios were developed at 8 sites along the Truckee River using 10 years of USGS streamflow data from October 1, 1996 through September 30, 2007. The FAR site was designated as an index site for setting model flow scenarios due to its historical significance in Truckee River operations (Horton 1997). Streamflow scenarios were defined at 2.83 m^3/s (100 cfs) flow increments as observed at FAR from 2.83 to 28.3 m^3/s (100 to 1,000 cfs) and at 42.5, 56.6, and 70.8 m^3/s (1,500; 2,000; and 2,500 cfs). Flows at other sites were determined by analyzing historical records for flows at each site that corresponded with each incremental flow at FAR.

To prepare for spill scenario simulations, calibrated cross-sectional areas were used with surveyed cross-sectional geometry and the Chezy-Manning equation to estimate Manning's n coefficients for each model reach (Table 2). Cross-sectional area A for each spill scenario was calculated with the calibrated Manning's n coefficients. This approach assumed that a constant Manning's n (and hence, constant cross-sectional area and slope) applied throughout each section.

In addition, dispersion values needed to be estimated for each spill scenario. Although OTIS-P could be used to estimate observed dispersion coefficients (K_m) that fit the dye study data, it was necessary to estimate K for spill simulations at flows that were not observed during dye studies. Estimation of the dispersion coefficient was especially important because it affects the amount of time a contaminant may be present at a particular site. Longitudinal dispersion is primarily the result of velocity profiles created from shearing processes around the wetted perimeter. Using data obtained from tracer studies, longitudinal dispersion can be estimated by matching observed concentrations to simulated concentrations modeled with the ADE (Stream Solute Workshop 1990; Graf 1995). There are also numerous theoretical equations for estimating longitudinal dispersion that have been derived from bulk flow parameters using channel geometry. For an average cross-sectional area, Fischer et al. (1979) defined the "longitudinal dispersion coefficient" in the form of a triple integral that accounted for shearing throughout the main channel. With recognition that rivers are generally much wider than they are deep, Fischer et al. (1979) simplified the triple integral equation through a series of laboratory experiments and dimensional analysis to propose a bulk flow parameter equation for longitudinal dispersion

Table 2. Cross-Sectional Areas Calculated by OTIS-P, Corresponding Cross-Sectional Areas Calculated with Manning's Equation for Calibration Flows Using Survey Data, and Fitted Manning's n Values for Each Cross-Section (Calibration Flows are the Flows Measured during Respective Dye Studies)

Model site	Calibration flow (m^3/s)	OTIS-P area (m^2)	Survey calculated area (m^2)	Manning's n
Upper portion calibration runs for 1999 tracer data at moderate (36% exceedance) flow				
THC	7.6	16.5	28.4	0.279
SQW	8.0	11.1	13.2	0.076
TRU	8.1	13.9	14.8	0.083
BRO	9.1	14.9	14.5	0.086
GLE	9.8	17.5	18.0	0.095
Middle portion calibration runs for 1999 tracer data at moderate (35% exceedance) flow				
GLE	11.2	19.7	19.5	0.095
BOC	17.8	23.2	23.6	0.088
FAR	17.8	26.7	25.0	0.091
Lower portion calibration runs for 1999 tracer data at moderate (45% exceedance) flow				
MOG	15.4	21.9	22.5	0.090
WMC	12.2	16.3	12.3	0.035
REN	11.8	21.4	15.2	0.031
Lower portion calibration runs for 1999 tracer data at high (7% exceedance) flow				
MOG	64	46.4	48.6	0.068
WMC	65	42.1	42.1	0.046
REN	60	43.1	42.1	0.031
Upper portion calibration runs for 2006 tracer data at moderate (50% exceedance) flow				
THC	1.9	12.0	11.1	0.279
SQW	4.0	8.7	8.6	0.076
TRU	5.5	11.6	11.7	0.083
BRO	7.5	14.0	13.0	0.086
GLE	7.6	16.0	15.3	0.095
Middle portion calibration for 2006 tracer data at high (5% exceedance) flow				
GLE	60.3	42.0	61.7	0.105
BOC	64.0	43.4	43.0	0.062
FAR	75.0	56.4	57.1	0.078
Lower portion calibration for 2006 tracer data at high (13% exceedance) flow				
MOG	39.4	34.0	35.0	0.068
WMC	38.2	30.0	30.1	0.046

Note: See Table 1 for site abbreviations.

$$K = \frac{0.011U^2w^2}{hU_*} \tag{3}$$

in which U = centroid velocity [L/T]; w = full channel width [L]; h = channel depth [L]; and U_* is shear velocity over the cross section [L/T], commonly estimated as

$$U_* = \sqrt{gr_hS} \tag{4}$$

where g = gravitational acceleration [L^2/T]; r_h = hydraulic radius [L]; and S = hydraulic gradient. Variables in Eq. (3) are measurable river characteristics using tracer studies and channel geometry. Fischer et al. (1979) found that Eq. (3) was able to predict

J. Water Resour. Plann. Manage. 2014.140:343-354.

dispersion coefficients within a factor of 4 of observed dispersion coefficients.

Numerous studies have built upon Eq. (3) (Liu 1977; Seo and Cheong 1998; Deng et al. 2002; Kashefipour and Falconer 2002). Seo and Cheong (1998) used dimensional analysis with a nonlinear, one-step Huber regression to derive an equation for dispersion (K_{SC}) based on 35 measured dispersion values. The relationship is defined as

$$\frac{K_{SC}}{hU_*} = 5.915\left(\frac{w}{h}\right)^{0.620}\left(\frac{U}{U_*}\right)^{1.428} \quad (5)$$

The equation was validated to 24 independent dispersion values and assessed using discrepancy ratios for predicted (K_p) and measured (K_m) dispersion values

$$\text{Discrepancy ratio} = \log\frac{K_p}{K_m} \quad (6)$$

A discrepancy ratio of zero indicates the predicted dispersion value exactly matches the measured dispersion value, whereas the prediction is overestimated for a ratio greater than zero and underestimated for a ratio less than zero (Seo and Cheong 1998). Seo and Cheong (1998) found that Eq. (5) estimated dispersion values with a range of discrepancy values from -0.6 to 1 and estimated 79% of dispersion ratios within a range of -0.3 to 0.3.

For the current study, a dispersion equation was developed for the Truckee River using data from the seven Truckee River tracer studies in 1999 and 2006/2007. First, the parameter estimation algorithm in OTIS-P was used to estimate the observed dispersion coefficient K_m for the dye study data for runs that included transient storage and runs that did not. Regression relationships between the OTIS-P K_m values and flow, reach slope (S), and OTIS-P estimated A values were examined, and the following equation was derived

$$K_{TR} = 10^{0.237102}S^{-0.60167}\left(\frac{Q}{A}\right)^{0.542335} \quad (7)$$

where K_{TR} = dispersion for the Truckee River. Eq. (7) was derived using OTIS-P estimated K_m values with transient storage ($r^2 = 0.35$; $n = 24$). Discrepancy ratios for Eq. (7) ranged from -0.6 to 0.3, and 70.8% of the discrepancy ratios were between -0.25 and 0.25. All K_{TR} values estimated with Eq. (7) were within a factor of 4 of the 24 observed dispersion values, and 79.2% were within a factor of 1.5. Fits from Eq. (7) were compared to fits using Eq. (5) to determine which equation was best to use for spill scenario simulations. Because of uncertainty associated with dispersion calculations, two additional simulations were made for each spill scenario using K_{TR} values that bracketed estimated values by $1.5K_{TR}$ (discrepancy ratio $= +0.18$) and $K_{TR}/1.5$ (discrepancy ratio $= -0.18$) to provide upper and lower bounds of travel times.

Storage was not simulated in spill model scenarios because the storage zone is a conceptual zone that is not measurable with survey data and there are no theoretical equations to estimate storage parameters. Also, initial simulations showed that the least conservative spill in terms of time of arrival and peak concentration was simulated when OTIS-P storage parameters were included. Because the simulated contaminant was assumed to be conservative, the decay coefficient for simulations was set to zero.

A MATLAB routine processed output to obtain time of arrival and departure as well as peak concentration at each TMWA diversion. Arrival and departure times were defined as the times at which simulated concentration for each spill reached a concentration of 5 μg/L (Shawn Stoddard, personal communication, 2008). Time series for each spill at each site were also output.

Results

Calibration Results

The performance of OTIS-P with and without transient storage varied between studies performed in 1999 and 2006/2007 (Figs. 2 and 3; Table 3). For the majority of model executions, OTIS-P simulations without storage tended to have the largest peak concentrations. OTIS-P models with and without storage were able to recreate arrival and departure of dye well, with model statistics generally better for calibration runs for moderate flows as compared to runs for high flows (Table 3). The difference between results with and without storage for OTIS-P was minimal. Therefore, because of the difficulty in estimating transient storage area for further runs, simulation scenarios were run without the transient storage component.

For most runs using calculated K_{SC} and K_{TR} values for calibration, model timing of peak concentrations were close to the time of observed peaks, which indicated that the cross-sectional areas used in those runs were appropriate. However, in most cases, K_{SC} values were overestimated, resulting in peak concentrations that were too low, as well as an overestimation of the duration over which tracer was present. In contrast, K_{TR} values were lower than K_{SC} values, which overall resulted in better estimates of peak concentrations, especially for high-flow dye studies. Model r^2 values for results with calculated K_{TR} values tended to be better for moderate flow, whereas high-flow conditions tended to have better percent bias results. Overall, calibration statistics for runs using K_{TR} values calculated with Eq. (7) were better than those for runs using K_{SC} values from Eq. (5), so Eq. (7) was used to estimate K values for spill scenarios. Although model runs with calculated K_{SC} and K_{TR} values did not model dispersion of observations as well as OTIS-P runs that used calibrated K values, runs with theoretically calculated K values usually had the most conservative estimates of arrival time. Thus, additional runs that used K_{TR} values calculated using Eq. (7) were expected to provide conservative estimates of arrival time as desired by TMWA.

Simulation Results

Figs. 4(a and b) show the change in estimated arrival time to the first TMWA intake at the Highland Diversion for train spills occurring at the SQW and FAR sites along the Truckee River. Upper and lower estimates using dispersion values set at $1.5K_{TR}$ and $K_{TR}/1.5$ as calculated using Eq. (7) are also shown. Results for spills at other sites were similar. Expected arrival times ranged from 3 h to almost 4 days, depending on location of spill, flow, and dispersion value used. The model parameter in OTIS [Eqs. (1) and (2)] with the strongest influence on simulated travel times was the main channel cross-sectional area, A, because it defines advective transport downstream. At lower flows, A is small, velocity is low, and the spill has a longer time to mix in the channel, resulting in a larger spread of travel times. This effect was also seen in examination of duration of impact at the Highland Diversion for train spills at different locations under different flows [Figs. 4(c and d)], with lower flows having longer durations of impacts. Simulated peak concentrations using calculated K_{TR} values for train spills at SQW and FAR ranged from 300 to 5,400 mg/L [Figs. 4(e and f)]. There were larger differences in peak concentrations between runs using $K_{TR}/1.5$ and $1.5K_{TR}$ values at low-flow scenarios, but differences decreased from being on the order of thousands of mg/L at low flows to about 200 mg/L at high flows. Results for spills from

J. Water Resour. Plann. Manage. 2014.140:343-354.

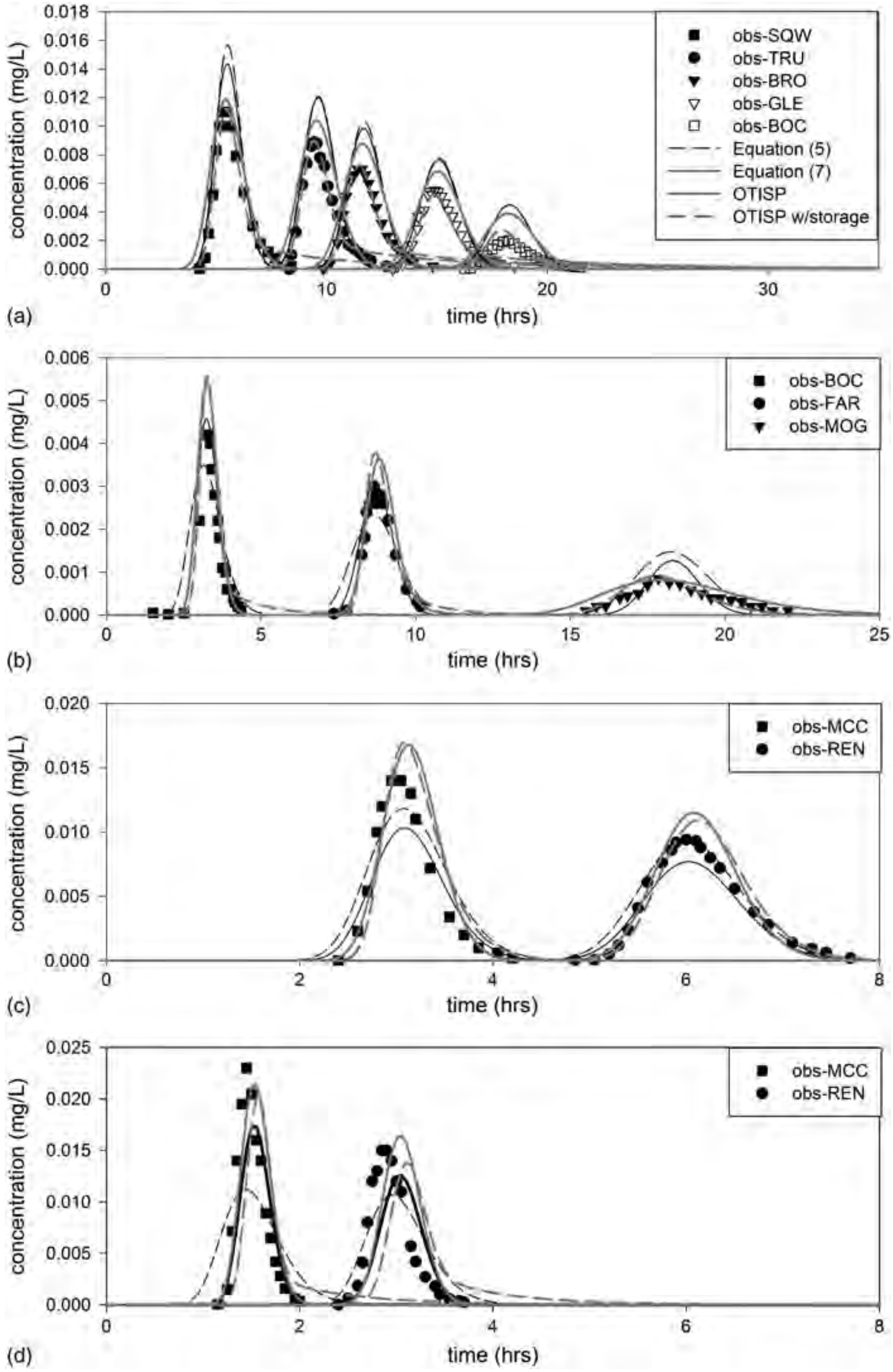


Fig. 2. 1999 tracer data and model output for (a) upper portion at moderate (36% exceedance) flow; (b) middle portion at moderate (35% exceedance) flow; (c) lower portion at moderate (45% exceedance) flow; (d) lower portion at high (7% exceedance) flow (model runs are for OTIS runs with and without storage using calibrated dispersion (K) coefficients, and for OTIS runs without storage using K_{SC} values calculated using Eq. (5) and K_{TR} values calculated using Eq. (7); site abbreviations are given in Table 1)

semitrucks showed the same patterns but were lower in magnitude and duration.

Discussion

Longitudinal Dispersion

Jobson (2001) questioned the appropriateness of certain simulation models as well as the application of theoretical estimates of dispersion due to their inability to adequately model longitudinal mixing processes. Prior to developing Eq. (7), several theoretically based longitudinal dispersion equations were investigated to be used in model simulation under flows that did not have tracer data (Fischer et al. 1979; Seo and Cheong 1998; Deng et al. 2002; Kashefipour and Falconer 2002). It was concluded that, of the prior developed equations, the Seo and Cheong (1998) equation [Eq. (5)] performed best with the Truckee River tracer data. Wallis and Manson (2004) noted that Eq. (5) had a tendency to overestimate dispersion values, which was observed in the current study (Fig. 5).

J. Water Resour. Plann. Manage. 2014.140:343-354.

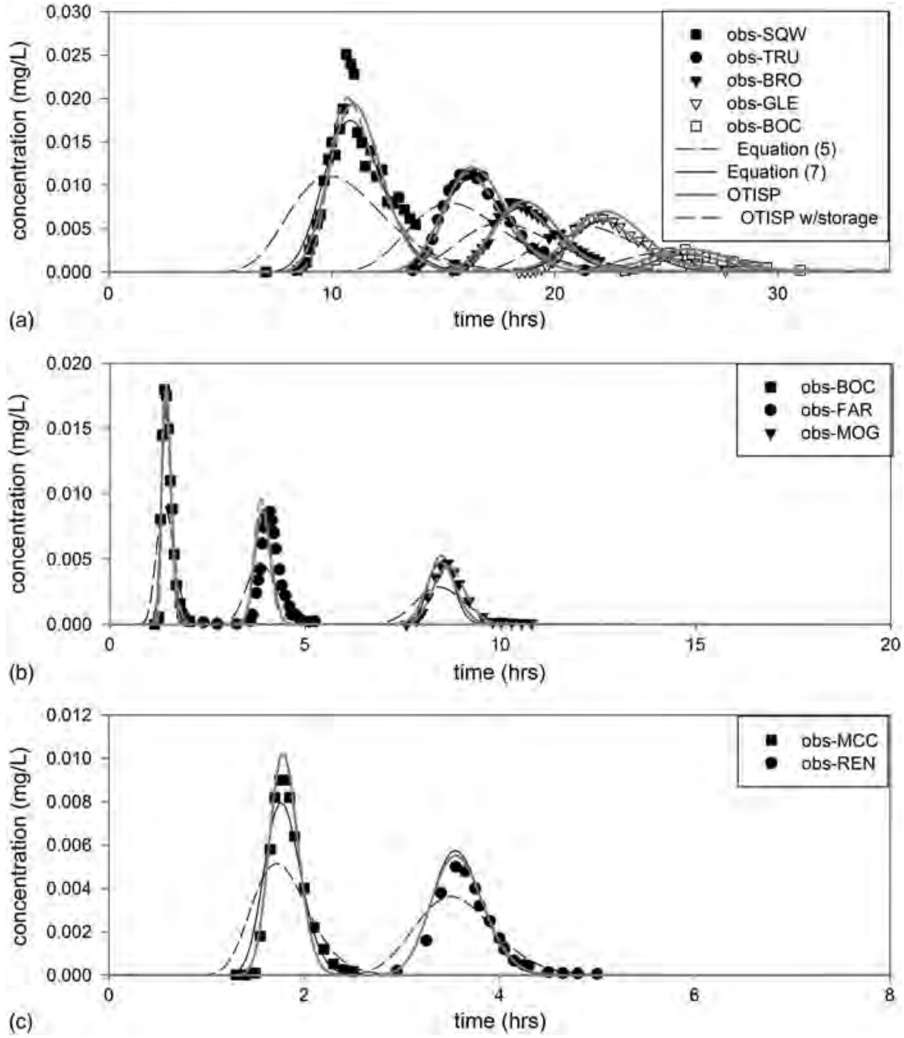


Fig. 3. 2006/2007 tracer data and model output for (a) upper portion at moderate (50% exceedance) flow; (b) middle portion at high (5% exceedance) flow; (c) lower portion at high (13% exceedance) flow (model runs are for OTIS runs with and without storage using calibrated dispersion (K) coefficients, and for OTIS runs without storage using K_{SC} values calculated using Eq. (5) and K_{TR} values calculated using Eq. (7); the model did not run under the with storage option for the lower portion; site abbreviations are given in Table 1)

Although Eq. (7) also tended to overestimate dispersion values, the overestimation was not as great as for Eq. (5) and the majority of discrepancy ratios were between −0.5 and 0.5. For the purposes of this project, overestimation of the dispersion coefficient was preferred to underestimation because overestimation produced conservative results in the Truckee River spill model in terms of arrival time. To account for uncertainty in the coefficient, dispersion coefficients were applied that were a factor of 1.5 greater or less than that estimated by Eq. (7). This ensured conservative estimates of dispersion for estimated arrival times and peak concentrations.

The magnitude of calibrated dispersion parameters determined using OTIS-P ranged from 14 to 109 m^2/s, which were similar to values found in previous studies. For rivers that have similar geometric parameters to the Truckee River, reported longitudinal dispersion values range from 8 to 38 m^2/s (Chapra 1997). Knust and Warwick (2009) estimated dispersion coefficients on the Truckee River below the VIS site to be about 20 m^2/s for a flow of 15 m^3/s. Given the highly variable results from applying dispersion equations developed using data from other rivers, we do not recommend using Eq. (7) on rivers besides the Truckee River without rigorously checking its applicability to such rivers. In addition, we did not estimate the numerical dispersion present in OTIS and thus the estimated dispersion is in addition to any inherent longitudinal dispersion.

Spill scenario results (Fig. 4) show that spill characteristics for the Truckee River are much more sensitive to flow than to dispersion. The use of dispersion values 50% greater and 50% smaller than that estimated with Eq. (7) resulted in much smaller changes in estimates of time of arrival, duration of impact, and peak concentration as compared to changes in flow, especially at low flows. In addition, it is noted that this study only modeled dispersion of a conservative constituent, and the response of actual pollutants to the dispersion term may be quite different.

Model Performance and Uncertainty

In addition to uncertainties about longitudinal dispersion, there were other uncertainties in the modeling process. For example, main channel cross sections were measured at 15 Truckee River locations over 90 km, and it was assumed that 1 measured cross-section characterized channel geometry for several km of a river segment that was in reality more heterogeneous. Errors in estimated channel geometry could affect estimated cross-sectional area and in turn the time of arrival. Measured cross sections were

J. Water Resour. Plann. Manage. 2014.140:343-354.

Table 3. Calibration Statistics for OTIS-P Runs without and with Transient Storage and for Calibrated Scenarios with K Values Calculated with Eqs. (5) and (7)

Site	n	OTIS-P no storage r^2	RMSE (mg/l)	Bias (%)	OTIS-P with storage r^2	RMSE (mg/l)	Bias (%)	OTIS with Eq. (5) K_{SC} r^2	RMSE (mg/l)	Bias (%)	OTIS with Eq. (7) K_{TR} r^2	RMSE (mg/l)	Bias (%)
Upper portion calibration runs for 1999 tracer data at moderate (36% exceedance) flows													
SQW	16	0.91	1.9×10^{-3}	28.6	0.99	5.0×10^{-4}	2.0	0.97	2.6×10^{-3}	33.7	**0.97**	**2.1×10^{-3}**	**29.3**
TRU	21	0.94	1.7×10^{-3}	32.5	0.99	3.6×10^{-4}	1.7	0.95	2.3×10^{-3}	39.9	**0.95**	**2.2×10^{-3}**	**36.8**
BRO	21	0.95	1.6×10^{-3}	39.6	0.99	2.8×10^{-4}	1.3	0.93	2.1×10^{-3}	45.0	**0.94**	**1.9×10^{-3}**	**40.1**
GLE	26	0.96	1.2×10^{-3}	41.9	0.99	3.4×10^{-4}	−4.0	0.96	1.5×10^{-3}	45.5	**0.96**	**1.4×10^{-3}**	**41.4**
BOC	22	0.94	1.3×10^{-3}	136.6	0.92	4.6×10^{-5}	45.5	0.96	1.5×10^{-3}	140.2	**0.97**	**1.4×10^{-3}**	**133.8**
Middle portion calibration runs for 1999 tracer data at moderate (35% exceedance) flows													
BOC	19	0.97	8.1×10^{-4}	35.3	0.99	6.9×10^{-4}	31.9	0.88	6.0×10^{-4}	**13.4**	**0.97**	**4.5×10^{-4}**	18.4
FAR	16	0.95	5.1×10^{-4}	21.5	0.98	5.2×10^{-4}	23.7	0.90	4.4×10^{-4}	**0.01**	**0.97**	**2.4×10^{-4}**	8.0
MOG	20	0.88	1.9×10^{-4}	42.2	0.88	1.2×10^{-4}	6.8	**0.94**	3.8×10^{-4}	60.2	0.86	**2.5×10^{-4}**	**−3.3**
Lower portion calibration runs for 1999 tracer data at moderate (45% exceedance) flows													
WMC	15	0.86	2.5×10^{-3}	15.4	0.85	2.5×10^{-3}	13.6	0.92	**2.0×10^{-3}**	**8.4**	**0.93**	2.2×10^{-3}	−12.0
REN	22	0.98	1.2×10^{-3}	14.6	0.94	1.2×10^{-3}	9.7	0.97	**7.9×10^{-4}**	**10.5**	**0.98**	9.8×10^{-4}	−12.0
Lower portion calibration runs for 1999 tracer data at high (7% exceedance) flows													
WMC	16	0.77	3.9×10^{-3}	13.4	0.42	6.2×10^{-3}	−5.2	0.75	5.6×10^{-3}	−7.9	**0.79**	**3.7×10^{-3}**	**−7.8**
REN	20	0.53	4.2×10^{-3}	4.9	0.12	5.9×10^{-3}	−18.5	**0.84**	**2.8×10^{-3}**	**1.6**	0.57	3.8×10^{-3}	−14.7
Upper portion calibration runs for 2006 tracer data at moderate (50% exceedance) flow													
SQW	30	0.87	2.5×10^{-3}	−2.9	0.92	2.1×10^{-3}	−6.8	0.22	6.5×10^{-3}	−20.1	**0.85**	**2.8×10^{-3}**	**−3.5**
TRU	22	0.97	7.9×10^{-4}	5.7	0.99	5.3×10^{-4}	−5.5	0.39	3.2×10^{-3}	**−4.0**	**0.97**	**7.7×10^{-4}**	−4.3
BRO	28	0.94	6.9×10^{-4}	6.0	0.98	4.4×10^{-4}	−5.4	0.46	1.9×10^{-3}	**−3.9**	**0.95**	**5.7×10^{-4}**	−4.8
GLE	27	0.96	6.9×10^{-4}	17.8	0.99	2.8×10^{-4}	−5.9	0.54	1.6×10^{-3}	20.9	**0.97**	**4.4×10^{-4}**	**−7.4**
BOC	19	0.92	4.5×10^{-4}	30.5	0.97	1.4×10^{-4}	−5.3	0.46	6.3×10^{-4}	25.9	**0.94**	**2.3×10^{-4}**	**−10.8**
Middle portion calibration for 2006 tracer data at high (5% exceedance) flow													
BOC	16	0.97	1.2×10^{-3}	−2.0	0.99	5.8×10^{-4}	−1.8	0.71	4.3×10^{-3}	−21.8	**0.96**	**1.4×10^{-3}**	**−4.9**
FAR	26	0.56	2.3×10^{-3}	−6.0	0.43	2.8×10^{-3}	−4.7	0.53	**2.3×10^{-3}**	−25.8	**0.54**	2.3×10^{-3}	**−6.7**
MOG	16	0.86	6.5×10^{-4}	−0.2	0.99	1.9×10^{-4}	−3.2	0.70	9.7×10^{-4}	−16.0	**0.85**	**7.3×10^{-4}**	**−4.7**
Lower portion calibration for 2006 tracer data at high (13% exceedance) flow													
WMC	16	0.98	7.5×10^{-4}	7.1	—[a]	—[a]	—[a]	0.70	2.3×10^{-3}	−11.6	**0.94**	**9.4×10^{-4}**	**0.6**
REN	17	0.97	4.0×10^{-4}	8.8	—[a]	—[a]	—[a]	0.87	7.1×10^{-4}	**−1.6**	**0.97**	**4.7×10^{-4}**	8.8

Note: RMSE = root mean squared error; n = number of observations compared. See Table 1 for site abbreviations. Bold font indicates best statistical results between Eqs. (5) and (7).

[a]OTIS-P did not run for lower portion with storage for 2006 calibration.

therefore assumed to apply to directly downstream reaches to increase the likelihood that errors in estimated main channel areas would be underestimations, which would result in prediction of faster downstream transport, providing conservative estimates of arrival time.

Uncertainty in streamflow scenarios also had the potential to alter simulated travel times. Truckee River streamflows vary daily due to reservoir operations and run-of-river diversions, and the 13 streamflow scenarios did not account for such variability of streamflow. To simulate lateral inflow from a tributary over a 30-m segment, each major tributary in the spill model had a flow value from which lateral inflow was calculated. These tributaries can exhibit variations in flow on a daily and seasonal basis that was not accounted for in the spill model. The OTIS model has been shown to be sensitive to the lateral inflow parameter, and the inability of the Truckee River spill model to account for different tributary contributions (and lateral inflow as a result) represents uncertainty in travel time estimates (Scott et al. 2003).

In the end, assumptions made to address these uncertainties in the Truckee River spill model were chosen to provide the most conservative estimate of time of arrival for TMWA operators. In the event of a spill, model estimates would primarily be used to determine the time available to mobilize for treatment options or plant shutdowns. In accordance with their emergency plan, TMWA operators would begin monitoring the river upstream of their intakes to provide actual data on the progression of the spill downstream, and model predictions of peak concentrations or duration of impact would not be as critical for making decisions about how to address the situation.

Recommendations for Further Work

To address several of the mentioned uncertainties, recommendations for further work are suggested. As is the case in much of science, more data are needed. High-flow tracer data were not available for the upper portion, which would provide data for the worst case scenario of a spill occurring on the Truckee River in terms of arrival time. It is also recommended that an additional tracer study take place for the entire model extent under low-flow conditions. The results of this study show that the largest range of uncertainty in arrival time occurs at low flows. Therefore, calibrating the OTIS model to data collected under low-flow conditions would increase the robustness of the Truckee River spill model.

Also, with any subsequent tracer studies, streamflow measurements are needed at diversions and tributaries as well as at sample sites. Streamflow and main channel cross-sectional area were the two most influential parameters of the spill model, but several of the 1999 and 2006–2007 streamflows were not actually measured; instead they were estimated using nearby stream gauge data. Similarly, none of the diversions were quantified

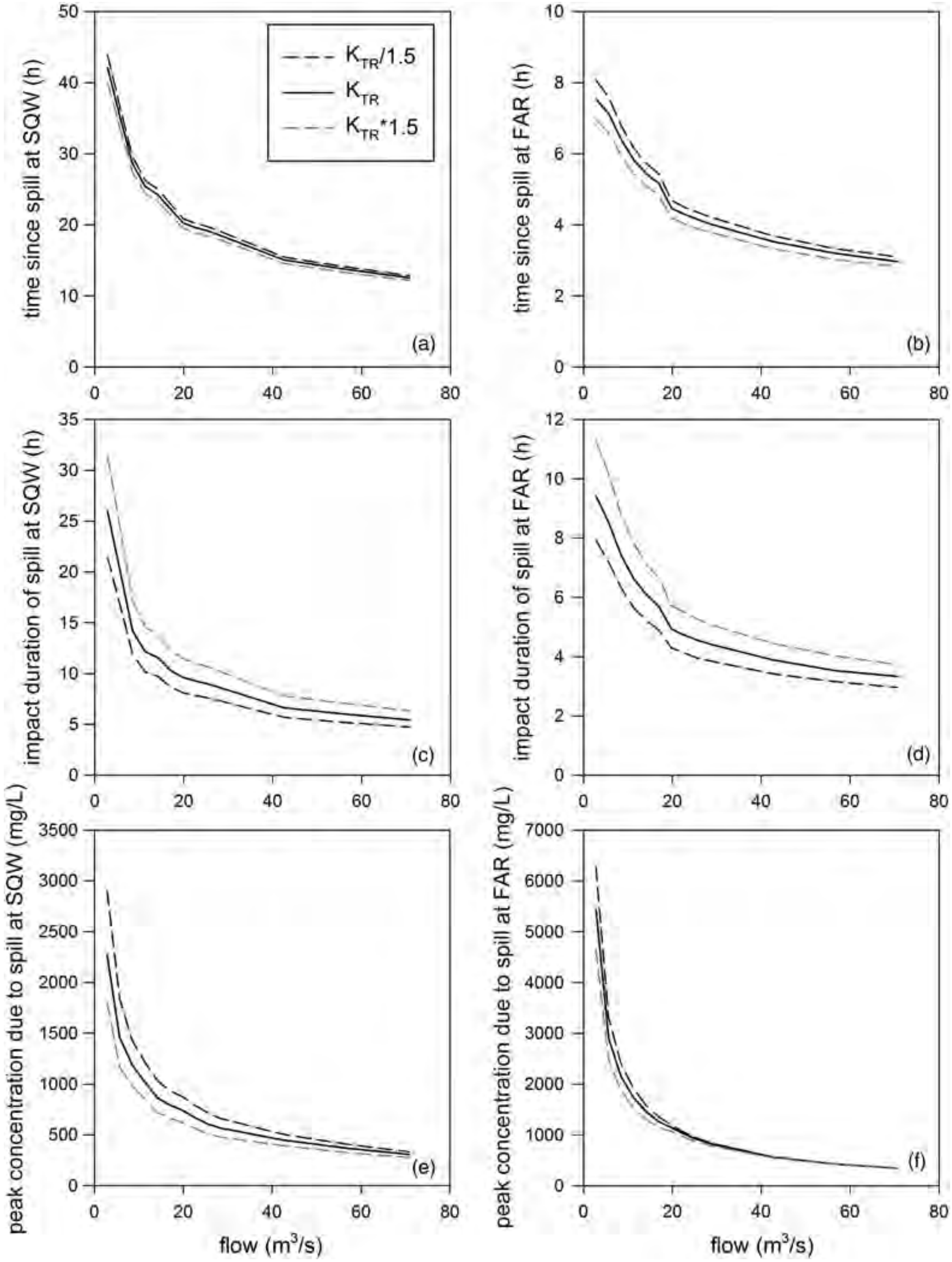


Fig. 4. Results of model simulations under different flow conditions for train spills occurring at SQW and FAR (see Table 1 for site abbreviations); simulated arrival times at TMWA Highland Diversion are shown for train spills occurring at (a) SQW and (b) FAR; simulated duration of impact at TMWA Highland Diversion are shown for (c) SQW and (d) FAR; simulated peak concentrations at TMWA Highland Diversion are shown for: (e) SQW and (f) FAR; results for runs with calculated K_{TR} values using Eq. (7) are shown, as well as results for runs with dispersion set at $K_{TR}/1.5$ and $1.5K_{TR}$)

during the two tracer studies. Calibrating the model with streamflows that are measured during tracer studies would benefit overall calibration.

To improve estimates with the existing model, the measurement of additional cross sections of the Truckee River would be beneficial for calibration of the spill model. With additional cross sections measured with corresponding streamflows, a hydrodynamic model of the Truckee River could be used to estimate better spill scenarios of streamflows along the river and corresponding cross-sectional areas. Several studies have linked unsteady hydrodynamic flow models with solute transport models to investigate the transport of hypothetical spills into a river (Wiley 1993; Nishikawa et al. 1999).

Continued research on estimation of longitudinal dispersion in rivers under different flow conditions would reduce uncertainty in model predictions. Theoretical estimates of longitudinal dispersion have evolved from early stages with an increase in estimation performance, but still are not able to make very precise predictions. Deng et al. (2002) developed an equation that accounted for the effects of river sinuosity on dispersion that performed within

J. Water Resour. Plann. Manage. 2014.140:343-354.

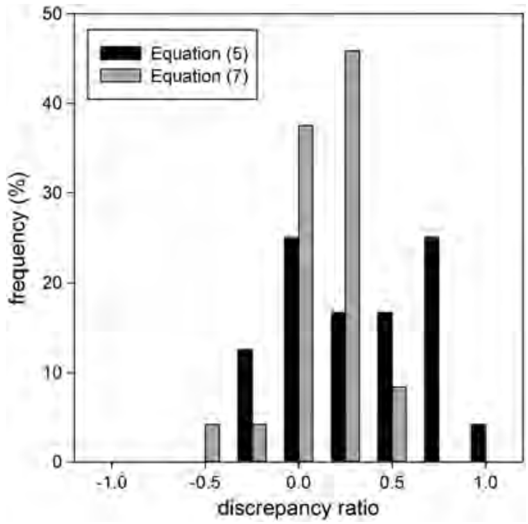


Fig. 5. Frequency plot of discrepancy ratios for dispersion values using Eq. (5) ($n = 24$) and Eq. (7) ($n = 24$)

a factor of 2 to observed values of dispersion, but the equations incorporate hydraulic parameters that are not easily measured. Further development of longitudinal dispersion equations should investigate the effects of river sinuosity on dispersion, as well as incorporating the effects of transient storage on dispersion.

Acknowledgments

The Truckee Meadows Water Authority funded this research. The authors thank Jim Crompton of the U.S. Geological Survey and Brendan Belby of Entrix for collecting and sharing data used in the model, Rob Runkel of the U.S. Geological Survey for assistance with developing the dispersion equation for the Truckee River, and Benjamin Trustman for preparing Fig. 1.

References

Bencala, K. E., and Walters, R. A. (1983). "Simulation of solute transport in a mountain pool-and-riffle stream: A transient storage model." *Water Resour. Res.*, 19(3), 718–724.

Brett, M. T., et al. (1995). "Impact of major soil fumigant spill on the planktonic ecosystem of Shasta Lake, California." *Can. J. Fish. Aquatic Sci.*, 52(6), 1247–1256.

Broshears, R. E., Bencala, K. E., Kimball, B. A., and McKnight, D. M. (1993). "Tracer-dilution experiments and solute-transport simulations for a mountain stream, Saint Kevin Gulch, Colorado." *U.S. Geological Survey Water Resour. Invest. Rep. No. 92-4081*. U.S. Geological Survey, Reston, VA.

Canadian Broadcasting Corporation. (2006). *B.C. river's recovery from spill could take decades*, ⟨http://www.cbc.ca/news/canada/b-c-river-s-recovery-from-spill-could-take-decades-1.578776⟩ (Dec. 8, 2013).

Chapra, S. C. (1997). *Surface water-quality modeling: International edition*, McGraw-Hill, Singapore.

Crompton, E. J. (2008). "Travel time data for the Truckee River between Tahoe City, California, and Vista, Nevada, 2006 and 2007." *U.S. Geological Survey Open-File Rep. No. 2008-1084*. U.S. Geological Survey, Reston, VA. ⟨http://pubs.usgs.gov/of/2008/1084/ofr20081084.pdf⟩ (Feb. 2012).

Crompton, E. J., and Bohman, L. R. (2000). "Travel time data for Truckee River between Tahoe City, California, and Marble Bluff Dam near Nixon, Nevada." *U.S. Geological Survey Open File Rep. No. 00-363*. U.S. Geological Survey, Reston, VA.

del Rosario, A., Remoy, J., Soliman, V., Dhaliwal, J., Dhoot, J., and Perera, K. (1994). "Monitoring for selected degradation products following a spill of VAPAM into the Sacramento River." *J. Environ. Quality*, 23(2), 279–286.

Deng, Z.-Q., Bengtsson, L., Singh, V. P., and Adrian, D. D. (2002). "Longitudinal dispersion coefficient in single-channel streams." *J. Hydraul. Eng.*, 10.1061/(ASCE)0733-9429(2002)128:10(901), 901–916.

Dennis, J. E., Gay, D. M., and Welsch, R. E. (1981). "An adaptive nonlinear least-squares algorithm." *ACM Trans. Math. Software*, 7(3), 348–368.

Fernald, A. G., Wigington, P. J., and Landers, D. H. (2001). "Transient storage and hyporheic flow along the Willamette River, Oregon: Field measurements and model estimates." *Water Resour. Res.*, 37(6), 1681–1694.

Fischer, H. B., List, E. J., Koh, C. Y., Imberger, J., and Brooks, N. H. (1979). *Mixing in inland and coastal waters*, Academic, San Diego.

Fox, F. L. (1982). "Chemical variations of the Truckee River from Lake Tahoe to Truckee, CA during low flow." M.S. thesis, Univ. of Reno, Reno, NV.

Government Accountability Office (GAO). (2006). "Clean water: Better information and targeted prevention could enhance spill management in the St. Clair-Detroit River corridor." *Rep. No. GAO-06-639*. ⟨http://www.gao.gov/new.items/d06639.pdf⟩ (Feb. 2012).

Graf, J. B. (1995). "Measured and predicted velocity and longitudinal dispersion at steady and unsteady flow, Colorado River, Glen Canyon Dam to Lake Mead." *Water Resour. Bull.*, 31(2), 265–281.

Holtzman, S. (1997). *Semi-truck color history*, MBI, Osceola, WI.

Horton, G. A. (1997). *Truckee River chronology: A chronological history of Lake Tahoe and the Truckee River and related water issues*, Nevada Division of Water Planning, Department of Conservation and Natural Resources, Carson City, NV, ⟨http://images.water.nv.gov/images/publications/River%20Chronologies/Truckee%20River%20Chronology.pdf⟩ (Feb. 2012).

Jobson, H. E. (2001). "Predicting river travel time from hydraulic characteristics." *J. Hydraul. Eng.*, 10.1061/(ASCE)0733-9429(2001)127:11(911), 911–918.

Kashefipour, S. M., and Falconer, R. A. (2002). "Longitudinal dispersion coefficients in natural channels." *Water Res.*, 36(6), 1596–1608.

Kilpatrick, F.A., and Wilson, J. F., Jr. (1989). "Measurement of time of travel in streams by dye tracing." *U.S. Geological Survey Tech. Water-Resour. Invest.*, Book 3, Chapter A9, US Geological Survey, Denver, CO.

Knust, A., and Warwick, J. J. (2009). "Using a fluctuating tracer to estimate hyporheic exchange in restored and unrestored reaches of the Truckee River, Nevada, USA." *J. Hydrol. Proc.*, 23(8), 1119–1130.

Laenen, A., and Bencala, K. E. (2001). "Transient storage assessments of dye-tracer injections in rivers of the Willamette Basin, Oregon." *J. Am. Water Resour. Assoc.*, 37(2), 367–377.

Liu, H. (1977). "Predicting dispersion coefficient in streams." *J. Environ. Eng. Div.*, 103(1), 59–69.

McKenna, S. A. (1990). "Examination of water quality and groundwater/surface water interaction during drought periods, Truckee River, California/Nevada." M.S. thesis, Univ. of Reno, Reno, NV.

Nishikawa, T., Paybins, K. S., Izbicki, J. A., and Reichard, E. G. (1999). "Numerical model of a tracer test on the Santa Clara River, Ventura County, California." *J. Am. Water Resour. Assoc.*, 35(1), 133–142.

Runkel, R. L. (1998). "One-dimensional transport with inflow and storage (OTIS): A solute transport model for streams and rivers." *U.S. Geological Survey Water-Resour. Invest. Rep. No. 98-4018*, U.S. Geological Survey, Denver.

Runkel, R. L. (2000). "Using OTIS to model solute in streams and rivers." *U.S. Geological Survey Fact Sheet FS-138-99*, U.S. Geological Survey, Denver, CO.

Scott, D. T., Gooseff, M. N., Bencala, K. E., and Runkel, R. (2003). "Automated calibration of a stream solute transport model: Implications for interpretation of biogeochemical parameters." *J. North Am. Benthol. Soc.*, 22(4), 492–510.

Seo, I. W., and Cheong, T. S. (1998). "Predicting longitudinal dispersion coefficient in natural streams." *J. Hydraul. Eng.*, 10.1061/(ASCE)0733-9429(1998)124:1(25), 25–32.

Stream Solute Workshop. (1990). "Concepts and methods for assessing solute dynamics in stream ecosystems." *J. North Am. Benthol. Soc.*, 9(2), 95–119.

Truckee Meadows Water Authority (TMWA). (2007). *Truckee River recreation map* ⟨http://tmwa.com/water_system/river_recreation_map/⟩ (Feb. 2012).

Truckee Meadows Water Authority (TMWA). (2012). *Your water. Water resources* ⟨http://tmwa.com/water_system/resources/⟩ (Feb. 2012).

Truckee River Area Committee (TRAC). (2005). *Truckee River geographic response plan: Truckee River corridor*, State of Nevada, Division of Environmental Protection, Carson City, NV, ⟨http://ndep.nv.gov/bca/response.htm⟩ (Dec. 8, 2013).

Wallis, S. G., and Manson, J. R. (2004). "Methods for predicting dispersion coefficients in rivers." *Proc., ICE-Water Management*, 157(3), 131–141.

Wiley, J. B. (1993). "Simulated flow and solute transport, and mitigation of a hypothetical spill for the New River in the New River Gorge National River, West Virginia." *U.S. Geological Survey Water-Resour. Invest. Rep. No. 93-4105*, U.S. Geological Survey, Charleston, WV.

J. Water Resour. Plann. Manage. 2014.140:343-354.

APPENDIX 2-7

Basin Summaries

Truckee Resource Area - Satellite Systems

SPANISH SPRINGS VALLEY – HYDROGRAPHIC BASIN 85

Introduction

Spanish Springs Valley (”SSV”), Hydrographic Basin 85, is a topographically closed basin bounded on the east by the Pah Rah range and on the west by the Hungry Ridge range covering an area of approximately 80 square miles. Figure 1 depicts the Spanish Springs Hydrographic Basin and location of TMWA production wells. The basin can be divided into two aquifer systems from which water is pumped into public water systems: (1) a volcanic rock aquifer located on the east side of the basin and (2) an alluvial aquifer in the western and central portion of SSV. A third portion of the basin, a granitic aquifer on the northeast basin slopes of the Pah Rah Range, is a meager aquifer that barely supports approximately 380 domestic wells.

Prior to development in the valley, which began in earnest in 1979, SSV supported various small-scale ranching and farming operations. The area has grown considerably since then from a population of 410 residents in 1979, to 2,974 in 1989, to 18,699 in 1999, 40,503 in 2010, and almost 44,000 in 2015. Water supply for SSV was from wells on the west side of SSV from the early 1960’s through the early 2000’s. Since that time, the majority of water to service the growth areas originated from the Truckee River and new wells on the east side of SSV.

Public Water Systems

TMWA currently operates eight active production wells in two distinct well fields serving almost 16,000 residential customers in SSV. The Desert Springs system is located on the west side of SSV and consists of four active production wells constructed between 1963 and 1990. One additional well, Desert Springs 4 (“DS4), currently operates as a recharge well only. The west side wells are completed in alluvial material and have production capacities ranging from 350 to 750 gallons per minute (“gpm”). The Spring Creek system is located primarily on the east side of SSV and consists of four newer wells constructed between 1997 and 2005. The east side wells are completed in fractured volcanic material and have production capacities ranging from 1,000 to 3,000 gpm.

Besides TMWA, Utilities, Inc. has facilities and customers in the Spanish Springs basin. Utilities, Inc., a Public Utilities Commission of Nevada (“PUCN”) regulated utility, has a service area north of La Posada Drive and east of Pyramid Highway and serves about 580 connections in the area previously referred to as “Sky Ranch”.

Domestic Wells

There are 410 domestic wells in SSV, most of which occur in the northeast portion of the valley. The State of Nevada allows each domestic well owner to pump up to 2 acre feet/year (“AF/yr”); 410 domestic wells have the potential to extract up to 820 AF/yr (see Figure 2).

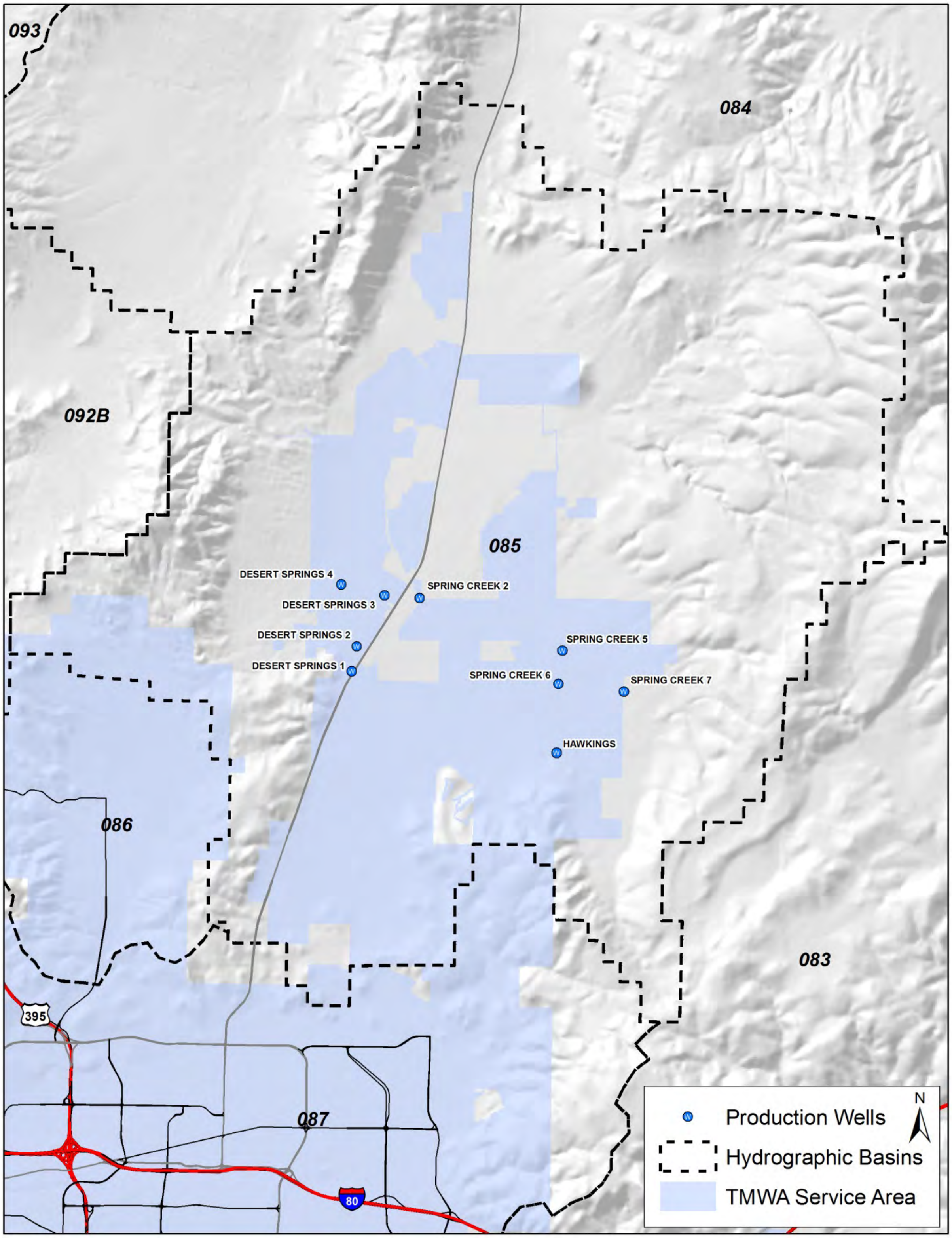


Figure 1. Spanish Springs Valley Hydrographic Basin 85 Location Map

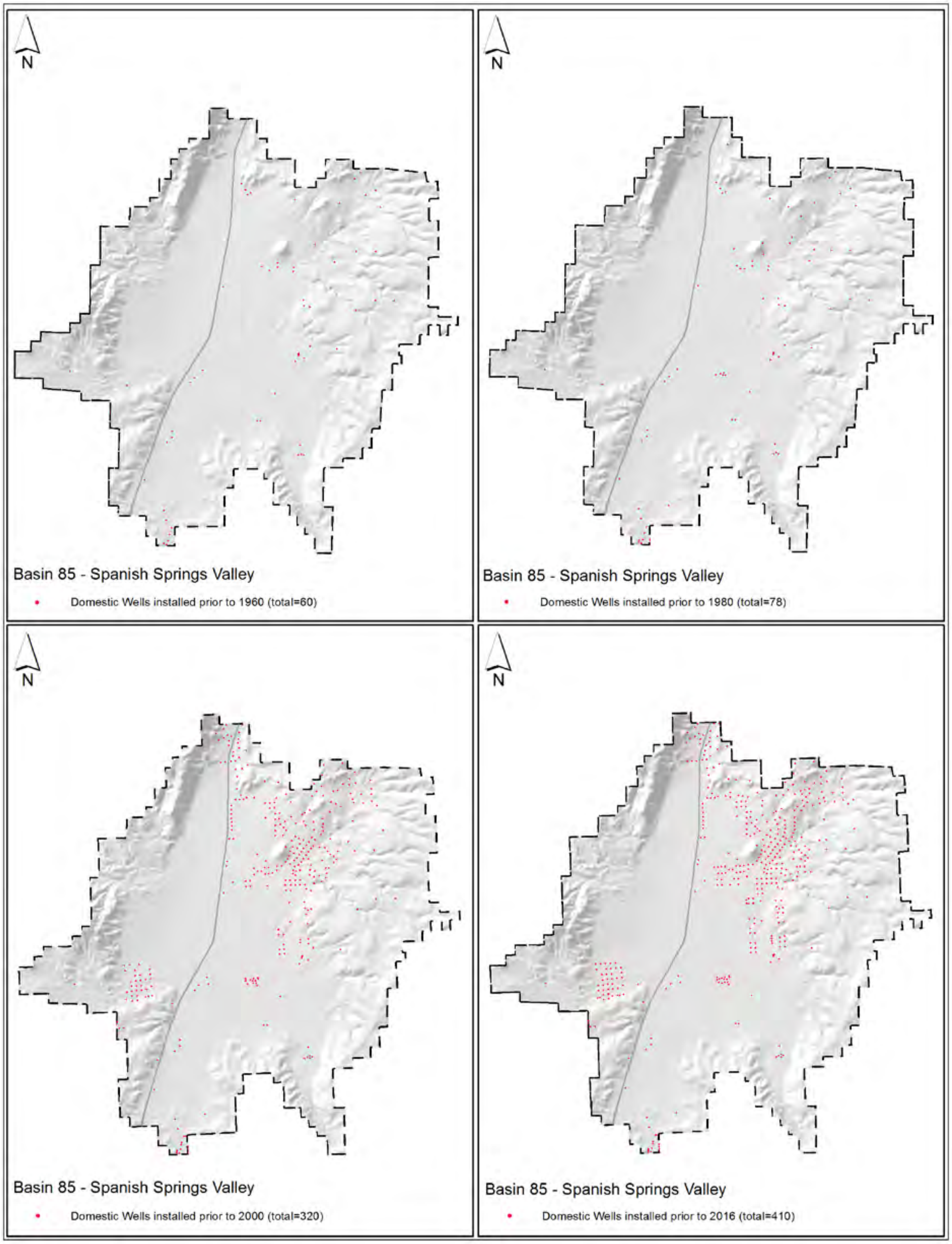


Figure 2. Change in the Number of Domestic Wells in Hydrographic Basin 85

Current Resource Management Practices

TMWA's primary source of water committed to the Spanish Springs basin is daily delivery of treated surface water from TMWA's Chalk Bluff and Glendale treatment plant. TMWA has eight wells in Spanish Springs with rights committed to serve customers in the area. The wells are used 2 to 6 months a year to augment summer peak demand or during emergency conditions. TMWA began groundwater recharge activities at its Hawkins Court well in 2009 and anticipates increasing recharge significantly over the next 5 years in several of the former Washoe County Department of Water Resources ("WDWR") wells.

Winter demands are met with treated Truckee River water. Surface water is also used in the summer irrigation season to meet base flow demand and increase water quality from water delivered from west side wells. Peak day demands during the summer are met by eight groundwater wells. Facilities were completed in 2009 that allows TMWA to increase the deliveries of Truckee River water so that reliance on wells for winter supplies can be reduced.

Water Resources

Natural Groundwater Recharge

About 67% of the annual 8 inches/year precipitation in SSV falls as snow and rain from November through April. Most of the precipitation on the valley floor is lost through evaporation and has an insignificant impact on groundwater recharge (Berger et al., 1997). Natural ephemeral streams are generated from intense rainstorms or large snow melt episodes and drains towards the center of SSV.

The Orr Ditch imports irrigation water from the Truckee River and the North Truckee Drain was constructed to return irrigation runoff to the Truckee Meadows. Natural groundwater recharge from mountain snowmelt and runoff to the basin is estimated at 1,300 AF/yr (Pohll, 2015). Recharge from the Orr Ditch is estimated at 140 AF/yr (Pohll, 2015). Water transported via the Orr Ditch has declined significantly over the past ten years due to conversion of irrigable lands and their water rights to residential housing and overall reductions of flow in the Orr Ditch.

Besides precipitation and Orr Ditch recharge, the main water inputs to the groundwater system are septic effluent, municipal well recharge, turf irrigation from domestic, public, and recreational parcels.

Groundwater Pumping

Over the past fifteen years, the majority of pumping has moved from the west side of SSV to the east side of SSV. Municipal groundwater withdrawals peaked in 2007, with over 3,100 AF/yr withdrawn from the aquifer. Since that time there has been a significant decline in pumping, with withdrawals continuing to decrease from almost 2,000 AF/yr in 2010 to less than 1,500 AF/yr in 2014. As shown in Figure 3, pumping has decreased on the east side by over 800 AF/yr and has increased on the east side by 300 AF/yr, with an overall decrease in pumping of 500 AF/yr.

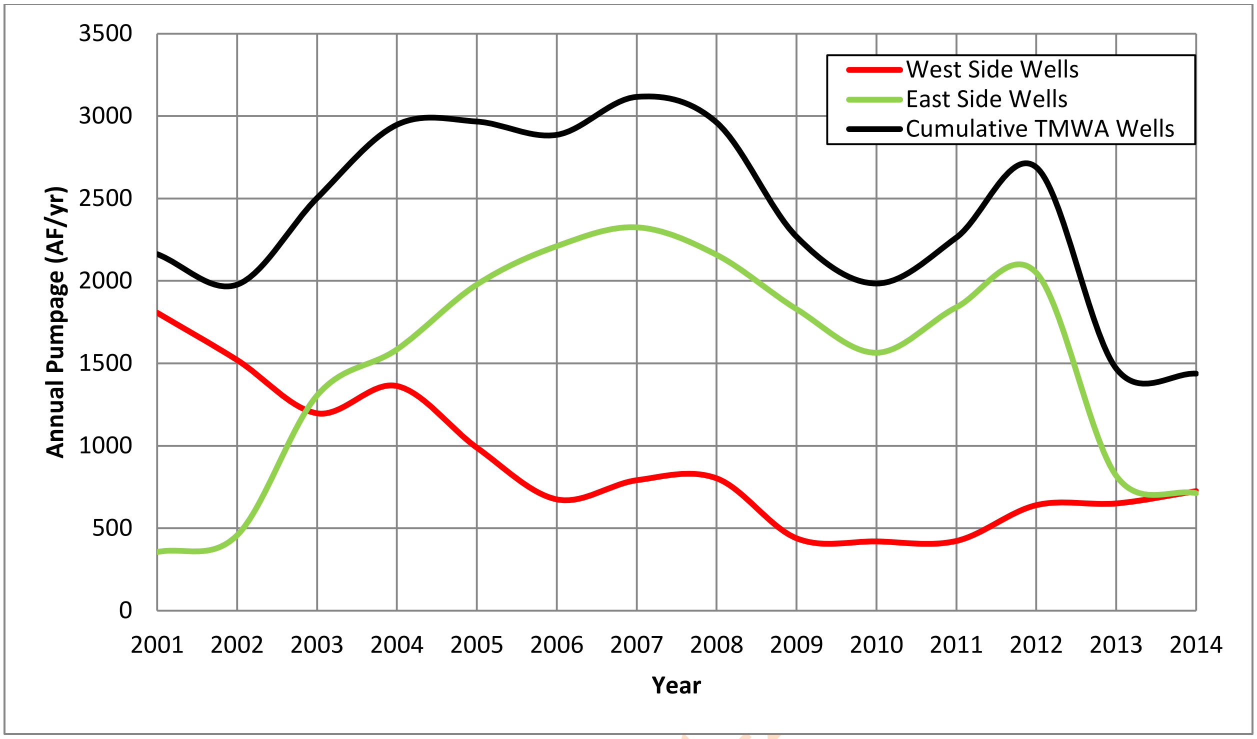


Figure 3. Cumulative Groundwater Pumping in Hydrographic Basin 85

Groundwater Levels

As depicted in Figure 4, regional groundwater elevations indicate flow towards the center of SSV off of mountain ranges from the east and west, and then north or south towards subsurface flow connections to neighboring basins.

Hydrographs from 2001 to 2015 represent changes in water levels resulting from the variation in precipitation, pumping, natural recharge, municipal recharge, evapotranspiration, and aquifer properties. The graphs indicate that water levels fluctuate seasonally with rises during non-pumping, natural recharge, and municipal recharge periods (winter months) and declines during pumping periods (summer months). Figures 5 and 6 depict water level changes over time in selected wells throughout SSV.

Groundwater levels have declined in the eastern part of SSV, while water levels have risen on the west side of SSV. This can be attributed to a transition over the last fifteen years to reduced pumping on the west side to avoid water quality issues associated with septic effluent, and increased pumping on the east side where water quality is unaffected. Municipal well recharge on the west side of SSV also contributed to the water level recovery. Surface water delivered to SSV over the past eight years has also reduced the need for pumping; which helps groundwater levels to rebound.

Figure 7 depicts water level declines of approximately six feet on the east side near the Spring Creek production wells, while increasing over five feet on the west side 2001 and 2005. Water levels on the west side have been recovering for almost 10 years due to reduced pumping on the west side and recharge at DS4.

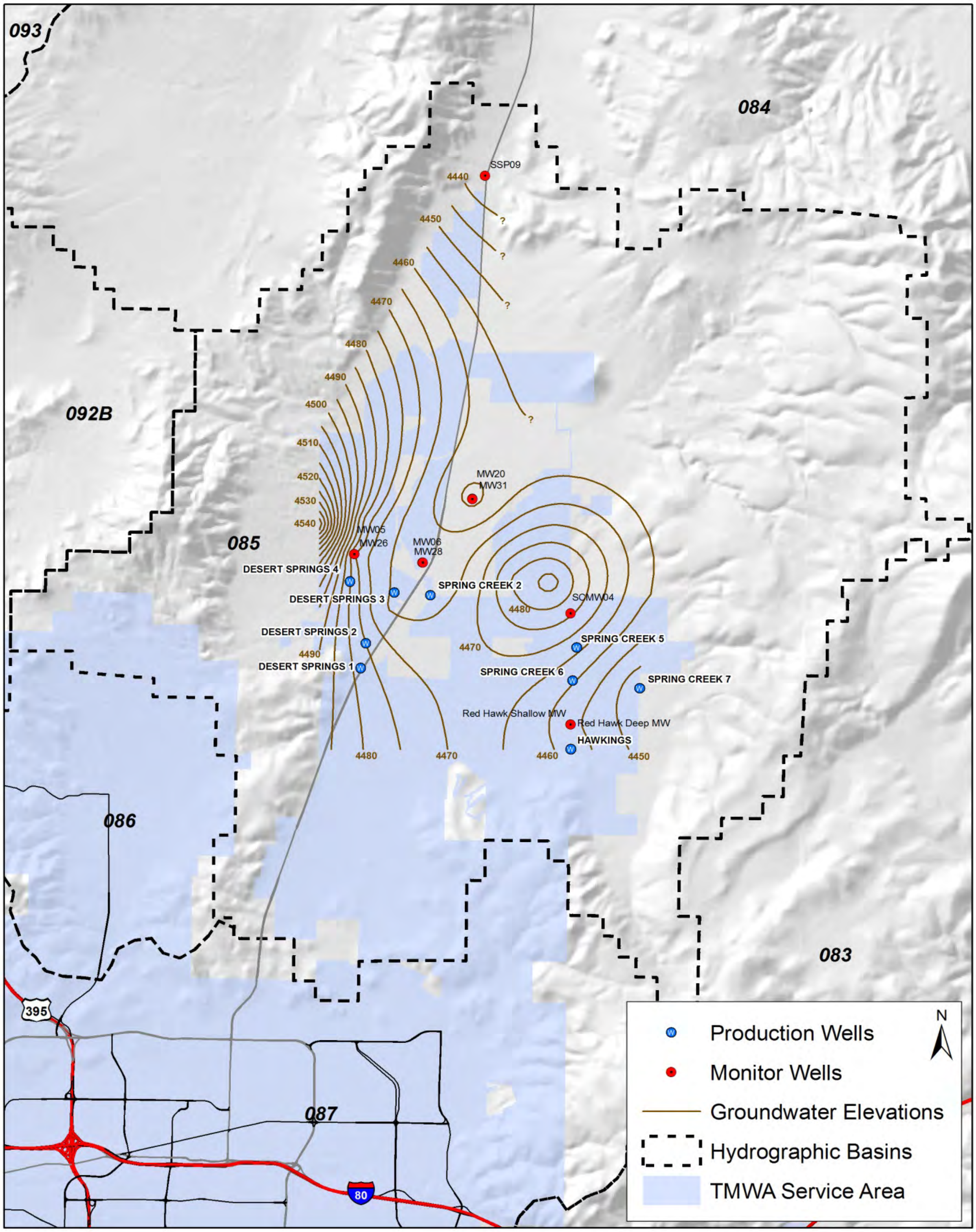


Figure 4. 2015 Groundwater Elevations Contour Map for Hydrographic Basin 85

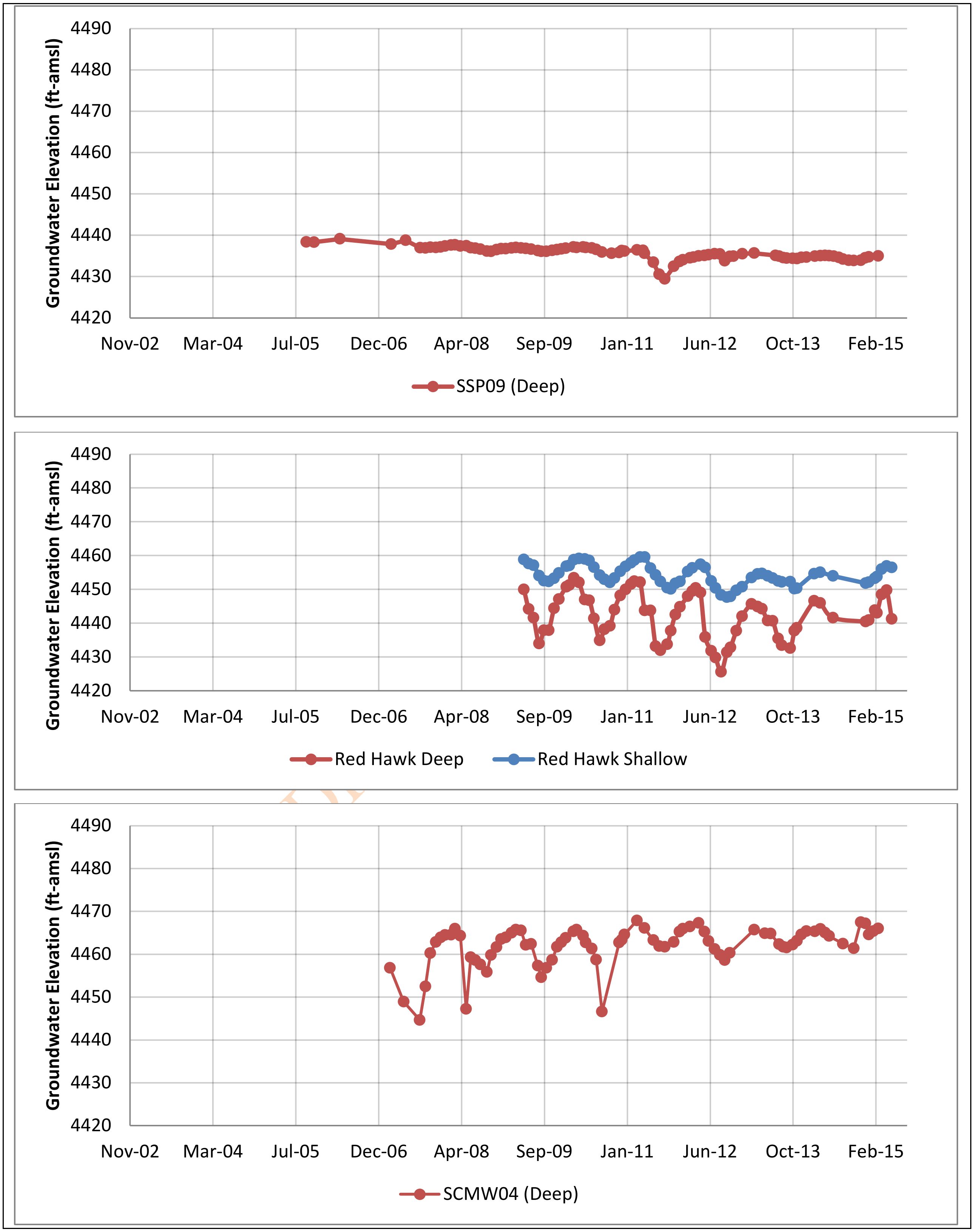


Figure 5. Change in Water Level in Selected Monitoring Wells

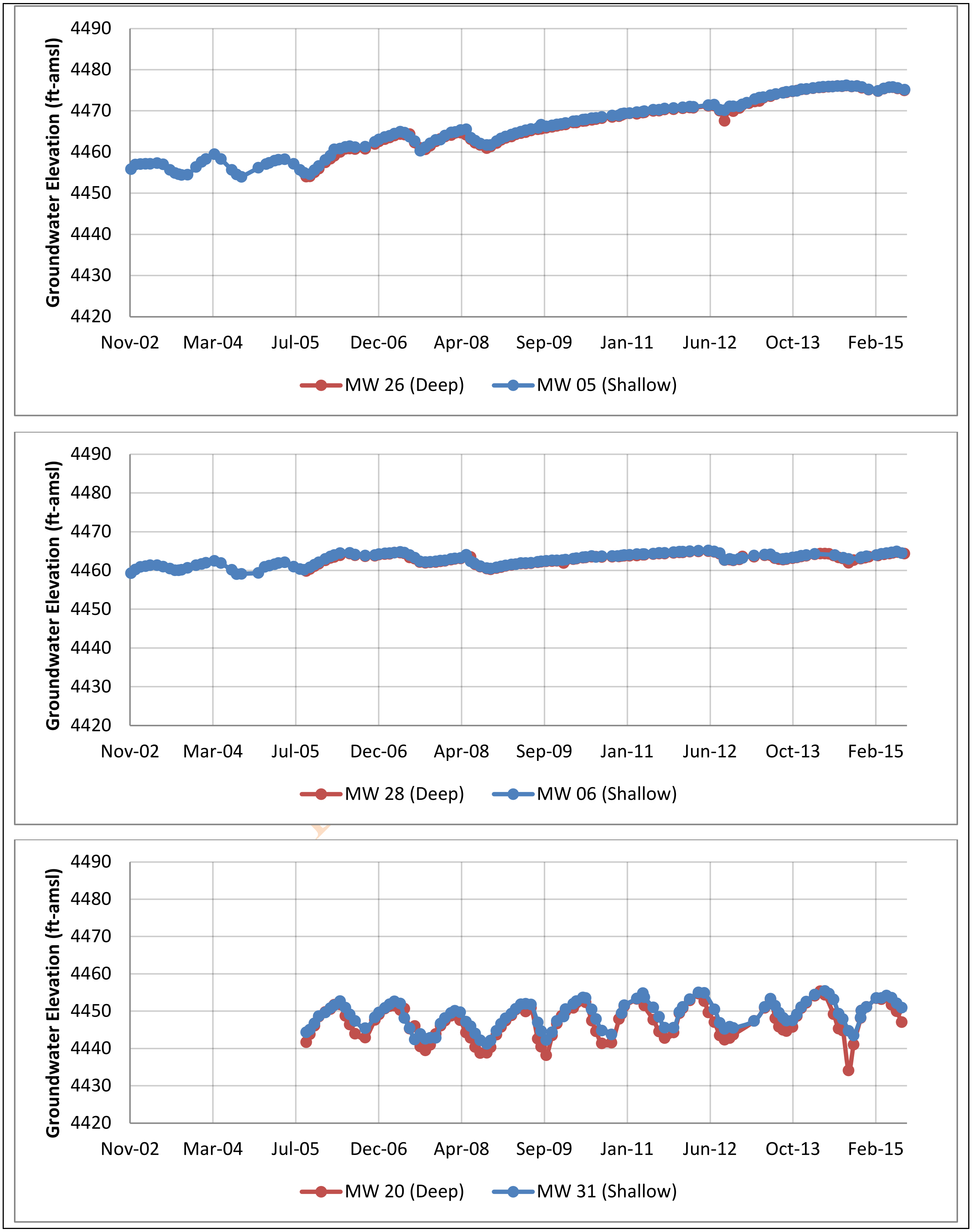


Figure 6. Change in Water Levels in Selected Monitoring Wells

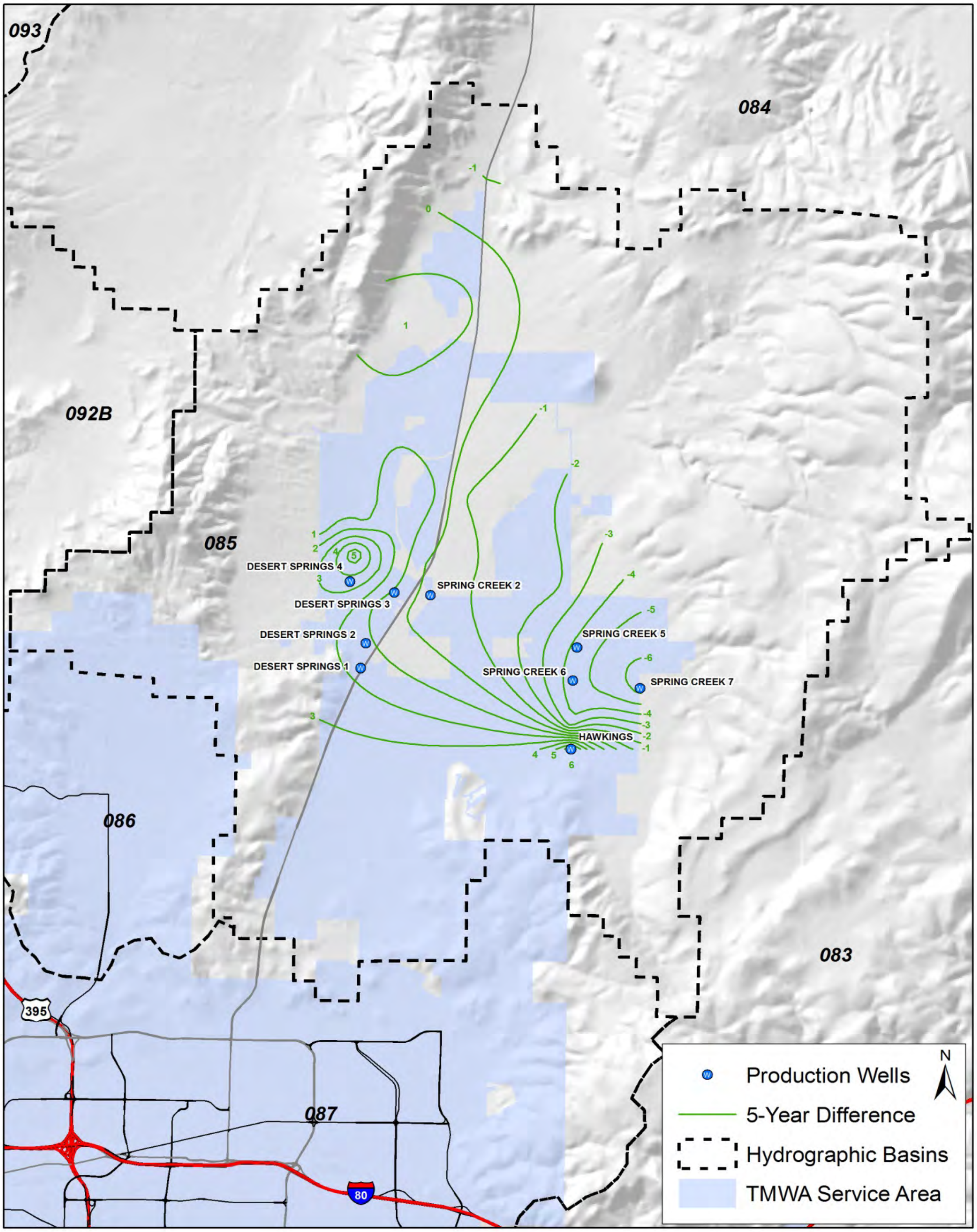


Figure 7. Difference in Groundwater Elevations 2010-2015 Hydrographic Basin 85

Groundwater Quality and Quantity

As depicted in Figure 8, poor groundwater *quality* exists in the central and southwest part of SSV whereas low water *quantity* dominates the northeast part of SSV. Poor groundwater quality is found in the southwest of SSV due to hydrothermally altered volcanic rock with high concentrations of arsenic and sulfate. In the center of SSV, septic tank effluent has polluted shallow groundwater with nitrate. Nitrate contamination has persisted over the past twenty years, rendering five production wells (Desert Springs 1, 2, 3, and 4 and Spring Creek 2) at risk. WDWR thoroughly investigated nitrate contamination and prepared full report that details sources, extent, and migration of nitrate titled, "Final Report: Spanish Springs Nitrate Remediation Pilot Project, Phase II: Nitrate Source, Extent, Magnitude, Migration, and Management Options" (Kropf and Dragan, 2010). Blending with Truckee River water and other well water is the current groundwater treatment practice for nitrate and arsenic. In addition to converting homes on septic to sewer, increasing the amount of artificial recharge ("ASR") in west side wells is a future alternative to help mitigate water quality issues.

All TMWA wells in SSV have been evaluated for future potential contamination through a Wellhead Protection Plan ("WHPP") updated in 2015. The plan includes the 2, 5, 10, and 20-year capture zones for each production well along with the locations of potential contamination sites. Additional information on groundwater contamination concerns in SSV is contained in TMWA's WHPP.

Aquifer Storage and Recovery

Recharge operations began in the east, southeast side of SSV in 2009. As of June 2015, TMWA has successfully injected 3,283 acre feet ("AF") of water to the groundwater system at the Hawkings Well. Water levels respond favorably and show a seasonal increase of approximately 7 feet in the Hawkings Well area. Information on the Hawkings Well ASR Program is contained in the 2015 semi-annual report titled, "Report on Aquifer Storage and Recovery, Spanish Springs Valley Hydrographic Basin; January 1 through June 30, 2015" filed with Nevada Divisions of Environmental Protection ("NDEP") and Nevada Division of Water Resources ("NDWR").

Pilot project recharge activities have been ongoing on the west side of SSV since 2012. As of June 2015, TMWA has successfully recharged 461 AF of water to the groundwater system at the DS4. Water levels respond favorably and show a seasonal increase of over 30 feet in the DS4 area. In response to recharge of treated surface water, water quality in the area has shown improvement. Concentrations of nitrate-N have decreased by as much as 70 mg/L in nearby shallow groundwater since pilot recharge activities began in 2012. Information on the DS4 Pilot Recharge Program is contain in the 2015 semi-annual report titled, " Recharge Pilot Project, Spanish Springs Valley, Washoe County, Nevada; Semi-Annual Report, January through June 2015" filed with NDEP.

TMWA currently recharges approximately 621 AF/yr in SSV, and plans to increase ASR considerably. As improvements are made over the next five years, there is the potential to recharge upwards of 5,000 AF in the east and west side wells on an annual basis.

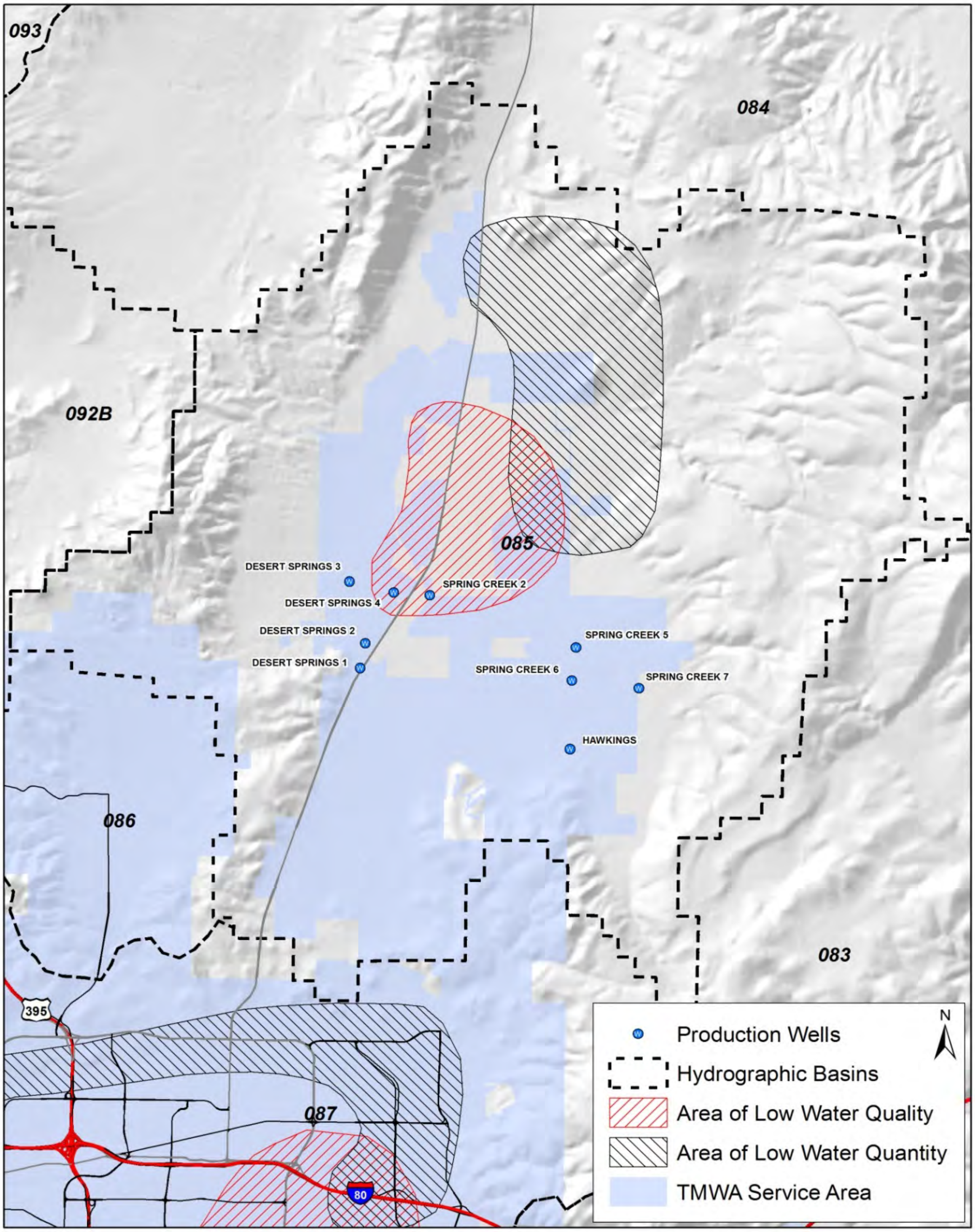


Figure 8. Areas of Poor Water Quality and Low Water Quantity in Hydrographic Basin 85

Groundwater Modeling

Several groundwater models have been completed for SSV over the years. The most recent version is an update to the 2009 Pohll et. al. model and is titled “Update to the Spanish Springs Valley Groundwater Model” (Pohll, 2015). Significant revisions in 2015 included:

- Updating the simulation period to include stresses from 2007 to 2014.
- Including injection at DS4 and Hawkings wells.
- Improving geologic model and spatial variability of hydraulic conductivity fields.
- Revising the spatial distribution of groundwater recharge including mountain-block recharge and transmission losses from the Orr Ditch and excess irrigation.
- Including water level measurements from domestic wells in the North-Northeast (Spring Creek East wells) in the calibration.
- Incorporating groundwater recharge from numerous turf irrigators.

The results of the updated model created the graphics and findings incorporated into this Basin Summary; are the basis of the capture zone analyses for TMWA’s production wells; and are the basis of analysis for TMWA’s WHPP.

Basin Challenges and Possible Solutions

The primary challenge is bringing groundwater back into balance given water demand and water quality concerns.

Water Demand

Well production constraints on the east side are limited by permitted duties at each well and sensitivity to domestic well owners to the north. Well production constraints on the west side are mostly limited to nitrate and arsenic contamination. Current base flow demands are being met with existing resources and facilities. However, additional and/or alternate sources of supply are needed to mitigate the effects of over pumping that has occurred in the basin and to meet future demands. Possible solutions include:

- *Increase Truckee River Use.* Increased use of Truckee River water to meet base flow demands and using wells for peaking is the current operational strategy and will increase into the future. This strategy has reduced the overall amount of pumping and has allowed water levels in areas to rebound. Increased surface water deliveries should have a cumulative positive effect.
- *Artificial Recharge*. Recharge (Desert Springs wells 1, 2, 3 and 4 and Spring Creek wells 4, 5, 6 and 7) with Truckee River water in winter months. This option could also help to improve the water quality issues at the Desert Springs water systems, particularly at Desert Springs 3. TMWA is completing permitting through the State Engineer’s Office and the Nevada Division of Environmental Protection (“NDEP”) to inject treated surface water in their wells, anticipated late 2015.

- *Indirect Potable Reuse (IPR)***.** An IPR program could be implemented to inject highly-treated-recovery water at the north end of the basin to offset over pumping and augment groundwater supplies.
- *Import Vidler Supplies***.** Redirect a portion of Vidler supplies to the basin to meet demands and/or for recharge. Other inter-basin sources could be considered as well.

Water Quality

Water quality issues in the basin are limited to arsenic (naturally-occurring) and nitrate (natural and septic) contamination in west side wells. Even if the high density septic systems are hooked-up to sewer, nitrate plumes are expected to persist. Over pumping on the west side may cause poor water quality to migrate from the shallow aquifer to municipal wells. Possible solutions include:

- *Convert Septics to Sewer*. Continued recharge of septic effluent to groundwater over time has a cumulative negative effect on groundwater quality. Converting homes on septic to sewer stops the flow of contamination and allows natural groundwater cycling and pumping to help dilute and remove nitrate from the groundwater system over time.
- *Increase Truckee River Use.* Increased use of Truckee River water to meet base flow demands and using wells for peaking is the current operational strategy and will increase into the future. Increased use of Truckee River water provides blending of surface with groundwater which also alleviates water quality issues associated with nitrate and arsenic in the short term. Increased surface water use may allow wells on the west side to relax and reduce the load of nitrate in the system.
- *Artificial Recharge*. Recharge (Desert Springs wells 1, 2, 3 and 4 and Spring Creek wells 4, 5, 6 and 7) with Truckee River water in winter months. This option could also help to improve the water quality issues at the Desert Springs water systems, particularly at Desert Springs 3. TMWA is completing permitting through the State Engineer's Office and the NDEP to inject treated surface water in their wells, anticipated late 2015.

TRUCKEE MEADOWS – HYRDOGRAPHIC BASIN 87

Introduction

The Truckee Meadows lies within a topographic basin that covers about 195 square miles and is bounded on the west by the Carson Range, on the east by the Virginia Range, on the north by lower mountains and on the south by the Steamboat Hills. The cities of Reno and Sparks are the major communities in the area.

Development began in Basin 87 in the 1850's as agricultural diversion of the Truckee River dominated the Truckee Meadows. Since that time, irrigated lands have given way to residential and commercial developments that service a population for the greater Reno/Sparks area.

The basin can be described as having two geographically and hydrogeologically distinct regions from which water is pumped into public water systems: (1) an alluvial fan and fractured volcanic rock aquifer located in the southwest part of the basin referred to as the southwest alluvial fan aquifer ("Alluvial Fan") and (2) a basin-fill aquifer in the central and northern part of the Truckee Meadows referred to generally as the basin-fill aquifer ("Basin-Fill").

Figure 1 depicts Hydrographic Basin 87 with the Alluvial Fan and Basin-Fill regions, and the location of Truckee Meadows Water Authority ("TMWA") production wells.

When compared to other basins in the Great Basin Province of Nevada, the uniqueness of the Truckee Meadows hydrographic basin is the presence of the Truckee River which flows west to east through the north Truckee Meadows ("NTM") portion of the Truckee Meadows basin. The Sierra Nevada Mountains on the west side of the basin and geologic units underlying the valley are complexly faulted. Regional faulting gave the mountains their large-scale size, shape, and relief. The present topography of the basin is the result of erosion and smaller scale fault structures. The resulting valley is a structural depression filled with unconsolidated basin-fill material comprised of weathered material from the surrounding mountain ridges including layers of clay, silt, fine- to coarse-grained sand, and gravel. Generally, basin-fill is coarser near the mountain ridges and becomes finer-grained in the center of the basin. The Basin-Fill is conceptualized as a complex aquifer system comprised of: 1) alluvium, 2) partly confined alluvium, 3) fractured volcanic sequences, and 4) granitic, volcanic, or metavolcanic basement rock. Alluvial sediments (1 & 2) are estimated at 500-1,000 feet thick in this area. The Truckee River deposited large quantities of coarse-grained alluvial materials along the river corridor and dominates the lithologies encountered by the majority TMWA production wells in the northern part of the basin. The southwest Alluvial Fan is conceptualized as a complex aquifer system comprised of: 1) thin alluvial fan deposits, 2) consolidated sedimentary deposits, 3) interbedded fractured volcanic sequences, and 4) granitic, volcanic, or metavolcanic basement rock. Alluvial sediments (1 & 2) are estimated at 300-500 feet thick in this area.

TMWA currently operates 44 active production wells in Basin 87. Active wells were completed from 1960 to 2011 and have production capacities range from a low of 200 to a high of 2,500 gallons per minute ("gpm"). Seven additional wells --I Street, Dilworth, Sparks High, Reed High, Innovation, Huffaker Place, and Double Diamond 3-- are currently unequipped and projected to be brought online over the next 10 years. Two other wells, Peckham and Stanford, are unsuitable for drinking purposes but are used for non-potable applications such as construction water. Twelve of the active wells are located in the Alluvial Fan and the remaining 32 wells are located in the Basin-Fill on the valley floor of the Truckee Meadows basin.[1]

Approximately 1,480 domestic wells are located in Basin 87. The majority of these wells are located in the southwest part of Basin 87 on the southwest fan. The State of Nevada allows each domestic well owner to divert up to 2 AF/yr; with a total potential extraction by all domestic wells of over 2,950 AF/yr. Figure 2 depicts the increase in domestic wells constructed in Basin 87. Over time, an increasing number of residential well owners have experienced well failures. These failures are generally attributed to the shared aquifer responding to drought conditions; shallow initial well construction; high domestic well density; the increased number of domestic wells; and municipal well production volumes.

Demands in Hidden Valley and Heron's Landing service areas are met with a combination of surface water and groundwater that is treated at the Longley Lane Treatment Plant. The well field to serve this area consists of four production wells. Treatment consists of manganese and arsenic filtration and chlorination. This treated water can also be pumped via pipeline to the south Truckee Meadows.

[1] As a result of the merger with Washoe County, the various groundwater resources and wells that were incorporated into TMWA are further categorized whether the well is part of the original TROA agreement or are an addition to non-TROA groundwater resources. Under this categorization, TMWA's 27 pre-merger wells are considered part of TROA groundwater resources and TMWA's addition of the former Washoe County Department of Water Resources ("WDWR") 18 wells in the Truckee Meadows basin are part of the non-TROA groundwater resources. The majority of TROA wells occur in the Basin-Fill whereas non-TROA wells, with a few exceptions (Hidden Valley and Double Diamond wells), generally occur in the Alluvial Fan.

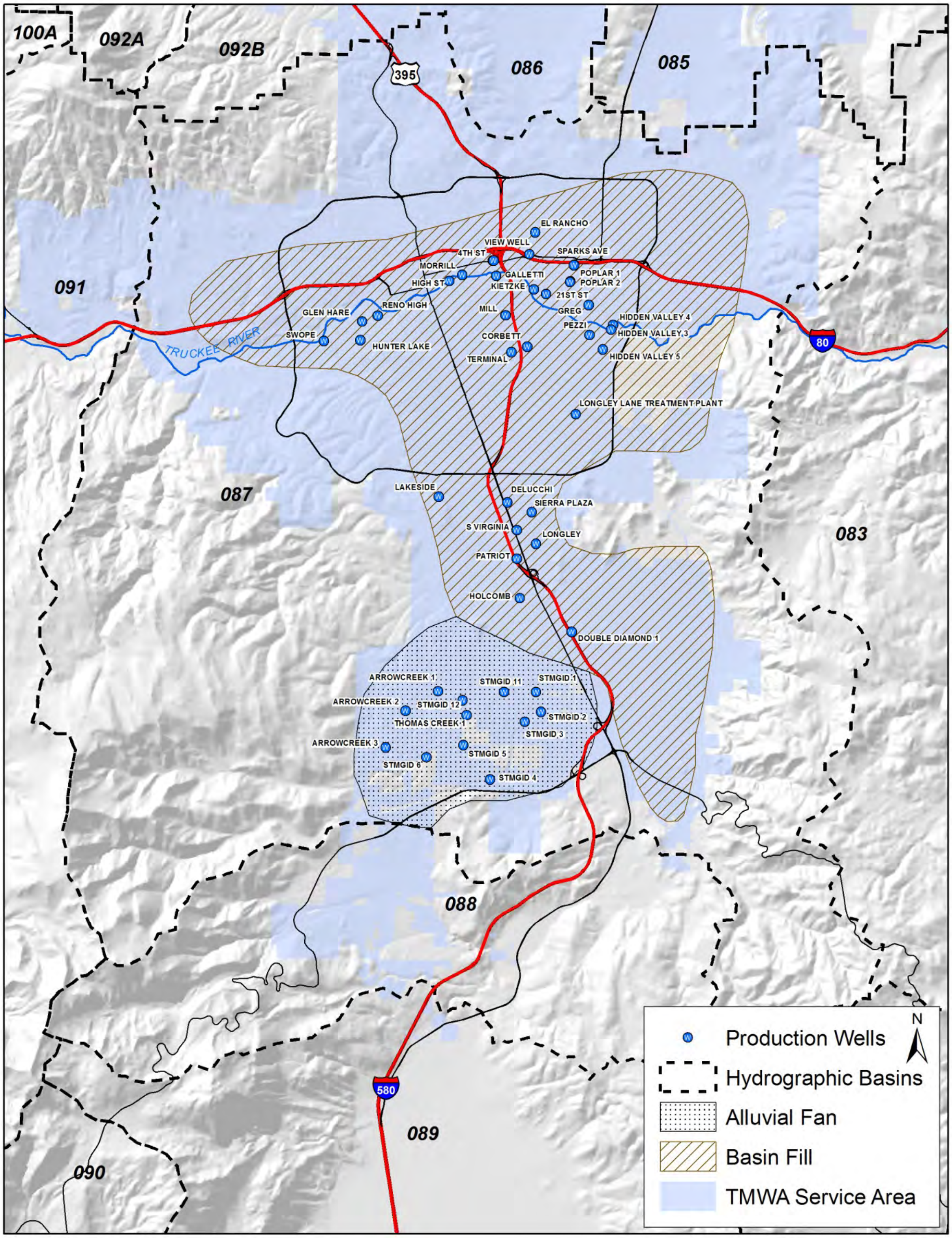


Figure 1. Truckee Meadows Hydrographic Basin 87 Location Map

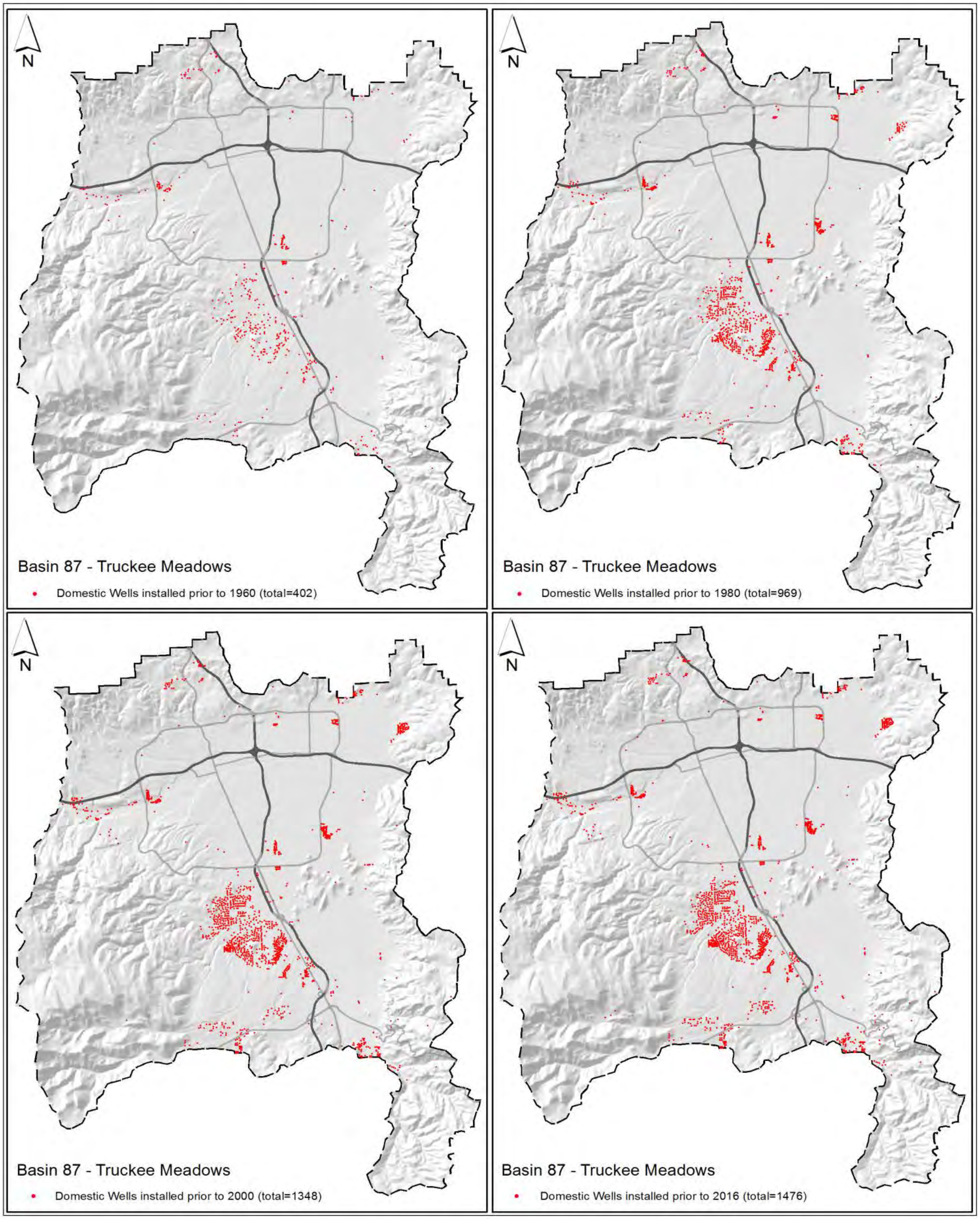


Figure 2. Changes in Number of Domestic Well in Hydrographic Basin 87

Water Resources

The Truckee River is the principal surface water source in the Truckee Meadows. The river's headwaters originate in the Sierra Nevada around Lake Tahoe where small streams feed the lake around its margins, and then discharges from the lake on the northwest side. The Truckee River enters the Truckee Meadows from the Carson Range on the west at an elevation of about 4,630 feet, meanders through the Truckee Meadows and leaves through a canyon in the Virginia Range at an elevation of about 4,370 feet. The Truckee River's principal tributary, Steamboat Creek and its tributaries Whites Creek, Thomas Creek and Dry Creek, drains to the south and southwest parts of the meadows. Steamboat Creek enters the area from the south through a bedrock constriction at an elevation of about 4,600 feet. Whites and Thomas Creeks enter at an elevation of about 5,900 feet and contribute flow to Steamboat Creek. The drainage basins of Whites and Thomas Creeks extend to near the crest of the Carson Range at an elevation of about 9,000 feet. Other streams that provide flow to the Truckee River are Alum, Hunter and Evans Creeks that drain the northwest part of the Carson Range.

A network of irrigation ditches supplies water to farms and ranches in the Truckee Meadows. Principal ditches that divert water from the Truckee River include Steamboat, Last Chance, Lake, Cochran and Pioneer ditches on the western side of the area and the Highland and Orr ditches on the northern side of the area. The Orr ditch delivers water to Spanish Springs Valley to the north of the Truckee Meadows and returns excess water to the Truckee River through the North Truckee Drain. Excess irrigation water from the ditches along the western side of the area is returned to the Truckee River by the Boynton Slough and Steamboat Creek.

Natural Groundwater Recharge

The climate in the Truckee Meadows is arid to semiarid because the area is in the rain shadow of the Sierra Nevada Mountains. Precipitation in Basin 87 falls as snow and rain typically from November through April. Precipitation for much of the Truckee Meadows ranges from about 6 to 10 inches a year on the valley floor and foothill areas, but the mountains to the west receive as much as 40 inches a year and provide the majority of the natural recharge for the basin. The natural groundwater discharge supports vegetation principally in the valley lowlands of the Truckee Meadows and provides water directly to drains and creeks passing through the Meadows.

The water-bearing materials in the Truckee Meadows are recharged from infiltration of precipitation, seepage from streams and portions of the Truckee River entering or crossing the Meadows, underflow from tributary valleys, seepage from irrigation ditches, deep percolation of water applied for irrigation of pasture, row crops, lawns and other greenscape areas, and from waste water discharged from septic tanks, and from the injection of treated surface water into public supply wells used for artificial recharge. A significant amount of recharge to the water-bearing materials in Truckee Meadows is due to seepage from irrigation canals and deep percolation of water applied for irrigation. In the past, it has been estimated that approximately 25% of water applied for irrigation percolates into the groundwater reservoir. It has been assumed that as land is converted from irrigated pasture or row crops to lawns or other types of water consumptive landscaping, the recharge from the land would be reduced.

The natural groundwater recharge estimate from upland precipitation and snow melt is about 27,000 acre feet/year ("AF/yr") for the entire basin (Van Denburgh, 1973). The southwest fan area alone is estimated to receive between 9,000 and 15,000 AF/yr as groundwater recharge from upland precipitation and snow melt.

Groundwater Pumping

Groundwater beneath the Truckee Meadows has been pumped from the aquifer system for over fifty years. Large quantities of groundwater are available from that part of the aquifer containing unconsolidated rocks of alluvial origin. Groundwater is also available from consolidated rocks, generally in the foothills surrounding Basin 87.

Twelve of TMWA's 44 wells, located in the southwest Alluvial Fan, are used up to 12 months a year; the remaining 32 wells are located in the Basin-Fill and are primarily used to augment summer peak demand or during emergency conditions. Facilities are being constructed over the next two years to allow TMWA to increase the deliveries of surface water to the higher elevations of the southwest alluvial fan so that reliance on wells for winter supplies can be reduced.

At the basin scale, the annual groundwater yield that can be withdrawn without depleting the aquifers on a sustainable basis is less than the annual recharge. Over the past five years, the average municipal groundwater withdrawals are about half of the average annual natural recharge to the basin.

Groundwater withdrawals from production wells in Basin 87 assigned to Truckee River Operating Agreement ("TROA") water supplies ranged between 5,480 and 16,580 AF/yr since 2001 (Figure 3). Pumping at non-TROA wells has decreased significantly since 2001. Groundwater withdrawals from all non-TROA production wells in Basin 87 ranged between 4,630 and 7,000 AF/yr since 2001 (Figure 4). Increased non-TROA well pumping is due to three new production wells installed in 2006, 2008, and 2012 to meet demands.

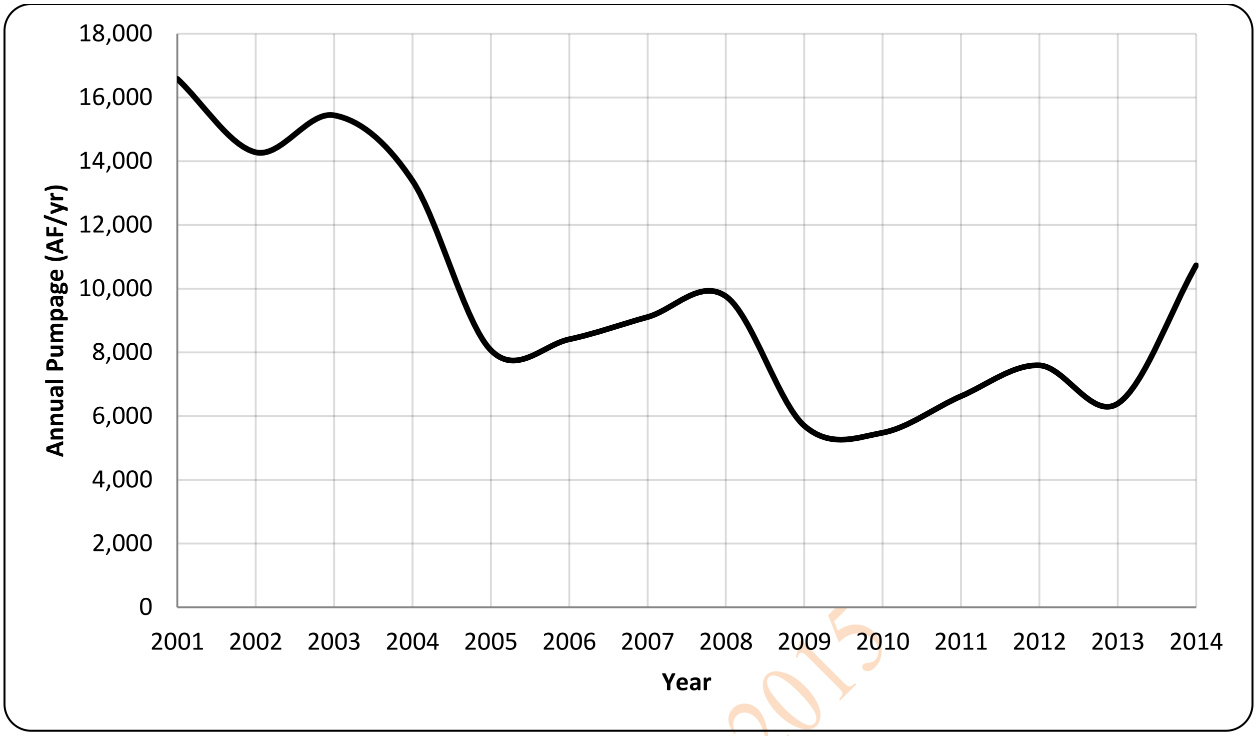


Figure 3. Groundwater Withdrawals from TROA Assigned Wells in Basin 87

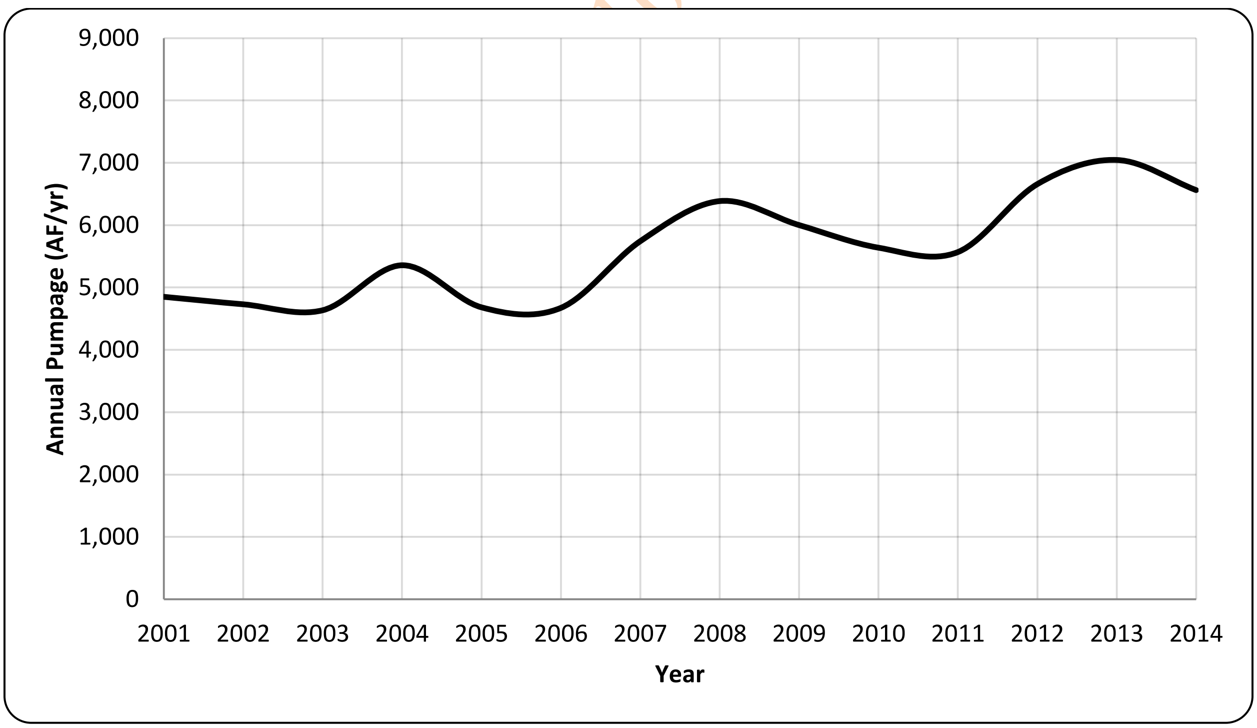


Figure 4. Groundwater Withdrawals in non-TROA Wells in Basin 87

Groundwater Levels

Groundwater elevations vary significantly throughout the basin, with groundwater at shallower depths in the Basin-Fill than groundwater in the Alluvial Fan aquifer system. Hydrographs from 2001 to 2015 represent changes in water levels resulting from the variation in precipitation, pumping, artificial recharge, evapotranspiration, and aquifer properties. The graphs indicate that water levels fluctuate seasonally with rises during non-pumping and recharge periods (winter months) and declines during pumping periods (summer months).

Figures 5 through 9 depict groundwater hydrographs for several wells within the Basin-Fill in Basin 87. Water levels are relatively stable in the Basin-Fill wells. Seasonal recharge activities allow groundwater levels to mound up, while short-duration seasonal pumping drops water levels for a brief time. As shown in the plots, water levels generally rebound immediately after pumping and especially so after recharge activities commence.

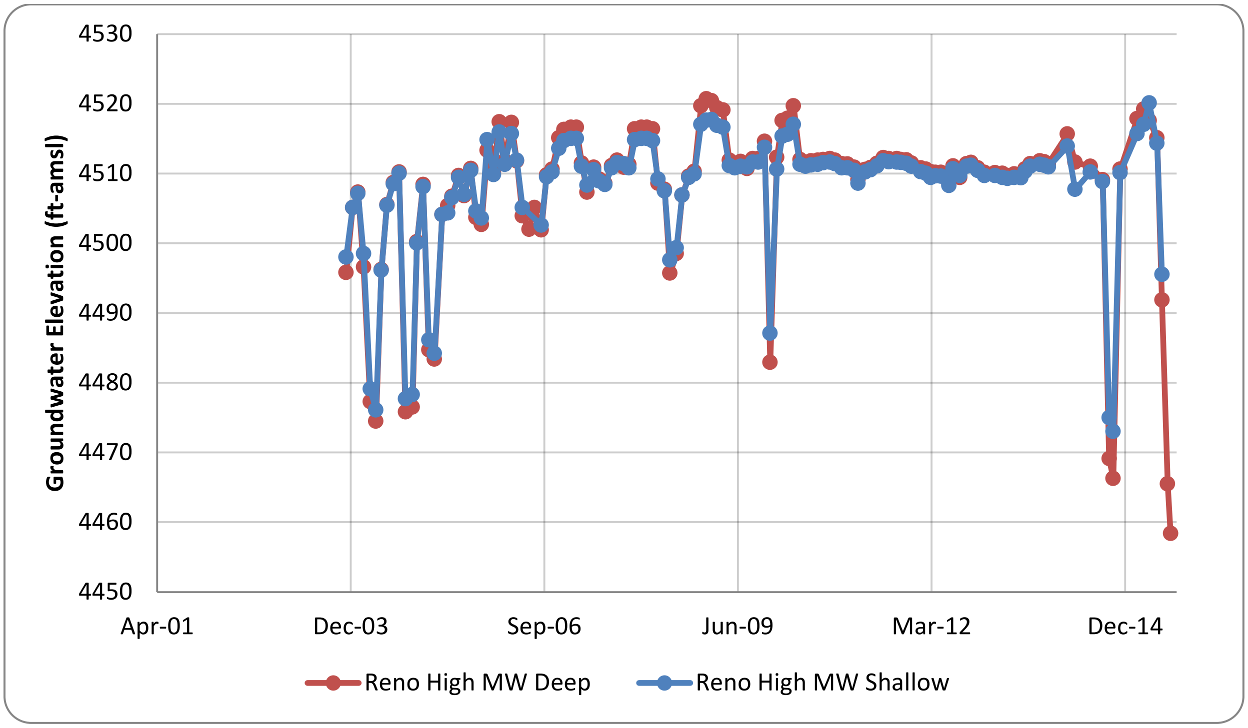


Figure 5. Basin-Fill Groundwater Hydrograph (northwest area) Basin 87

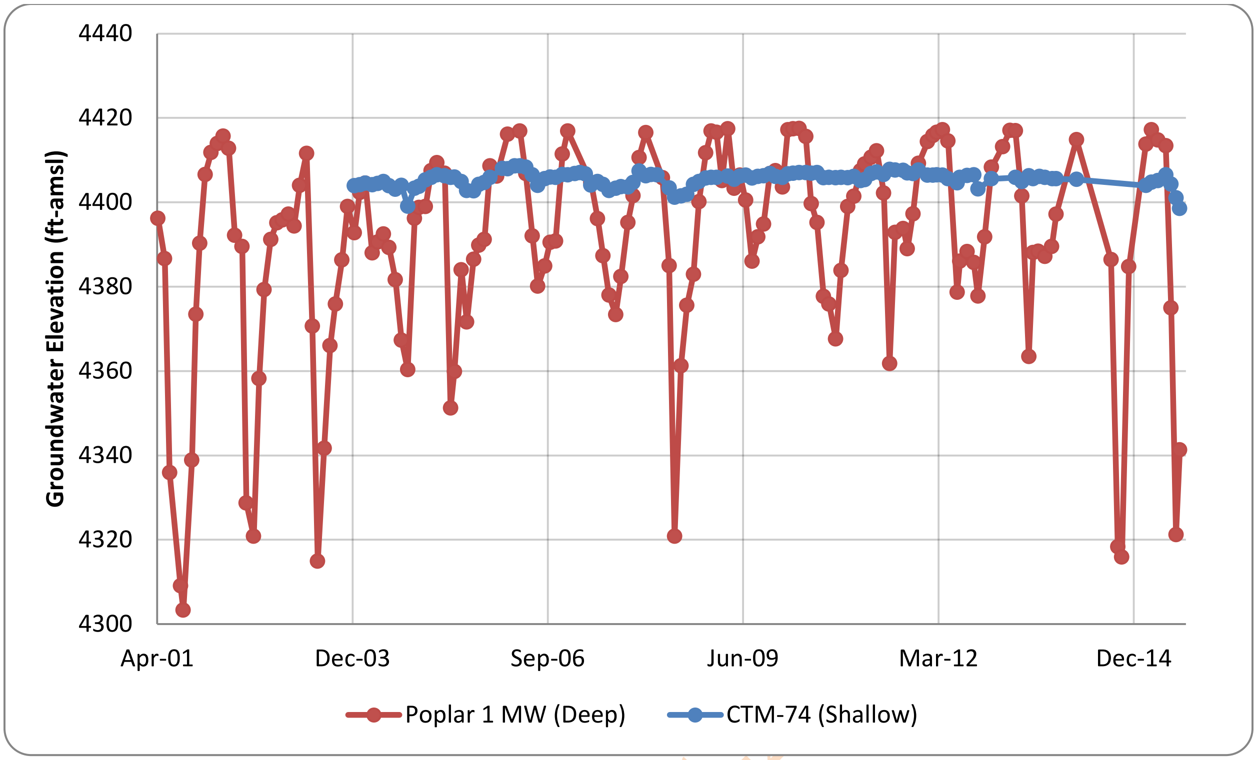


Figure 6. Basin-Fill Groundwater Hydrograph (east-central area) Basin 87

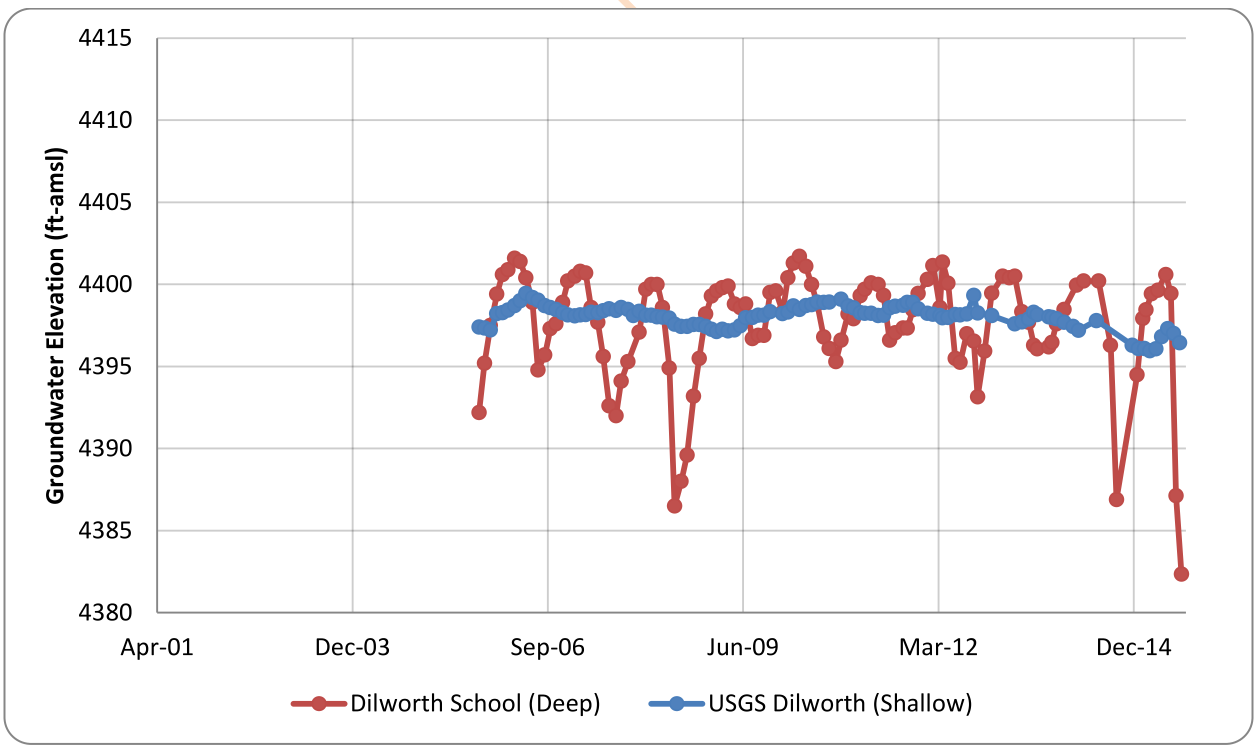


Figure 7. Basin-Fill Groundwater Hydrograph (northeast area) Basin 87

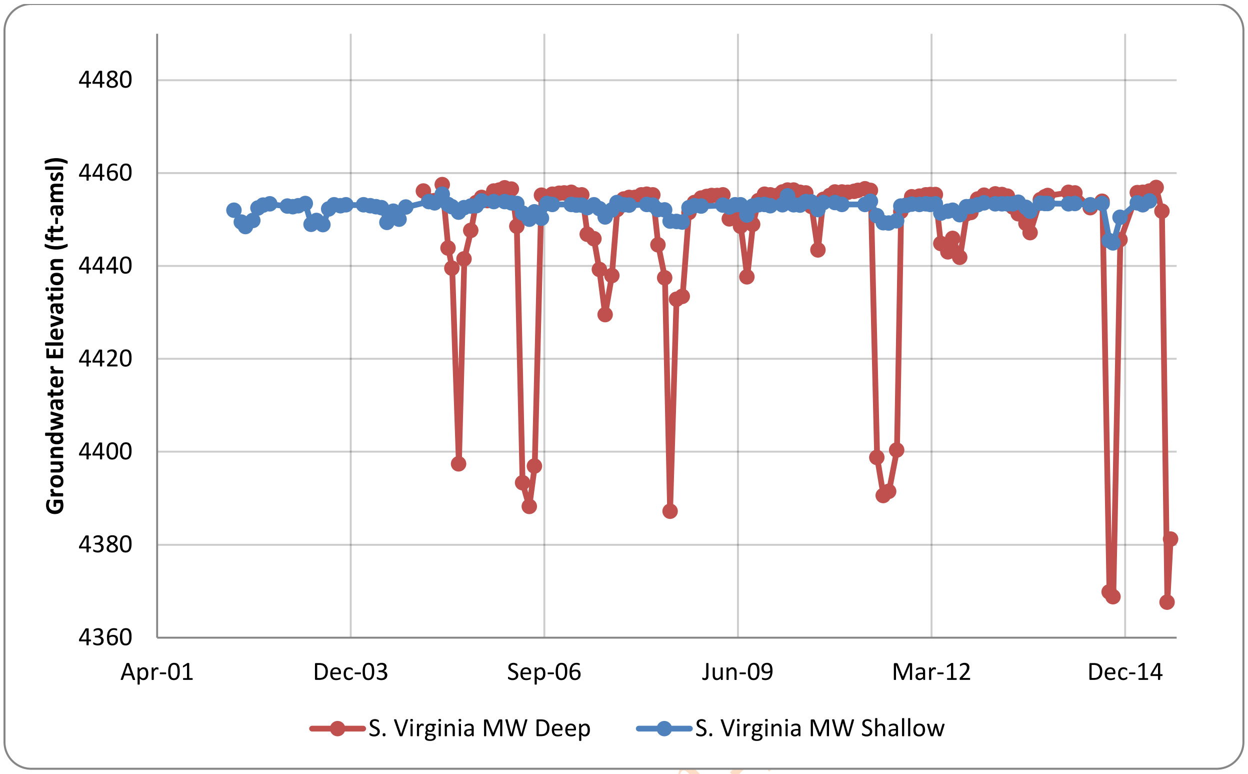


Figure 8. Basin-Fill Groundwater Hydrograph (central area) Basin 87

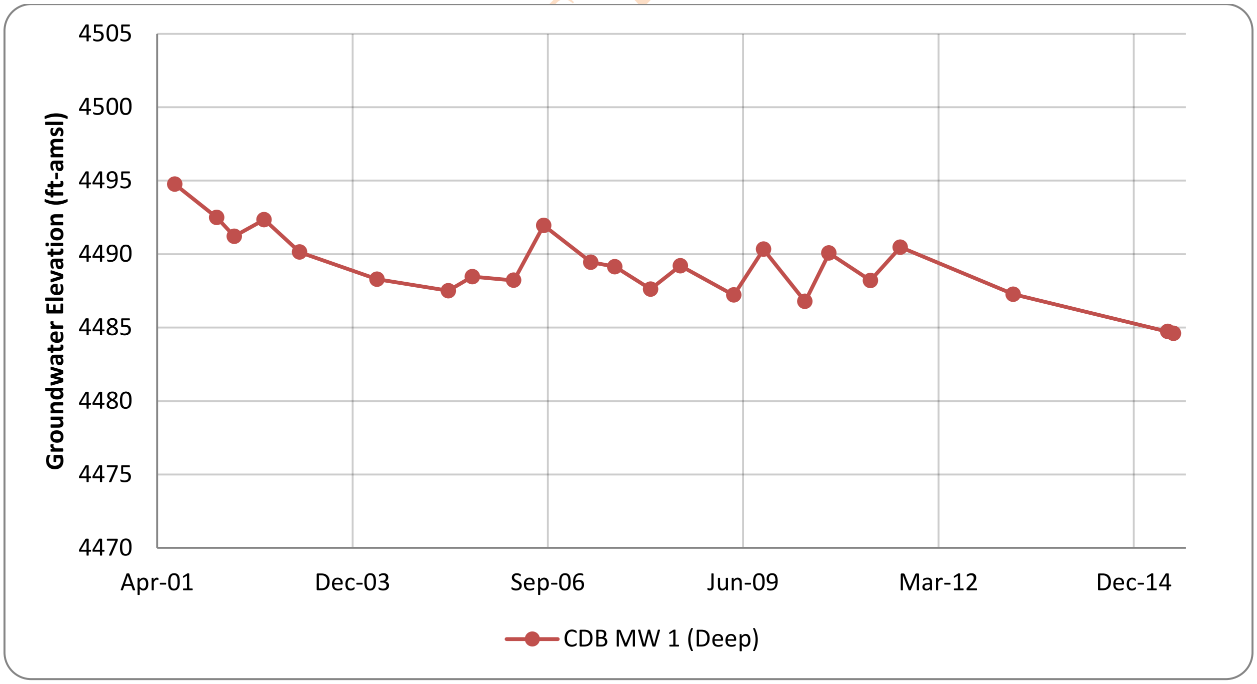


Figure 9. Basin-Fill Groundwater Hydrograph (southeast area) Basin 87

Figures 10 through 15 depict groundwater hydrographs for several wells within the southwest alluvial fan area in Basin 87. Water levels are depicted for wells on the upper elevations of the fan (Figure 10) and decrease with elevation (Figure 12) from southwest to northeast. Figures 12 through 14 depict water levels from west to east along the top of the fan (Figure 13) to the east side of the valley floor (Figure 15).

Water levels have been in decline on the southwest alluvial fan for a number of years. Municipal pumping and the high density of domestic wells in the area compound water level declines over time. The compartmentalization of aquifer materials due to numerous faults on the southwest alluvial fan may impede groundwater recharge and amplify the effects of groundwater withdrawals at wells adjacent to these faults.

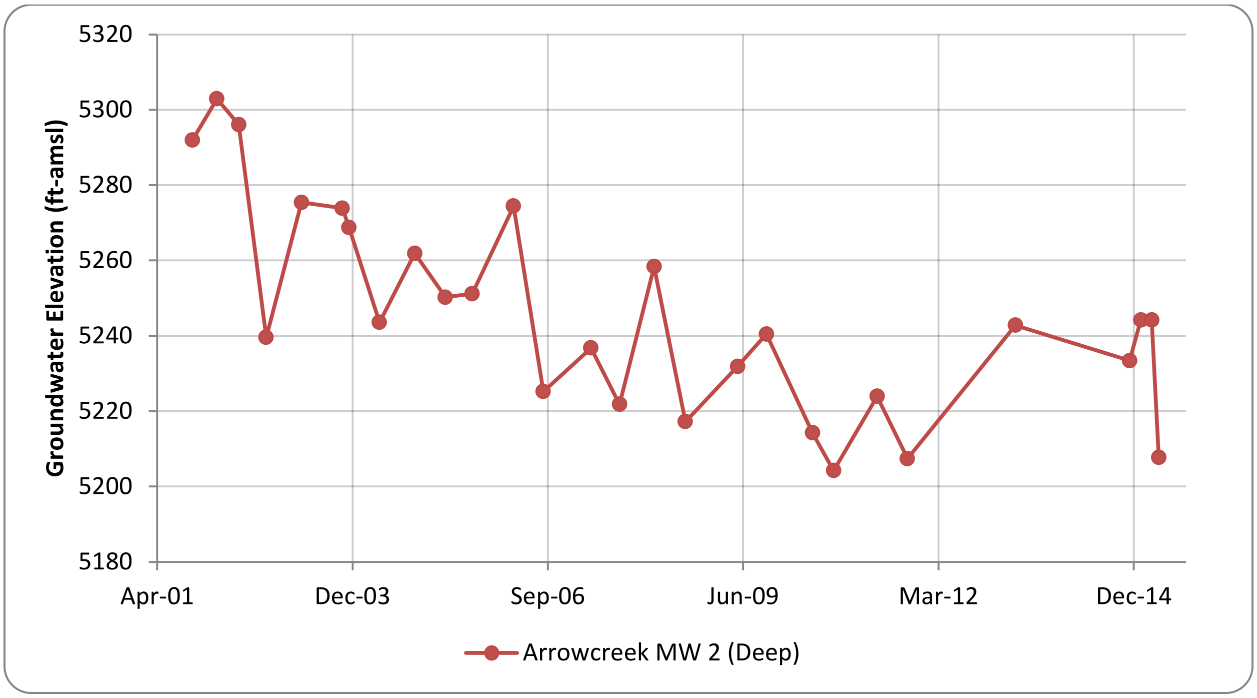


Figure 10. Southwest Alluvial Fan Groundwater Hydrograph (top of fan) Basin 87

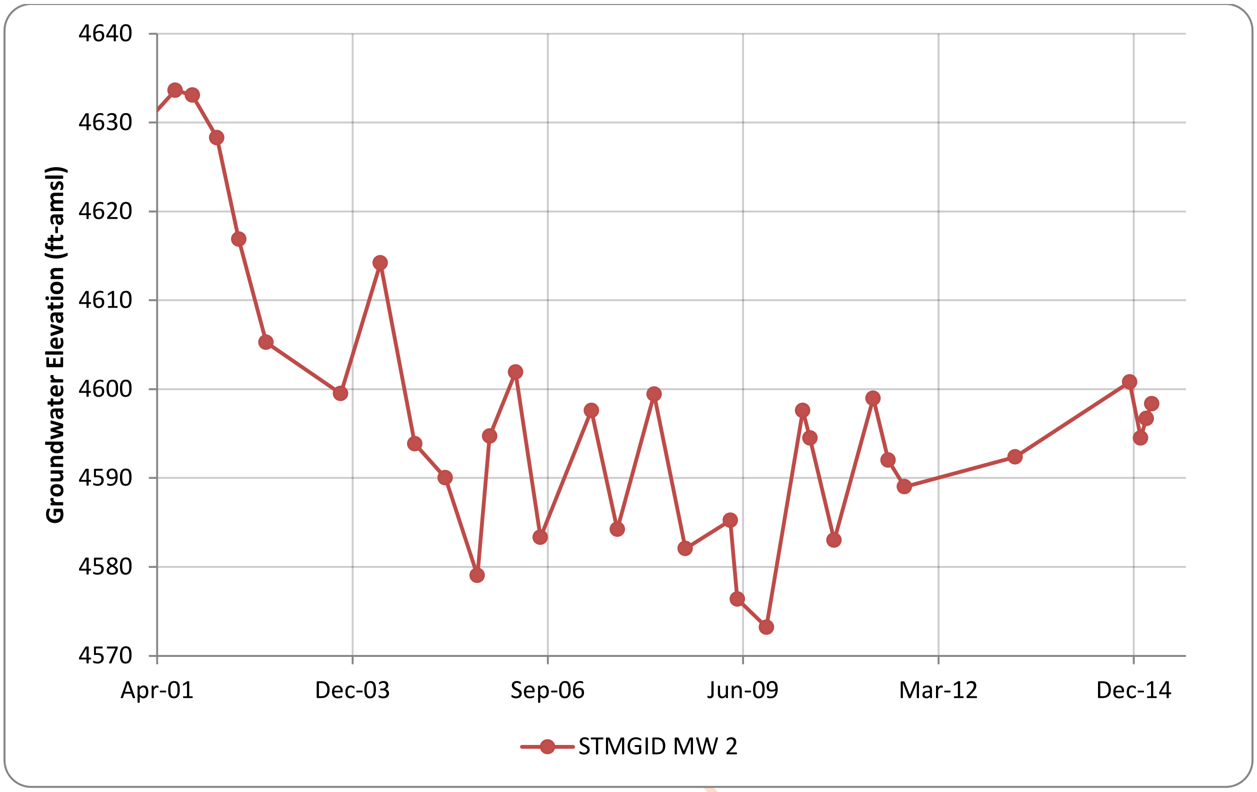


Figure 11. Southwest Alluvial Fan Groundwater Hydrograph (middle of fan) Basin 87

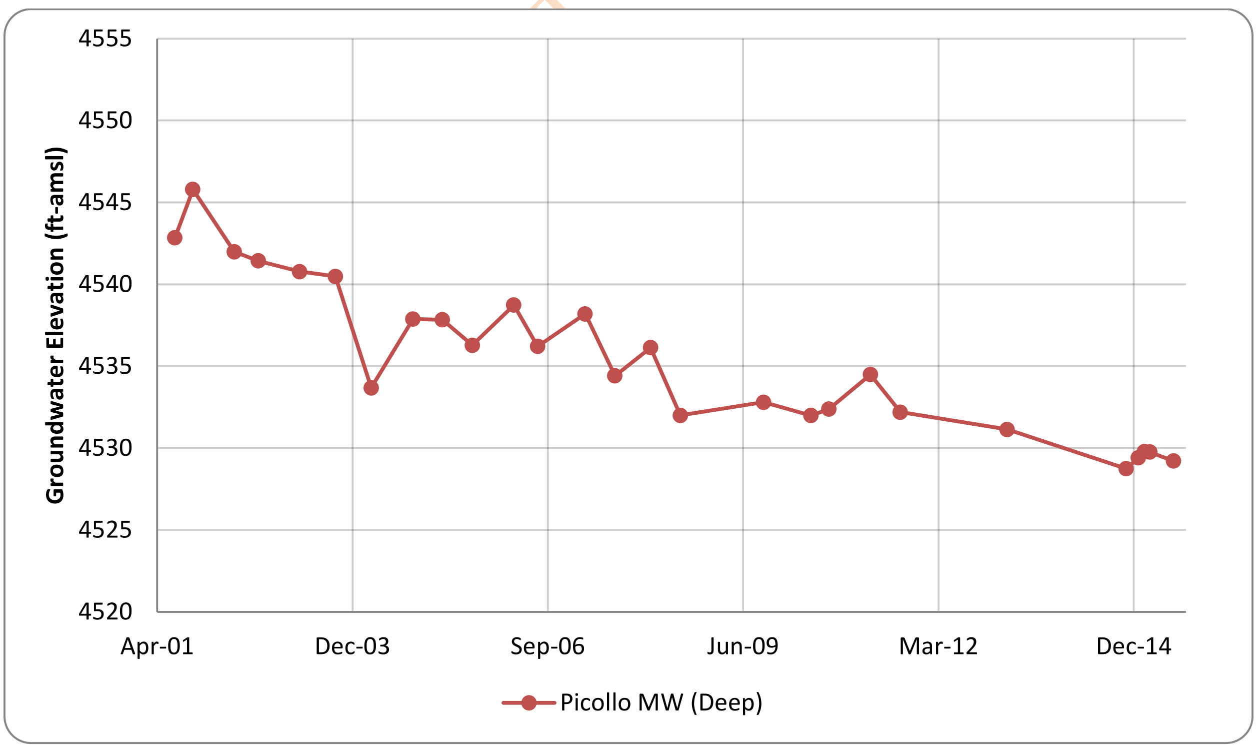


Figure 12. Southwest Alluvial Fan Groundwater Hydrograph (lower fan) Basin 87

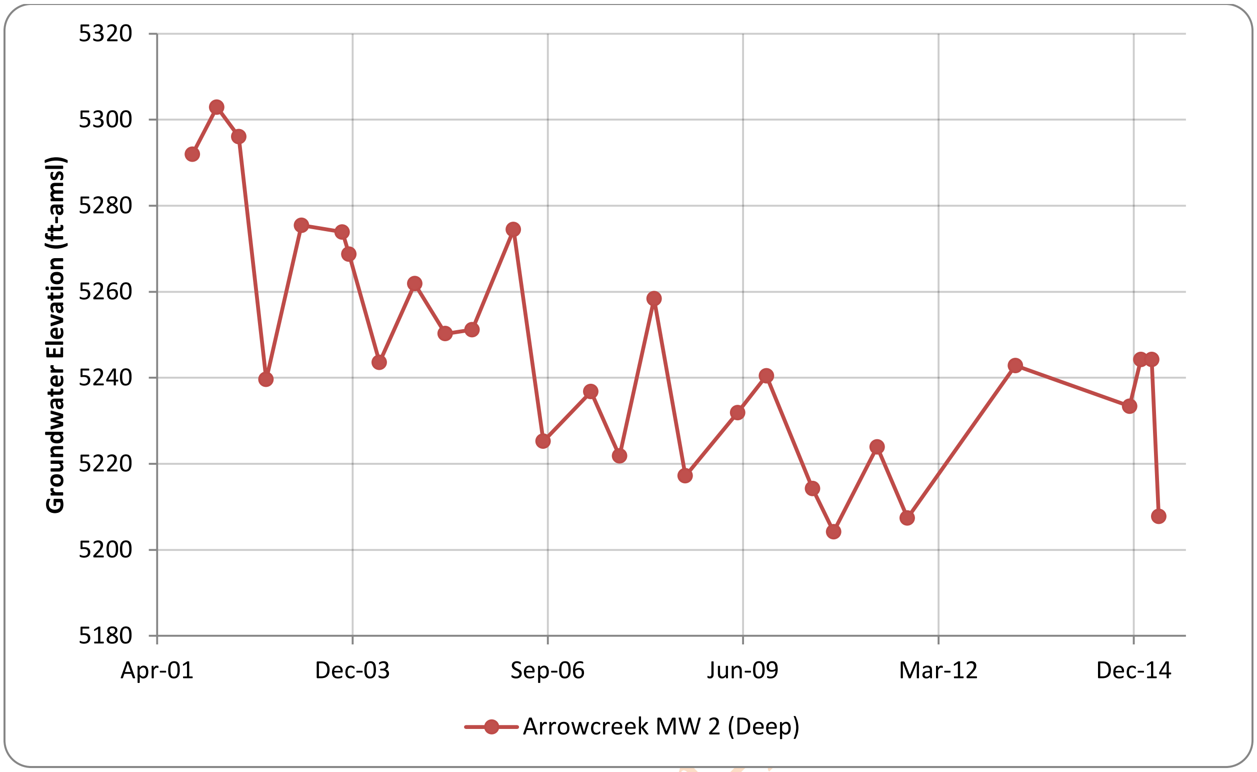


Figure 13. Southwest Alluvial Fan Groundwater Hydrograph (top of fan) Basin 87

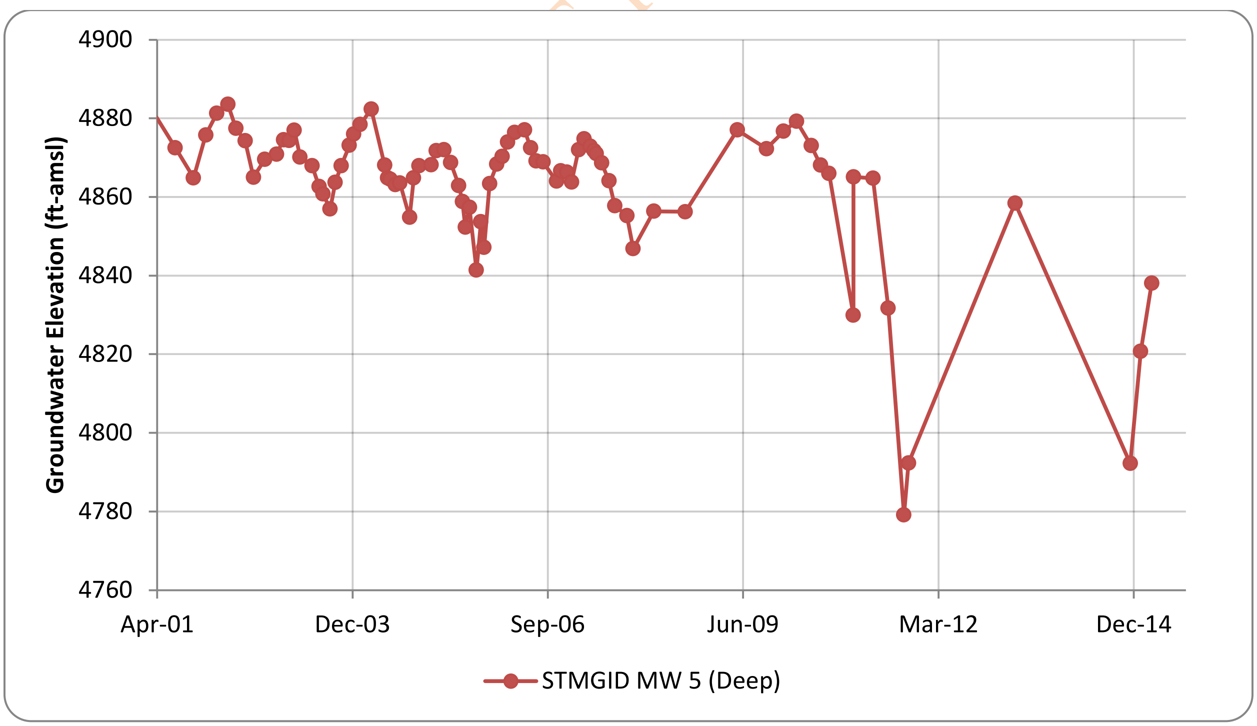


Figure 14. Southwest Alluvial Fan Groundwater Hydrograph (middle of fan) Basin 87

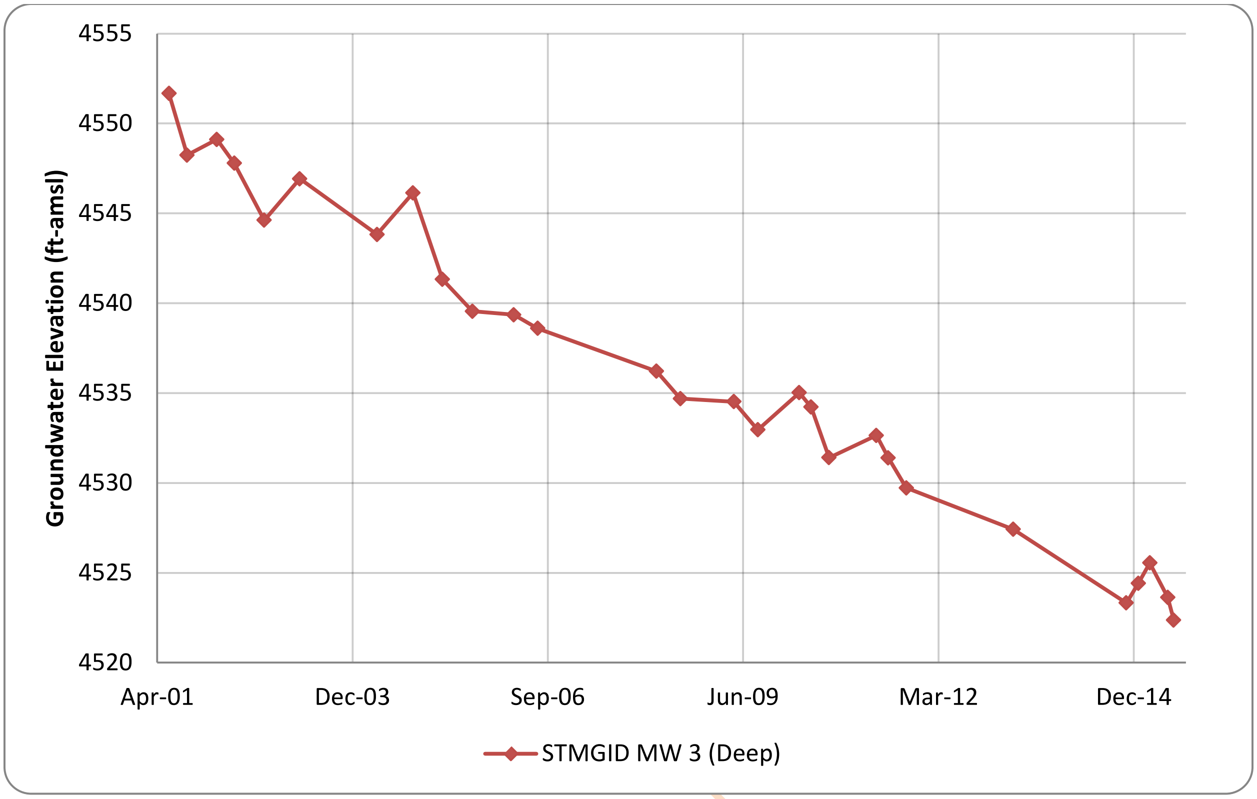


Figure 15. Southwest Alluvial Fan Groundwater Hydrograph (bottom of fan) Basin 87

Figure 16 shows how groundwater flow in Basin 87 can be generalized as flowing northeasterly from the southwest fan to the valley floor, north from the valley floor in the southern Truckee Meadows to the northern Truckee Meadows where it combines with groundwater that flows generally from west to east along the path of the Truckee River and exits the basin at the east Truckee Canyon.

Figure 17 depicts the change in water levels over time between 2010 and 2015. On a localized basis, groundwater levels rose up to 16 feet in basin-fill areas where TMWA is actively injecting water. In the southwest fan area, where injection has yet to occur, groundwater levels declined as much as 16 feet in the upper reaches of the fan on a localized basis.

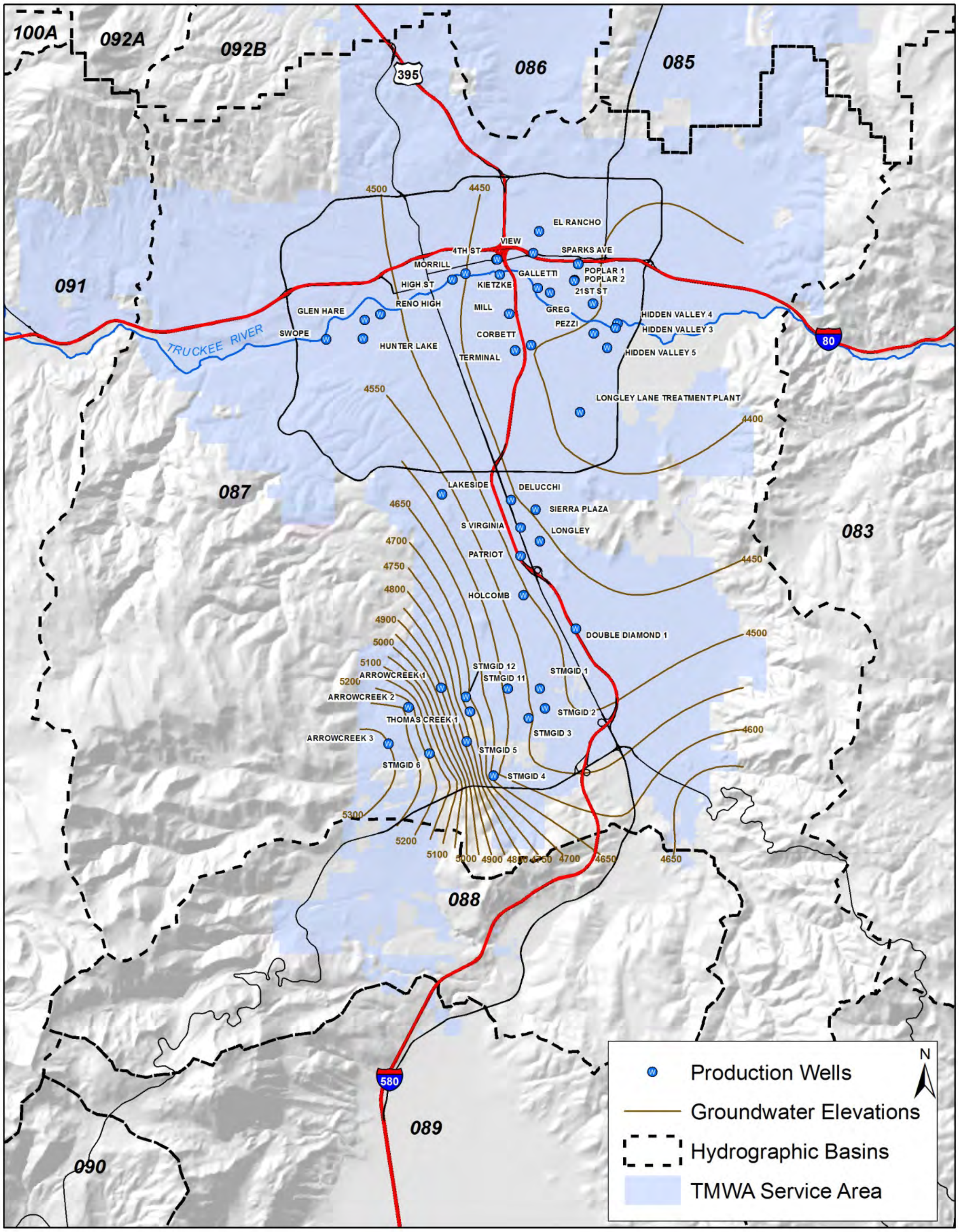


Figure 16. 2015 Groundwater Elevations Contour Map for Hydrographic Basin 87

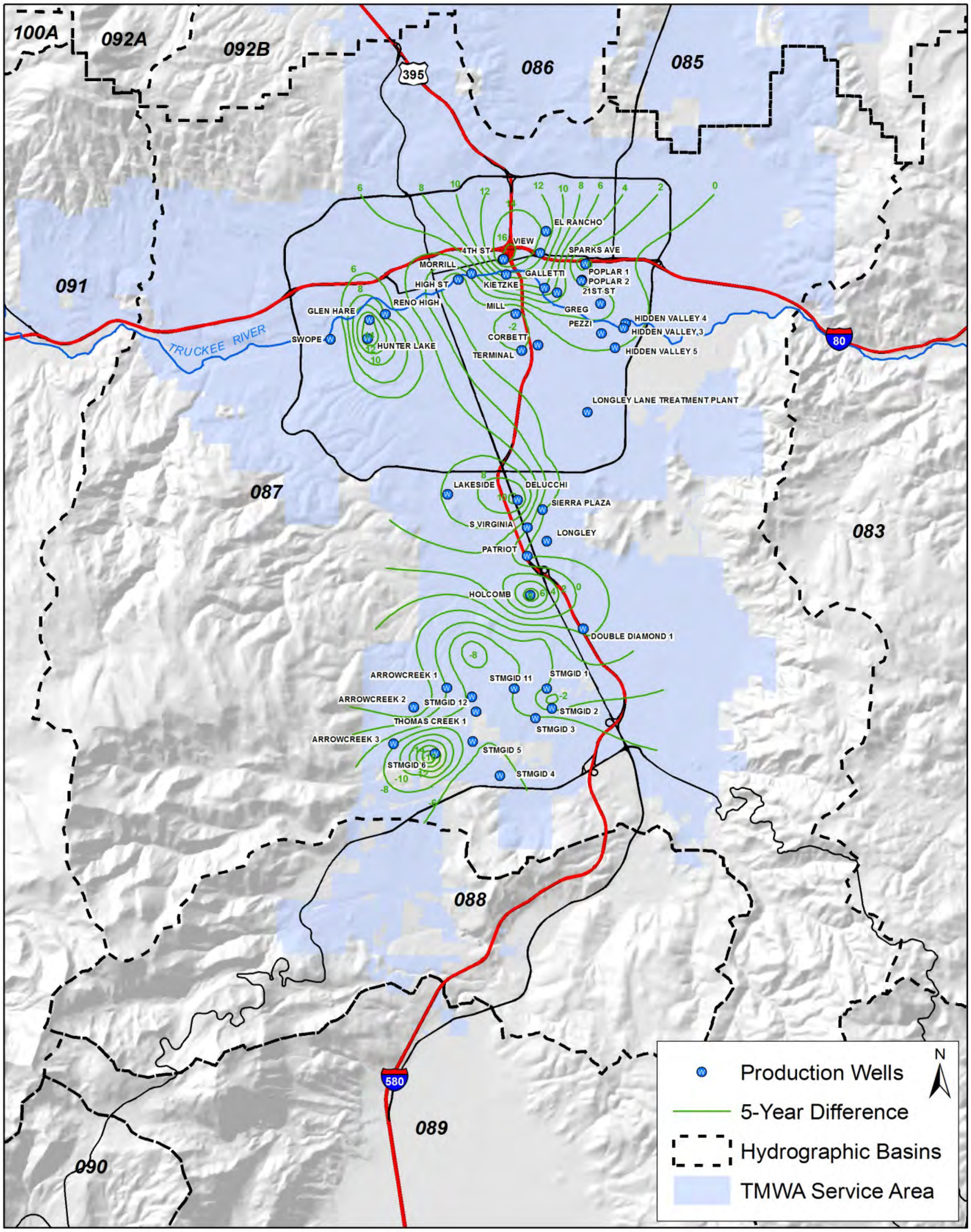


Figure 17. Difference in Groundwater Elevations 2010-2015 Hydrographic Basin 87

Groundwater Quality and Quantity

Groundwater *quality* and *quantity* varies throughout the Truckee Meadows hydrographic basin. Figure 18 depicts the areas generally characterized as having poor water *quality* or low water *quantity*.

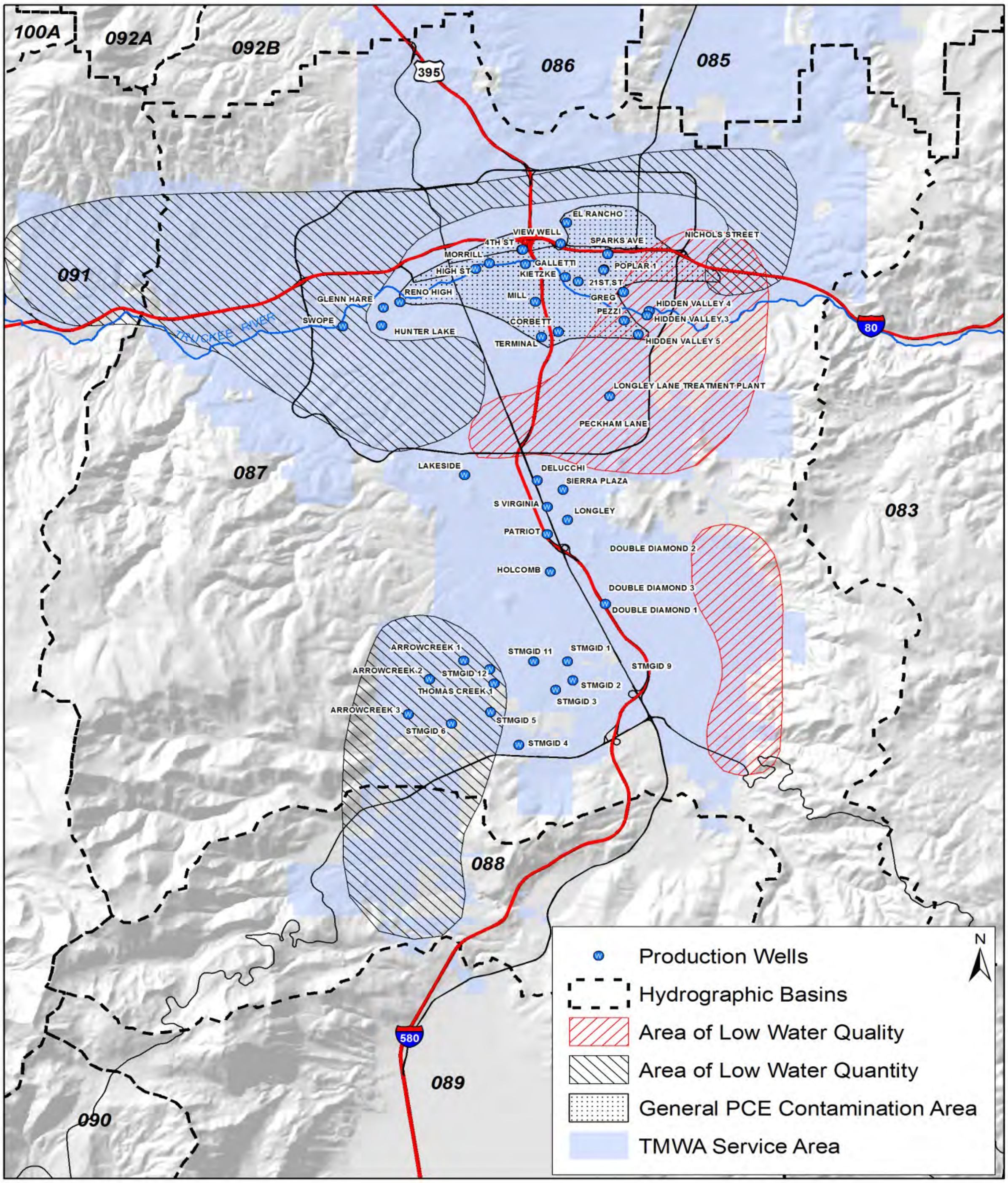


Figure 18. Areas of Poor Water Quality and Low Water Quantity in Hydrographic Basin 87

In the southern part of the Basin 87, low total-dissolved solids ("TDS") groundwater is found within the southwest alluvial fan at the base of the Sierra. The water quality deteriorates at the valley floor where it mixes with highly mineralized geothermal waters discharged from the Steamboat Springs Geothermal Area at the far south end of the basin, the Steamboat Hills area.

In the northern part of Basin 87, poor water *quality*, due to highly mineralized groundwater, is found generally in the Hidden Valley and Huffaker Hills regions. Geothermal areas are present in the west and southwest near the Moana Hills region. Groundwater with high arsenic levels is also treated by TMWA.

In 1987, testing of TMWA wells identified the presence of an organic solvent known as tetrachloroethylene ("PCE"). Mitigation of legacy (the responsible party is unknown) PCE contamination is addressed through the Washoe County Central Truckee Meadows Remediation District ("CTMRD") program. Management practices include using five TMWA wells to pump and treat groundwater at three air stripping-treatment facilities that remove PCE. The five TMWA wells are: Kietzke, Mill, High, Morrill, and Corbett. The CTMRD has identified 8 PCE contamination plumes in Basin 87. This solvent has been used since the 1930's in a variety of commercial/industrial operations such as commercial dry cleaning, paint manufacturing, and auto repair. The CTMRD program has achieved success in plume capture and containment resulting from the implementation of a prescriptive pumping schedule of the 5 TMWA wells fitted with PCE treatment equipment. According to the CTMRD, the PCE plumes do not appear to be moving or growing. TMWA is an active participant with the CTMRD program in planning for and implementing mitigation of PCE. Additional CTMRD information can be found at:

https://www.washoecounty.us/csd/utility/ctmrd/downloads.php

Attaining allowable arsenic levels (the maximum contaminant level ("MCL") of 10 parts per billion ("ppb")) from groundwater sources is an issue for TMWA's well operations. Table 1 shows the number of TMWA's wells in Basin 87 affected by arsenic. Four of the wells that exceed the 10 ppb MCL (Greg, Pezzi, Poplar #1, and Terminal) are piped to Glendale Treatment Plant ("GTP") for treatment and/or blending with treated surface water and two of the five PCE wells (Mill and Corbett) are also piped to GTP for treatment. Because of TMWA's ability to maximize Truckee River water and minimize groundwater use to the summer months, the United States Environmental Protection Agency recognizes annual running average of TMWA's water supplies to attain drinking water standards.

Other groundwater contamination sites, with potentially responsible parties, include the Sparks Solvent Fuel Site, leaky underground storage tanks sites, and additional solvent corrective action sites overseen by the Nevada Division of Environmental Protection ("NDEP"). Maps of the contamination sites are included in the TMWA Wellhead Protection Plan ("WHPP").

Relatively low water *quantity* areas run east-to-west to the north of the Truckee River. The NTM aquifer has lower transmissivity in several areas which results in lower water yield. Areas with lower water yield mostly occur where the aquifer is in bedrock or finer-grained sediments.

Table 1. Basin 87 Wells with Arsenic and Treatment

	Well Name		Average Arsenic Value (ppb)	Treat at Glendale	Sample at EPTDS*	RAA** (ppb)
1	Terminal Way	1	88	X		1.84
2	Poplar No. 1	1	85	X		1.84
3	Pezzi	1	72	X		1.84
4	Mill Street	1	37	X		1.84
5	Greg Street	1	19	X		1.84
6	Corbett	1	17	X		1.84
7	Morrill Avenue		12		X	4.42
8	Silver Lake		10		X	4.61
9	High Street		9		X	4.42
10	Kietzke Lane		9		X	4.71
11	Sparks Avenue		9		X	4.87
12	Poplar No. 2		7		X	3.97
13	View Street	2	5		X	2.38

1. Well output blended and treated with surface water at Glendale Treatment Plant

2. The historical arsenic concentration has been as high as 13 ppb; however extensive artificial recharge activities (underground blending) result in a current wellhead concentration of approximately 5 ppb

* EPTDS - Entry Point To Distribution System

** RAA - Running Annual Average, average of four quarterly As testing results

Aquifer Storage and Recovery – Existing and Potential

The Nevada Division of Water Resources ("NDWR") permit allows TMWA to recharge up to 7,000 AF/yr through 23 wells in the Basin-Fill. TMWA recharged 266 acre feet in 2014 and has already recharged over 2,548 AF in the first half of 2015 using 14 of the permitted wells. Since recharge began in 1993, TMWA has recharged 25,100AF (through June 2015). As shown in the water level hydrographs, water levels have been relatively stable in areas where TMWA's recharge operations are on-going. Information on the NTM ASR Program is contained in the 2015 semi-annual report titled, "Report on Aquifer Storage and Recovery, Truckee Meadows Hydrographic Basin; January 1 through June 30, 2015"filed with NDEP and NDWR.

Groundwater Modeling

Groundwater models for the Truckee Meadows have been completed and updated several times over the years. In 2015, the larger Truckee Meadows Basin 87 model was converted into two separate models: the North Truckee Meadows model and the South Truckee Meadows model.

The 2015 model updates for both models included:

1. Developing a revised geologic model for both areas.
2. Reducing the model grid spacing to 300 by 300 feet.
3. Updating groundwater levels, pumping, and recharge through 2014.
4. Revising the model to include current estimates of recharge from irrigation and irrigation ditches.
5. Updating the distribution of aquifer properties using newly acquired data from aquifer tests.
6. Re-calibrating the model in the transient state.
7. Refining the model time steps to monthly.
8. Developing well capture zones for 2, 5, 10, and 20 year time periods.

The results of the updated model created the graphics and findings incorporated into this Basin Summary; are the basis of the capture zone analyses for TMWA's production wells; and are the basis of analysis for TMWA's WHPP.

Basin Challenges and Possible Solutions

The primary challenge in the basin is bringing groundwater levels on the southwest alluvial fan back into balance and continuing to provide safe drinking water despite water quality affected by PCE and arsenic in the northern part of the basin.

Water Demand

Availability of Truckee River water, TWMA's primary water supply, is challenged during periods of drought. TMWA manages its reservoir and groundwater supplies to meet the worst 8-year-drought cycle (1987-1994) of record, and is capable of meeting 9 to 10-years. Another challenge is to drill and construct additional water wells, or increase diversion capacities from the Truckee River to meet future demands as they occur. Current demands can be met with existing resources and facilities. However, additional and/or alternate sources of peaking supply are needed to meet future demands. Possible solutions include:

- *Increase Truckee River Use.* As the TROA is implemented, managing droughts should be less of a burden on resources. Increased use of Truckee River water in this basin would require more water rights to augment use of ground water and increase blending of surface with ground water to improve water quality issues. Facilities are in place to implement this option.
- *Artificial Recharge*. Continue artificial recharge at the 23 permitted wells in Basin 87, and possibly increase the rate of recharge, duration of recharge, or both. TMWA is completing permitting through the State Engineer's Office and the NDEP to inject treated surface water in former WDWR wells in the southwest fan area, anticipated late 2015
- *Extend System Reach.* Extend distribution system facilities to the upper elevations of the southwest fan to support demand in that area.

Water Quality

PCE and arsenic mitigation is another challenge at several wells in the northern part of Basin 87. TMWA, through the CTMRD program, currently uses air-stripping technology to remove PCE from well water. Possibly additional water quality solutions include:

- *Contaminant Source Control.* The CTMRD is working toward implementing source mitigation technologies throughout the NTM. Source mitigation will reduce long-term treatment costs which will be a benefit to TMWA customers. The CTMRD is also working with local and state agencies to reduce and possibly eliminate PCE discharges at their various source locations such as dry cleaners.
- *Artificial Recharge*. Continue artificial recharge at the 23 permitted wells in Basin 87, and possibly increase the rate of recharge, duration of recharge, or both. Including wells contaminated by PCE should help push contaminated water away from the wells and may dilute contamination within the aquifer.

Groundwater Levels

Water levels have been declining in the Alluvial Fan area over the years. There is a significant challenge to meet customer demands from production wells while taking care not to adversely impact water levels in the area. TMWA is constructing service lines to help meet winter time demands to allow groundwater wells in the area to rebound over a six to eight month period. Since the merger, TMWA has already tested and developed a plan to recharge a number of former WDWR wells and is aggressively pursuing groundwater recharge opportunities in the southwest fan area to enhance the recovery of groundwater levels in this region.

- *Extend System Reach.* Extend distribution system facilities to the upper elevations of the southwest fan to support demand in that area. Meeting non-pumping season demands with surface water will allow municipal wells in the upper fan area to rest, and support the recovery of groundwater levels in the area.
- *Artificial Recharge*. TMWA is completing permitting through the State Engineer's Office and the NDEP to inject treated surface water in former WCWD wells in the southwest fan area, anticipated late 2015. This option will boost the recovery of groundwater levels in the non-pumping season.

PLEASANT VALLEY - HYDROGRAPHIC BASIN 88

Introduction

The Pleasant Valley area, Hydrographic Basin 88, encompasses 39 square miles and is bound to the north by the Steamboat Hills, to the east by the Virginia Range, and to the west by the Carson Range. Pleasant Valley is separated from Washoe Valley to the south by a topographic and hydrologic divide created by low hills of granitic, volcanic, and metavolcanic rocks.

The basin can be described as having two geographically and hydrogeologically distinct regions from which water is pumped into public water systems: (1) an alluvial fan and fractured volcanic rock aquifer located in the western, higher elevation part of the basin referred to as West Pleasant Valley ("WPV") and (2) a basin-fill aquifer in the lower, eastern part of the basin referred to as East Pleasant Valley ("EPV"). Figure 1 depicts Hydrographic Basin 88, the West and East Pleasant Valley regions, and the location of TMWA production wells.

From west to east, the alluvial fan and basin-fill aquifers are similar to those described in Basin 87. In West Pleasant Valley, the alluvial fan aquifer is conceptualized as a complex aquifer system comprised of: 1) thin alluvial fan deposits, 2) consolidated sedimentary deposits, 3) thick interbedded fractured volcanic sequences, and 4) granitic, volcanic, or metavolcanic basement rock. The basin-fill aquifer system is conceptualized as a complex aquifer system comprised of: 1) alluvium, 2) partly confined alluvium, 3) fractured volcanic sequences, and 4) granitic, volcanic, or metavolcanic basement rock.

Public Water Systems

TMWA currently operates nine active production wells in Basin 88, serving approximately 54 services in EPV and 1,221 services in WPV. Three additional wells, Sunrise Estates 3, Mt. Rose 2, and STMGID 8, operate infrequently as back-up wells. Two more wells, Callamont 1 and Callamont 2, are currently unequipped and projected to be brought online over the next 10 years. All but one of the nine active wells (Sunrise Estates 1) are located in the West Pleasant Valley. Active wells were completed from 1974 to 2000 with production capacities ranging from a low of 150 to a high of 800 gallons per minutes ("gpm").

Domestic Wells

Approximately 820 domestic wells are located in Basin 88. The majority of these wells (509) are located in West Pleasant Valley on the alluvial fan. The State of Nevada allows each domestic well owner to pump up to 2 acre feet/year ("AF/yr"); 820 domestic wells have the potential to extract an estimated 1,640 AF/yr. Figure 2 depicts the increase in domestic wells constructed in Basin 88. As development continued in West Pleasant Valley, there was an increase in the number of domestic well owners who experienced well failures. These failures are generally attributed to: the shared aquifer experiencing persistent drought conditions; shallow initial well construction; high domestic well density; increasing numbers of domestic wells; and municipal well production.

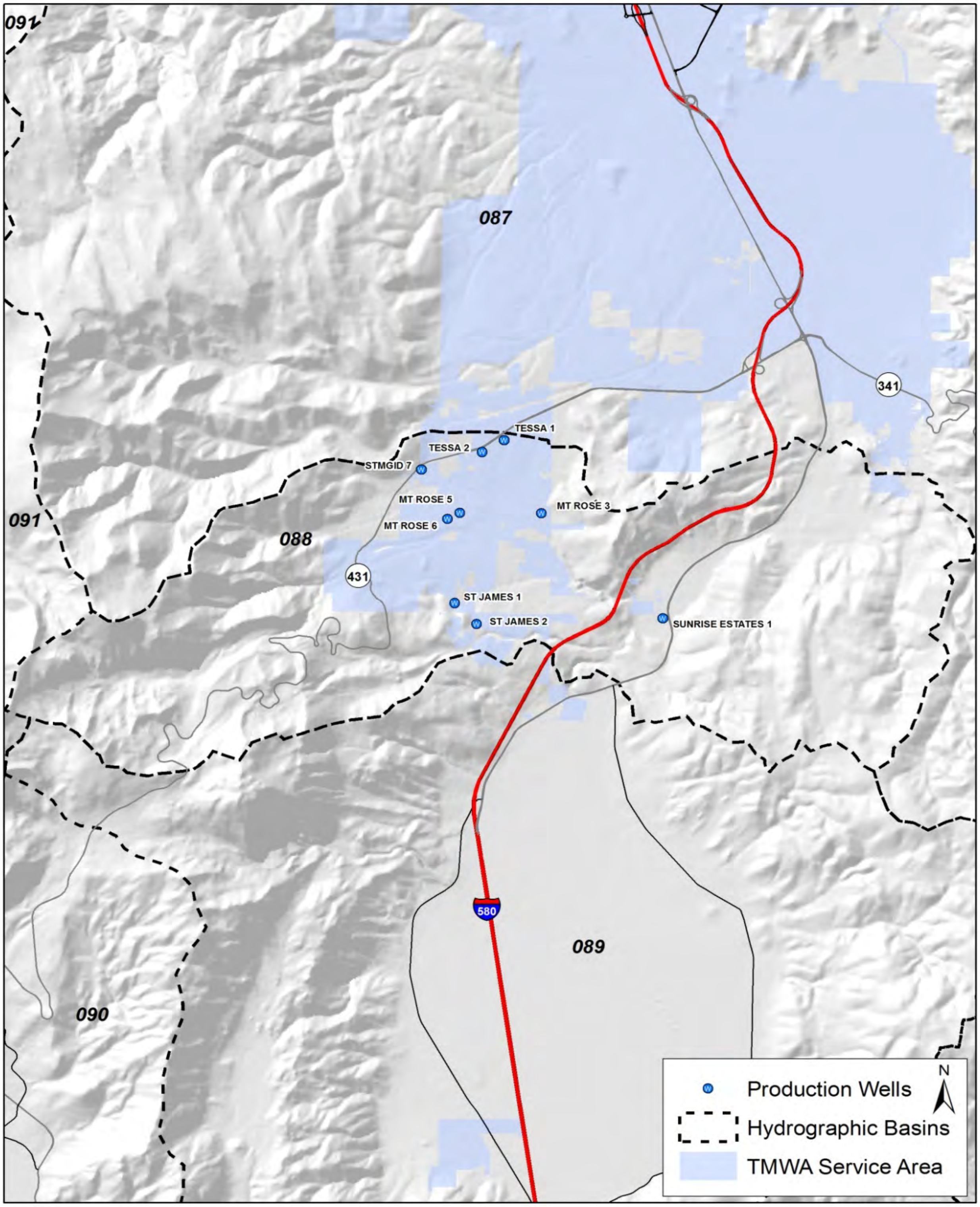


Figure 1. Pleasant Valley Hydrographic Basin 88 Location Map

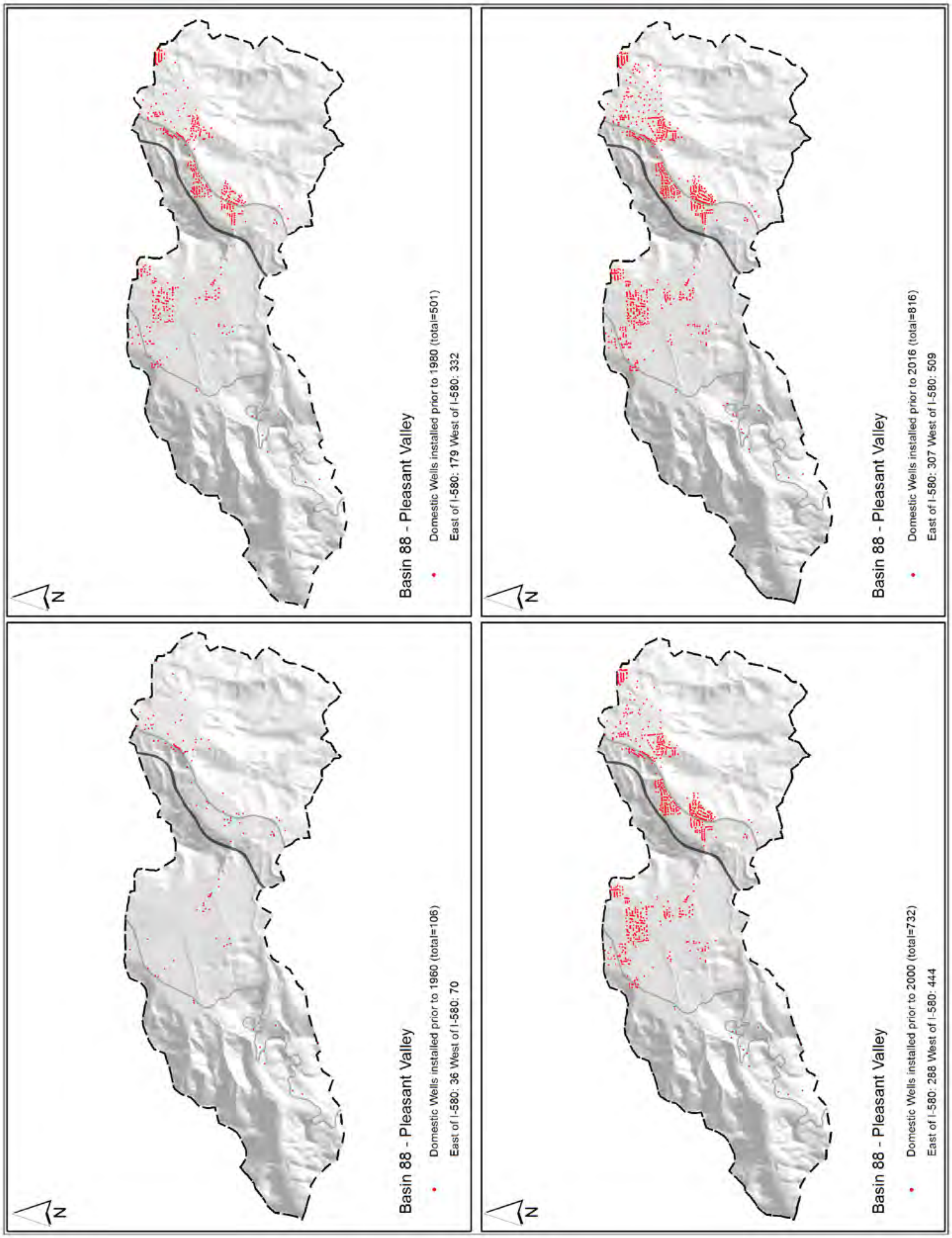


Figure 2. Change in the Number of Domestic Wells in Hydrographic Basin 88

Current Resource Management Practices

TMWA has nine wells in Pleasant Valley with water rights committed to serve customers in the area. The wells are used all year to meet demands. Although there are no recharge wells in the basin, TMWA has prepared select wells for groundwater recharge permitting and testing activities in West Pleasant Valley in 2015. TMWA anticipates implementing significant recharge operations over the next five years in several of the former WDWR production wells.

Water Resources

Surface Water

Galena and Browns Creeks enter at an elevation of about 6,400 and 6,000 feet above mean sea level ("amsl"), respectively, contribute flow to Steamboat Creek. The drainage basins of Galena and Browns Creeks extend to near the crest of the Carson Range at an elevation of about 9,000 feet.

Natural Groundwater Recharge

The climate in Pleasant Valley is arid to semiarid because the area lies in the rain shadow of the Sierra Nevada Mountains. Annual precipitation for the area ranges from about 6 to 10 inches, but the mountains to the west receive as much as 40 inches a year. The normally abundant precipitation in the mountains results in plentiful surface water in the area.

Precipitation in Basin 88 falls as snow and rain typically from November through April. The natural groundwater recharge estimate from precipitation and snow melt in the Carson Range is about 10,000 AF/yr for the entire basin (Van Denburgh, 1973).

Groundwater generally flows east from the Carson Range through the alluvial fan highlands to the basin fill lowland areas and Steamboat Creek to the east. From here it follows Steamboat Creek north into Basin 87.

Groundwater Pumping

Groundwater in Pleasant Valley has been pumped from the aquifer system for over forty years. Large quantities of groundwater are available from that part of the aquifer containing unconsolidated rocks of alluvial origin. Groundwater also is available from consolidated sediments and fractured volcanic sequences, generally in the foothills surrounding Basin 88.

The annual groundwater yield that can be withdrawn without depleting the aquifers on a sustainable basis is less than the annual recharge. Over the past five years, the average municipal groundwater withdrawals were about 20% of the average annual natural recharge to the basin.

It should be noted that each time groundwater extraction is increased or new wells are installed, groundwater surface elevations will lower as the aquifer adjusts to a new equilibrium in response to the additional pumping. This lowering of the water table can be significant in the immediate vicinity of a municipal production well.

Groundwater withdrawals from all production wells in Basin 88 ranged between 630 AF/yr and 1,950 AF/yr since 2001 (Figure 3). When plotted by east and west basin, it's easy to see the difference in pumpage and trends in each area. Groundwater pumping from east-side-basin-fill wells averages about 60 AF/yr and has decreased since 2004. Groundwater pumping from west side alluvial fan wells averages about 1,360 AF/yr and increased from 2001 through 2007, but has remained relatively stable if not decreasing over the last 7 years.

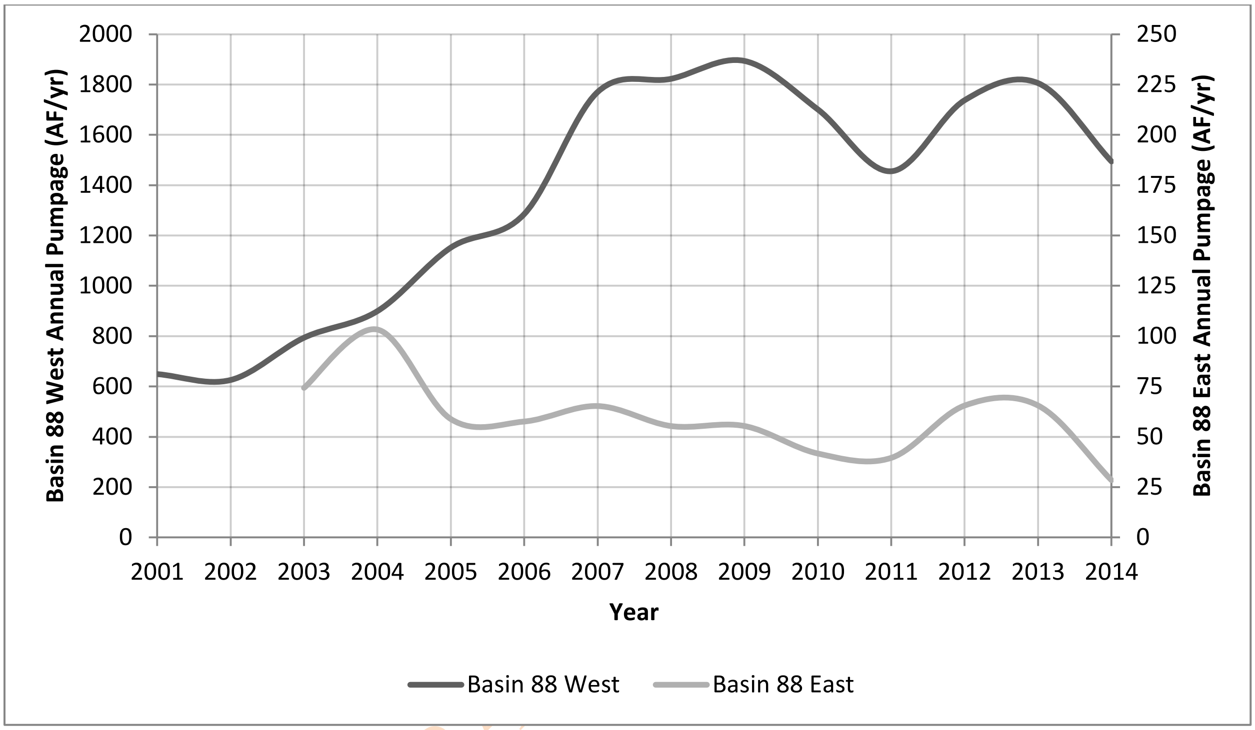


Figure 3. Groundwater Pumping East and West Basin 88

Groundwater Levels

Groundwater elevations vary significantly throughout the basin, with groundwater occurring in the West Pleasant Valley alluvial fan system at greater depths than the basin-fill aquifer in East Pleasant Valley. Hydrographs from 2001 to 2015 represent changes in water levels resulting from the variation in precipitation, pumping, natural recharge, evapotranspiration, and aquifer properties. The graphs indicate that water levels fluctuate seasonally with rises during non-pumping and natural recharge periods (winter months) and declines during pumping periods (summer months).

Figures 4 through 6 depict groundwater hydrographs for several wells within the alluvial fan aquifer on the western side of Basin 88. Water levels are steadily declining in this region. Municipal pumping and the high density of domestic wells in the area compound water level declines over time. The compartmentalization of aquifer materials due to numerous faults on the southwest alluvial fan may impede groundwater recharge and amplify the effects of groundwater withdrawals at wells adjacent to these faults.

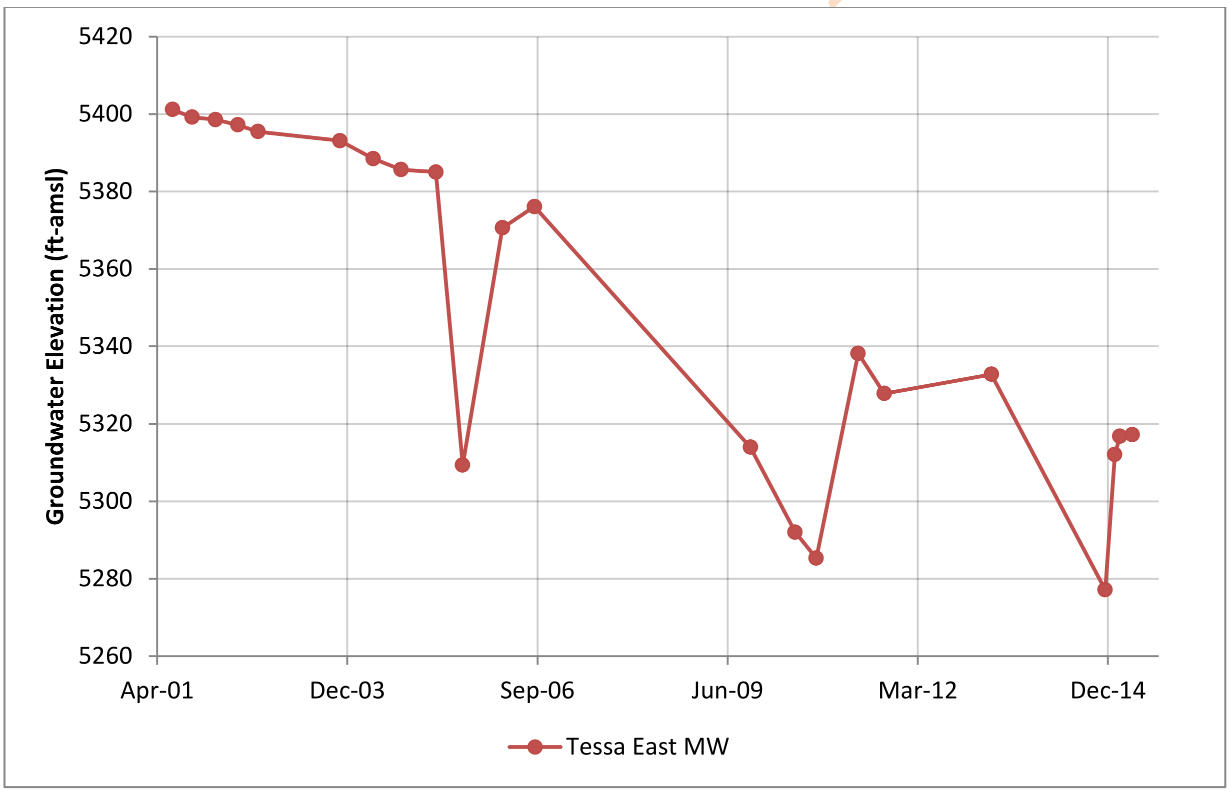


Figure 4. West Alluvial Fan Groundwater Hydrograph (northwest area) Basin 88

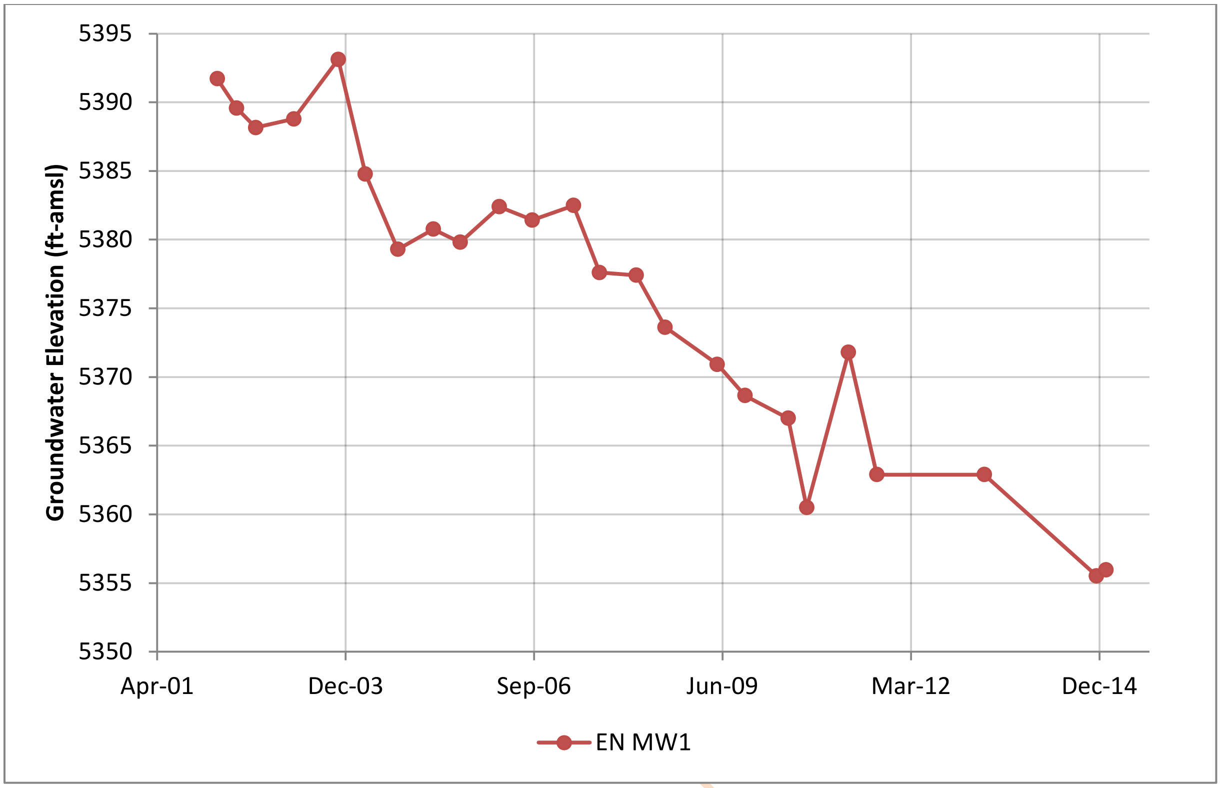


Figure 5. West Alluvial Fan Groundwater Hydrograph (west-central area) Basin 88

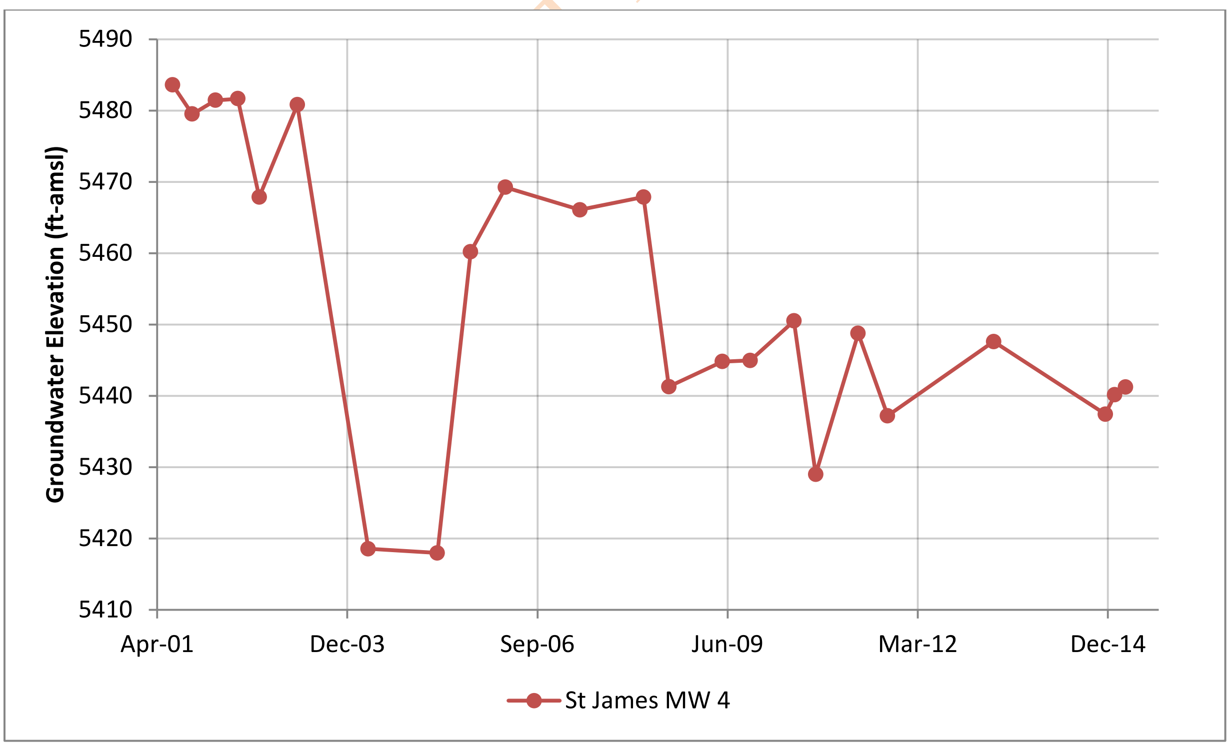


Figure 6. West Basin-Fill Groundwater Hydrograph (northeast area) Basin 88

Figures 7 and 8 depict groundwater hydrographs for two wells within the basin-fill aquifer on the east side of Basin 88. Water levels are relatively stable in the basin-fill wells. Natural seasonal recharge allows groundwater levels to recover, while short-duration seasonal pumping drops water levels for a brief time. As shown in the plots, water levels generally rebound immediately after pumping.

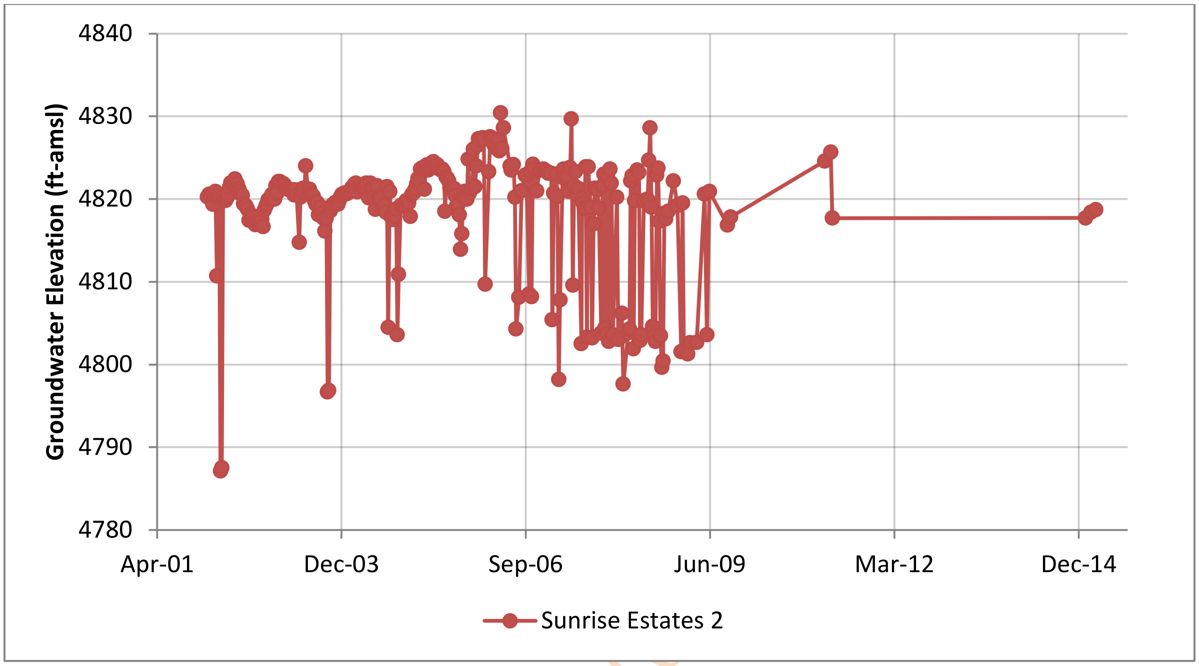


Figure 7. East Basin-Fill Groundwater Hydrograph (central area) Basin 88

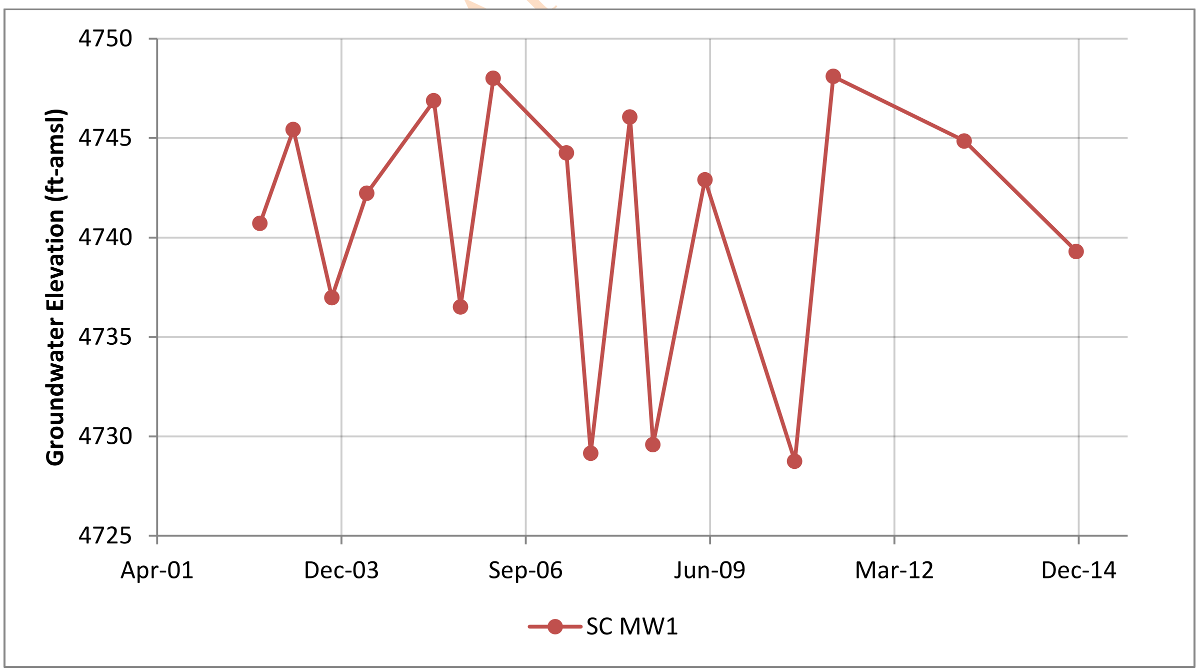


Figure 8. East Basin-Fill Groundwater Hydrograph (eastern area) Basin 88

As depicted in Figure 9, groundwater generally flows east from the Carson Range through the alluvial fan highlands to the basin fill lowland areas and Steamboat Creek to the east. From here it follows Steamboat Creek north into Basin 87.

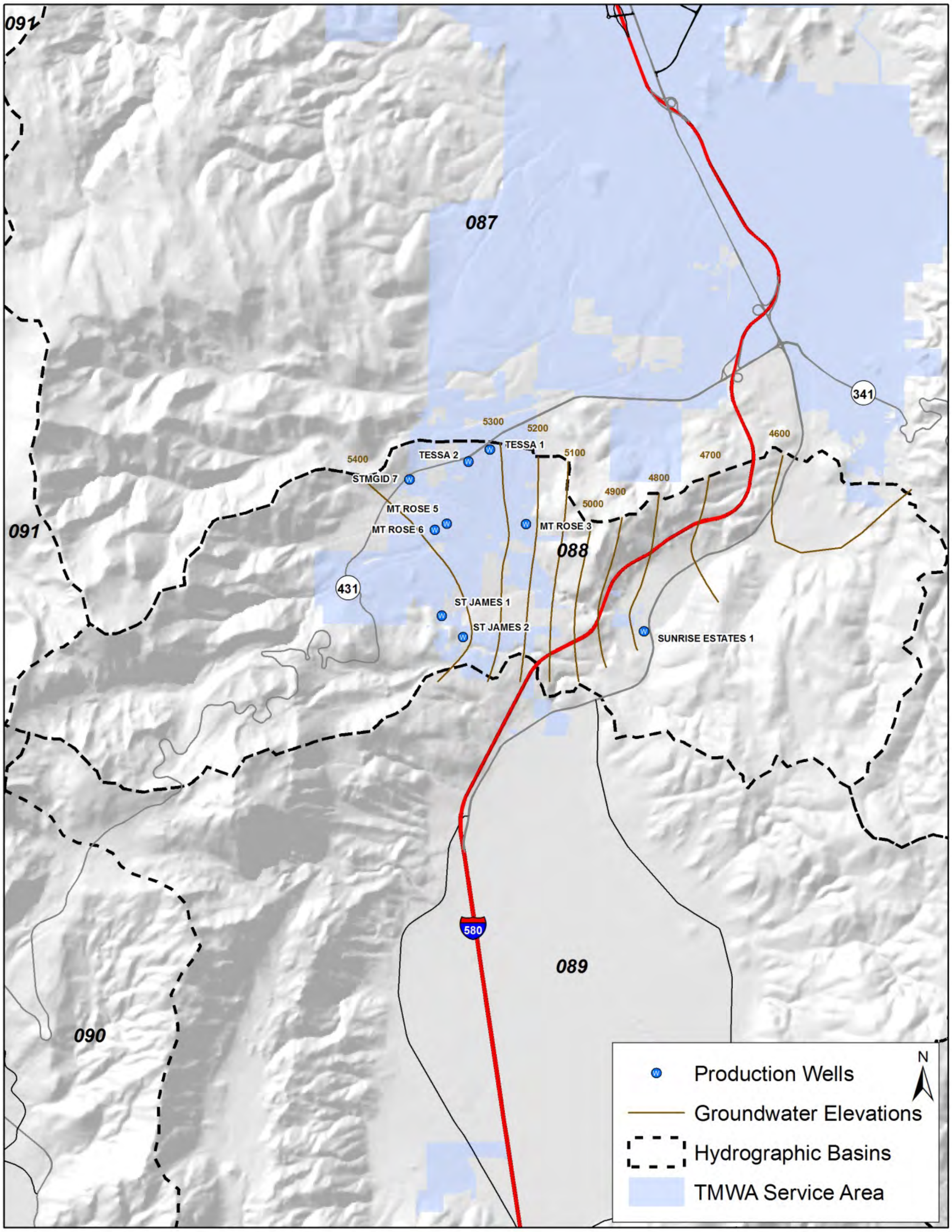


Figure 9. 2015 Groundwater Elevations Contour Map for Hydrographic Basin 88

Figure 10 depicts the change in water levels over time between 2010 and 2015. Groundwater levels declined over seven feet near production wells in Basin 88 West and over five feet in Basin 88 East.

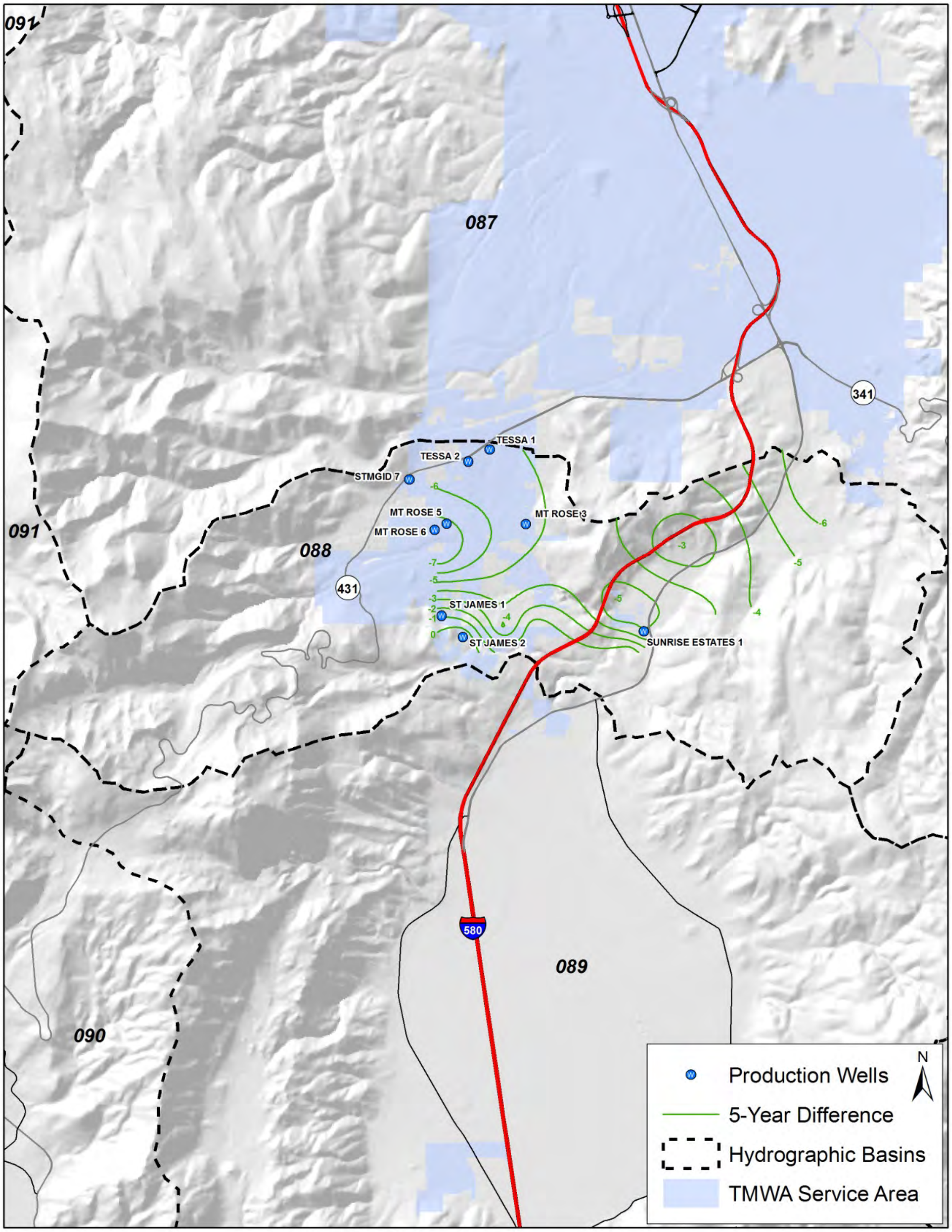


Figure 10. Difference in Groundwater Elevations 2010-2015 Hydrographic Basin 88

Groundwater Quality and Quantity

Groundwater *quality* and *quantity* varies throughout Basin 88. Figure 11 depicts the areas generally characterized as having poor water *quality* or low water *quantity*.

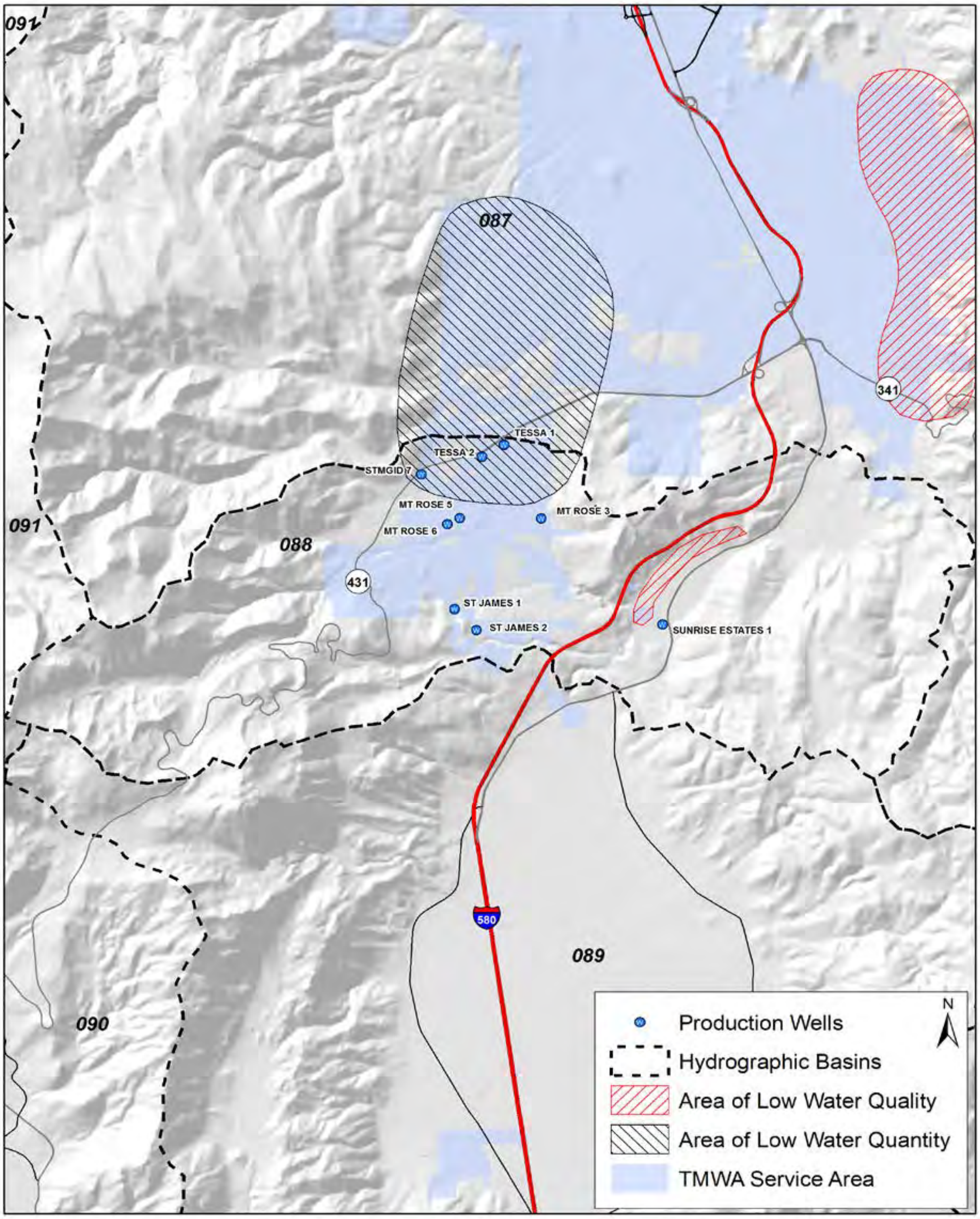


Figure 11. Areas of Poor Water Quality and Low Water Quantity in Hydrographic Basin 88

Poor water *quality*, due to highly mineralized groundwater, is found generally in the eastern portion of the basin near the eastern flank of the Steamboat Hills where geothermal influences are most pronounced.

Relatively low water *quantity* areas run south-to-north from STMGID 7 and the Tessa wells to the north out of Basin 88 and into Basin 87. The alluvial fan aquifer has lower transmissivity in several areas due to relatively thin alluvial materials and low transmissivities in fractured volcanics which results in lower water yield. Areas with lower water yield mostly occur where the aquifer is in consolidated rock and/or finer-grained alluvial sediments.

TMWA's Wellhead Protection Plan ("WHPP") has not identified obvious threats to groundwater in Basin 88, however septic effluent may impact groundwater in areas of high septic system density and shallow groundwater occurrence.

Aquifer Storage and Recovery – Existing and Potential

TMWA does not currently inject treated surface water into production wells in Basin 88 for aquifer storage and recovery ("ASR"). TMWA has applied for a permit through the Nevada Department of Environmental Protection ("NDEP") to begin injection activities in select wells (Tessa 1, Tessa 2, and Mt. Rose 3) by the end of 2015. TMWA is also extending service to the top of the alluvial fan areas in Basin 87 and 88 to supply demand during winter months, allowing production wells to rest and groundwater levels to rebound. Excess water not used for supply will be available for groundwater recharge.

Groundwater Modeling

Groundwater models for the Truckee Meadows have been completed and updated several times over the years. In 2015, the larger Truckee Meadows Basin 87 model was converted into two separate models: the North Truckee Meadows model and the South Truckee Meadows model. The South Truckee Meadows model included Basin 88.

The 2015 model updates for the Basin 88 section of the model included:

1. Developing a revised geologic model for both areas.
2. Reducing the model grid spacing to 300 feet by 300 feet.
3. Updating groundwater levels, pumping, and recharge through 2014.
4. Revising the model to include current estimates of recharge from irrigation and irrigation ditches.
5. Updating the distribution of aquifer properties using newly acquired data from aquifer tests.
6. Re-calibrating the model in the transient state.
7. Refining the model time steps to monthly.
8. Developing well capture zones for 2, 5, 10, and 20 year time periods.

The results of the updated model created the graphics and findings incorporated into this Basin Summary; are the basis of the capture zone analyses for TMWA's production wells; and are the basis of analysis for TMWA's WHPP.

Basin Challenges

Water levels have been declining in the alluvial fan area over the years. There is a significant challenge to meet customer demands from production wells while taking care not to adversely impact water levels in the area. TMWA is constructing service lines to help meet winter time demands to allow groundwater wells in the area to rebound over a six to eight month period. Since the merger, TMWA has already tested and developed a plan to recharge a number of newly-acquired wells and is aggressively pursuing groundwater recharge opportunities in the alluvial fan area to enhance the recovery of groundwater levels in this region.

Another challenge is to drill and construct additional water wells, or increase diversion capacities from the Truckee River to meet future demands as they occur. Current demands can be met with existing resources and facilities. However, additional and/or alternate sources of peaking supply are needed to meet future demands. Increased use of Truckee River water in this basin would require more water rights to augment use of groundwater and increase blending of surface with groundwater to improve water quality issues. Facilities are in place to implement this option.

LEMMON VALLEY – HYDROGRAPHIC BASIN 92A and 92B

Introduction

Lemmon Valley ("LV"), Hydrographic Basins 92A and 92B, are topographically closed basins encompassing about 97 square miles. LV is designated by the State Engineer as Basin 92, and is subdivided into the east and west subbasins by the Airport Fault that runs down the middle of the basin: West Lemmon Valley is identified as Basin 92A ("WLV") and East Lemmon Valley is Basin 92B ("ELV").

The mountains surrounding and bedrock underlying the valley are complexly faulted. The mountains are comprised of igneous, volcanic, and metavolcanic rocks. Regional faulting gave the mountains their large-scale size, shape, and relief. The change in elevation ranges from approximately 4,914 feet above mean sea level ("amsl") at the eastern sub-area playa to 8,266 feet amsl at highest peak on Peavine Mountain at the south end of the basin. The present topography of the basin is the result of erosion and smaller scale fault structures. Figure 1 depicts the Lemmon Valley hydrographic basin and the locations of Truckee Meadows Water Authority ("TMWA") production wells.

The valley is a structural depression filled with unconsolidated basin-fill. Features other than mountain ridges and basin-fill deposits include two playa lakes. The basin-fill is comprised of weathered material from the surrounding mountain ridges including layers of clay, silt, fine- to coarse-grained sand, and gravel. Generally, basin-fill is coarser near the base of the mountain ridges and becomes finer-grained in the center of the valley near the playas. Playa lake deposits are mostly clay, silt, and fine-grained sand. The aquifer system is conceptualized as three hydrostratigraphic units (from top to bottom): 1) playa deposits; 2) alluvium; and 3) fractured bedrock. These units are identified as distinct units based on differences in geologic, hydraulic, and water yield characteristics.

WLV contains the Silver Lake playa in the center with TMWA servicing large commercial/ industrial properties and residential properties to the east, and additional residential properties to the southeast. North of Silver Lake is the Silver Knolls subdivision with about 500 residences that utilize domestic wells and septic tanks, and west of the Silver Knolls subdivision is the Silver Knolls Water Mutual system serving about 60 residential lots.

ELV includes the Swan Lake playa located in the central portion of the basin. TMWA serves customers located to the north, east, and south of the playa. Golden Valley is a hydrographic subarea in the southeast corner of Basin 92B which includes both residential and commercial properties in the Golden Valley area. There are over 550 properties on domestic wells and septic tanks in this subarea.

LV development began in 1948 when the United States constructed the Stead Air Force Base and surrounding military residences. Residential development using domestic wells occurred in the northeast portion of the basin in the 1960's and more so in the 1970's. Utility-supplied developments also began in the 1970's in Silver Lake, Horizon Hills, and ELV.

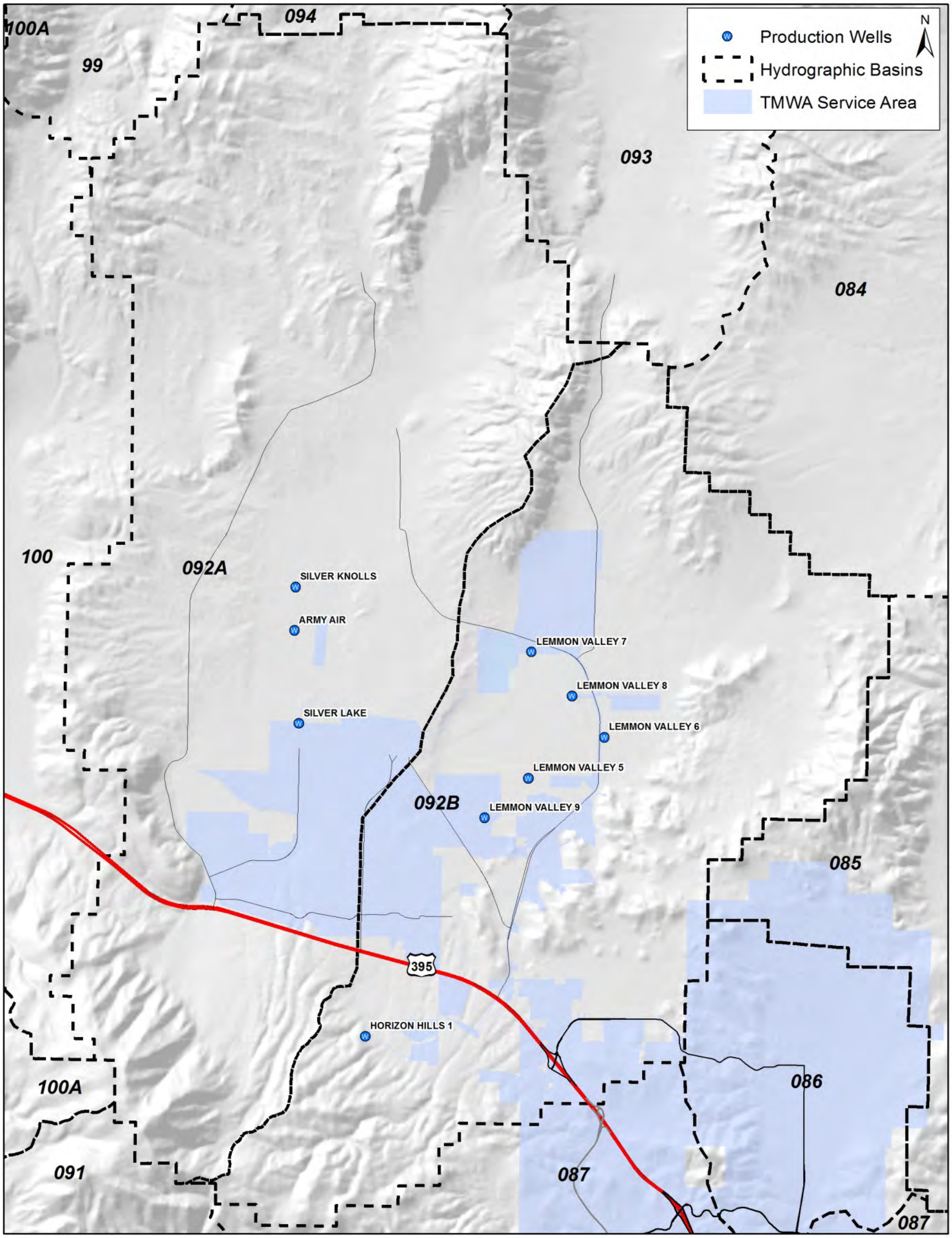


Figure 1. Lemmon Valley Hydrographic Basins 92A and 92B Location Map

By the 1980's, with the full commitment of existing ground water resources in the basin, little to no development occurred in the basin until additional Truckee River rights were dedicated to the valley. With the completion of the Vidler Importation Project in 2007 and its subsequent dedication to Washoe County, now owned and operated by TMWA as a result of the 2014 Merger, TMWA can deliver up to 8,000 acre feet/year ("AF/yr") of ground water from the Fish Spring Ranch project ("FSR") located in Honey Lake Valley Basin 97, a distance of 35 miles to the north of LV. Subject to certain permitting conditions, an additional 5,000 AF/yr from FSR may be available for future demand.

Public Water Systems

TMWA operates a wellfield in WLV and another in ELV. The WLV wellfield consists of three active wells and one unequipped well. These wells are completed in alluvium and have production capacities ranging from 800 to 2,500 gallons per minute ("gpm"). The ELV production wellfield consists of five wells completed in alluvium that have production capacities ranging from approximately 200 to 1,000 gpm.

Domestic Wells

Approximately 730 domestic wells are located in WLV with approximately 1,370 located in ELV. Areas with higher densities of domestic wells include the Silver Knolls area west of the Stead Airport, the Heppner subdivision located north and east of the Swan Lake playa in ELV, and Golden Valley in the southeast corner of ELV. These domestic well owners also utilize septic tanks. The State of Nevada allows each domestic well owner to pump up to 2 AF/yr. The 2,100 domestic wells in LV have the potential to extract up to 4,200 AF/yr. Figure 2 depicts the increase in domestic wells constructed over the years in LV. As development continued in LV, there was an increase in the number of domestic well owners who experienced well failures. These failures are generally attributed to: the shared aquifer experiencing persistent drought conditions; shallow initial well construction; high domestic well density; increasing numbers of domestic wells; and municipal well production.

Current Resource Management Practices

TMWA has three active production wells in WLV and five active wells in ELV with water rights committed to serve customers in the area. In WLV, groundwater from the three production wells is used to augment peak treated surface water demand during four to six months of the year, or during emergency conditions. The treated surface water originates at TMWA's Chalk Bluff Water Treatment Plant. During the winter months, TMWA injects treated surface water into the aquifer using two of the production wells. Over 4,600 acre feet ("AF") of surface water has been injected since 2000.

In ELV, most demand is met with groundwater extracted by the five production wells. An exception occurs in Horizon Hills and along the U. S. 395 corridor in the southern part of valley where treated surface water is delivered.

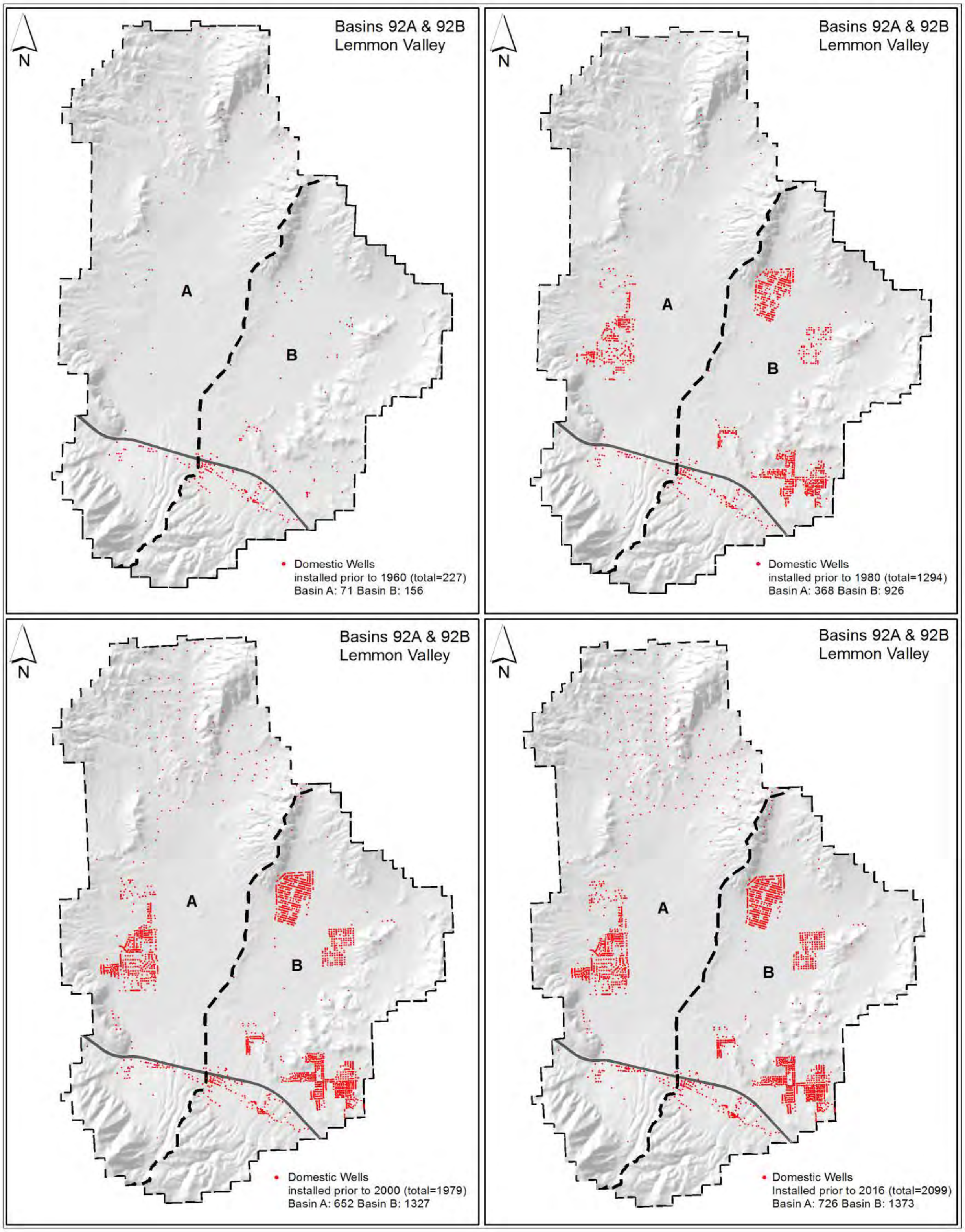


Figure 2. Change in the Number of Domestic Wells in Hydrographic Basins 92A and 92B

Since 2005, domestic well owners in Golden Valley have funded an artificial recharge program. The recharge program, managed by Washoe County, includes the purchase of approximately 120AF/yr of treated surface water from TMWA to offset declining groundwater levels in the Golden Valley subarea.

Water Resources

Surface Water

There are no perennial streams in LV. Ephemeral streams can exist during storm events or spring runoff if precipitation is sufficient. Runoff can reach the playa areas in the center of WLV and ELV but is dependent on the amount of precipitation that falls during winter months.

Natural Groundwater Recharge

The climate in LV is arid to semiarid because the area lies in the rain shadow of the Sierra Nevada Mountains. Annual precipitation for the area ranges from about 6 to 10 inches, but Peavine Mountain, the highest area of the valley, can receive more than 20 inches a year.

Precipitation in Lemmon Valley falls as snow and rain typically from November through April. Most precipitation that falls on the valley floor is lost through evaporation and has an insignificant impact on groundwater recharge. The natural recharge estimate is about 1,300 AF/yr for all of Lemmon Valley, with each subbasin getting approximately half of this amount.

Groundwater flows from the mountain ridges toward the lower-lying playa areas. Most groundwater originates from precipitation falling in the southwest part of the valley at the higher elevations of Peavine Mountain. The highest point of Peavine Mountain is 8,266 feet amsl.

Groundwater Pumping

Groundwater withdrawals from production wells ranged between 109 and 454 AF/yr in WLV over the past five years (Figure 3). Ground water pumping ranged from 507 to 634 AF/yr in ELV over the past five years (Figure 4). Domestic wells also withdraw groundwater in both subbasins. Approximately 1,800 AF/yr would be withdrawn if approximately 1,800 domestic wells pumped 1 AF/yr (domestic wells are allowed to pump about 2 AF/yr). In the past, groundwater pumping exceeded groundwater recharge which resulted in water level declines in most areas of Lemmon Valley. Recharge at production wells in WLV has been successful at increasing groundwater levels, and is discussed further below.

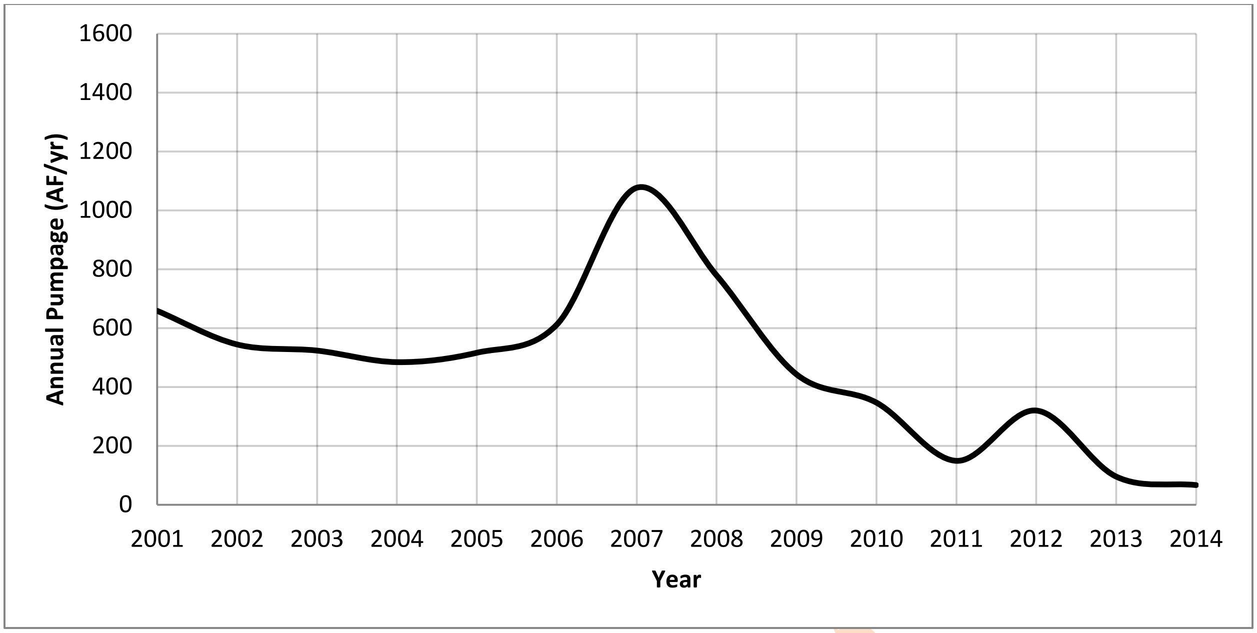


Figure 3. Groundwater Pumping West Lemmon Valley Basin 92

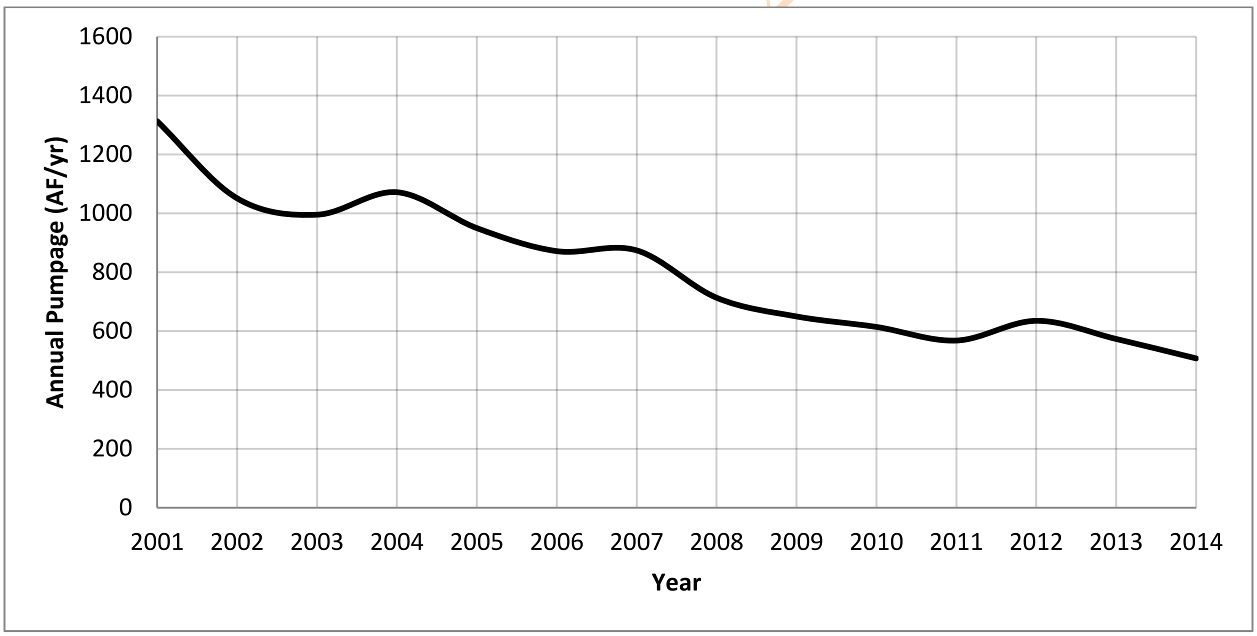


Figure 4. Groundwater Pumping East Lemmon Valley Basin 92

Groundwater Levels

Figures 5 and 6 depict groundwater hydrographs for several wells in WLV. The hydrographs represent the changes in water levels between 2001 and 2015. The water level changes are the result of the variation in precipitation, pumping, recharge, evapotranspiration, and aquifer properties. The graphs indicate that water levels in WLV fluctuate annually with rises during non-pumping and recharge periods (winter months) and declines during pumping periods (summer months). Figures 7 and 8 show the groundwater contours for April 2015 and the difference in water levels between April 2010 and April 2015. Overall, recharge at TMWA production wells has kept water levels relatively stable in WLV.

Figures 9 and 10 are groundwater hydrographs for several wells in ELV. The hydrographs represent the changes in water levels between 2010 and 2015. As in WLV, the water level changes are the result of the variation in precipitation, pumping, recharge, evapotranspiration, and aquifer properties. The graphs indicate that water levels fluctuate annually with rises during non-pumping periods (winter months) and declines during pumping periods (summer months).

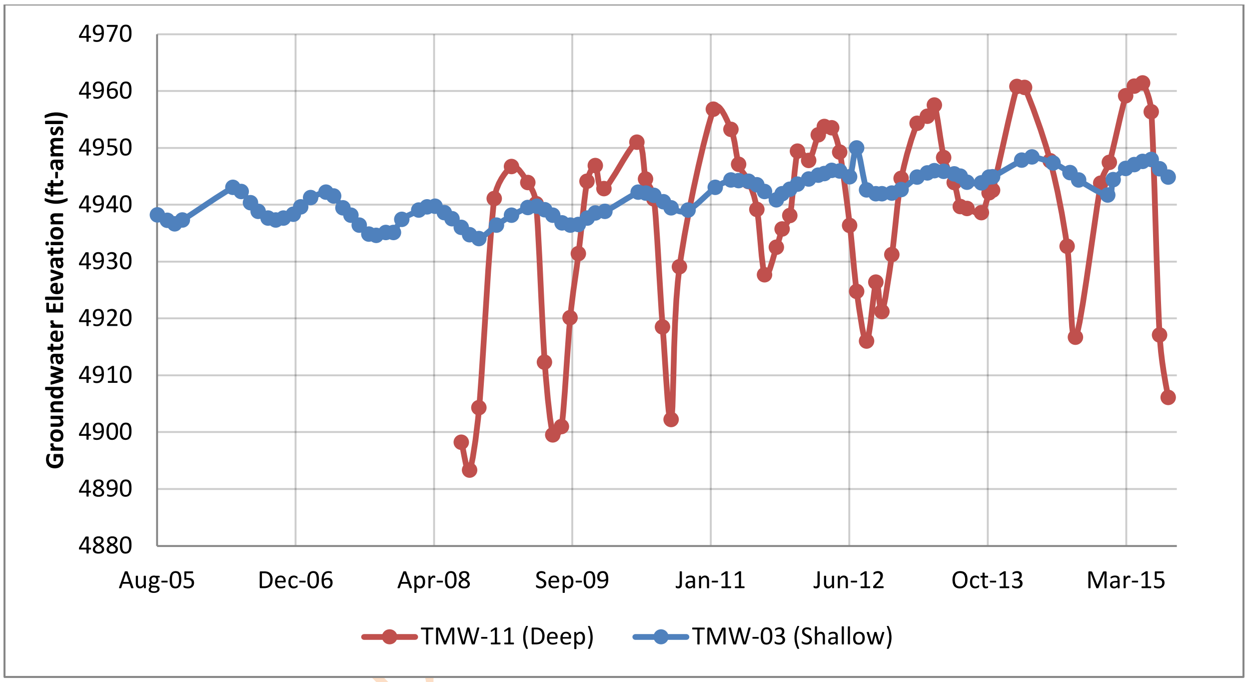


Figure 5. Water Level Changes West Lemmon Valley Basin 92

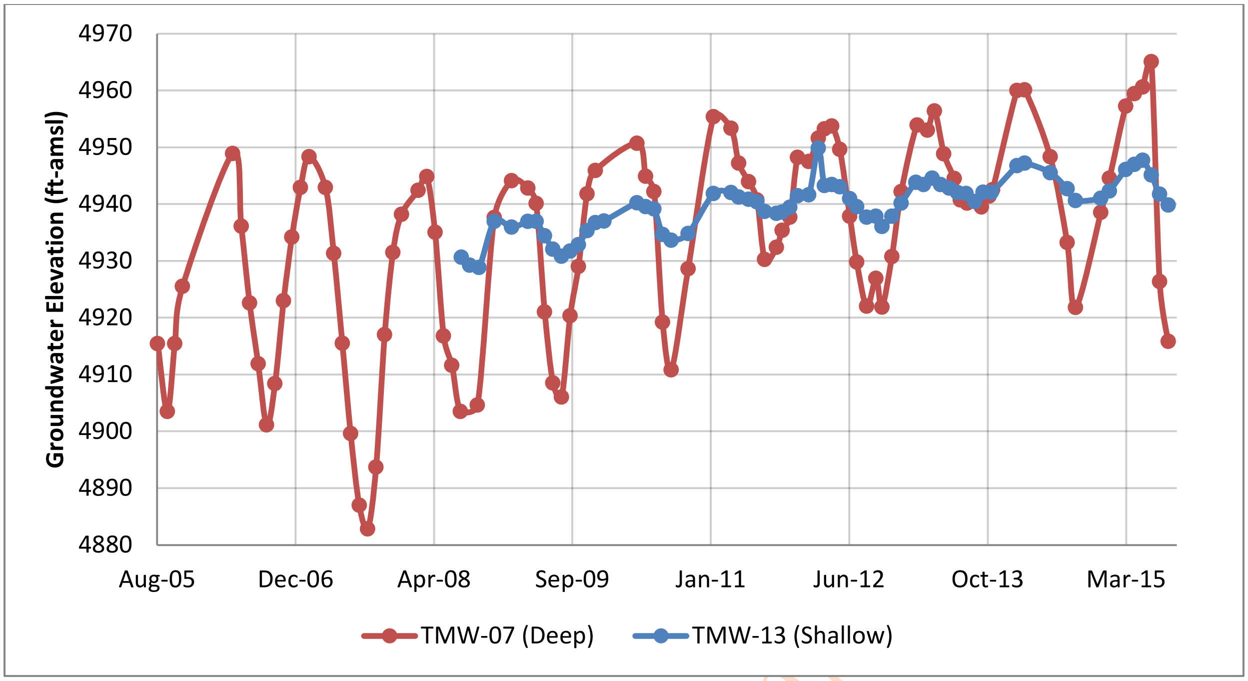


Figure 6. Water Level Changes West Lemmon Valley Basin 92

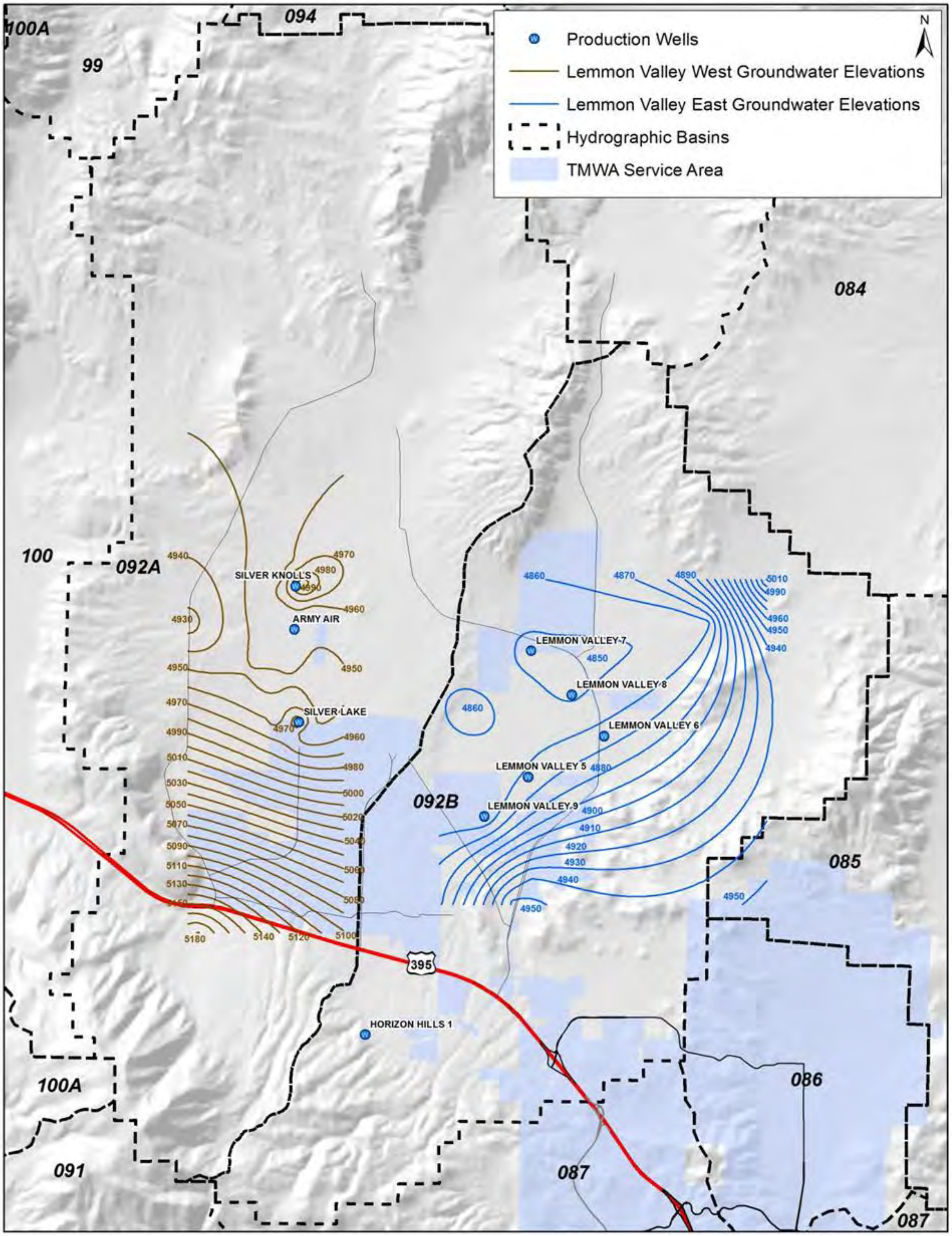


Figure 7. 2015 Groundwater Elevations Contour Map for Hydrographic Basin 92

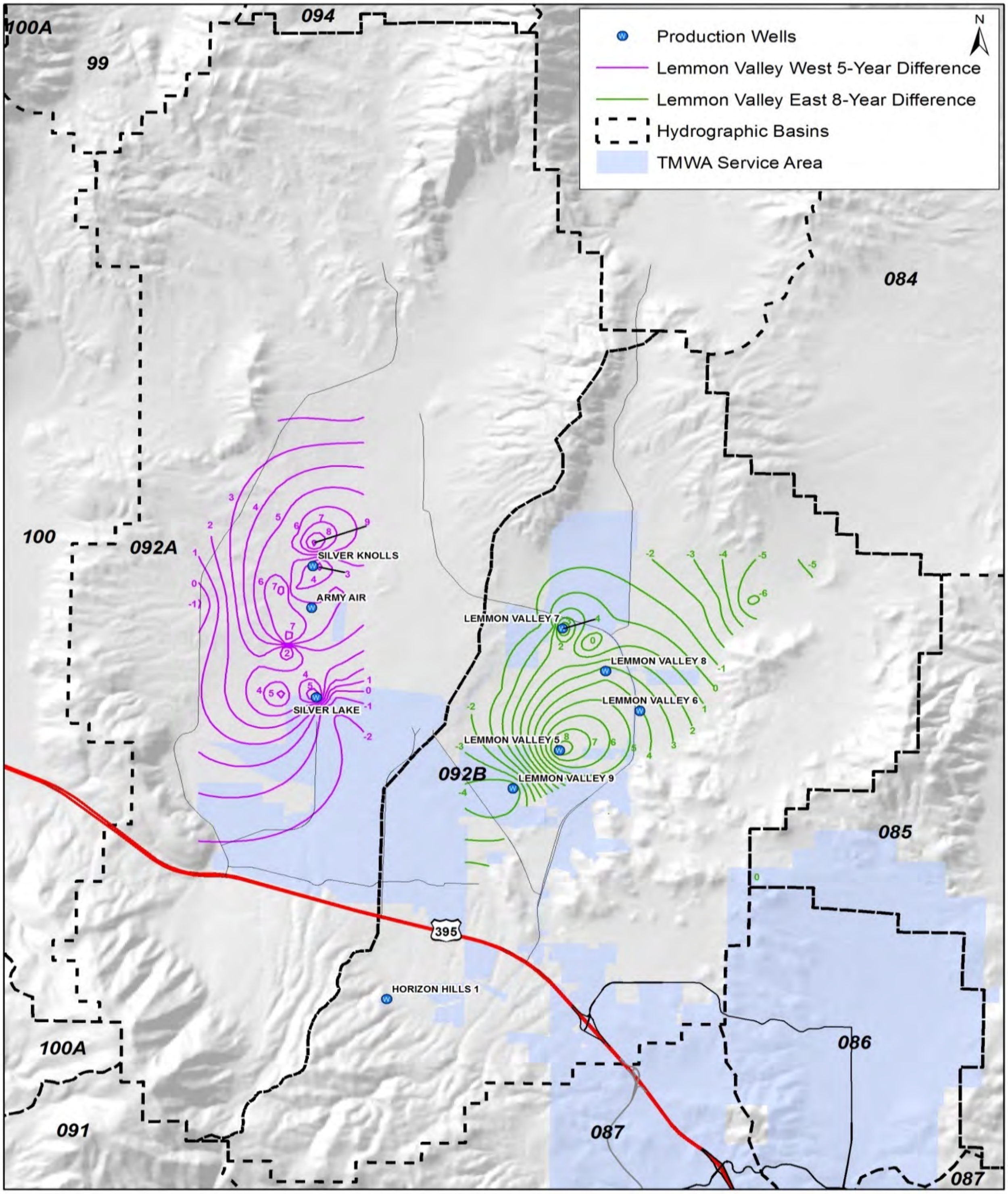


Figure 8. Difference in Groundwater Elevations 2010-2015 Hydrographic Basin 92

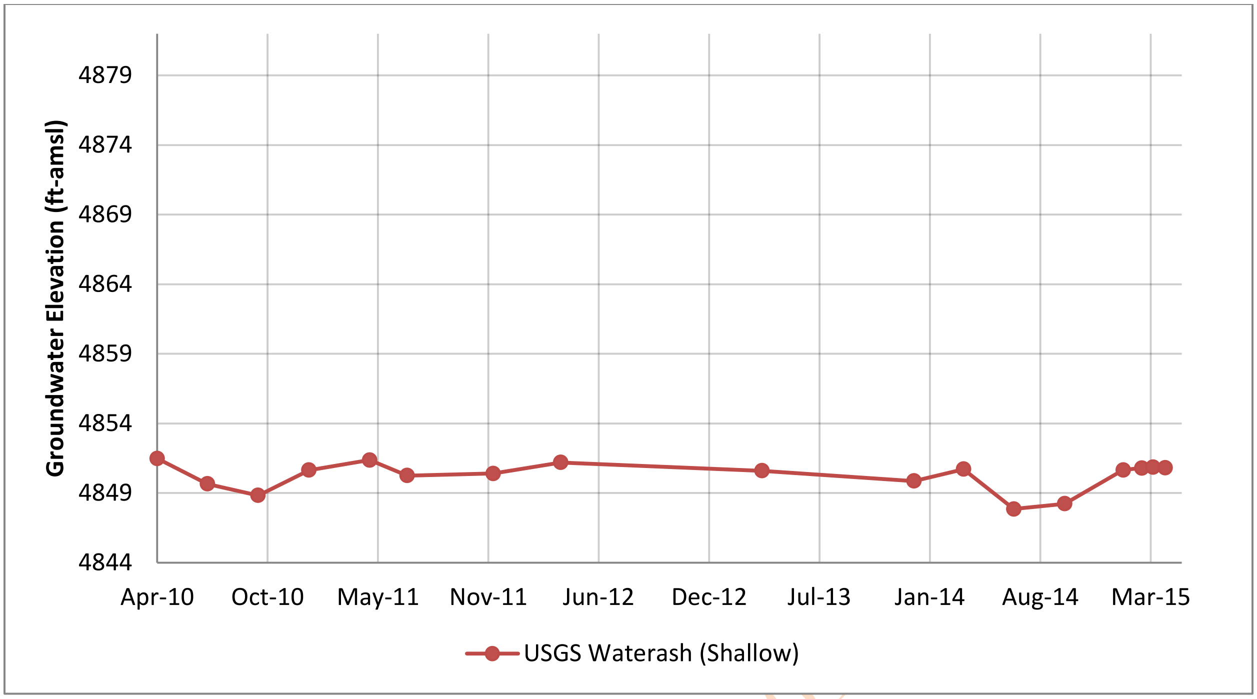


Figure 9. Change in Water Level East Lemmon Valley Basin 92

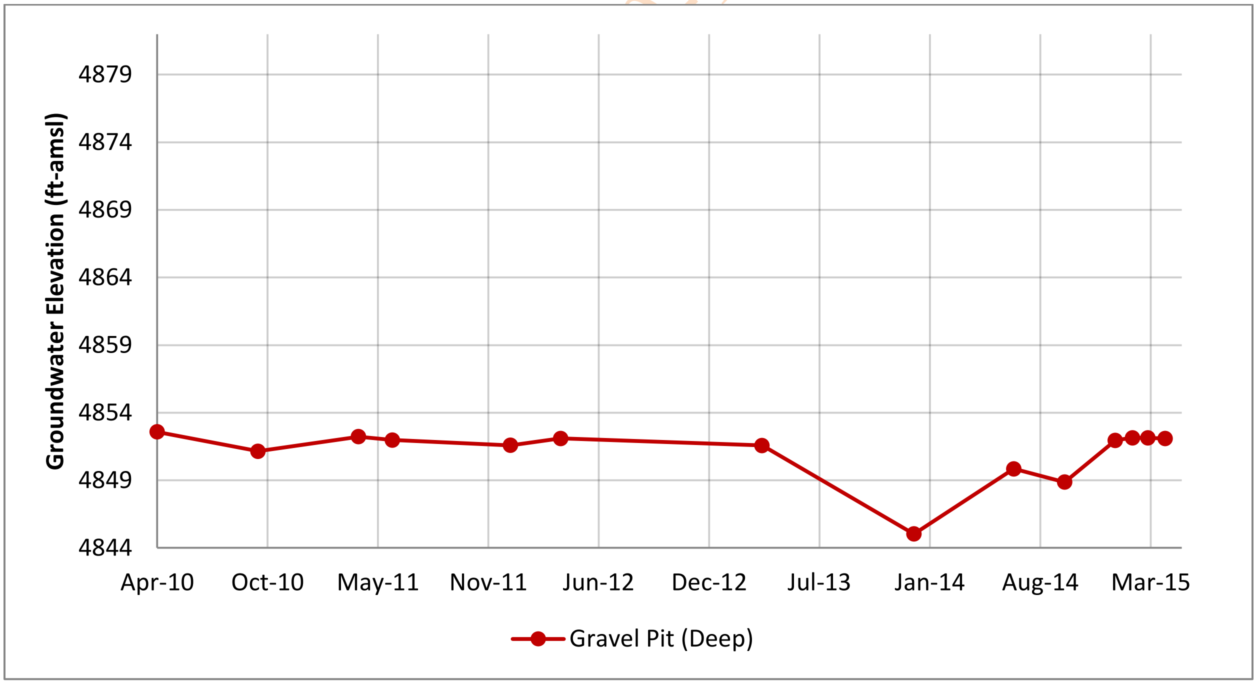


Figure 10. Change in Water Level East Lemmon Valley Basin 92

Currently, production wells in ELV are not utilized for recharge. Water levels have risen since 2010, potentially the result of reduced pumping in production wells and possibly at domestic wells.

Groundwater Quality and Quantity

Groundwater *quality* and *quantity* varies throughout LV. Highly mineralized, poor groundwater quality exists in shallow groundwater near the playa areas in both basins (Figure 11).

Locally, higher nitrate levels are associated with a higher density of septic tanks. The nitrate level found in wells are well-specific and depends on depth to groundwater, flow direction, well screen depth, and the soil types between the septic tanks and well screen.

Remediation of solvent-related contamination at the Stead Solvent Site near the southern boundary of the Stead Airport in Basin 92A began in the late 1990s. The clean-up activities have successfully reduced the migration of the contaminant plume. More information on this remediation site can be found at the Nevada Division of Environmental Protection ("NDEP") website: http://ndep.nv.gov/admin/new.htm.

All TMWA wells in Lemmon Valley have been evaluated for future potential contamination through a Wellhead Protection Plan ("WHPP") updated in 2015. The plan includes the 2, 5, 10, and 20-year capture zones for each production well along with the locations of potential contamination sites. Additional information on groundwater contamination concerns in Lemmon Valley is contained in TMWA's WHPP.

Areas with generally low water quantity are also depicted in Figure 11. Generally, lower water quantity exists in the low transmissivity zones of the fractured rock and in areas where the aquifer is predominantly finer-grained material. Fractured rock wells are located closer to the mountain ridges and away from the center of both West and East Lemmon Valleys. Areas where wells have had water quantity issues include the northern and southern parts of ELV.

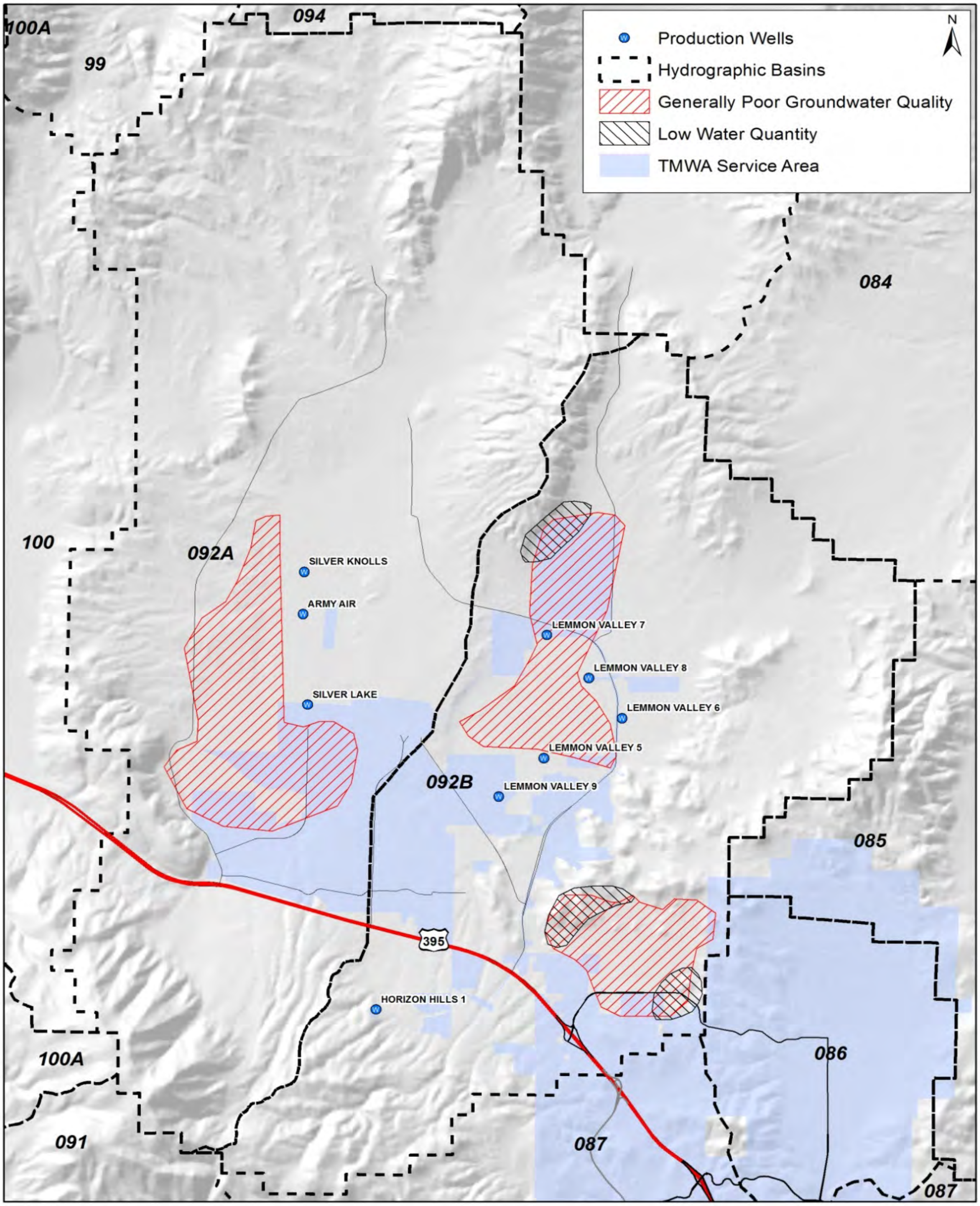


Figure 11. Areas of Poor Water Quality and Low Water Quantity in Hydrographic Basin 92

Aquifer Storage and Recovery – Existing and Potential

Recharge has occurred at the three production wells in WLV since 2000. As of June 2015, TMWA has recharged over 4,650 AF using three production wells. As shown in the WLV hydrographs, recharge has successfully contributed to water level increases in both deeper and shallow screened wells on an annual basis between 2001 and 2015. Information on the WLV aquifer storage and recovery ("ASR") Program is contained in the 2015 semi-annual report titled, "Report on Aquifer Storage and Recovery, West Lemmon Valley Hydrographic Basin; January 1 through June 30, 2015" filed with NDEP and NDWR.

Currently, recharge does not occur at production wells in ELV.

Groundwater Modeling

Groundwater models have been completed and updated for all of LV several times over the years. In 2015, the WLV model was updated while a separate model was created for ELV. Developing two models is appropriate because the low-permeability Airport Faults minimizes groundwater east-west subsurface flow between the two subbasins.

The 2015 model update for the WLV model included:

9. Updating groundwater levels, pumping, and recharge through 2014.
10. Updating the distribution of aquifer properties using newly acquired data from aquifer tests.
11. Re-calibrating the model in the transient state.
12. Refining the model time steps to daily.
13. Develop well capture zones for 2, 5, 10, and 20 year time periods.

The 2015 model development for ELV included:

1. Updating groundwater levels, and pumping through 2014.
2. Revisiting the Airport Fault and determining that developing the stand-alone ELV model was appropriate.
3. Developing a separate model for the Golden Valley subarea.
4. Updating the distribution of aquifer properties using newly acquired data from aquifer tests.
5. Calibrating the ELV model in the steady-state and transient conditions.
6. Develop well capture zones for 2, 5, 10, and 20 year time periods.

The results of the updated model created the graphics and findings incorporated into this Basin Summary; are the basis of the capture zone analyses for TMWA's production wells; and are the basis of analysis for TMWA's WHPP.

Basin Challenges and Possible Solutions

In LV, groundwater pumping exceeded natural groundwater recharge in the past. This resulted in declining water levels which had negative impacts on wells that were not screened in deeper parts of the aquifer. Addressing water quality issues in areas where wells are impacted by elevated nitrate levels is another challenge in LV. Pumping has decreased since TMWA began the ASR program in WLV. The ASR program in Golden Valley, managed by Washoe County, has also lessened the negative impacts of over-pumping by domestic wells and poor water quality in some parts of that subarea of ELV.

Current demands can be met with existing resources and facilities. However, additional and/or alternate sources of supply are needed to mitigate the effects of over-pumping that has occurred in the basin and to meet future demands. Possible solutions include:

- *Increase Truckee River Use.* Increased use of Truckee River water in this basin would require an additional 0.5 to 1.0 AF of water rights be dedicated for Truckee River return flows for every acre foot of demand, whether that demand is for new development or to offset the use of groundwater. Increased use of Truckee River water provides blending of surface with groundwater which also solves water quality issues.
- *Artificial Recharge*. TMWA currently injects about 300 AF/yr in 3 wells in Basin 92A. Implementing additional recharge with FSR water is an option for LV. This option could also help to improve the water quality issues in the basin. Increase use of FSR supplies to meet demands and/or for recharge. Other interbasin sources could be considered as well.
- *Groundwater Replenishment Systems.* Groundwater Replenishment Systems ("GWRS") could inject highly-treated-recovery water at the north end of the basin to offset the over pumping and provide supply augmentation. Washoe County operates a 0.3 million gallons/day ("MGD") wastewater treatment plant in Basin 92B and the City of Reno operates a 2.25 MGD wastewater treatment in Basin 92B. An investigation is underway to determine the feasibility associated with a combined plant and GWRS.

non-Truckee Resource Area - Satellite Systems

WASHOE VALLEY – HYDROGRAPHIC BASIN 89 (LIGHTNING W SYSTEM)

Introduction

The Lightning W water system is located in southwest Washoe Valley, west of Highway 395 and along Franktown Road. The relatively small water system is near the south–central boundary of Hydrographic Basin 89. Lightning W is on the east side of the Carson Range. The service area covers roughly one square mile.

Public Water Systems

Three production wells are included in the Lightning W system, serving 98 services. Through 2008, Lightning W Wells 1 and 2 were the water supply wells. From 2003 through 2008 these two wells produced almost equal amounts of water. Lightning W Well 3 was constructed in 2008 and became the primary groundwater source. Lightning W Wells 1 and 2 are completed in fractured rock. Well 3 is completed mostly in alluvial material with the bottom five feet being positioned in weathered granite.

Lightning W Well 1 was constructed in 1994 to a depth of 400 feet with 8-inch casing. The recommended pumping rate for this well is 90 gallons per minute (“gpm”).

Lightning W Well 2 (previously identified as the Ag Well or Upper Well) was constructed in 1963 to a depth of 622 feet with 10-inch casing. The recommended pumping rate for this well is 110 gpm.

Lightning W Well 3 was constructed in 2008 to a depth of 225 feet with 12-¾ inch casing. The recommended pumping rate for this well is 225 gpm.

Groundwater Pumping

Figure 1 depicts the groundwater pumping for the Lightning W system since 2001. Overall, annual pumping has increased over time but remains relatively low at approximately 100 acre feet/year (“AF/yr”).

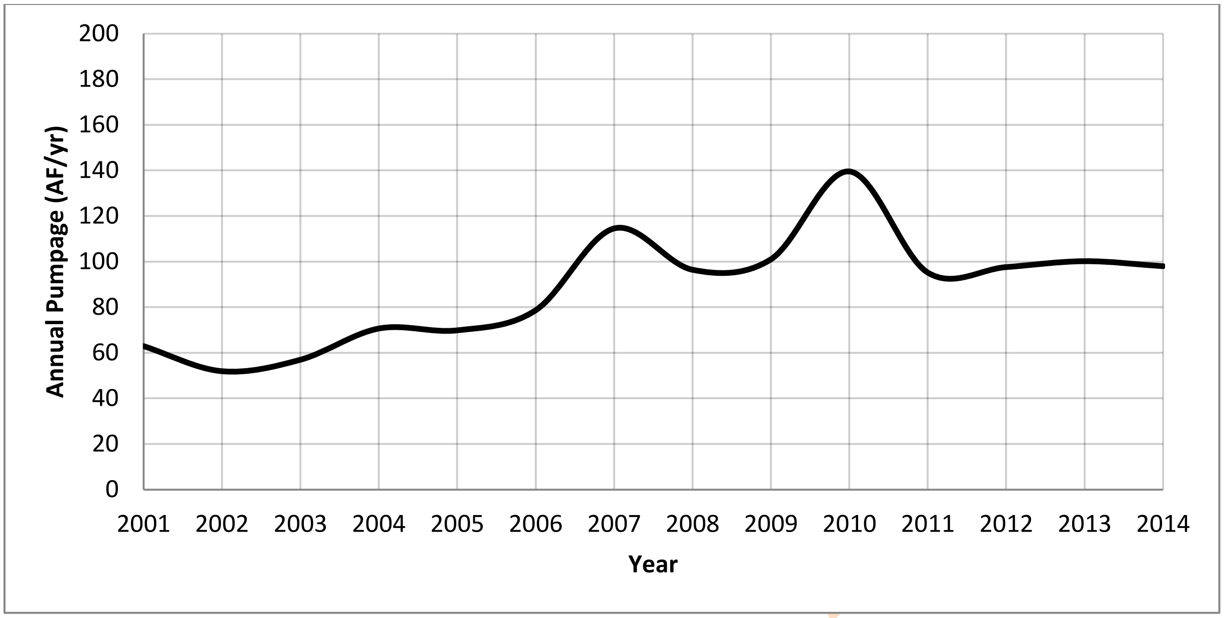


Figure 1. Groundwater Pumping Hydrographic Basin 89 - Lightning W Production Wells

Groundwater Levels

Groundwater level data for Lightning W Well 1 are shown in Figure 2. The data indicate that water levels were declining until 2009. Lightning W Well 3 began pumping in 2008 which allowed for less pumping at Lightning W Well 1. The decreased pumping at Well 1 is the likely reason for the water level trend to reverse and begin rising at this well in 2009. Historic water level data are not available for Lightning W Well 2 or Lightning W Well 3.

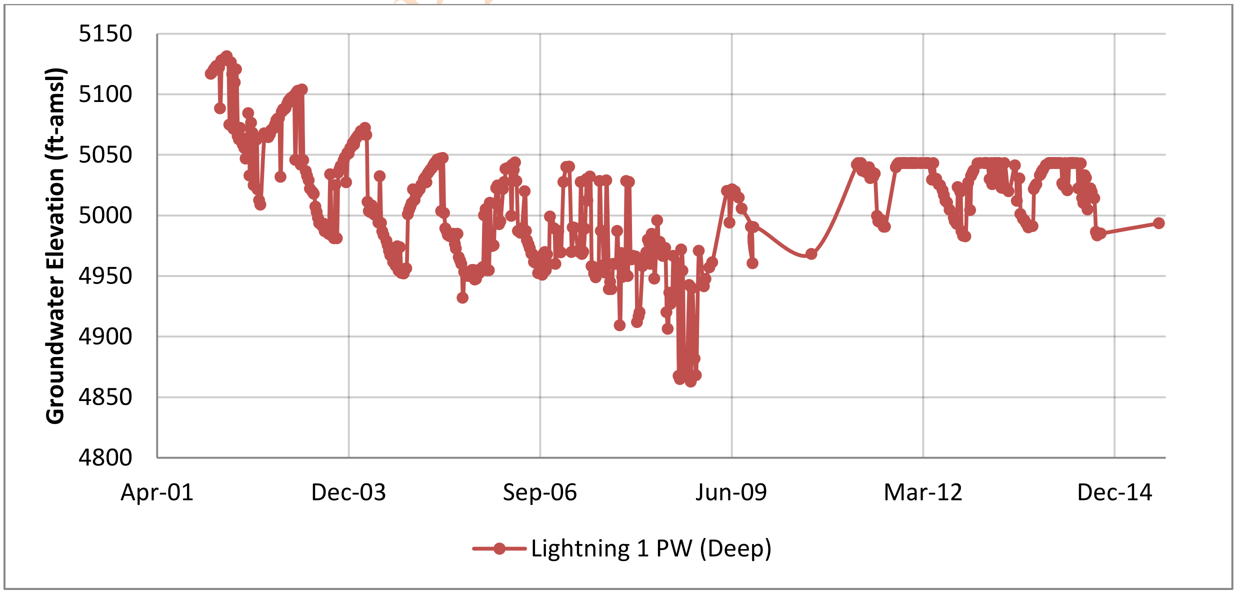


Figure 2. Water Level Changes at Lightning W Well 1

Groundwater Quality and Quantity

In the past, water quality constituents impacting the Lightning W system include uranium, gross alpha, and iron. Lightning W Well 2 is run in a back-up mode due to its low production rate. Lightning W Wells 2 and 3 are run through a treatment system to remove uranium.

The wells are able to produce sufficient groundwater quantity to serve the current customer base.

Basin Challenges

Water quality and quantity are issues for the Lightning W water system. Water quality constituents that may need to be addressed in the future include uranium, gross alpha, iron, and possibly radon if the drinking water standard is lowered for this groundwater constituent.

Groundwater quantity could also be an issue in the future. The addition of Lightning W Well 3 did provide relief for Lightning W Well 1 which allowed water levels to stabilize at this well.

WASHOE VALLEY – HYDROGRAPHIC BASIN 89 (OLD WASHOE ESTATES)

Introduction

The Old Washoe Estates water system, serving 53 services, is located at the north end of Washoe Valley in Washoe City. The production well and water system are east of Highway I-580. The relatively small water system is near the north boundary of Hydrographic Basin 89 and just south of Basin 88. The service area covers roughly one square mile.

Public Water Systems

The water system consists of one production well, Old Washoe Estates Well 3, and one unequipped backup well, Old Washoe Estates Well 4. Approximately 53 lots are included in the service area. Both production wells are completed in fractured rock.

Old Washoe Estates Well 3 was constructed to a depth of 300 feet and has 8-inch casing and screen. Its recommended pumping capacity is 150 gpm.

Old Washoe Estates Well 4 was constructed to a depth of 470 feet and has 8-inch casing and screen. Its recommended pumping capacity is 100 gpm.

Groundwater Pumping

Figure 1 depicts the groundwater pumping for the Old Washoe Estates water system since 2001. Overall, annual pumping has been stable over time at approximately 50 AF/yr.

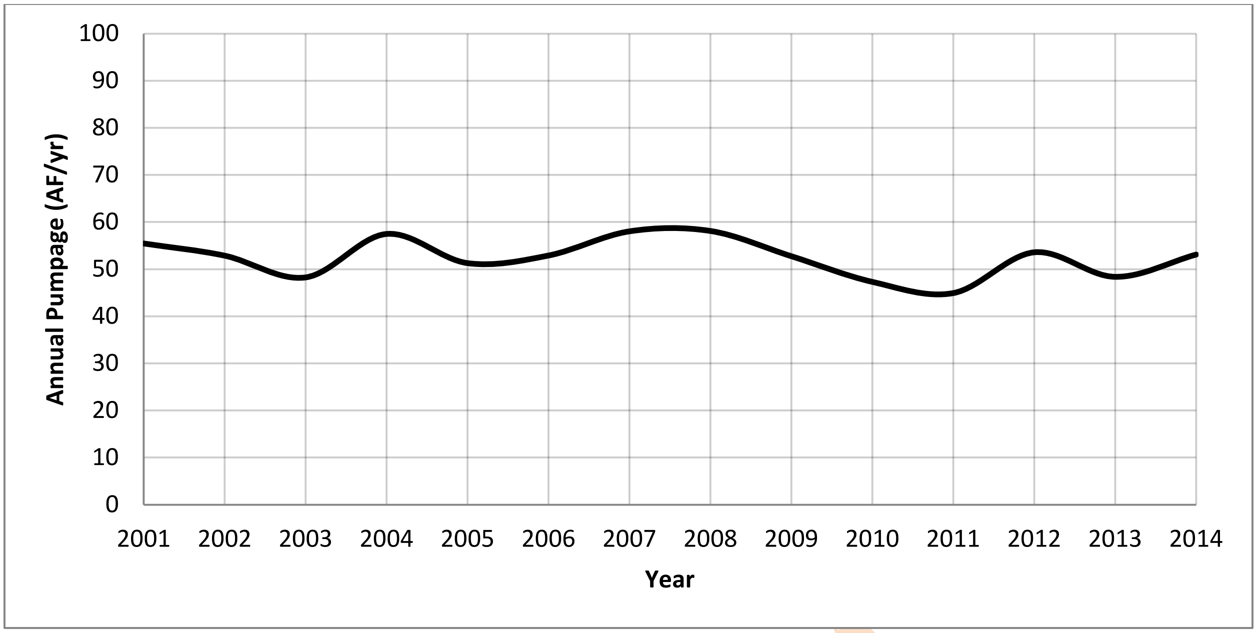


Figure 1. Groundwater Pumping Hydrographic Basin 89 - Old Washoe Estates Production Wells

Groundwater Levels

Groundwater level data for Old Washoe Estates Well 3 are shown in Figure 2. The data indicate that there has been a relatively small decline in water levels since 2006, approximately 5 feet.

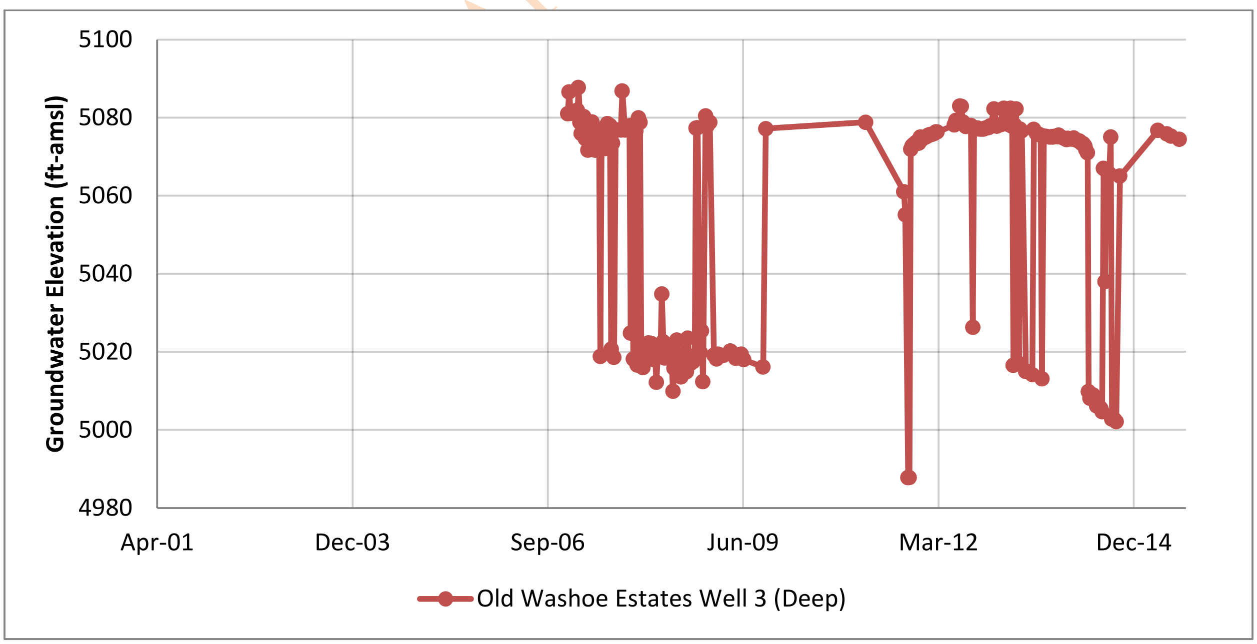


Figure 2. Groundwater Level Changes Old Washoe Estates Well 3

Groundwater Quality and Quantity

There are no water quality issues with Old Washoe Estates Well 3. Old Washoe Estates 4 also produces good quality water.

Old Washoe Estates 3 is able to produce sufficient groundwater quantity to serve the customer base. Equipping the backup well will increase the reliability of the system capacity.

Basin Challenges

Groundwater quantity could be an issue in the future. Additional wells may be required if the customer base expands.

TRACY SEGMENT HYDROGRAPHIC BASIN 83 – TRUCKEE CANYON SYSTEM

Introduction

The Truckee Canyon Water Supply System, serving 13 services, is located east of Sparks and south of I-80 near the Mustang exit. The water system is near the western boundary of Hydrographic Basin 83 and approximately 1,400 feet northwest of the Truckee River. The small water system serves an industrial park.

Public Water Systems

The water system consists of one active well and one unequipped backup well. The active well Truckee Canyon Well 1, was constructed in 1978 and is completed in volcanic rock. The unequipped backup well, Truckee Canyon 3, was completed in 2009 and is also completed in volcanic rock.

Truckee Canyon Well 1 was completed to a depth of 530 feet with 8 5/8-inch casing to 490 feet. The recommended pumping rate is approximately 100 gpm.

Truckee Canyon Well 3 was completed to a depth of 310 feet with 8 5/8-inch casing. The recommended pumping capacity has not been determined at this well.

Groundwater Pumping

Figure 1 depicts the groundwater pumping for the Truckee Canyon system since 2001. Overall, annual pumping has increased over time but remains relatively low at approximately 18 AF/yr.

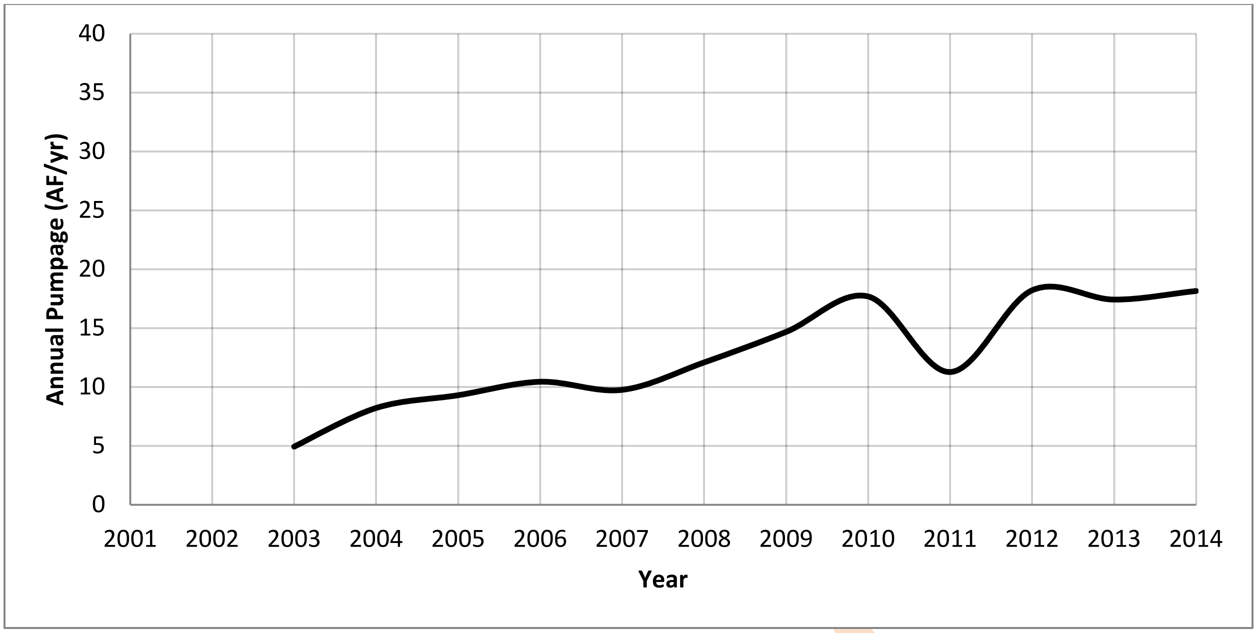


Figure 1. Groundwater Pumping Hydrographic Basin 83 - Truckee Canyon Well 1

Groundwater Levels

No water level data are available.

Groundwater Quality and Quantity

Water quality constituents impacting the Truckee Canyon system include arsenic, iron, and manganese. The groundwater is treated to meet drinking water standards.

The one-well system is able to produce sufficient groundwater quantity to serve the customer base. The unequipped well is scheduled to be online in 2016, which will increase the reliability of the system capacity.

Basin Challenges

Water quality and quantity are issues for the Truckee Canyon water system. Water quality issues are addressed with a treatment system. The treatment system will be upgraded as appropriate when the unequipped well is connected to the system.

Groundwater quantity could also be a challenge in the future. Additional wells may be required if the customer base expands.

TRACY SEGMENT HYDROGRAPHIC BASIN 83 – STAMPMILL WATER SYSTEM

The Stampmill system is located north of I-80 and Wadsworth exit. The system serves 45 customers in the Stampmill Community. The system is on the eastern edge of Hydrographic Basin 83. The service area covers less than 1 square mile.

Public Water Systems

The water system consists of two production wells, Stampmill 1 and Stampmill 2. Both production wells were constructed in 1979 and are completed in alluvial materials.

Stampmill 1 was constructed to a depth of 202 feet and has10¾-inch casing and screen. Its recommended pumping rate is 200 gpm.

Stampmill 2 was constructed to a depth of 230 feet and has inch 8⅝–inch casing and screen. Its recommended pumping rate is 400 gpm

Groundwater Pumping

Figure 1 depicts the groundwater pumping for the Stampmill water system since 2001. Overall, annual pumping has been stable over time at 25 AF/yr.

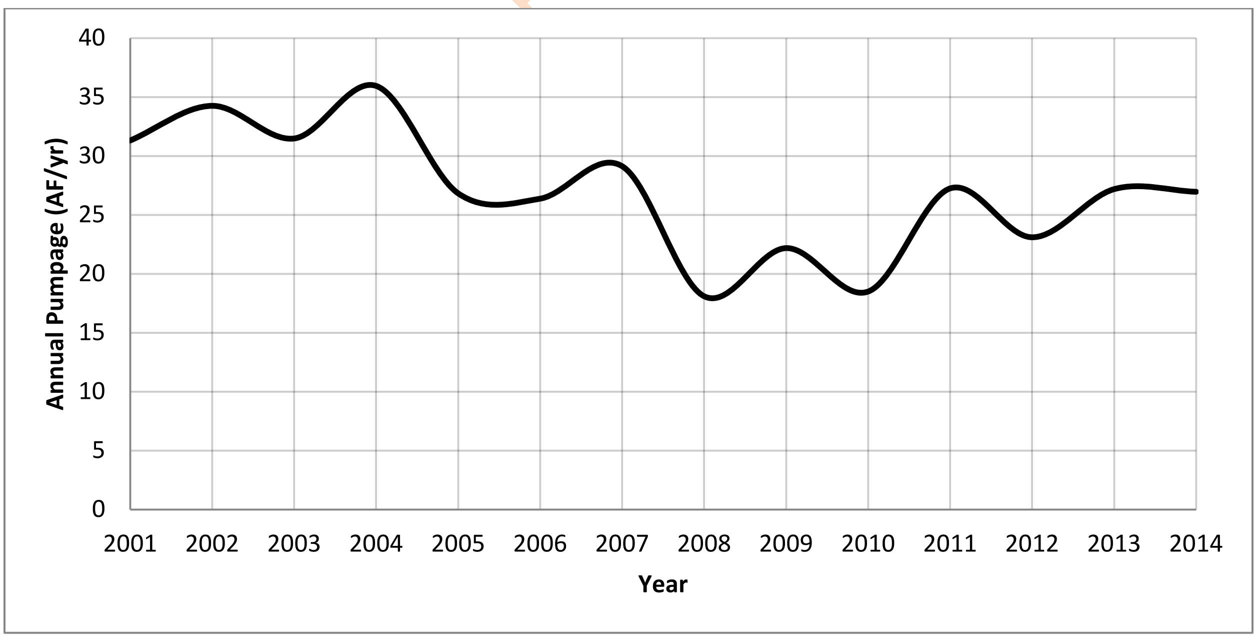


Figure 1. Groundwater Pumping Hydrographic Basin 83 - Stampmill Production Wells

Groundwater Levels

No water level data are available.

Groundwater Quality and Quantity

Iron has been a water quality issue at Stampmill 2 in the past while Stampmill 1 produces good water quality. Septic tanks are in the area which could result in nitrate issues in the future.

The wells are able to produce sufficient groundwater quantity to serve the customer base so water quantity is not a concern.

Basin Challenges

Groundwater quality could be an issue in the future. Septic tanks in the area could contribute nitrate to groundwater and degrade the water quality.

APPENDIX 2-8

Draft TMWA's Wellhead Protection Program

September 24, 2015

TRUCKEE MEADOWS WATER AUTHORITY

WELLHEAD PROTECTION PROGRAM

September 24, 2015

TABLE OF CONTENTS

List of Tables

List of Appendices

1.0 Introduction

In 1986, amendments to the Safe Drinking Water Act (SDWA) mandated that each state develop a Wellhead Protection Program (WHPP) for the purpose of protecting groundwater that serves as a source for public drinking water supplies. The driving philosophy behind these efforts is that the cost of *cleaning up* contamination far exceeds that of *preventing* contamination.

The Wellhead Protection Program is an active tool, to be used by the Truckee Meadows Water Authority (TMWA) for the coordinated protection of public drinking water resources. Operated voluntarily, under local jurisdiction and control, the program utilizes both Environmental Protection Agency (EPA) and Nevada Division of Environmental Protection (NDEP) guidance and criteria to provide for State endorsement.

Both the EPA and NDEP suggest the inclusion of the following seven elements:

1. A team of local participants.
2. Delineation of the wellhead protection area (WHPA) around drinking water wells where contaminants may find their way into the community's drinking water system.
3. The identification of potential contaminant sources (PCS) that may affect the groundwater.
4. Management strategies for the identified and potential contaminant sources.
5. Plans for locating new wells.
6. Contingency plans to address potential contamination events.
7. Activities for public participation.

In 1996, the first WHPP was completed for the Hidden Valley wells and endorsed by the NDEP. Additional WHPPs were completed in 1998 (STMGID wells), 2000 (Lemmon Valley wells), 2005 (Mt. Rose wells), and 2008 (Spanish Springs wells) and all were endorsed by the NDEP. The first WHPP for TMWA wells was completed in 2005 and was also endorsed by NDEP.

Groundwater protection has received even more attention with the 2014 consolidation of Washoe County Department of Water Resources (WCDWR) and South Truckee Meadows General Improvement District (STMGID) with TMWA. This WHPP update integrates previous wellhead protection planning efforts of all three entities under the planning and direction of one unified water utility (TMWA). This update also incorporates significant improvements including: all production wells for the three consolidated utilities, new wellhead protection areas, an updated PCS inventory, an updated wellhead protection team, and revised management strategies.

1.1 Purpose and Goals

The ultimate objective of a Wellhead Protection Program is summarized in the following statement:

"The goal of wellhead protection is to provide protection from contaminant releases, so that drinking water standards can be maintained at the well. It must be emphasized that it requires much less effort and money to protect an aquifer than to clean up a contaminated one."

The following summarizes the goals of the WHPP:

- Inform concerned individuals in the community about local drinking water resources and their management
- Identify and evaluate threats to drinking water resources
- Provide management tools to address potential sources of contamination
- Provide ongoing protection for current and future drinking water resources
- Involve the community through public activities, and provide information and education regarding resource protection
- Update the program regularly and monitor significant events over time

1.2 Wellhead Protection Team

A successful WHPP requires the participation and support of the appropriate TMWA staff, as well as jurisdictional authorities that affect water use and land use practices in or around the program's designated wellhead protection areas. The project team serves to notify land use planning, health, the development community and fire protection representatives of the program and associated concerns. The efforts of the team will have bearing on groundwater protection for present and future development.

Because the program is active and ongoing, the membership of the team is expected to change over time. As one member leaves, other people from the community should be asked to join. These members may include representatives of any group that may be affected by, or interested in, wellhead protection activities.

Table 1 lists the current members of the WHPP Team. Included in the table are the names, titles, contact information, and corresponding roles and responsibilities of each team member.

Table 1
Wellhead Protection Team

Name & Agency	Title	Contact Info
Christian Kropf TMWA	Senior Hydrogeologist	1355 Capital Blvd, Reno, Nevada 89502 775-834-8016 ckropf@tmwa.com
Paul Miller TMWA	Manager, Water Operations & Water Quality	PO Box 30013, Reno, Nevada 89520-3013 775-834-8106 pmiller@tmwa.com
Wes Rubio Washoe County Health District	Senior Environmental Health Specialist	1001 E. Ninth St. Reno, Nevada 89512 775-328-2635 wrubio@washoecounty.us
Chris Anderson Washoe County Health District	Licensed Engineer	1001 E. Ninth St., Reno, Nevada 89512 775-328-2632 CAnderson@washoecounty.us
Ryan Bird City of Reno	Environmental Services Supervisor	PO Box 1900, Reno, Nevada 89505 775-334-2167 birdr@reno.gov
Toby Ebens City of Sparks	Environmental Control Supervisor	PO Box 857, Sparks, Nevada 89432-0857 775-861-4152 tebens@cityofsparks.us

2.0 Background

2.1 Introduction and Background

TMWA is a not-for-profit, community-owned water utility, overseen by elected officials and citizen appointees from Reno, Sparks and Washoe County. TMWA began operations in June 2001 through a Joint Powers Agreement between the City of Reno, City of Sparks and Washoe County. TMWA provides high-quality drinking water to approximately 400,000 residents of the Truckee Meadows.

TMWA obtains its water supply from surface water and groundwater sources. Surface water from the Truckee River system, including water released from Lake Tahoe, Boca and Stampede Reservoirs, Independence Lake and Donner Lake, provide most of TMWA's water supply. The Chalk Bluff and Glendale plants treat the water from the Truckee River prior to it being delivered to customers through a complex distribution system. Groundwater is pumped from wells throughout the service territory and depending on the location, either supplements surface water during the summer months or provides water supply year-round.

Groundwater sources are a critical component of the TMWA water supply. TMWA currently owns and operates almost 90 active production wells which are used both as a primary source and to supplement the water supply from the treatment plants in the peak summer months and provide backup reliability throughout the year. In winter months, selected wells are recharged with treated surface water to enhance drought supplies and water quality.

The TMWA retail area covers 155 square miles with a distribution system comprised of more than 2,500 miles of underground mains and pipelines, over 110 booster pump stations, 331 pressure regulator stations, 93 storage tanks, three water treatment plants, and two treated water reservoirs. This WHPP covers almost 90 wells in eight different hydrographic basins (Nevada State Engineer's designated basin numbers 83, 85, 87, 88, 89, 92A, 92B, and 97) in northwestern Nevada. Most of the wells are located in basins 87, 88, 85, 92A, and 92B; basin characteristics are discussed in more detail below.

2.2 Basin 87 – North Truckee Meadows

Physical Setting

The Truckee Meadows can be thought of as two regions: North Truckee Meadows (NTM) and South Truckee Meadows (STM). The NTM region extends as far south as the South McCarran Blvd. area and includes Hidden Valley. The STM region starts at South McCarran Blvd. and extends south including Double Diamond, the Mt. Rose fan and foothill areas, and the Virginia Foothills. Together, NTM and STM make up the State Engineer's designated Basin 87. The geologic and hydrogeologic characteristics of STM differ from NTM in that the NTM is dominated by deep basin-fill and Truckee River deposits and the STM is dominated by a large alluvial fan complex consisting of thin alluvial fan deposits overlaying fractured volcanic sequences. Appendix B contains figures showing Hydrographic Basin 87, the NTM and STM areas, and location of TMWA production wells.

When compared to other basins in the Great Basin Province of Nevada, the uniqueness of the Truckee Meadows hydrographic basin is the presence of the Truckee River which flows west to east through NTM. The Sierra Nevada mountain range on the west side of the basin and underlying the valley are complexly faulted. Regional faulting gave the mountains their large-scale size, shape, and relief. The change in elevation ranges from approximately 4,380 feet above mean sea level at the eastern edge of the basin along the Truckee River to 8,269 feet above mean sea level at Peavine Peak in the northwest quadrant of the basin. The present topography of the basin is the result of erosion and smaller scale fault structures.

Along the east side of the basin, the Virginia Range and Pah Rah Mountains are comprised of igneous, volcanic, and metavolcanic rocks. The resulting valley is a structural depression filled with unconsolidated valley-fill material comprised of weathered material from the surrounding mountain ridges including layers of clay, silt, fine- to coarse-grained sand, and gravel. The Truckee River deposited large quantities of coarse-grained alluvial materials along the river corridor and dominates the lithologies encountered by TMWA production wells in the NTM.

Public Water Systems

TMWA currently operates 24 active or back-up production wells in NTM. Four additional wells, I Street, Dilworth, Sparks High, and Reed High are currently unequipped and projected to be brought online over the next 10 years. Two other wells, Peckham and Stanford, are unsuitable for drinking purposes but are used for non-potable applications such as construction water. All of the 24 active wells are screened in alluvium with production capacities ranging from approximately 300 to 2,500 gpm.

Groundwater Quality

Groundwater quality varies throughout the Truckee Meadows hydrographic basin.

Poor water quality, due to highly mineralized groundwater, is found generally in the southeast portion of the basin. Geothermal areas are present in the west and southwest areas of NTM. Groundwater with high arsenic levels is also treated by TMWA. The Central Truckee Meadows Remediation District (CTMRD) has identified 8 PCE contamination plumes in NTM. This solvent has been used since the 1930's in a variety of commercial/industrial operations such as commercial dry cleaning, paint manufacturing, and auto repair. The CTMRD program has achieved success in plume capture and containment resulting from the implementation of a prescriptive pumping schedule of the 5 TMWA wells fitted with PCE treatment equipment. According to the CTMRD, the PCE plumes do not appear to be moving or growing. TMWA is an active participant with the CTMRD program in planning for and implementing mitigation of PCE. Additional CTMRD information can be found at:

https://www.washoecounty.us/csd/utility/ctmrd/downloads.php

Other groundwater contamination sites, with potentially responsible parties, include the Sparks Solvent Fuel Site, leaky underground storage tanks sites, and additional solvent corrective action sites overseen by NDEP.

2.3 Basin 87 – South Truckee Meadows

Physical Setting

The STM region starts at South McCarran Blvd. and extends south including Double Diamond, the southwest alluvial fan and foothill areas, and the Virginia Foothills. Together, NTM and STM make up the State Engineer's designated Basin 87. Appendix B contains figures that depict Hydrographic Basin 87, the NTM and STM areas, and the location of TMWA production wells. South Truckee Meadows (STM) is identified as the southern extent of Basin 87 from South McCarran Blvd. to the topographic high along Mt. Rose Highway separating Basin 87 from Basin 88. The STM area is dominated by a large alluvial fanon the southwest with its perennial streams originating in the Sierra Nevada Mountains to the west and the central valley lowland groundwater discharge areas to the east near Double Diamond.

Regional faulting gave the mountains their large-scale size, shape, and relief. The change in elevation in the STM ranges from approximately 4,400 feet above mean sea level at the northeastern lowland discharge area along Steamboat Creek to 10,620 feet above mean sea level at the highest peak on Mt. Rose at the southwest quadrant of the basin. The west side of the basin is comprised primarily of granodiorite overlain by fractured volcanic andesitic and basaltic rock sequences. Along the east side of the basin, the Virginia Range is comprised of igneous, volcanic, and metavolcanic rocks. The resulting valley is a structural depression filled with unconsolidated valley-fill material comprised of weathered material from the surrounding mountain ridges including layers of clay, silt, fine- to coarse-grained sand, and gravel. Generally, valley fill is coarser near the mountain ridges and becomes fine-grained in the center of the valley.

The basin can be divided into two aquifer systems from which water is pumped into public water systems: (1) alluvial fan and fractured volcanic rock aquifer located on the southwest side of the basin and (2) a basin-fill aquifer in the central and northern portion of the STM.

Public Water Systems

TMWA currently operates two distinct well fields penetrating two distinct aquifer types and can be referenced as alluvial fan wells and basin-fill wells in the South Truckee Meadows area.

Mt. Rose Fan wells are completed in the alluvial fan and fractured rock aquifer on the southwest alluvial fan and are bounded on the east by S. Virginia St., on the south by the Mount Rose Hwy. and on the west by Timberline Dr. and the Carson Range. The alluvial fan well field consists of 12 active or back-up production wells constructed between 1978 and 2011 with production capacities ranging from 200 to 1,500 gpm.

Wells to the north of the Mt. Rose Fan wells are completed in the basin-fill aquifer and are located between South McCarran Blvd. and Damonte Ranch Pkwy. This well field consists of 12 active or back-up production wells constructed between 1968 and 2015 with production capacities ranging from 550 to 1,800 gpm.

Groundwater Quality

Groundwater quality varies throughout the STM basin. Low TDS groundwater is found within the alluvial fans at the base of the Sierra. The water quality deteriorates at the valley floor where it mixes with highly mineralized geothermal waters discharged from the Steamboat Springs Geothermal Area at the south end of the valley (Steamboat Hills). Localized areas of high density septic tanks may contribute to high nitrate in shallow groundwater.

2.4 Basin 88 – Pleasant Valley

Physical Setting

The Pleasant Valley area, Hydrographic Basin 88, encompasses 39 square miles and is bound to the north by the Steamboat Hills, to the east by the Virginia Range, and to the west by the Carson Range. Pleasant Valley is separated from Washoe Valley to the south by a topographic and hydrologic divide created by low hills of granitic, volcanic, and metavolcanic rocks.

The basin can be described as having two geographically and hydrogeologically distinct regions from which water is pumped into public water systems: (1) an alluvial fan and fractured volcanic rock aquifer located in the western higher elevation part of the basin referred to as West Pleasant Valley and (2) a basin-fill aquifer in the lower, eastern part of the basin referred to as East Pleasant Valley.

Appendix B contains figures that depict Hydrographic Basin 88, the West and East Pleasant Valley regions, and the location of TMWA production wells.

From west to east, the alluvial fan and basin-fill aquifers are similar to those described in Basin 87. In West Pleasant Valley, the alluvial fan aquifer is conceptualized as a complex aquifer system comprised of: 1) thin alluvial fan deposits, 2) consolidated sedimentary deposits, 3) thick interbedded fractured volcanic sequences, and 4) granitic, volcanic, or metavolcanic basement rock. The basin-fill aquifer system is conceptualized as a complex aquifer system comprised of: 1) alluvium, 2) partly confined alluvium, 3) fractured volcanic sequences, and 4) granitic, volcanic, or metavolcanic basement rock.

Public Water Systems

TMWA currently operates 9 active production wells in Basin 88, serving approximately 30 lots. Three additional wells, Sunrise Estates 3, Mt. Rose 2, and STMGID 8, operate infrequently as back-up wells. Two more wells, Callamont 1 and Callamont 2, are currently unequipped and projected to be brought online over the next 10 years. All but two of the active wells (Sunrise Estates 1 and 3) are located in the West Pleasant Valley. Active wells were completed from 1974 to 2000 with production capacities ranging from a low of 150 to a high of 800 gpm.

Groundwater Quality

Groundwater quality varies throughout the Pleasant Valley basin. Poor water quality, due to highly mineralized groundwater, is found generally in the eastern portion of the basin near the eastern flank of the Steamboat Hills where geothermal influences are most pronounced.

2.5 Basin 85 – Spanish Springs Valley

Physical Setting

Spanish Springs Valley (SSV) is a topographically closed basin bounded on the east by the Pah Rah range and on the west by the Hungry Ridge range covering an area of approximately 80 square miles. The basin can be divided into two aquifer systems from which water is pumped into public water systems: (1) a volcanic rock aquifer located on the east side of the basin and (2) an alluvial aquifer in the western and central portion of SSV. A third portion of the basin, a granitic aquifer on the northeast basin slopes of the Pah Rah Range, is a meager aquifer that barely supports approximately 380 domestic wells. Appendix B contains figures depicting the Spanish Springs Hydrographic Basin and location of TMWA production wells.

Public Water Systems

TMWA currently operates two distinct well fields in SSV. The Desert Springs system is located on the west side of SSV and consists of five active or back-up production wells constructed between 1963 and 1990. The west side wells are completed in alluvial material and have production capacities ranging from 350 to 750 gpm. The Spring Creek system is located primarily on the east side of SSV and consists of four newer wells constructed between 1997 and 2005. The east side wells are completed in fractured volcanic material and have production capacities ranging from 1,000 to 3,000 gpm.

Besides TMWA, Utilities, Inc. has facilities and customers in the Spanish Springs basin. Utilities, Inc., a PUCN regulated utility has a service area north of La Posada Drive and east of Pyramid Highway and serves about 580 connections in the area previously referred to as “Sky Ranch.”

Groundwater Quality

Poor groundwater quality exists in the central and southwest part of SSV. Poor groundwater quality is found in the southwest of SSV due to hydrothermally altered volcanic rock with high concentrations of arsenic and sulfate. In the center of SSV, septic tank effluent has polluted shallow groundwater with nitrate. Nitrate contamination has persisted over the past twenty years, rendering five production wells (Desert Springs 1, 2, 3, and 4 and Spring Creek 2) at risk.

WCDWR thoroughly investigated nitrate contamination and prepared full report that details sources, extent, and migration of nitrate titled, “Final Report: Spanish Springs Nitrate Remediation Pilot Project, Phase II: Nitrate Source, Extent, Magnitude, Migration, and Management Options” (Kropf and Dragan, 2010). There are two figures included in Appendix E that depict the extent of nitrate contamination in SSV. Blending with Truckee River water and other well water is the current groundwater treatment practice for nitrate and arsenic. In addition to converting homes on septic to sewer, increasing the amount of artificial recharge (ASR) in west side wells is a future alternative to help mitigate water quality issues.

2.6 Basin 92A & 92B – Lemmon Valley

Physical Setting

Lemmon Valley (LV) is a topographically closed basin typical of those in the Basin and Range region (Harrill, 1973). The mountains surrounding and bedrock underlying the valley are complexly faulted. The mountains are comprised of igneous, volcanic, and metavolcanic rocks. Regional faulting gave the mountains their large-scale size, shape, and relief. The change in elevation ranges from approximately 4914 feet above mean sea level at the eastern sub-area playa to 8266 feet above mean sea level at highest peak on Peavine Mountain at the south end of the basin. The present topography of the basin is the result of erosion and smaller scale fault structures. Appendix B contains figures depicting the Lemmon Valley hydrographic basin and the locations TMWA production wells.

The valley is a structural depression filled with unconsolidated valley-fill. Features other than mountain ridges include valley-fill deposits and playa lakes. The valley-fill is comprised of weathered material from the surrounding mountain ridges including layers of clay, silt, fine- to coarse-grained sand, and gravel. Generally, valley-fill is coarser near the base of the mountain ridges and becomes finer-grained in the center of the valley near the playas. Playa lake deposits are mostly clay, silt, and fine-grained sand. The aquifer system is conceptualized as three hydrostratigraphic units, from top to bottom: 1) playa deposits; 2) alluvium; and 3) fractured bedrock. These units are identified as distinct units based on differences in geologic, hydraulic, and water yield characteristics.

Lemmon Valley is designated by the State Engineer as basin number 92, and is subdivided into the east and west subbasins by the Airport Fault which runs down the middle of the basin: West Lemmon Valley is identified as Basin 92A (WLV) and East Lemmon Valley is Basin 92B (ELV).

WLV contains the Silver Lake playa in the center of the subbasin with large commercial/ industrial properties and residential properties to the east, and additional residential properties to the southeast. North of Silver Lake is the Silver Knolls subdivision with about 500 residences that utilize domestic wells and septic tanks, and west of the Silver Knolls subdivision is the Silver Knolls Water Mutual system serving 64 residential lots.

ELV includes the Swan Lake playa located in the central portion of the basin. Golden Valley is a hydrographic subarea in the southeast corner of Basin 92B which includes both residential and commercial properties in the Golden Valley area. There are over 550 properties on domestic wells and septic tanks in this subarea.

Public Water Systems

TMWA operates two distinct wellfields in West and East Lemmon Valleys. The WLV wellfield consists of three equipped wells and one unequipped well. These wells are completed in alluvium and have production capacities ranging from 800 to 2,500 gpm. The ELV production wellfield consists of 5 wells completed in alluvium that have production capacities ranging from approximately 200 to 1,000 gpm.

Besides TMWA, there is a minor utility in the Silver Knolls area, Silver Knolls Mutual Water, which serves about 64 connections. TMWA provides service in the Silver Lake development, the Stead area, and in northwest and the east side of Basin 92B.

Groundwater Quality

Highly mineralized, poor ground water quality exists in shallow groundwater near the playa areas in both basins. Locally, higher nitrate levels are associated with a higher density of septic tanks. The nitrate level found in wells are well-specific and depends on depth to groundwater, flow direction, well screen depth, and the soil types between the septic tanks and well screen.

Remediation of solvent-related contamination at the Stead Solvent Site near the southern boundary of the Stead Airport in Basin 92A began in the late 1990s. The clean-up activities have successfully reduced the migration of the contaminant plume. More information on this remediation site can be found at the Nevada Division of Environmental Protection website: http://ndep.nv.gov/admin/new.htm.

2.7 Inventory of TMWA Wells

Appendix A includes a table of active TMWA production wells, which provides pertinent information for each of TMWA's wells.

3.0 Delineation of Wellhead Protection Areas

Sections 3.1 and 3.2 generalize the approach used to create capture zones for TMWA production wells within the various basins modeled. Text was assimilated from groundwater modeling reports provided by LBG Guyton and Dr. Greg Pohll.

3.1 Introduction

Six groundwater flow models were updated to reflect actual pumping from TMWA (and others) through the year 2014. Updated models included:

- West Lemmon Valley (Basin 92A)
- East Lemmon Valley (Basin 92B)
- Spanish Springs Valley (Basin 85)
- North Truckee Meadows (Basin 87)
- South Truckee Meadows (Basin 87)
- Pleasant Valley (Basin 88)

Future scenarios were constructed to simulate groundwater flow over a 20-year period (2014-2034) for each of the modeled areas. Projected pumping rates were based on the past 7 years of production well pumping and were simulated for 20 years through the year 2034. The models were then used to simulate water levels and groundwater velocity throughout the valley. This information was then used to estimate capture zone areas around production wells.

3.2 Methodology

Capture zones around TMWA production wells were estimated by using the results of each of the MODFLOW groundwater models (heads and groundwater velocity estimates) as input into the program MODPATH. MODPATH is a particle tracking post-processing package that was developed to compute three-dimensional flow paths using output from steady-state or transient groundwater flow simulations by MODFLOW, the U. S. Geological Survey finite-difference groundwater flow model. MODPATH uses a semi-analytical particle-tracking scheme that allows an analytical expression of the particle's flow path to be obtained within each finite-difference grid cell. Particle paths are computed by tracking particles from one cell to the next until the particle reaches a boundary, an internal sink/source, or satisfies some other termination criterion.

Capture zones are estimated by reverse-tracking multiple particles from the well. In reverse tracking, the particles move away from the well instead of toward the well as they normally do in the aquifer under pumping conditions. Therefore, the reverse-tracked particles placed around the well typically diverge away from the well in a fashion that indicates the location of the groundwater particle at a particular point in time. By carefully defining the starting locations of particles, it is possible to perform a wide range of analyses, such as delineating capture areas. Capture zones can be estimated from these particle locations by connecting the locations of particles that have been reverse tracked from a production well for the same amount of time.

3.3 Results

The finalized wellhead protection areas are shown on a series of figures in Appendix B. Capture zones representing time frames of 2, 5, 10 and 20 years are shown for most production wells. Some wells are located in areas where groundwater modeling has not been completed. The capture zones for those wells are represented by the area within a ½ mile radius of the well.

4.0 Potential Contaminant Source Inventory

4.1 Background

The identification of potential contamination sources in the vicinity of existing wells is a critical component of this program. An accurate knowledge of the potential threats to groundwater quality will allow TMWA to create the best plan to protect local water resources.

To begin the process of identifying PCSs, searches from EPA's Envirofacts database and NDEP's underground storage tank databases were conducted. From Envirofacts, the RCRAInfo (Resource Conservation and Recovery Act Information) search engine was utilized to conduct searches for four categories of PCSs: large quantity hazardous waste generators (LQGs), small quantity hazardous waste generators (SQGs), conditionally exempt small quantity hazardous waste generators (CEGs) and other PCSs not classified as hazardous waste generators. Through RCRAInfo, all generators, transporters, treaters, storers, and disposers of hazardous waste are required to provide information about their activities to state environmental agencies.

NDEP maintains databases for federally regulated underground storage tanks, active underground storage tank cases undergoing investigation for leaks or remediation, and closed underground storage tank sites that have been successfully remediated. All active underground storage tanks and all tank sites closed within the last five years, have been included in the PCS database.

4.2 Methodology

4.2.1 Framework

Six tables have been created providing TMWA with a fairly comprehensive list of PCSs. These tables, located in Appendix C, depict the PCSs broken into LQGs, SQGs, CEGs, other potential sources, active underground storage tanks and closed underground storage tanks.

4.2.2 Compilation of Data

Using ArcGIS software and information from the sources described above, a database containing PCSs within TMWA service territory was developed. The database includes information from the following sources:

- Envirofacts Data Warehouse. This source of data is available on the EPA website. This website provides access to several EPA databases that provide information about environmental activities that may affect air, water, and land anywhere in the United States. Envirofacts provides many different databases for contaminants such as hazardous wastes, toxins and radiation. Depending on which search engine is utilized (RCRAInfo, TRI, etc.), it is possible to conduct searches for the generation, management, minimization, investigation or handling of different contaminants.
- RCRAInfo Search. Hazardous waste information is contained in the Resource Conservation and Recovery Act Information (RCRAInfo) database, a national program management and inventory system about hazardous waste handlers. In general, all generators, transporters, treaters, storers, and disposers of hazardous waste are required to

provide information about their activities to state environmental agencies. This search engine was the primary search engine utilized.

- NDEP Bureau of Correction Actions. NDEP maintains databases for corrective actions/leaking underground storage tanks and federally regulated underground storage tanks. These databases provide information regarding active cases and closed cases.
- Washoe County Community Services Department, Central Truckee Meadows Remediation District (CTMRD). The CTMRD Program provided access to a database that contained historical and current PCE users, wells that are being used to monitor the PCE plumes, and PCE plume contour information.

4.3 Summary of Results

The PCS database was used to create a series of highly detailed figures showing the locations of PCSs in proximity to TMWA wells and capture zones. These figures are included in Appendix B. The WHPAs managed by TMWA contain numerous PCSs. PCSs fall into six broad categories: LQGs, SQGs, CEGs, Other PCSs, Active UST Sites and Closed UST Sites. Typical examples of each of these PCS categories are provided below.

1. Large Quantity Generators (LQGs)

Large quantity generators generate 1,000 kilograms per month or more of hazardous waste, or more than one kilogram per month of acutely hazardous waste. Many of the LQGs are industrial facilities.

Examples:
- RR Donnelley – Commercial printing
- Renown Regional Medical Center – General medical and surgical hospitals

2. Small Quantity Generators (SQGs)

Small quantity generators generate more than 100 kilograms, but less than 1,000 kilograms, of hazardous waste per month.

Examples:
- Bill Pearce Body Shop – Equipment repair and maintenance
- Bobby Page's Dry Cleaners – Dry cleaning and laundry services

3. Conditionally Exempt Generators (CQGs)

Conditionally exempt generators generate 100 kilograms or less per month of hazardous waste or one kilogram or less per month of acutely hazardous waste.

Examples:
- 7 Eleven – Gasoline Stations with Convenience stores
- Lindells Painting Service – Painting and wall covering contractors

4. Other Potential Contaminant Sources

These facilities are not classified as hazardous waste generators; however, they are classified as facilities containing potential contaminants. These facilities are a compilation of gas stations, auto body shops, paint shops, laundromats, and many other facilities that pose threats.

Examples:

- A1 Body Shop – Automotive Body, Paint, and Interior Repair and Maintenance
- Quickie Mart – Pharmacies and Drug Stores

5. Underground Storage Tanks

These are underground storage tanks that are federally regulated and active. These tanks have either leaked or are being investigated for leaks. There are many active tank sites in the TMWA service area. Some of the sites are being managed, but others are not.

6. Closed Storage Tanks

These are underground storage tanks that have either leaked or required remediation in the past and are now closed. The cases used in this study have been closed within the last five years.

4.4 Updating the PCS Database

The PCS inventory should be updated regularly, at least every 5 years.

4.5 PCS Observations

TMWA has responded to groundwater quality issues for a number of years, and TMWA has historically located and constructed wells which avoid aquifer intervals having inferior water quality. A few wells have been abandoned as potable sources or have been converted to non-potable uses over the years, most notably the Stanford Way Well in Sparks and the Peckham Lane Well in Reno. Both of these wells had high levels of arsenic, iron and manganese exceeding drinking water standards.

Even so, a number of important TMWA wells have experienced water quality problems prompting TMWA to take action. Six wells (Greg, Pezzi, Poplar #1, Terminal, Mill and Corbett) are piped to Glendale Treatment Plant (GTP) for treatment and/or blending with treated surface water.

Other wells near the urban center of Reno have been impacted with the contamination from a volatile organic chemical called tetrachloroethylene (PCE). PCE is a solvent that is used in dry cleaning and metallurgical operations. For many years the disposal of PCE was not regulated, it has only been recently that PCE has been regulated in drinking water. Wells that have been impacted by PCE have been equipped with treatment technologies to effectively remove the PCE prior to the distribution system. PCE has also been found at locations that threaten other production wells. The treatment and operation of these wells has been coordinated with a Washoe County organized "Remediation District" which helps to offset the cost of treatment. A map showing the extent of PCE contamination and other useful information is included in Appendix D.

There have been other instances where groundwater contamination has threatened TMWA wells. TMWA wells on South Virginia Street have been threatened by leaking underground gasoline tanks (benzene). In addition, solvent based contamination has been found in the shallow aquifer near TMWA wells in the Stead (North Valleys) area. Even though many leaking tanks have been replaced or removed, the threat of contamination remains and TMWA continues to closely monitor groundwater quality in the affected area.

High nitrate levels exist in the groundwater in several areas of the TMWA service territory, which can usually be attributed to residential septic tanks. WCDWR and TMWA have been actively addressing this issue for many years.

In outlying, sparsely populated and predominantly residential areas, there are few PCSs. However, in commercial and industrial areas, there are a number of PCSs that should be monitored.

4.6 Using the Figures and Data Tables

A list of all the wells included in this report are included in Appendix A. The wells are listed in the order that they appear in Appendix B, which includes individual figures for each well, their respective capture zones and all identified PCSs. PCSs are shown on the figures using symbols that indicate the PCS category (LQG, SQG, Active Release Site, etc.) and are assigned an ID number. The ID numbers correspond with the data tables that are included in Appendix C.

4.7 Significant Findings

Review of the PCS data and capture zone overlays indicate the following significant concerns:

Basin No.	Well Potentially Impacted	Capture Zone (year)	PCS No.	PCS of Concern
87	Hidden Valley 3 & 5	N/A	51	Groundwater impacted Solvents: PCE, Trichloroethene, cis-1,2-Dichloroethene
87	Hidden Valley3	2	46, 47	Brownfields, Unknown Contaminants
87	High	10	62	Petroleum product in soil
87	Reno High	10	71	Gasoline in soil and groundwater
87	Delucchi	2	106	Solvents in soils and groundwater
92A	Silver Lake	20	55	Transformer oil in soil

5.0 Contaminant Source Management Plan

5.1 Purpose

A contaminant source management plan is a plan that contains specific strategies for controlling or eliminating the known threats to local drinking water sources. The State of Nevada Bureau of Water Pollution Control provides the following direction regarding management strategies (NDEP, 2004):

"*Following the delineation of wellhead protection areas and the identification of actual and potential sources of contamination within them, an approach to managing those sources must be developed and implemented. The Bureau of Water Pollution Control recommends that a management plan be developed for all public water systems. However, because the degrees of need, financial resources, and control over land use activities vary by community, there is no model plan that can be followed uniformly. It is the responsibility of the WHPP Team and the implementing agencies to assess the level of risk to the aquifer and the level of threat posed by various contaminant sources. Based on this evaluation, each community must balance the issues of potential threats, acceptable risk, and degree of management the community is willing to support. The WHPP Team will then define the levels of management that are deemed appropriate for the community's wellhead protection areas.*"

5.2 TMWA Management Plan

The wellhead protection areas managed by TMWA contain numerous potential sources of contamination. In addition, areas and features adjacent to, and in some cases up-gradient of these WHPAs also contain potential sources of contamination. Therefore, the identification of the appropriate management strategies is helpful.

Two types of management strategies were developed to address the variety of potential contaminant sources of concern to TMWA. Management strategies for specific PCS categories were developed. In addition, a few general management tools are also proposed to address area-wide concerns, and engender cooperation between local agencies and citizens' groups.

5.2.1 Management Strategies for Specific PCS Categories.

This section addresses management strategies for specific PCS categories, such as underground storage tanks. Management strategies are summarized in Table 2 and explained in detail following the table. Potential contaminant sources located in or near WHPAs are of the highest priority.

Table 2
Management Strategies for Specific PCS Categories

PCS Category	Management Strategy
PCE Sites	TMWA, CTMRD
Leaking Underground Storage Tanks	Identification and Reduction Plan Regulatory Enforcement WHPP Team Involvement
Abandoned or Private Wells	Well Survey Contact Owners and Drillers
Monitoring Wells	Management and Reduction Plan WHPP Team Involvement
Septic Systems	Septic Survey Contact Owners and Installers
Auto Repair, Gas Stations, Fueling Facilities, Manufacturing, Businesses	Regulatory Enforcement Contact Owners
Recreation Facilities	Interagency Cooperation WHPP Team Involvement
Government Installations	Interagency Cooperation WHPP Team Involvement

PCE Sites
In 1995, at the direction of the Nevada Department of Environmental Protection and the Washoe County Board of Health, the Nevada State Legislature and Board of County Commissioners created the Central Truckee Meadows Remediation District (CTMRD) to address the tetrachloroethylene (PCE) contamination of the Central Truckee Meadows aquifer.

TMWA is fortunate that this District, which targets the PCS with the highest relative risk ranking, is already in place. Coordination between CTMRD and TMWA is essential. TMWA should continue to obtain updated information from CTMRD, such as contaminant plume areas to add to the PCS maps.

Leaking Underground Storage Tanks
The Nevada Division of Environmental Protection, Bureau of Corrective Actions (BCA) is responsible for remedial activities within the State. The Washoe County Health District may also play a role coordinating remedial activities. Coordination between BCA, the Health District and TMWA is essential.

It is recommended that a LUST Identification and Reduction Plan be developed by TMWA, with the cooperation of the BCA. This Plan should address tank sites with the highest potential for impacting local groundwater quality near TMWA's drinking water wells first. The integration of information compiled for the WHPP, and BCA data on remedial activities, will result in a data set that clearly highlights areas requiring immediate action.

The best way to ensure the proper organization of relevant data is for the WHPP Team to identify a member (possibly a TMWA employee) to act as a point of contact with BCA, to supervise the exchange of information, and coordinate the warranted action.

Abandoned or Private Wells

Any well without a surface seal, or unplugged, abandoned, or unused wells in the area could provide a route for contaminants to reach the aquifer used by the utility. The following recommendations are applicable to wells that might be located near the WHPAs established herein:

- Collect information from private well owners using a form letter, and incorporate this information into the WHPP. Information collected via form letter can be used to plan a survey of private wells within WHPAs managed by TMWA.
- Conduct a survey of private wells that exist within the wellhead protection areas using information collected via form letter and PCS Maps.
- Educate private well owners in the protection area about protecting wells from contamination, and proper well plugging and abandonment procedures.
- Water wells should be properly sealed and cased to prevent inundation from surface runoff.
- Ensure that all abandoned wells are properly plugged by the owner. Proper decommissioning of abandoned wells is required by State law.
- Elimination of unused private wells or septic systems as a condition of the transfer of ownership of real properties within the service area; provided that municipal water and sewer services are readily available.

Monitoring Wells

It is recommended that a Monitoring Well Management and Reduction Plan be developed by TMWA, with the cooperation of CTMRD. This Plan should address monitoring wells with the highest potential for impacting local groundwater quality near production wells first. The integration of information compiled for the WHPP, and CTMRD data on remedial activities will result in a data set that clearly highlights areas requiring immediate action.

In addition, it is recommended that every effort be made to minimize the visibility of monitoring wells. TMWA should endeavor to strictly control information regarding the locations of monitoring wells.

The potential benefit of each monitoring well must be judged against the potential harmful impact of each monitoring well. Areas with a high density of monitoring wells are particularly vulnerable. These areas may be adequately served by fewer monitoring wells. This measure would decrease area-wide risk without severely limiting the data available to planners and engineers.

Septic Systems
Septic systems within WHPAs are already being addressed by TMWA and the WCHD. In general, TMWA's approach to this issue includes the following:

- Educate septic system owners in the area. Contact owners directly and provide helpful information while opening a channel for future communication on the subject.
- Incorporate information about the environmental impacts of septic system operation into broader public education efforts.
- Educate residents about alternatives for products considered to be household hazardous waste and the proper disposal of household hazardous waste.
- Ensure that existing septic systems are properly constructed, maintained, and removed from service.
- Use existing monitoring wells to track nitrate levels within and near WHPAs.
- Ensure closure of unused septic systems in all instances where homes or businesses have reasonable access to municipal sewer service.

Auto Repair, Gas Stations, Commercial Fueling Facilities, Manufacturing, Businesses
Fabrication and auto painters and repair shops should be made aware that disposal of hazardous wastes onto the ground or into a well of any kind is illegal.

- If identified, all activity should cease, and the NDEP's Underground Injection Control Program should be contacted. Disposal of hazardous wastes into wells constitutes one of the most serious threats to groundwater. Distribution of the NDEP Fact Sheet on Underground Injection Control to all local businesses is recommended.
- Ensure that automotive fluids are collected, contained and disposed of or recycled. Recycling should be actively encouraged as part of the Public Education portion of the program.
- Educate small business owners and managers on groundwater protection and best management practices.
- Recommend the closure of shop floor drains to business owners. Explain the increased risk of groundwater contamination associated with these drains.
- Work with local building departments to prohibit the construction of floor drains in new facilities.

Public education and outreach is the key strategy for these PCS categories. Owners of potentially problematic businesses located within WHPAs should be contacted and provided with information regarding wellhead protection (best management practices). The operators should be informed that their business is located within a WHPA.

Many local businesses are served by Underground Storage Tanks (USTs) containing heating oil. Heating oil tanks are installed according to local building code. However, older tanks may be in use beyond their design life, leading to failure. Failures in older tanks are particularly hard to detect.

- Educate any business owners with heating oil tanks about proper maintenance and decommissioning.
- Careful monitoring of utility bill may reveal problems.

Another way TMWA may work with local businesses is by coordinating with the Environmental Control Officers of Reno and Sparks. These individuals make routine visits to regulated facilities. They perform inspections and hand out useful information, such as best management practices. With a little coordination, TMWA could integrate wellhead protection issues into this program. TMWA could investigate funding opportunities through the Small Business Development Center.

Recreation Facilities and Government Installations

Government agencies in charge of operating recreation facilities and government installations that have the potential to impact local groundwater quality should be contacted and provided with information regarding wellhead protection. Maintenance facilities associated with parks and golf courses are examples of potential contaminant sources managed by local agencies. The cooperation of local agencies, such as Parks and Recreations Departments, should be sought whenever possible.

The best way to foster cooperation between TMWA and local agencies is for the WHPP Team to identify a member (possibly a TMWA employee) to act as a point of contact with the various agencies, to supervise the exchange of information, and coordinate any warranted actions. Alternatively, key representatives of local government agencies not already involved with the Well Head Protection Program should be invited to join the WHPP Team.

5.2.2 General Management Tools

The following list details management ideas that can be used to address general threats that are dispersed throughout the community.

1. Zoning Ordinances: Zoning ordinances are typically comprehensive land-use requirements designed to direct the development of an area, where certain land uses may be restricted or regulated in WHPAs. The support of Washoe County, City of Reno and City of Sparks are critical to the long-term success of the Wellhead Protection Program. The ultimate objective is to have the WHPP included in development master plans and to have ordinances or other acceptable controls that address land use issues (zoning) in specified WHPAs. Zoning ordinances should be established to direct the development of the wellhead protection areas, to minimize incompatible land use.

2. Subdivision Ordinances: Subdivision ordinances are applied to land that is divided into four or more sub-units for sale or development. This tool may be used for WHPAs in which ongoing development is a potential or current source of contamination, or in areas where there is inadequate well recharge. Future development projects should be evaluated by Washoe County, Reno and Sparks to ensure compatibility with the WHPP.

3. Site Plan Review: Regulations requiring developers to submit, for approval, plans for development occurring within a given area, can ensure compliance with regulations or other requirements made within a WHPA.

4. Design Standards: Design standards are typically regulations that apply to the design and construction of buildings or structures. This tool can be used to ensure that new buildings or structures placed within a WHPA are designed to minimize the potential for contaminant releases.

5. Operating Standards: Operating standards are regulations that apply to ongoing land-use activities, put in place to promote safety or environmental protection. Such standards can minimize the threat to the WHPA from ongoing activities such as the application of agricultural pesticides or the storage of hazardous substances.

6. Source Prohibitions: Source prohibitions are regulations that prohibit the presence or use of chemicals or hazardous activities within a given area. Local governments have used restrictions on the storage or handling or large quantities of hazardous material within a WHPA to reduce the threat of contamination.

7. Purchase of Property or Development Rights: This tool may be used to ensure complete control of land uses in or surrounding a WHPA. This method may be preferred if regulatory restrictions on land use are not politically feasible, and the land purchase is affordable.

8. Public Education: Section 8.0 of this report addresses Public Education. Public education often consists of brochures, pamphlets, or seminars designed to present wellhead issues and protection efforts to the public in an understandable fashion. This tool promotes the use of

voluntary protection efforts and builds public support for a community's wellhead protection program. This is an ongoing process that will certainly pay dividends well into the future. The residents of the Truckee Meadows must become aware of the importance of protecting their drinking water resources. An awareness of where the water comes from, and what can be done to keep the water pure, empowers the entire community.

9. Groundwater Monitoring: Groundwater monitoring generally consists of sinking a series of wells and developing an ongoing water quality testing program. However, through the CTMRD, data from hundreds of monitoring wells throughout the area is already available. A water quality testing program could consist of the review of data, as it is generated through other efforts.

   This tool allows the WHPP Team to monitor the quality of the ground water supply or the movement of contaminant plumes.

10. Household Hazardous Waste Collection: Residential hazardous waste management programs can reduce the quantity of household hazardous waste being disposed of improperly. These programs have been used in localities where disposal of wastes in municipal landfills potentially threatens groundwater.

11. Visual Inspection. Visually inspect the wellhead protection areas for surface spills at least every six months.

12. Integration of the WHPP into the Washoe County 208 Water Quality Management Plan. Non-point source contamination is an important factor in the plan.

13. Coordination with the Truckee Meadows Interlocal Stormwater Committee and the Washoe County Watershed Protection Planning Group. These groups have developed great programs that address issues that are similar to those of the WHPP. They have also developed effective public education programs.

5.2.3 Implementation

TMWA will evaluate and prioritize the management strategies identified in this report. After the strategies are prioritized, TMWA will make assignments to carry out the management plan. Implementation progress will be tracked and evaluated and the management plan will be refined over time.

6.0 Locating New Wells

In the event that TMWA develops or acquires a new public water supply well, the proposed well(s) will be subject to evaluation by the WHPP Team with respect to the guidelines for all the WHPP elements, followed by incorporation into the plan. The well's WHPA will be delineated and assessed for potential contaminant sources. The WHPA will also be managed in accordance with current WHPP goals. In addition, the contingency plan will be modified to include new wells. Management practices being implemented at existing wells may be utilized for new wells or modified where appropriate.

All new water wells and related drilling are regulated by the Nevada Division of Water Resources (NDWR) as specified in the Nevada Administrative Code (NAC) 534.010-534.500. A notice of intent to drill must be filed with the NDWR prior to drilling. In addition, a permit must be obtained to drill or replace a water well within a water basin designated by the State Engineer.

The Bureau of Safe Drinking Water mandates that the horizontal distance between a supply of water and any source of pollution must be as great as practical, but no less than one hundred feet. However, this distance is generally inadequate for wellhead protection. WHPAs should be delineated for all proposed or new wells in the same manner as for existing wells. The only difference being that the delineations and potential contaminant source inventories will be completed prior to the construction of the wells.

7.0 Contingency Plan

7.1 Introduction

Contingency planning within the context of the WHPP means being prepared to take action in response to a threat to the quality or quantity of the drinking water supply. TMWA's response plans for emergencies that threaten the quality of drinking water are covered in other agency documents, such as operation and maintenance manuals and emergency response plans.

8.0 Public Education and Participation

The primary goal regarding public education and participation is to raise the awareness of local citizens to wellhead protection issues and enlist their support and involvement. The following are suggestions that may be used in an effort to encourage public participation:

- Develop wellhead protection flyers to be included in water billings. Flyers may be sent to customers providing information on various topics, such as how to properly dispose of household hazardous wastes and septic system management.
- Develop a public education program for local schools.
- Consult with Citizen Advisory Boards and Neighborhood Advisory Boards. TMWA may consider working with these Boards to disseminate information about wellhead protection.
- Coordinate with the Truckee Meadows Stormwater Permit Coordinating Committee (SWPCC) This group has developed great programs that address issues that are similar to those of the WHPP. They have also developed effective public education programs.
- Work with the Environmental Control Officers of Reno and Sparks. These officers can be provided with information pertaining to wellhead protection that can be provided to owners and managers of regulated facilities.
- Target specific businesses identified in this report, such as gas stations and auto repair shops. These businesses can be sent specific information that tells them that they are located in a wellhead protection area, along with some suggested management practices.

9.0 References

USEPA Washington, D.C. (April, 1989) (Pub# EPA/440/6-89-002), *Wellhead Protection Programs: Tools for Local Governments*.

State of Nevada Division of Environmental Protection, Bureau of Water Pollution Control (January, 2002) *State of Nevada Wellhead Protection Program Guide.*

County, City, State and Federal Databases.

UNR (2003) *A Source Water Assessment for the Truckee River and Lake Tahoe in Northern Nevada*

Harrill, J.R., 1973, *Evaluation of the water resources of Lemmon Valley*, Washoe County, Nevada, with emphasis on effects of ground-water development to 1971: Nevada Division of Water Resources Bulletin 42, 130 p

Washoe County Department of Water Resources (March, 2010), *Final Report, Spanish Springs Valley Nitrate Remediation Pilot Project, Phase II: Nitrate Source, Extent, Magnitude, Migration and Management Options.*

APPENDIX A

INVENTORY OF TMWA PRODUCTION WELLS

Inventory of TMWA Wells

Well Name	In-Service Year	Rated Capacity [MGD]	Figure No. In Appendix B
Honey Lake Valley (Basin 97)			
Fish Spring Ranch Well 1 (A)	2006	4.3	Figure 1
Fish Spring Ranch Well 2 (B)	2006	2.9	Figure 2
Fish Spring Ranch Well 2 (C)	2006	2.2	Figure 2
Fish Spring Ranch Well 4 (D)	2006	2.2	Figure 4
Fish Spring Ranch Well 5 (E)	2006	3.2	Figure 5
Fish Spring Ranch Well 6 (F)	2017*	2.9	Figure 6
Lemmon Valley East (Basin 92B)			
Lemmon Valley 5	1970	1.2	Figure 1
Lemmon Valley 6	1998	0.3	Figure 2
Lemmon Valley 7	1970	0.6	Figure 3
Lemmon Valley 8	1974	0.9	Figure 4
Lemmon Valley 9	1997	0.8	Figure 5
Lemmon Valley West (Basin 92A)			
Army Air Guard	1968	1.6	Figure 1
Silver Knolls	2006	1.7	Figure 2
Silver Lake	2005	3.2	Figure 3
Pleasant Valley (Basin 88)			
Mt Rose 3	1990	0.4	Figure 1
Mt Rose 5	1990	1.0	Figure 2
Mt Rose 6	2000	0.8	Figure 3
St James 1	1995	0.5	Figure 4
St James 2	1995	0.6	Figure 5
STMGID 7	1983	0.2	Figure 6
Sunrise Estates 1	1983	0.4	Figure 7
TESSA 1 (East)	2000	1.2	Figure 8
TESSA 2 (West)	1999	0.9	Figure 9
Spanish Springs Basin 85			
Desert Springs 1	1990	0.6	Figure 1
Desert Springs 2	1963	0.6	Figure 2
Desert Springs 3	1979	1.1	Figure 3
Hawkings	2008	4.3	Figure 4

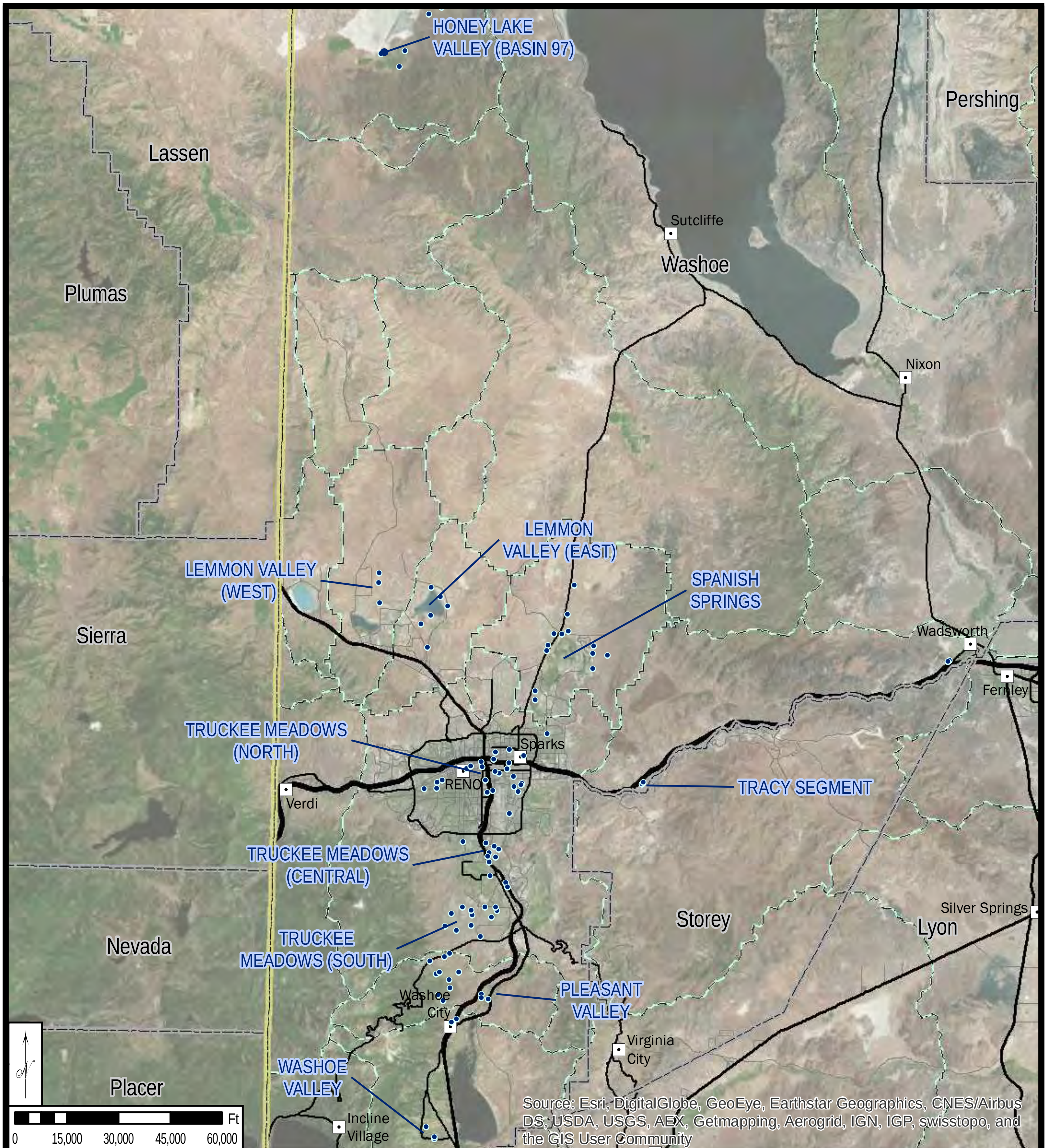
Spring Creek 2	1988	0.7	Figure 5
Spring Creek 5	2000	1.4	Figure 6
Spring Creek 6	1997	2.5	Figure 7
Spring Creek 7	2000	2.9	Figure 8
Tracy Segment Basin 83			
Stampmill 1	1979	0.6	Figure 1
Stampmill 2	1979	0.3	Figure 2
Truckee Canyon 1	1997	0.1	Figure 3
Truckee Canyon 3	2016*	0.1	Figure 4
Truckee Meadows Basin 87(Central Wells)			
Delucchi	1972	0.8	Figure 1
Holcomb	1988	1.0	Figure 2
Huffaker Place	2016*	1.2	Figure 3
Innovation	2016*	1.0	Figure 4
Lakeside	1985	0.9	Figure 5
Longley	2000	2.2	Figure 6
Patriot	1990	1.8	Figure 7
South Virginia	1969	1.5	Figure 8
Sierra Plaza	2002	2.0	Figure 9
Truckee Meadows Basin 87(North Wells)			
21st St.	1991	2.0	Figure 1
4th St.	1971	2.2	Figure 2
Corbett	1993	2.1	Figure 3
El Rancho	1992	1.2	Figure 4
Galletti	2000	2.3	Figure 5
Glen Hare	1999	1.7	Figure 6
Greg	1967	2.0	Figure 7
Hidden Valley 3	1984	1.4	Figure 8
Hidden Valley 5	1992	0.6	Figure 9
High	1961	2.2	Figure 10
Hunter Lake	1995	3.3	Figure 11
Kietzke	1972	3.3	Figure 12
Longley Water Treatment Plant	2005	3.6	Figure 13
Mill	1960	2.6	Figure 14
Morrill	1963	2.0	Figure 15
Pezzi	1974	1.3	Figure 16
Poplar #1	1963	2.3	Figure 17
Poplar #2	1967	2.2	Figure 18
Reno High	1991	3.3	Figure 19

Sparks	1967	0.9	Figure 20
Swope	1993	0.9	Figure 21
Terminal	1961	1.7	Figure 22
View	1969	2.4	Figure 23
Truckee Meadows Basin 87(South Wells)			
ArrowCreek 1	1995	0.5	Figure 1
ArrowCreek 2	1995	1.1	Figure 2
ArrowCreek 3	1998	0.7	Figure 3
Double Diamond 1	1981	0.8	Figure 4
Double Diamond 3	2016*	2.6	Figure 5
STMGID 1	1984	1.1	Figure 6
STMGID 2	1984	0.4	Figure 7
STMGID 3	1984	0.7	Figure 8
STMGID 4	1981	0.3	Figure 9
STMGID 5	1988	1.1	Figure 10
STMGID 6	1988	2.1	Figure 11
STMGID 11	2000	0.7	Figure 12
STMGID 12	2011	1.0	Figure 13
Thomas Creek	1978	0.6	Figure 14
Washoe Valley (Basin 89)			
Lightning W 1	1994	0.1	Figure 1
Lightning W 2	1963	0.2	Figure 2
Lightning W 3	2008	0.3	Figure 3
Old Washoe Estates 3	1994	0.2	Figure 4
Old Washoe Estates 4	2016*	0.1	Figure 5

* = TMWA production wells that are unequipped or currently being drilled
** = Privately owned unequipped well

APPENDIX B

FIGURES SHOWING WELLS, CAPTURE ZONES, AND PCS's



WELLHEAD PROTECTION PROGRAM

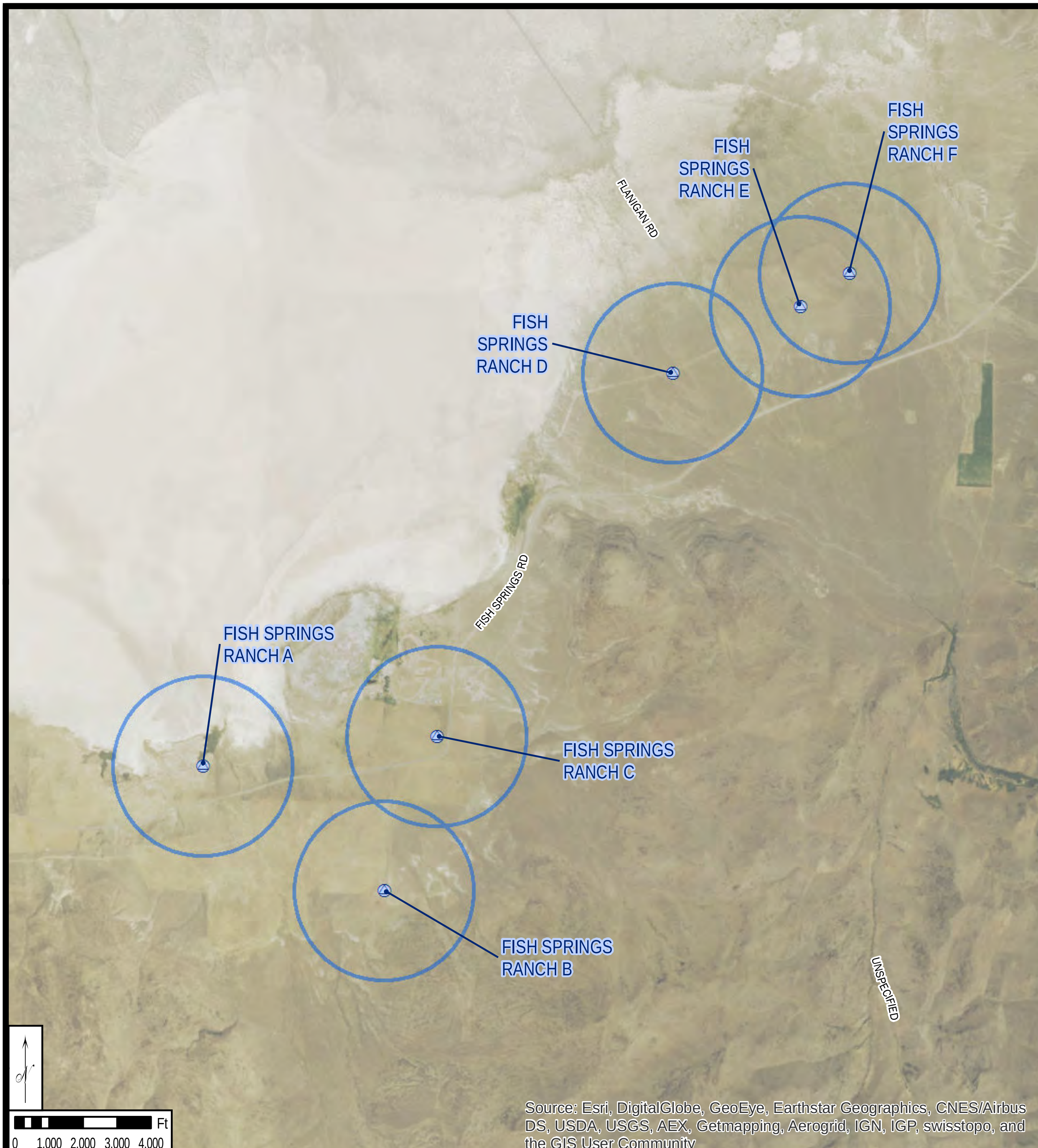
OVERALL AREA INDEX MAP

Water Supply Well
Cities and Towns
USA States
USA Counties
Nevada Hydrobasins
Interstate Route
US Highway
State Route
Local Streets

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_OverallAreaIndex_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELLHEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

HONEY LAKE VALLEY (BASIN 97) AREA INDEX

TMWA

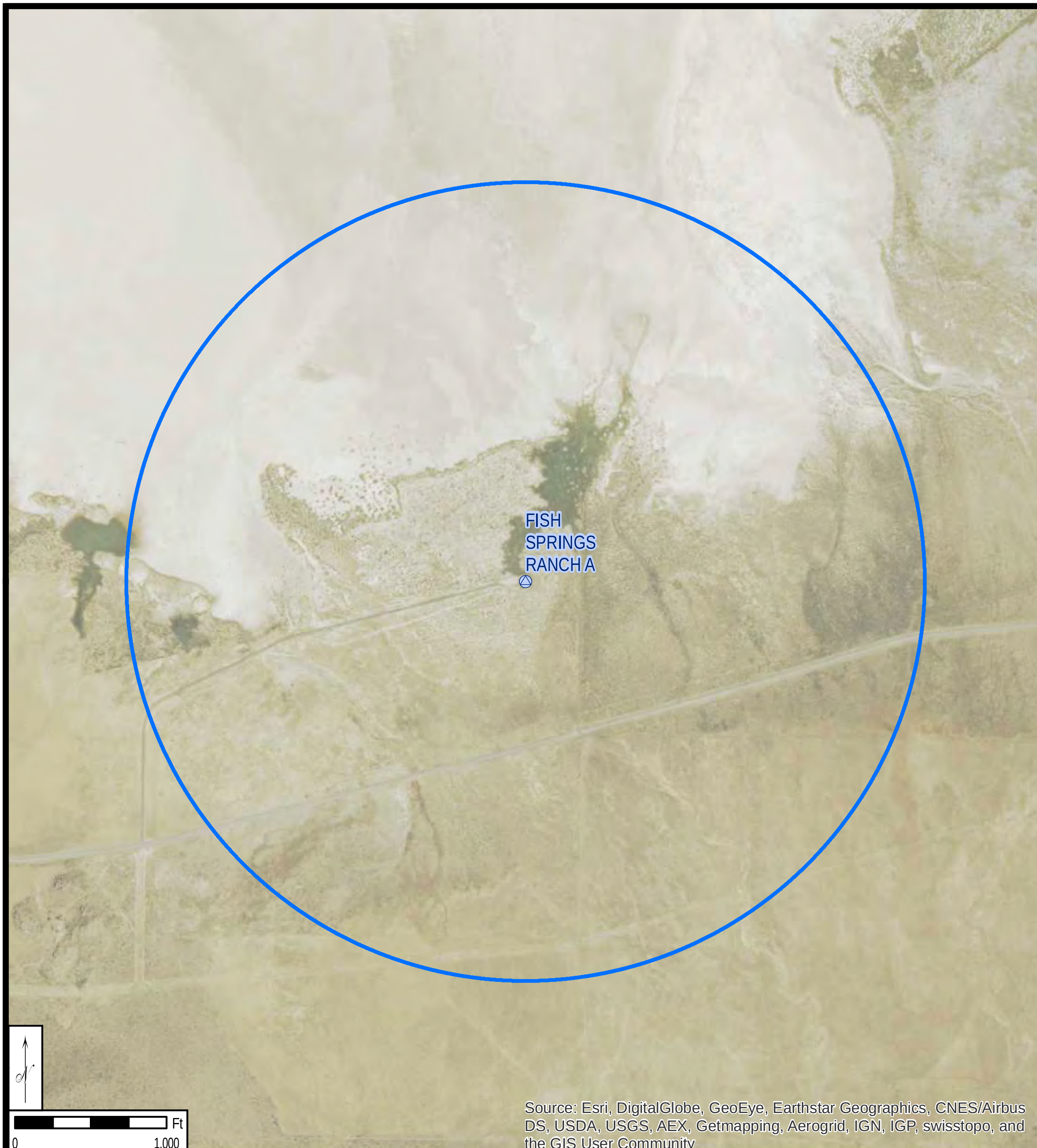
NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

WATER SUPPLY WELL

1/2 MILE CAPTURE ZONE

NEVADA HYDROBASIN BOUNDARY

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_AreaIndex_DD_8.5X11.mxd, Editor: Michael, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

HONEY LAKE VALLEY (BASIN 97) -- FIGURE: 1

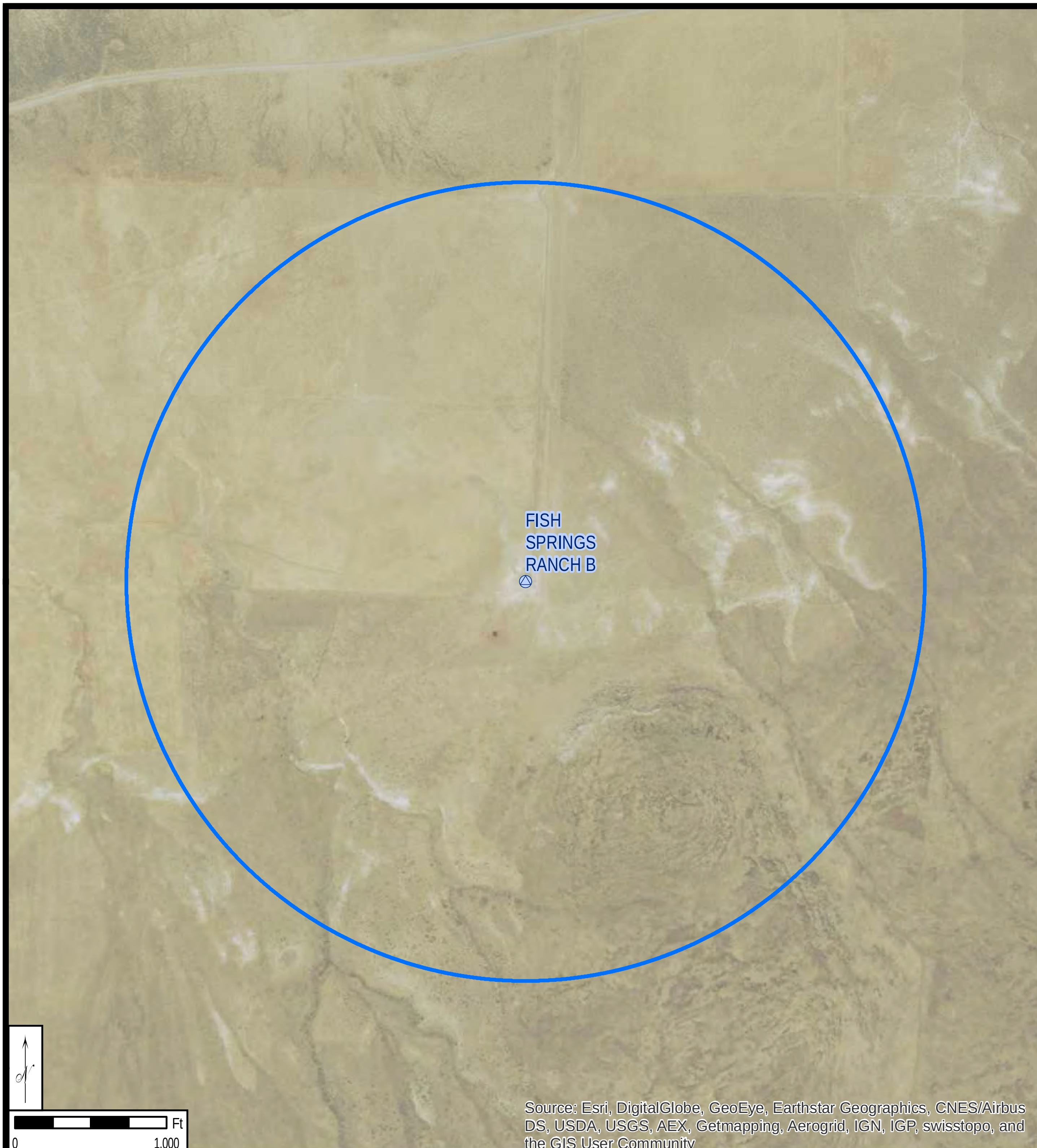
FISH SPRINGS RANCH A WELL SITE

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

WATER SUPPLY WELL   1/2 MILE CAPTURE ZONE

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

HONEY LAKE VALLEY (BASIN 97) -- FIGURE: 2

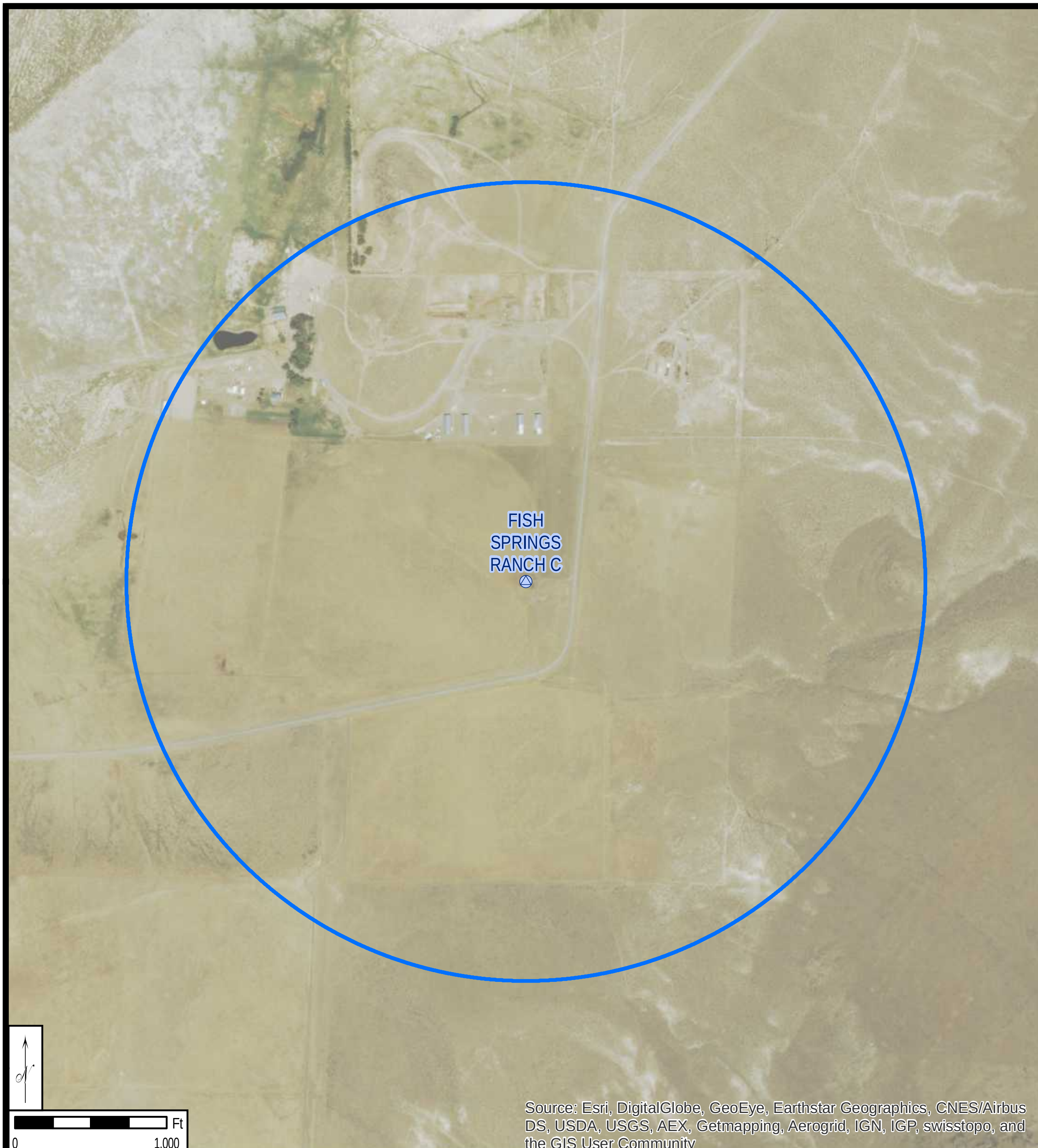
FISH SPRINGS RANCH B WELL SITE

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

WATER SUPPLY WELL   1/2 MILE CAPTURE ZONE

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

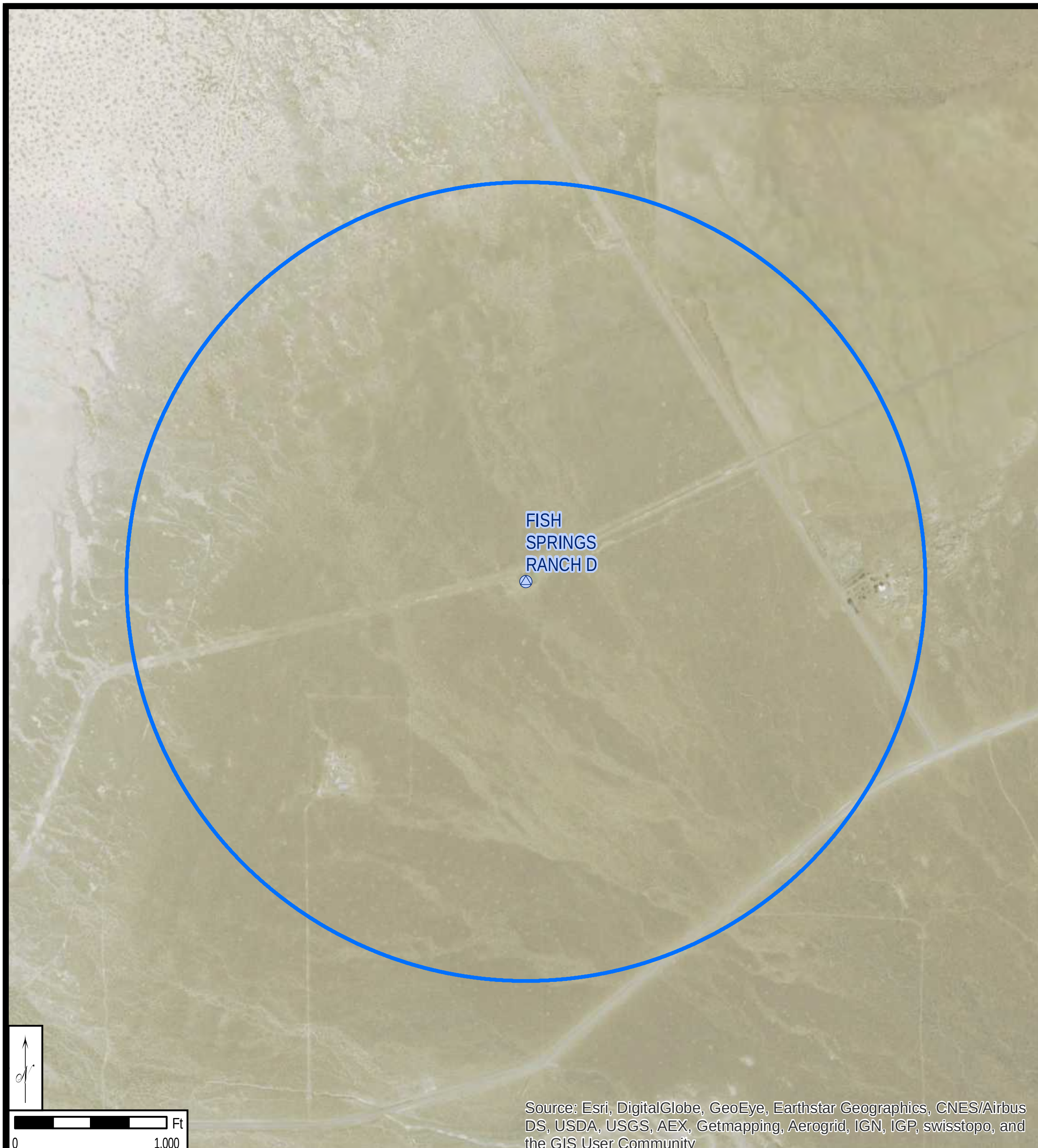
HONEY LAKE VALLEY (BASIN 97) -- FIGURE: 3

FISH SPRINGS RANCH C WELL SITE

TMWA

WATER SUPPLY WELL   1/2 MILE CAPTURE ZONE

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

HONEY LAKE VALLEY (BASIN 97) -- FIGURE: 4

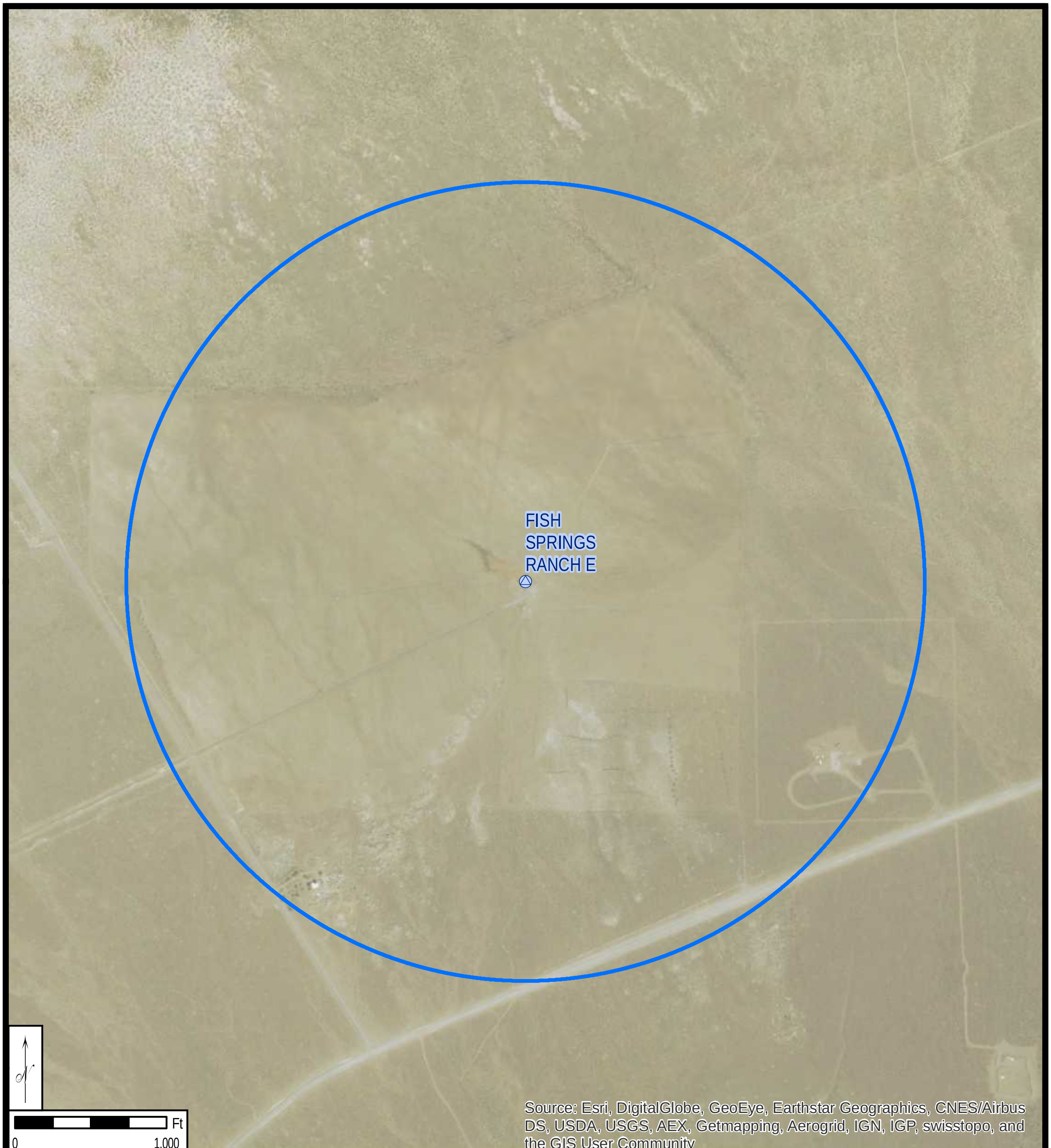
FISH SPRINGS RANCH D WELL SITE

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

WATER SUPPLY WELL 1/2 MILE CAPTURE ZONE

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

HONEY LAKE VALLEY (BASIN 97) -- FIGURE: 5

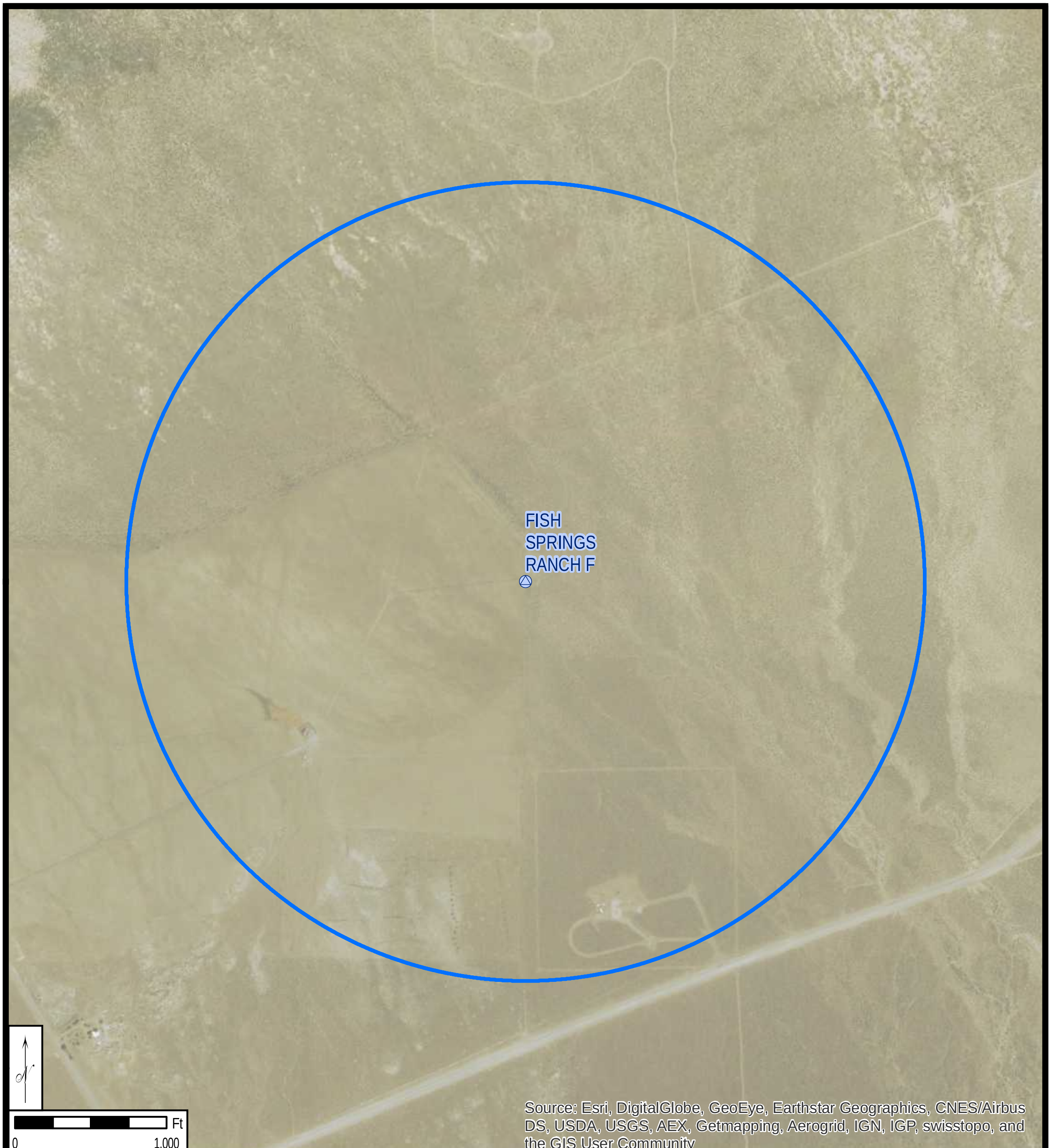
FISH SPRINGS RANCH E WELL SITE

TMWA

WATER SUPPLY WELL 1/2 MILE CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

HONEY LAKE VALLEY (BASIN 97) -- FIGURE: 6

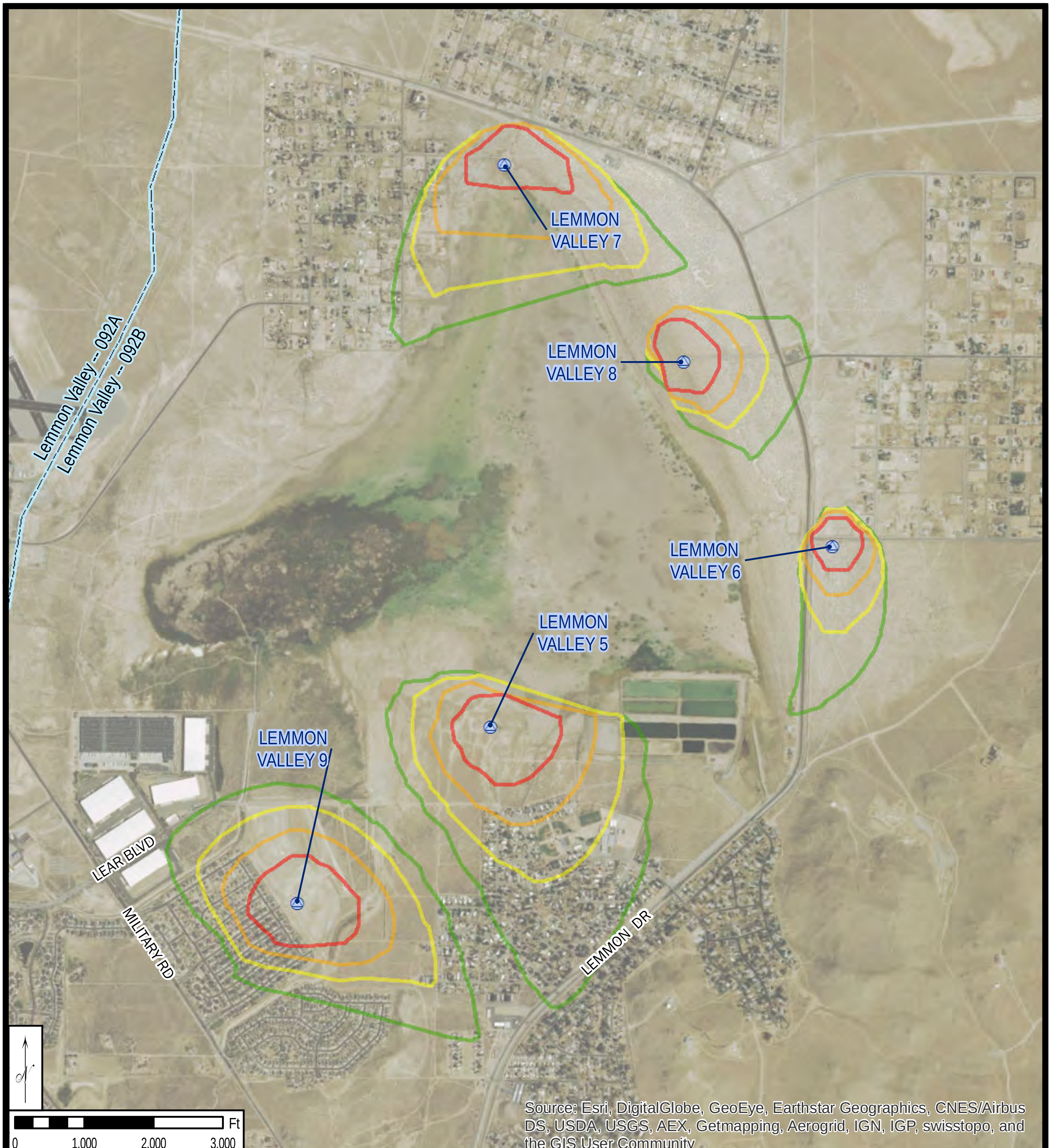
FISH SPRINGS RANCH F WELL SITE

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

WATER SUPPLY WELL 1/2 MILE CAPTURE ZONE

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELLHEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

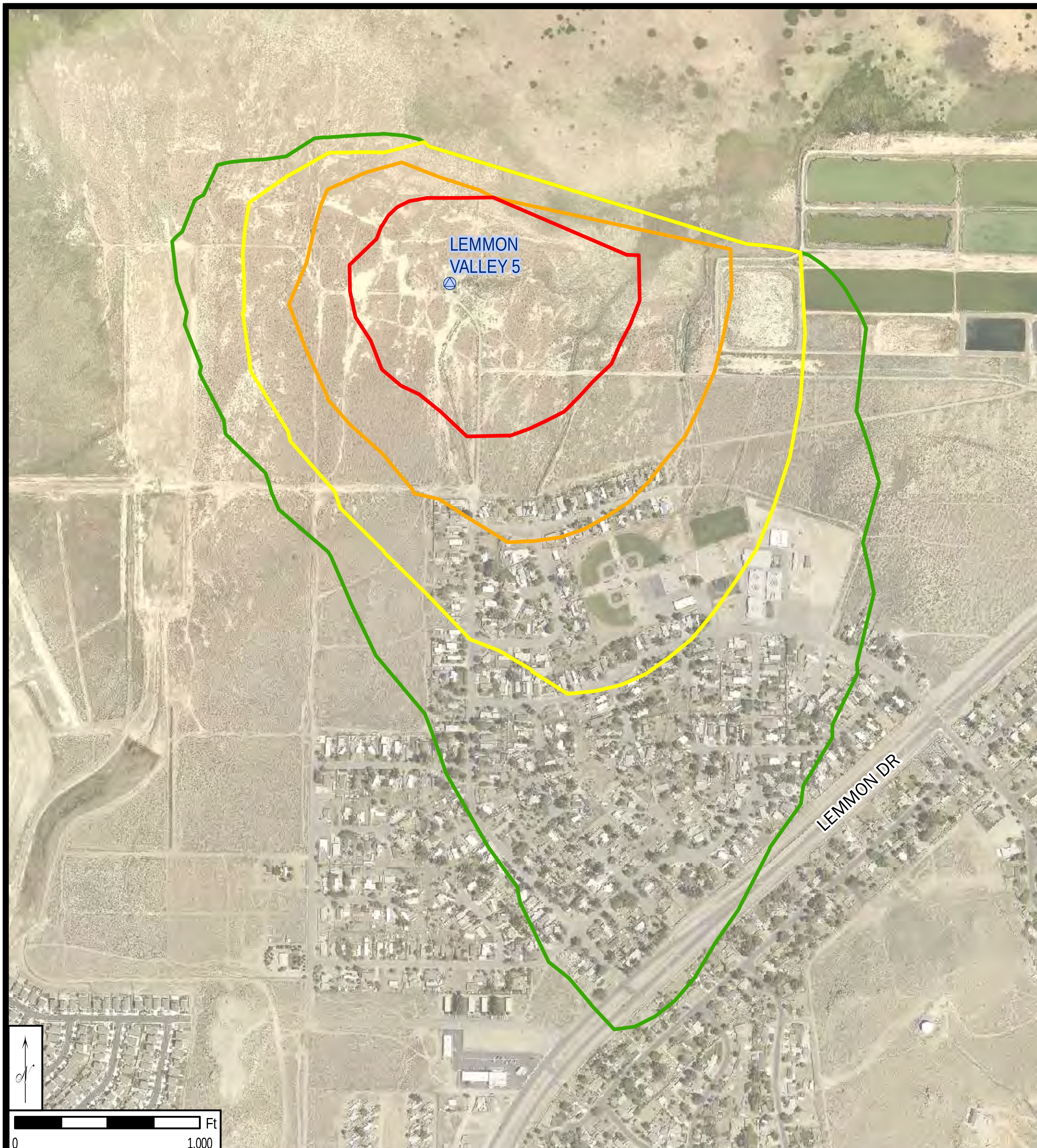
LEMMON VALLEY (EAST) (BASIN 92B) AREA INDEX

- WATER SUPPLY WELL
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE
- NEVADA HYDROBASIN BOUNDARY

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_AreaIndex_DD_8.5X11.mxd, Editor: Michael, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

LEMMON VALLEY (EAST) (BASIN 92B) -- FIGURE: 1

LEMMON VALLEY 5 WELL SITE

WATER SUPPLY WELL

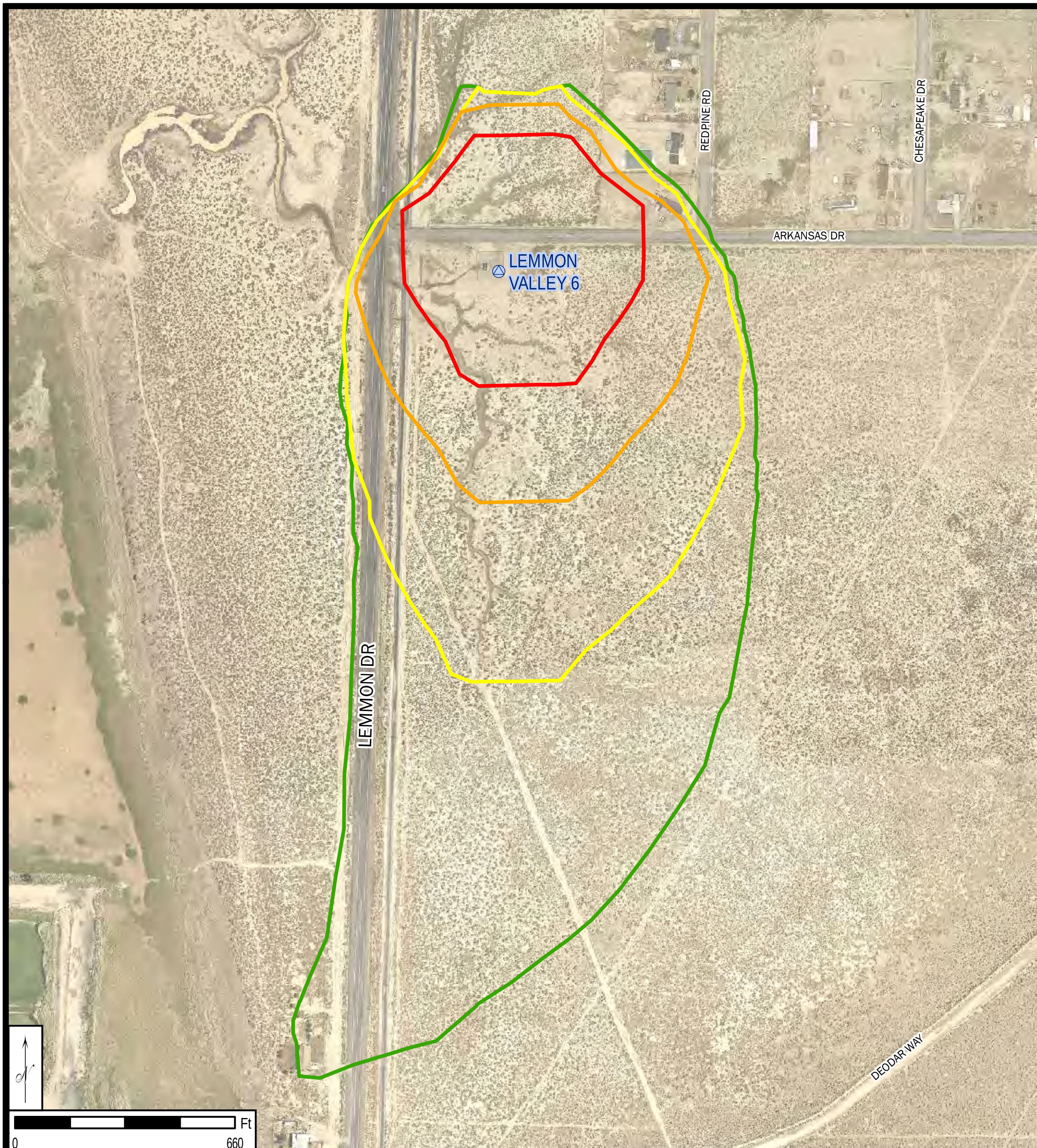
2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

TMWA



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

LEMMON VALLEY (EAST) (BASIN 92B) -- FIGURE: 2

LEMMON VALLEY 6 WELL SITE

TMWA

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

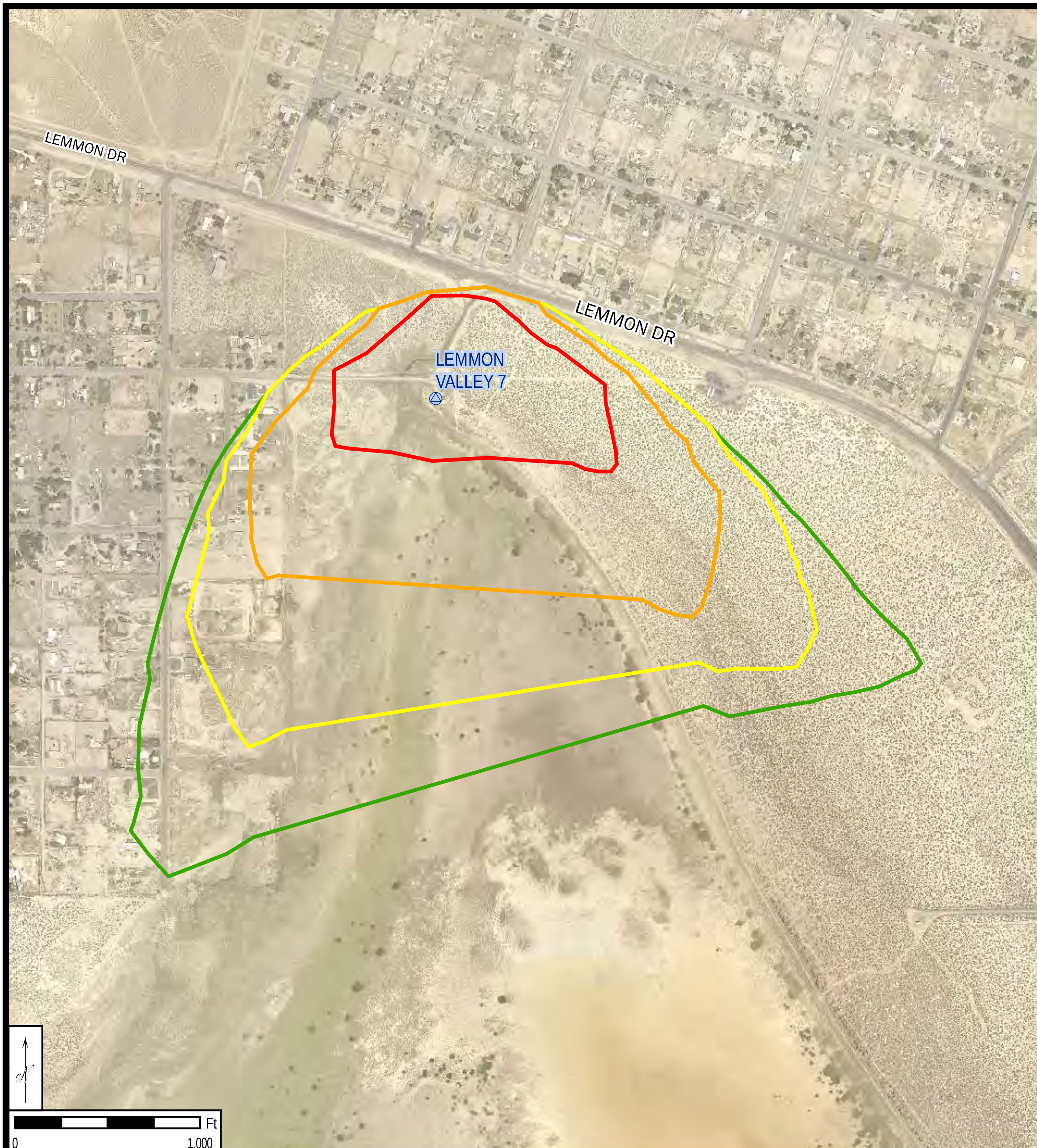
5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

LEMMON VALLEY (EAST) (BASIN 92B) -- FIGURE: 3

LEMMON VALLEY 7 WELL SITE

TMWA

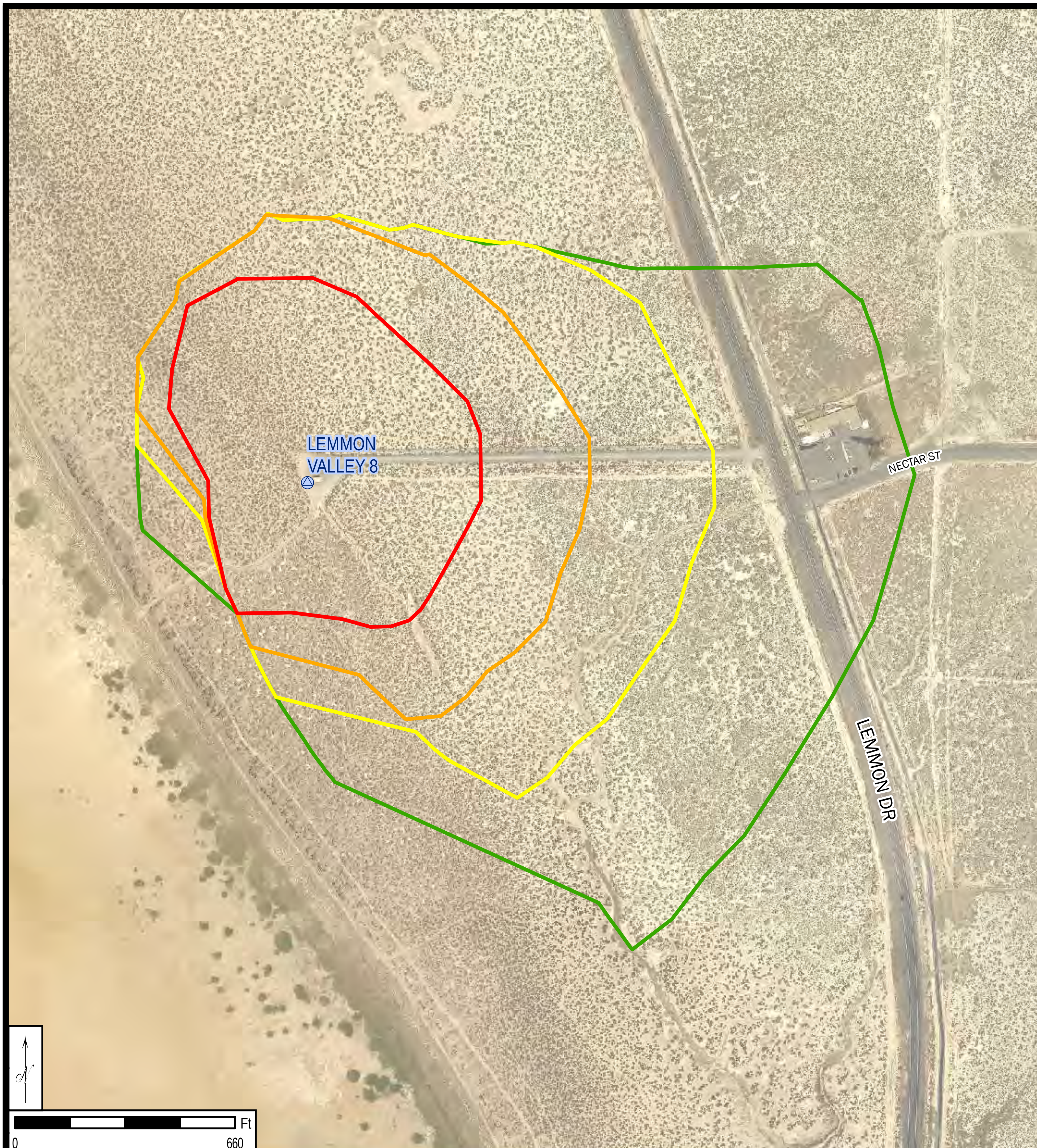
WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

LEMMON VALLEY (EAST) (BASIN 92B) -- FIGURE: 4

LEMMON VALLEY 8 WELL SITE

WATER SUPPLY WELL

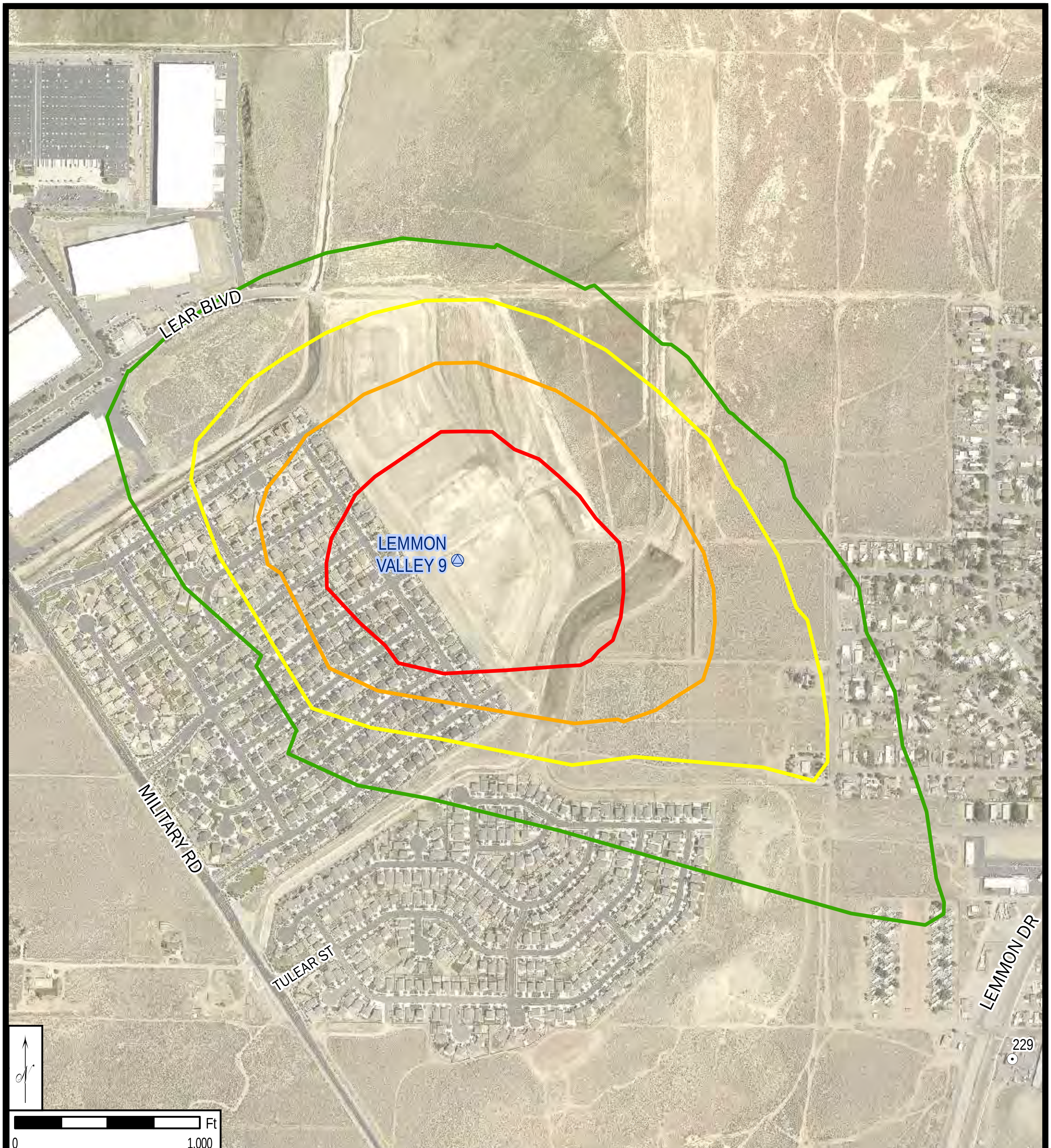
2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

TMWA



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

LEMMON VALLEY (EAST) (BASIN 92B) -- FIGURE: 5

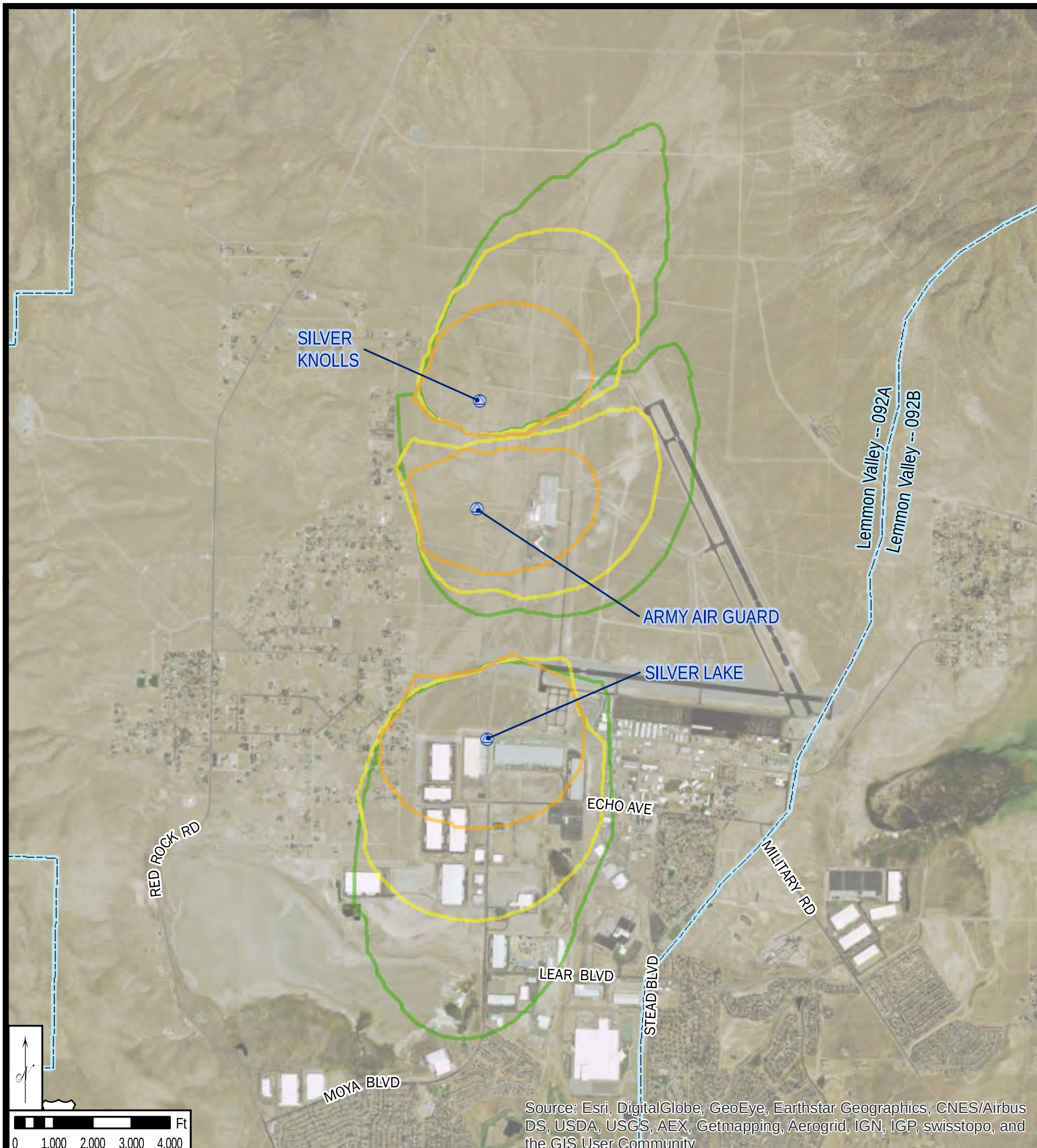
LEMMON VALLEY 9 WELL SITE

TMWA

- POTENTIAL CONTAMINANT SOURCE -- (EPA)
- WATER SUPPLY WELL
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELLHEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

LEMMON VALLEY (WEST) (BASIN 92A) AREA INDEX

TMWA

WATER SUPPLY WELL

5 YEAR CAPTURE ZONE

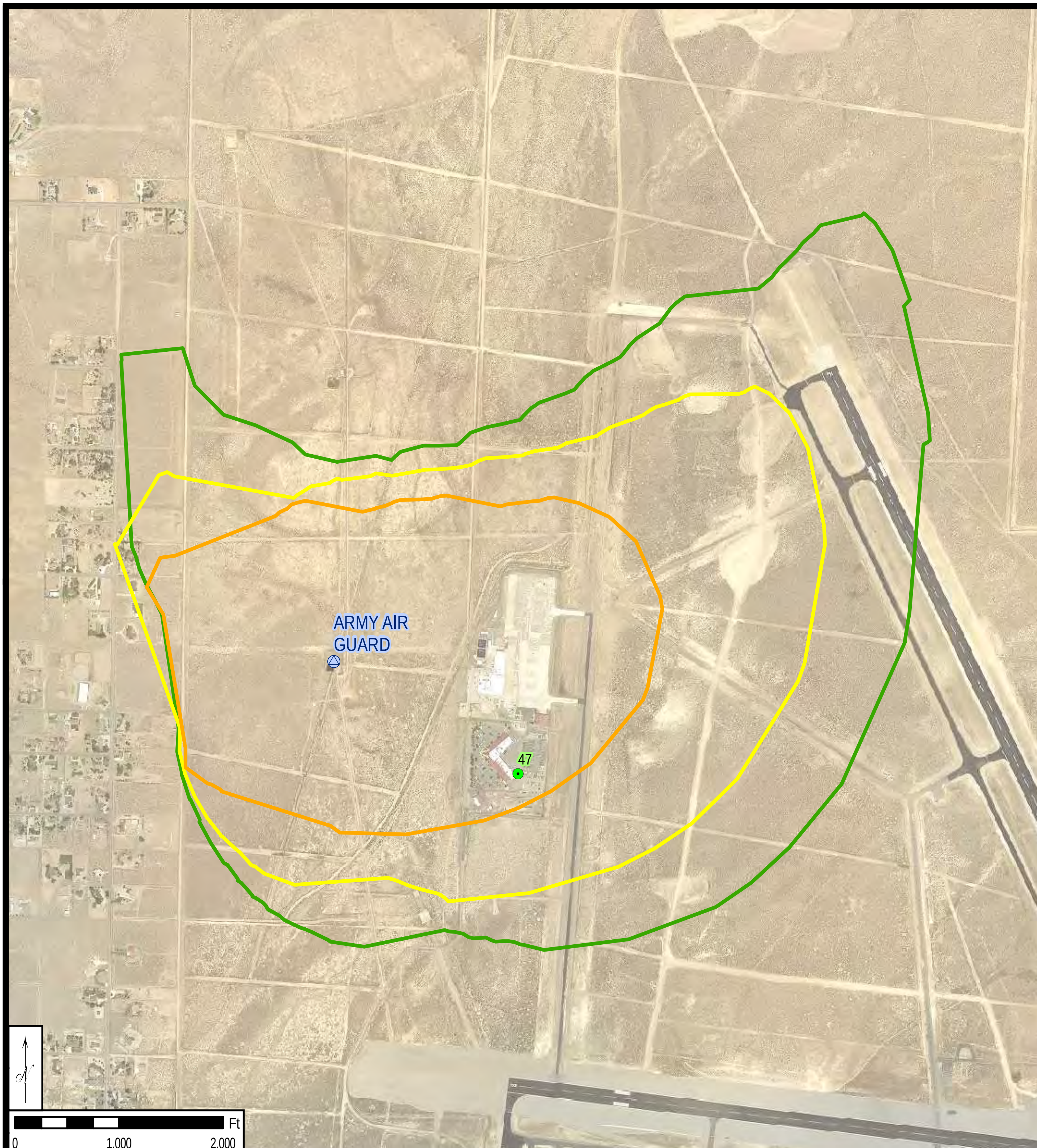
10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NEVADA HYDROBASIN BOUNDARY

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_AreaIndex_DD_8.5X11.mxd, Editor: Michael, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

LEMMON VALLEY (WEST) (BASIN 92A) -- FIGURE: 1

ARMY AIR GUARD WELL SITE

TMWA

POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)

WATER SUPPLY WELL

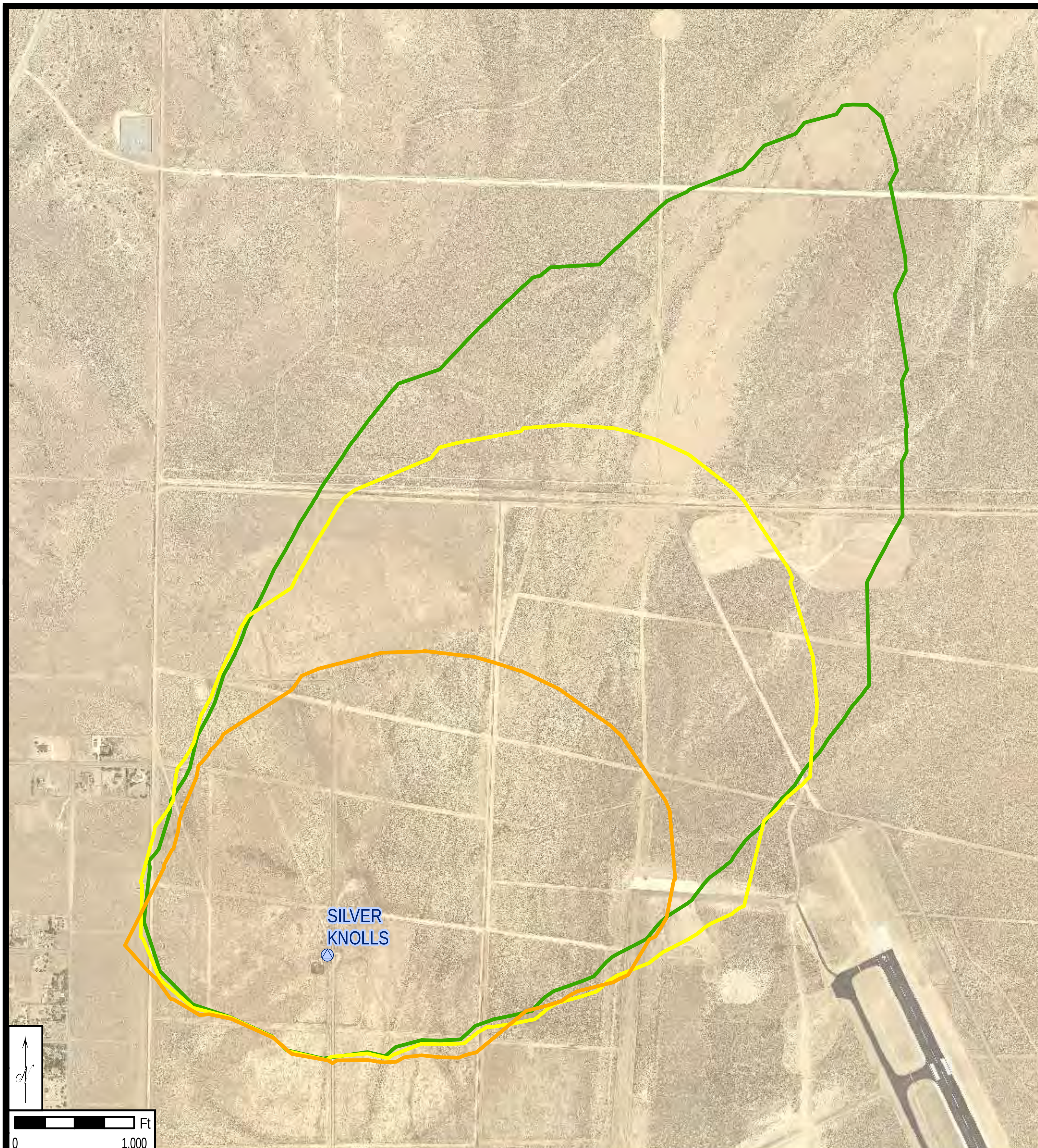
5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

LEMMON VALLEY (WEST) (BASIN 92A) -- FIGURE: 2

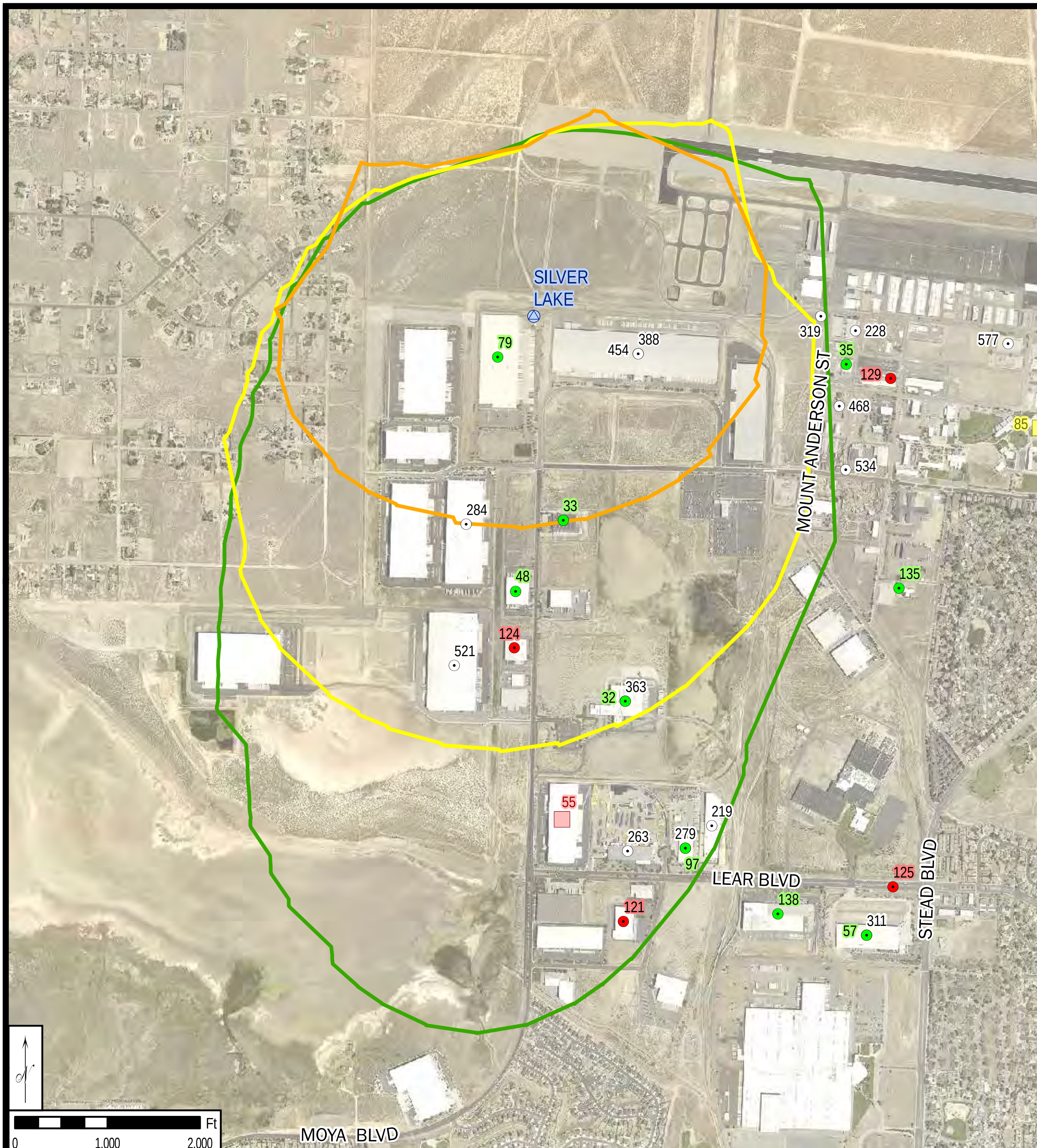
SILVER KNOLLS WELL SITE

TMWA

WATER SUPPLY WELL
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

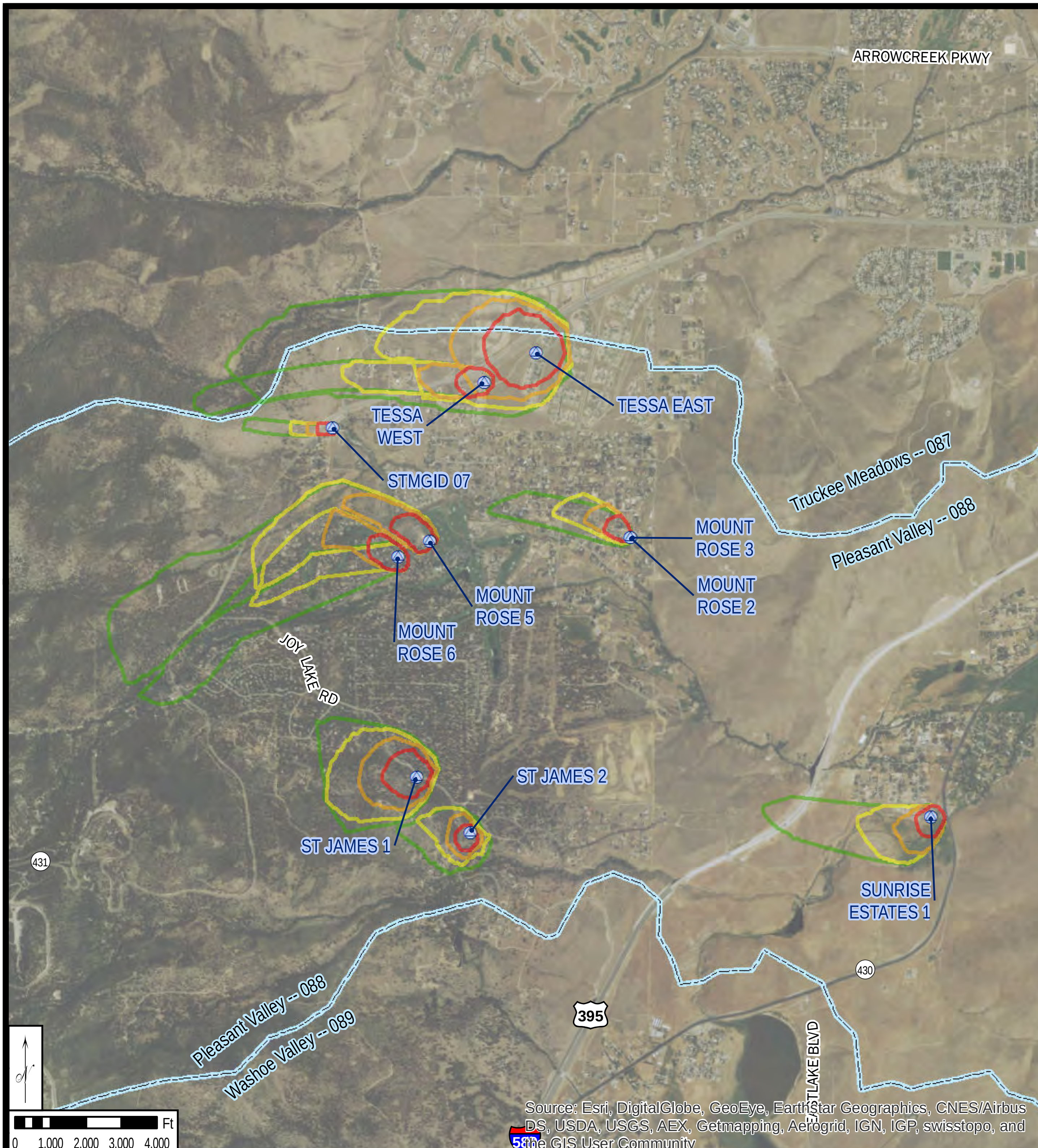
LEMMON VALLEY (WEST) (BASIN 92A) -- FIGURE: 3

SILVER LAKE WELL SITE

POTENTIAL CONTAMINANT SOURCE -- LQG (EPA)	5 YEAR CAPTURE ZONE
POTENTIAL CONTAMINANT SOURCE -- SQG (EPA)	10 YEAR CAPTURE ZONE
POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)	20 YEAR CAPTURE ZONE
POTENTIAL CONTAMINANT SOURCE -- (EPA)	CONTAMINANT RELEASE SITE - INACTIVE (NDEP)
WATER SUPPLY WELL	
CONTAMINANT RELEASE SITE - ACTIVE (NDEP)	

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.



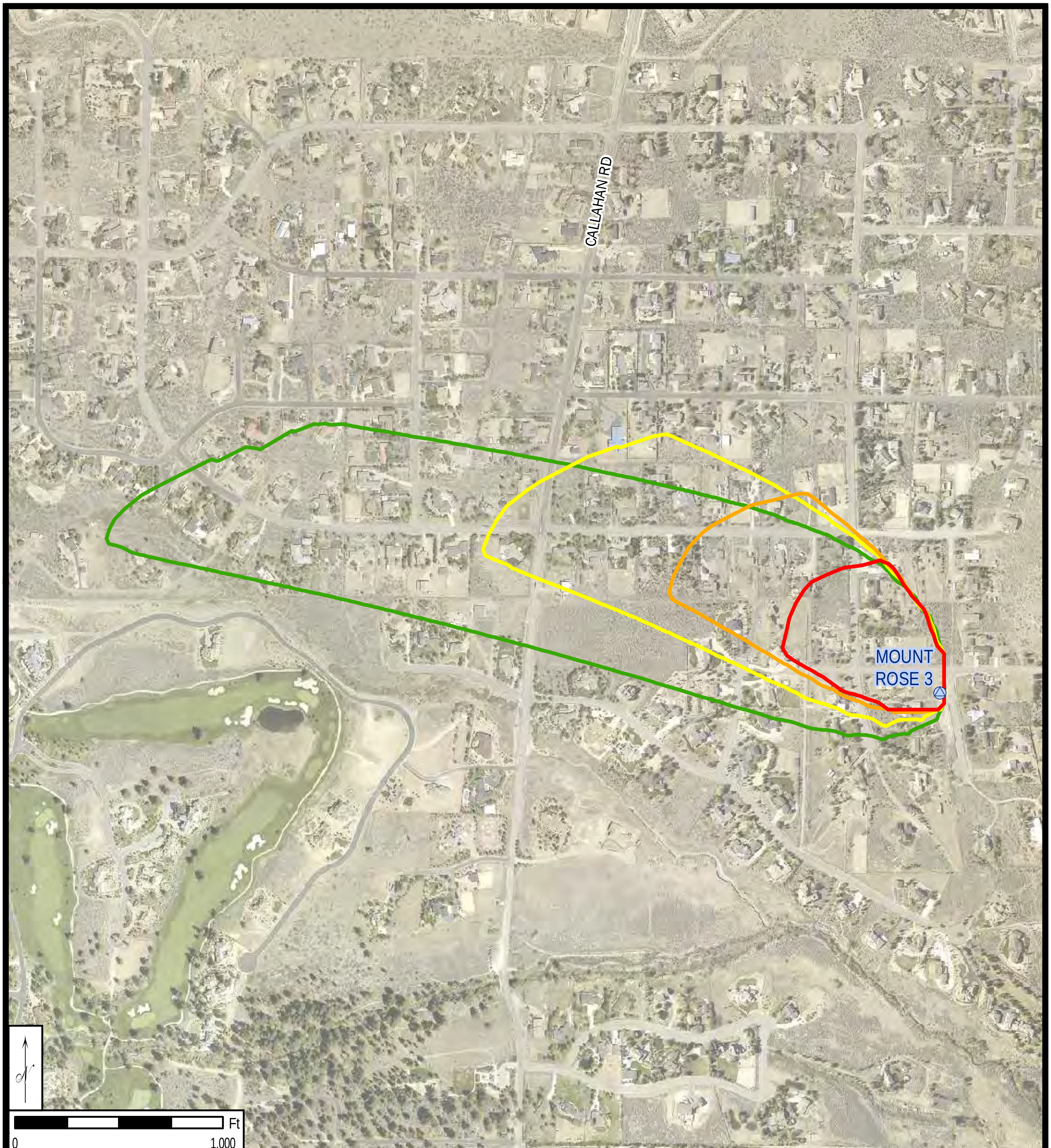
WELLHEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

PLEASANT VALLEY (BASIN 88) AREA INDEX

- WATER SUPPLY WELL
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE
- NEVADA HYDROBASIN BOUNDARY

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

PLEASANT VALLEY (BASIN 88) -- FIGURE: 1

MOUNT ROSE 3 WELL SITE

TMWA

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

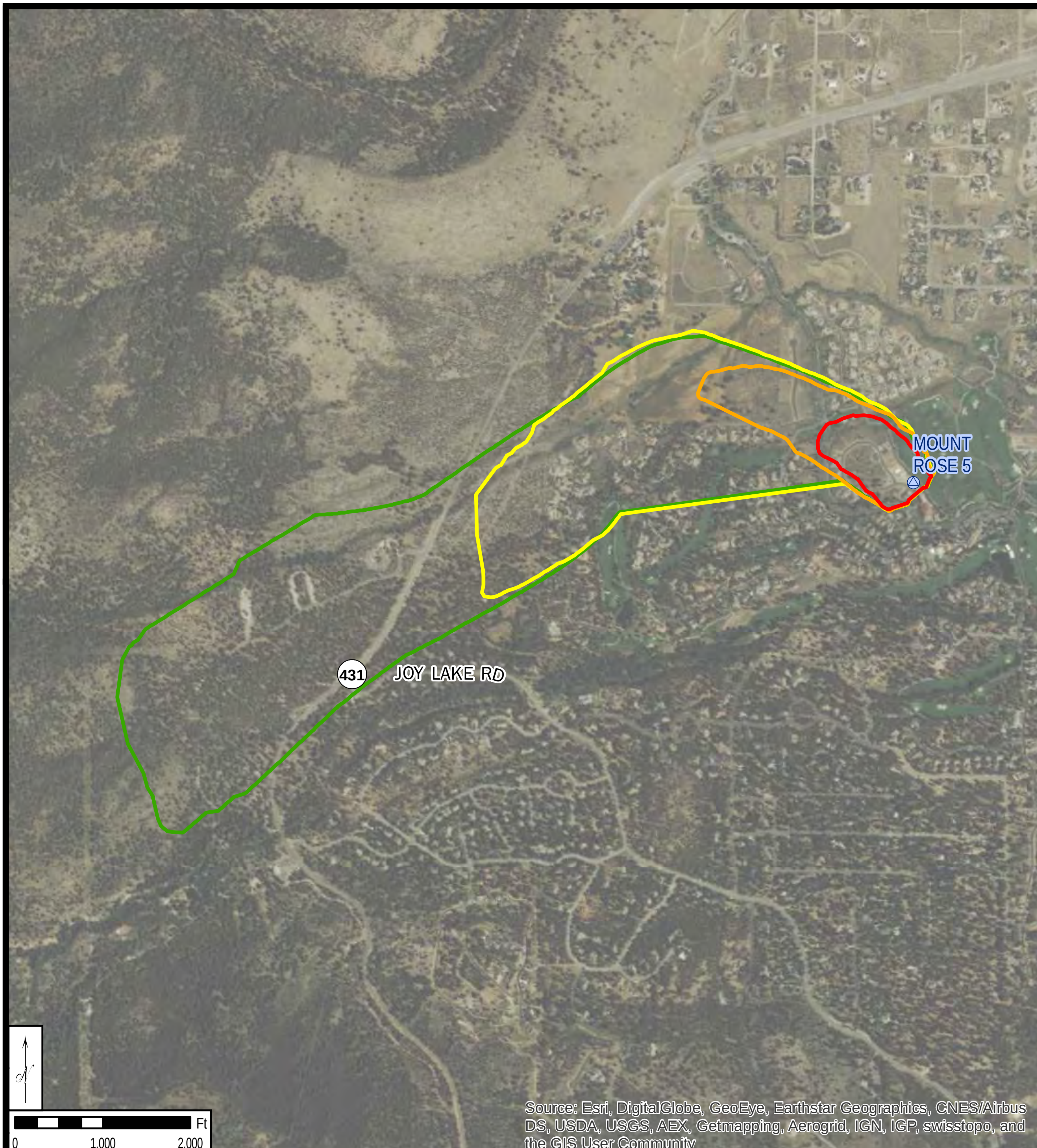
5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

PLEASANT VALLEY (BASIN 88) -- FIGURE: 2

MOUNT ROSE 5 WELL SITE

TMWA

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

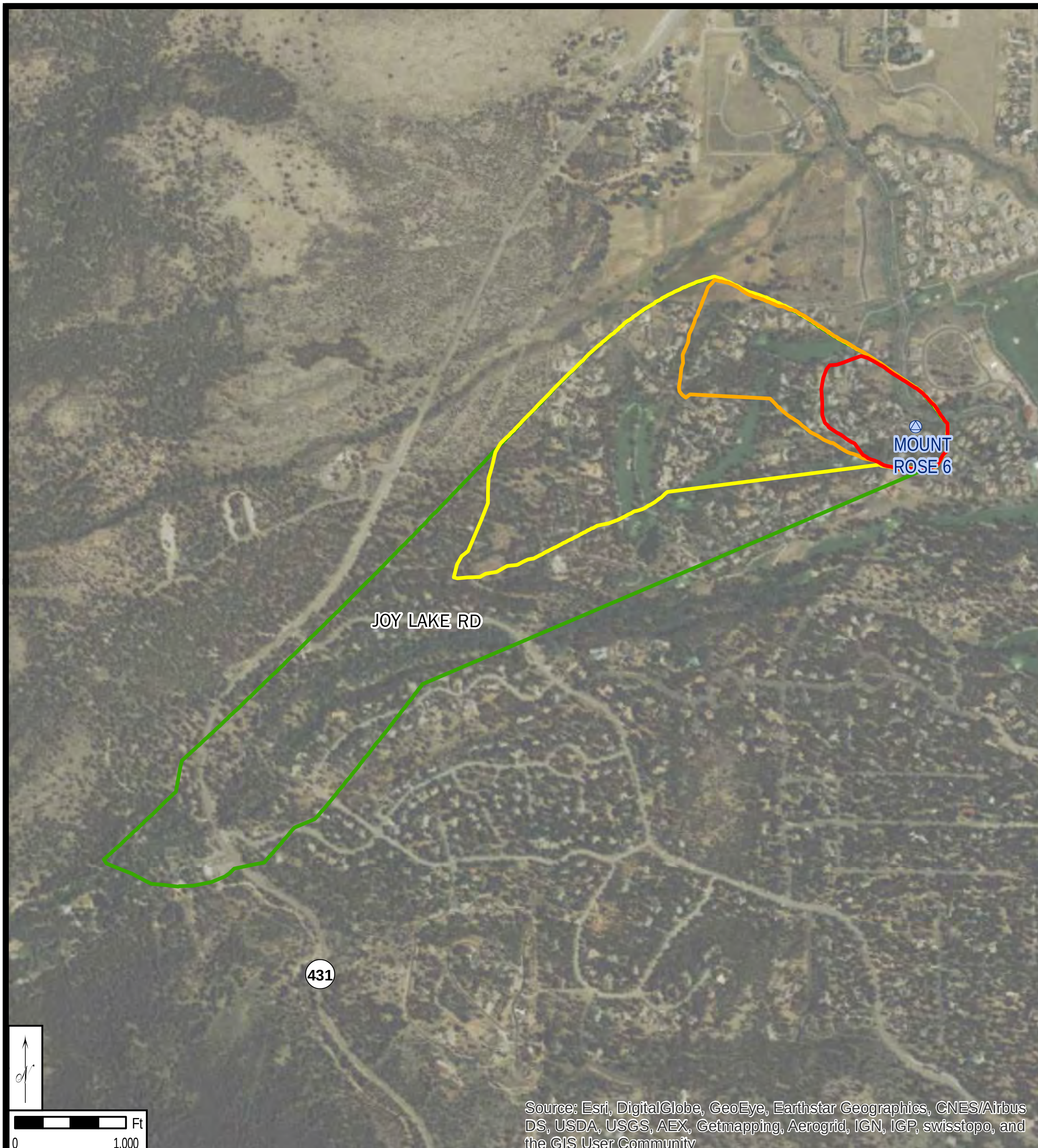
5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

PLEASANT VALLEY (BASIN 88) -- FIGURE: 3

MOUNT ROSE 6 WELL SITE

TMWA

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

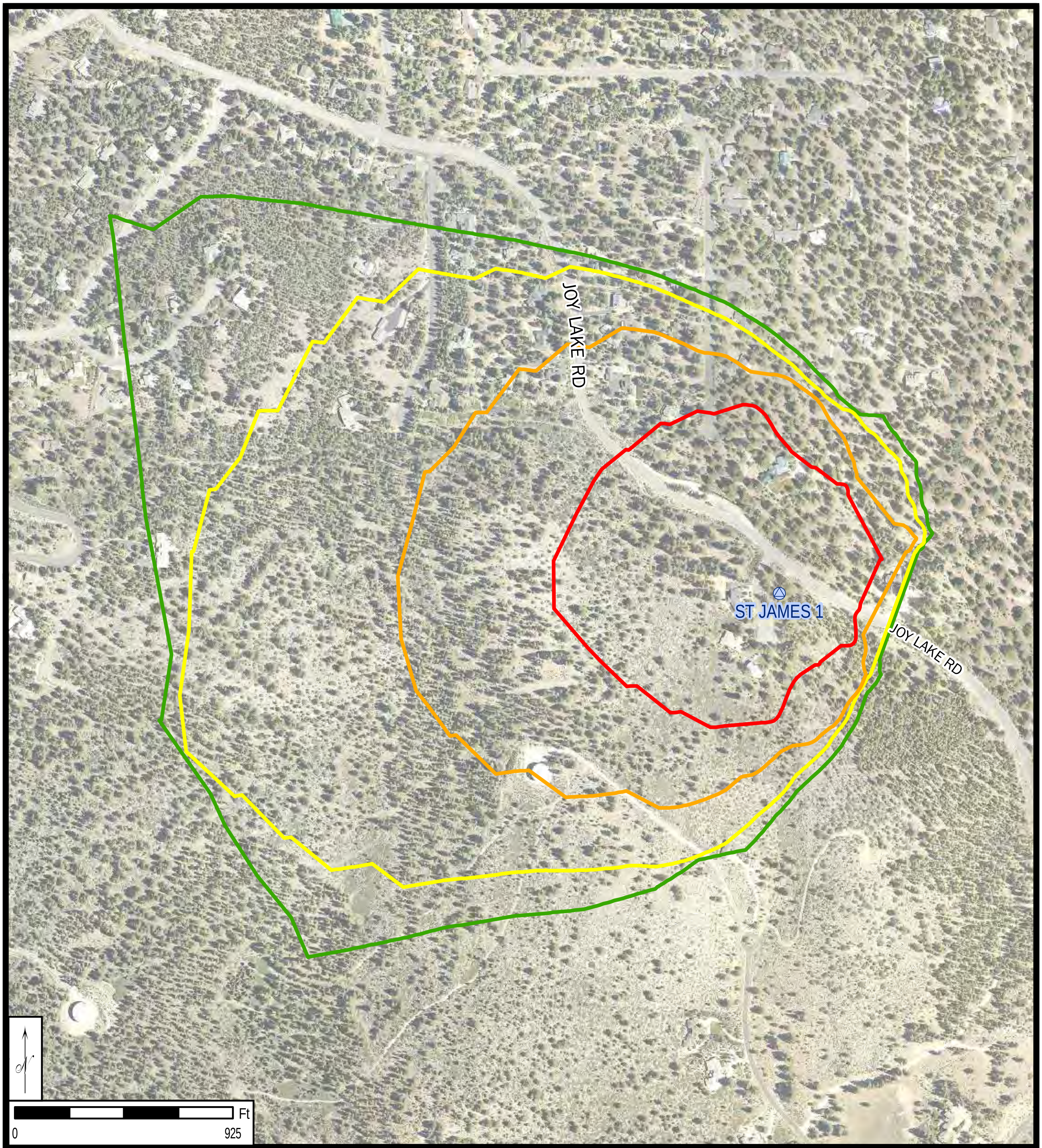
5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

PLEASANT VALLEY (BASIN 88) -- FIGURE: 4

ST JAMES 1 WELL SITE

TMWA

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

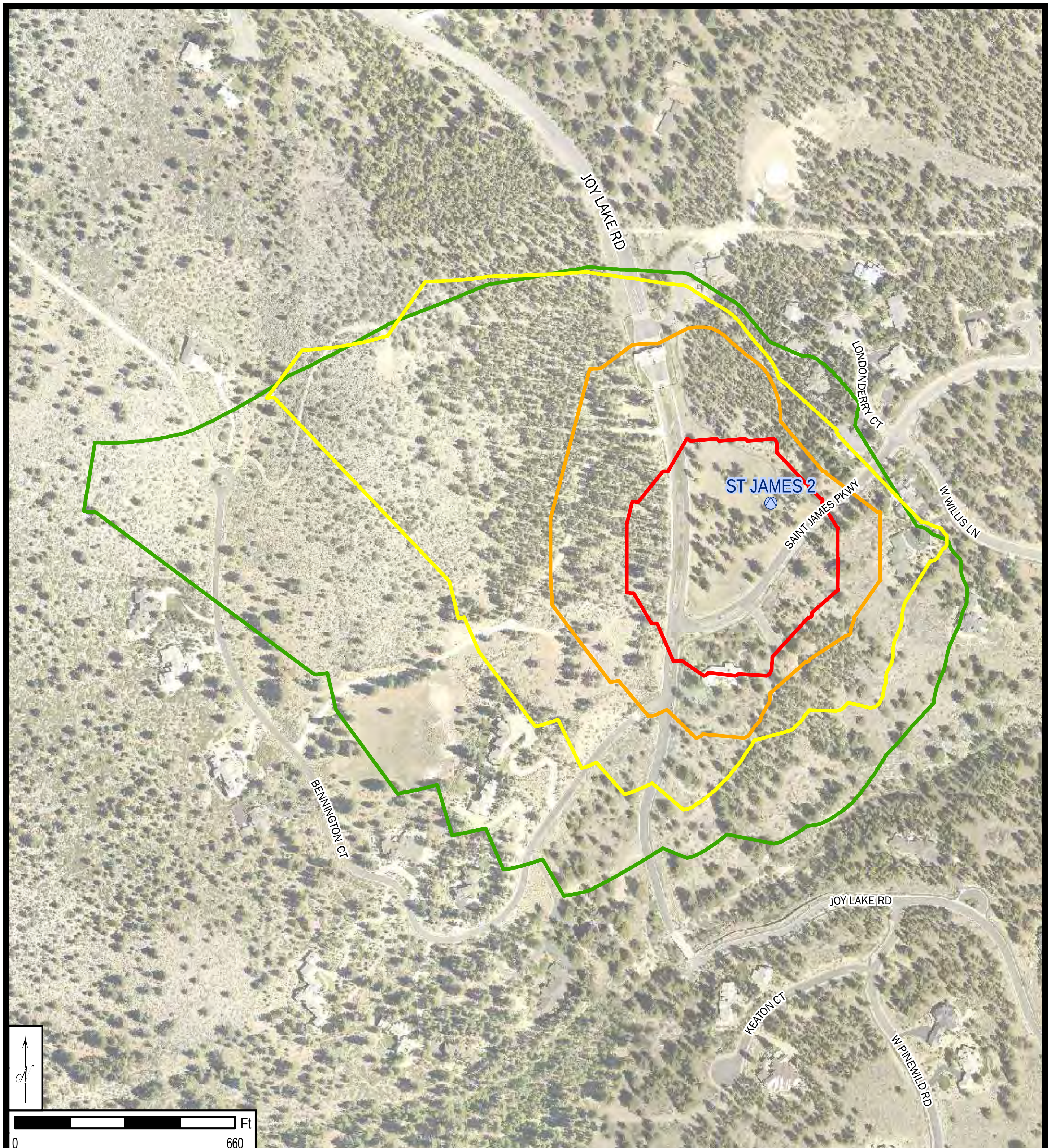
5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

PLEASANT VALLEY (BASIN 88) -- FIGURE: 5

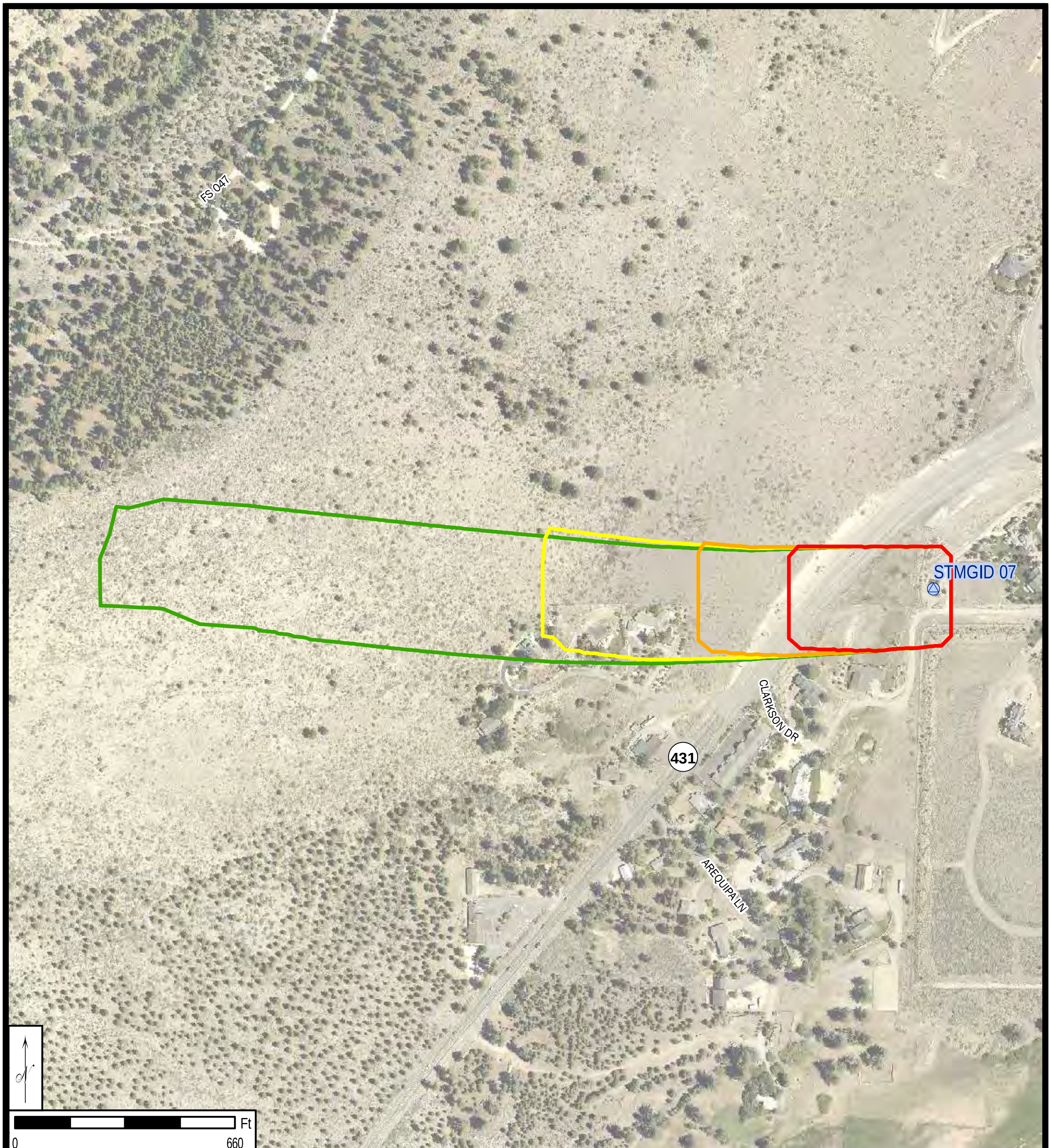
ST JAMES 2 WELL SITE

TMWA

WATER SUPPLY WELL
2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

PLEASANT VALLEY (BASIN 88) -- FIGURE: 6

STMGID 07 WELL SITE

TMWA

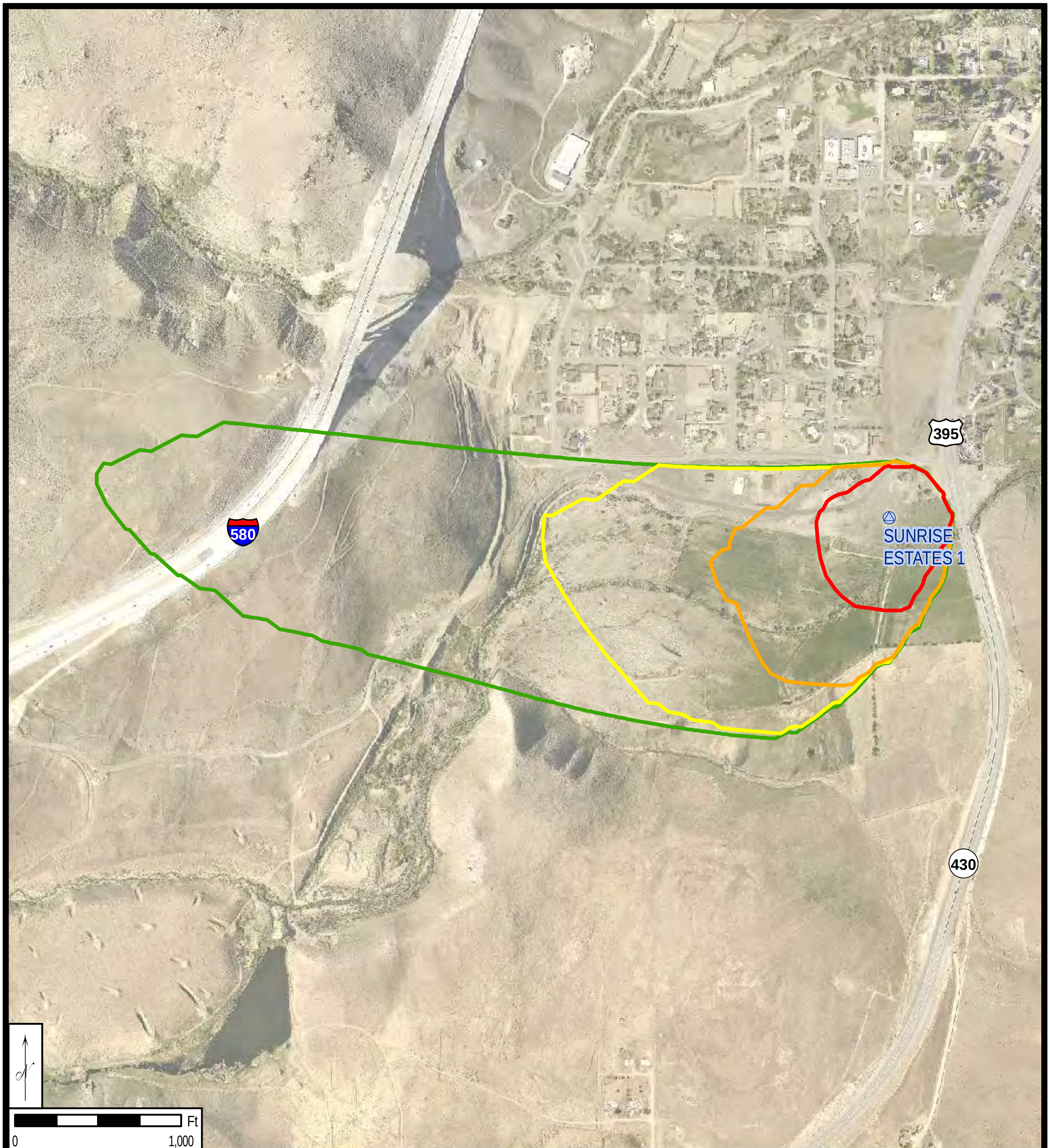
WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

PLEASANT VALLEY (BASIN 88) -- FIGURE: 7

SUNRISE ESTATES 1 WELL SITE

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

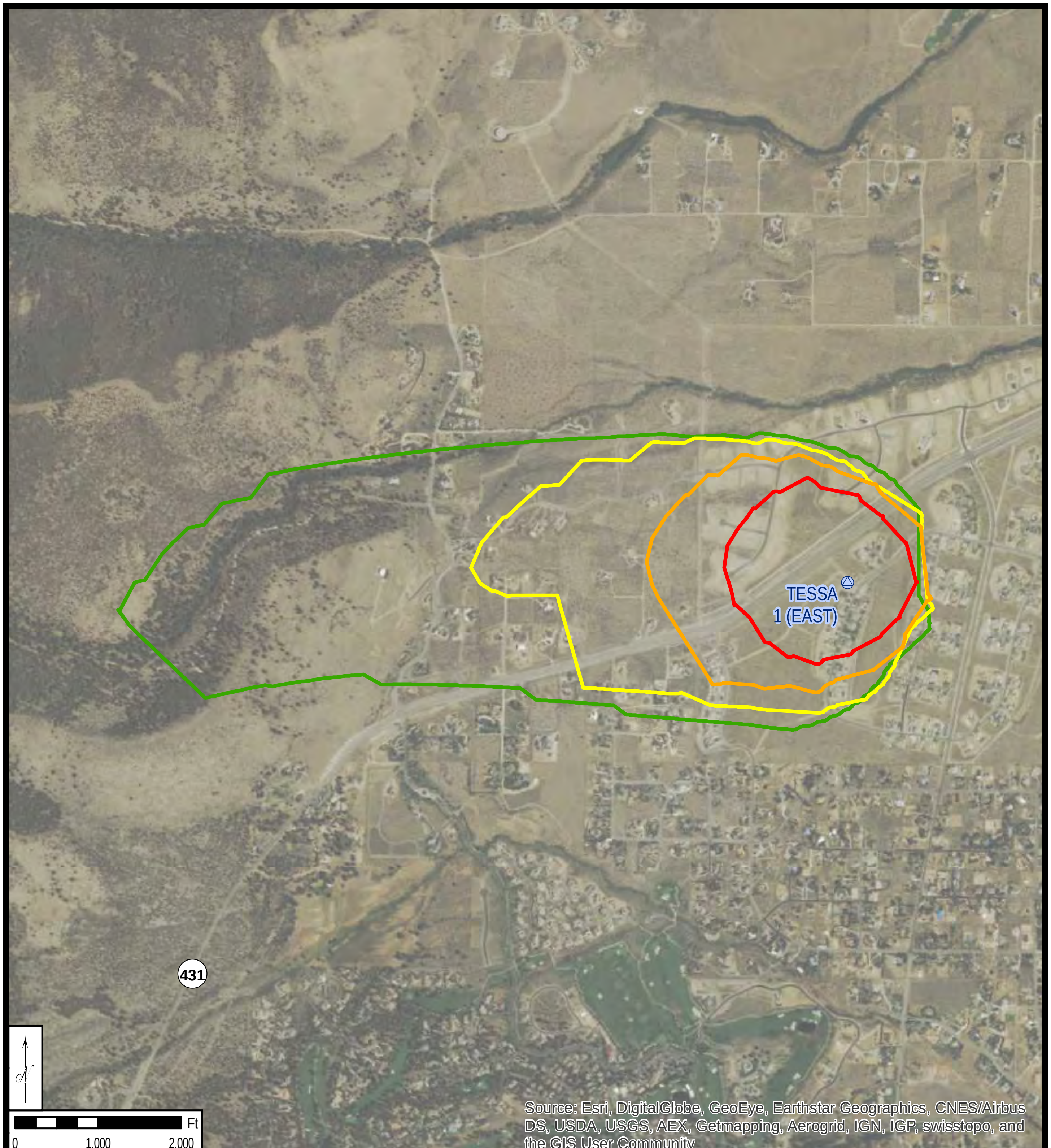
10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

PLEASANT VALLEY (BASIN 88) -- FIGURE: 8

TESSA 1 (EAST) WELL SITE

TMWA

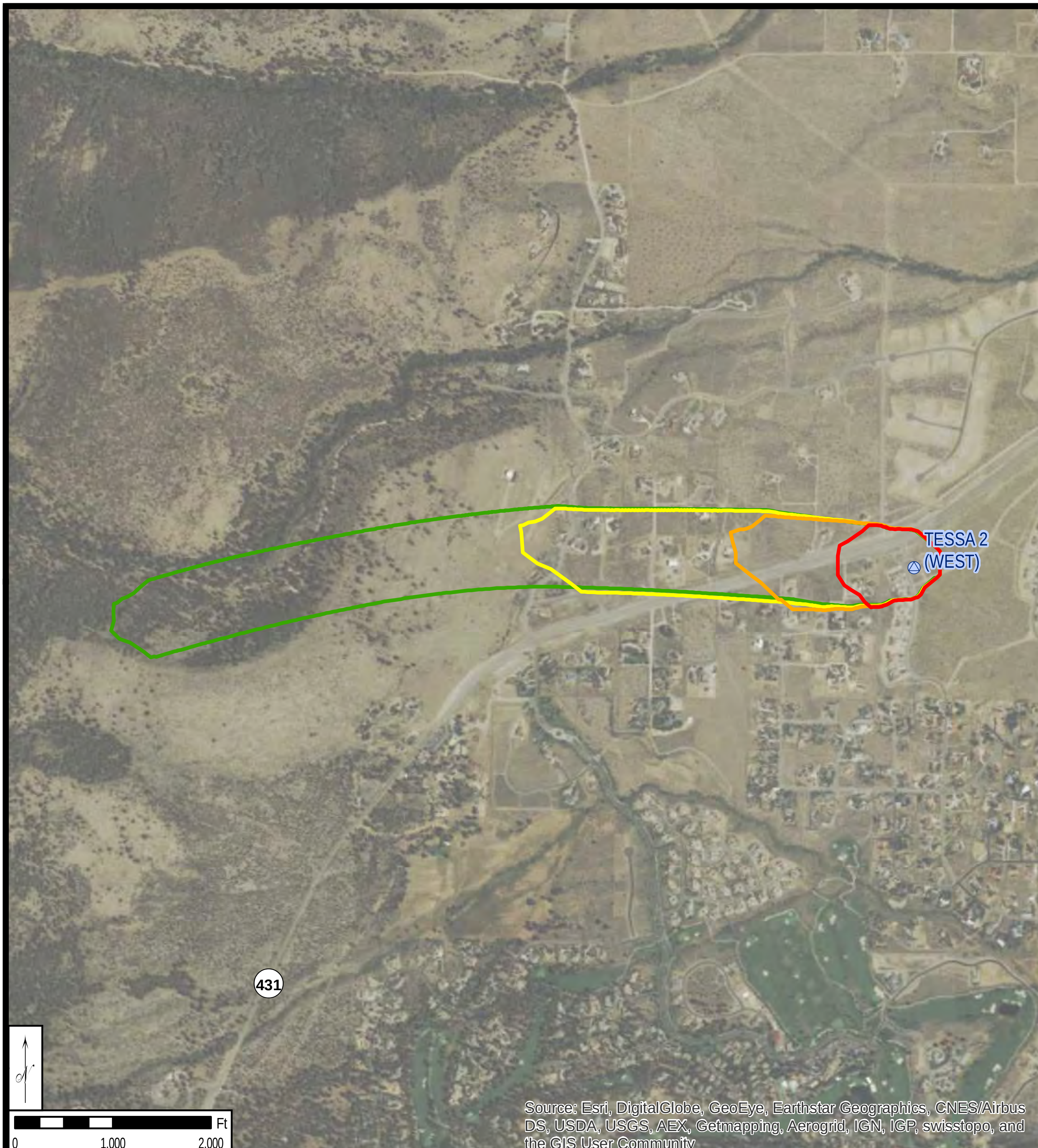
WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

PLEASANT VALLEY (BASIN 88) -- FIGURE: 9

TESSA 2 (WEST) WELL SITE

TMWA

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

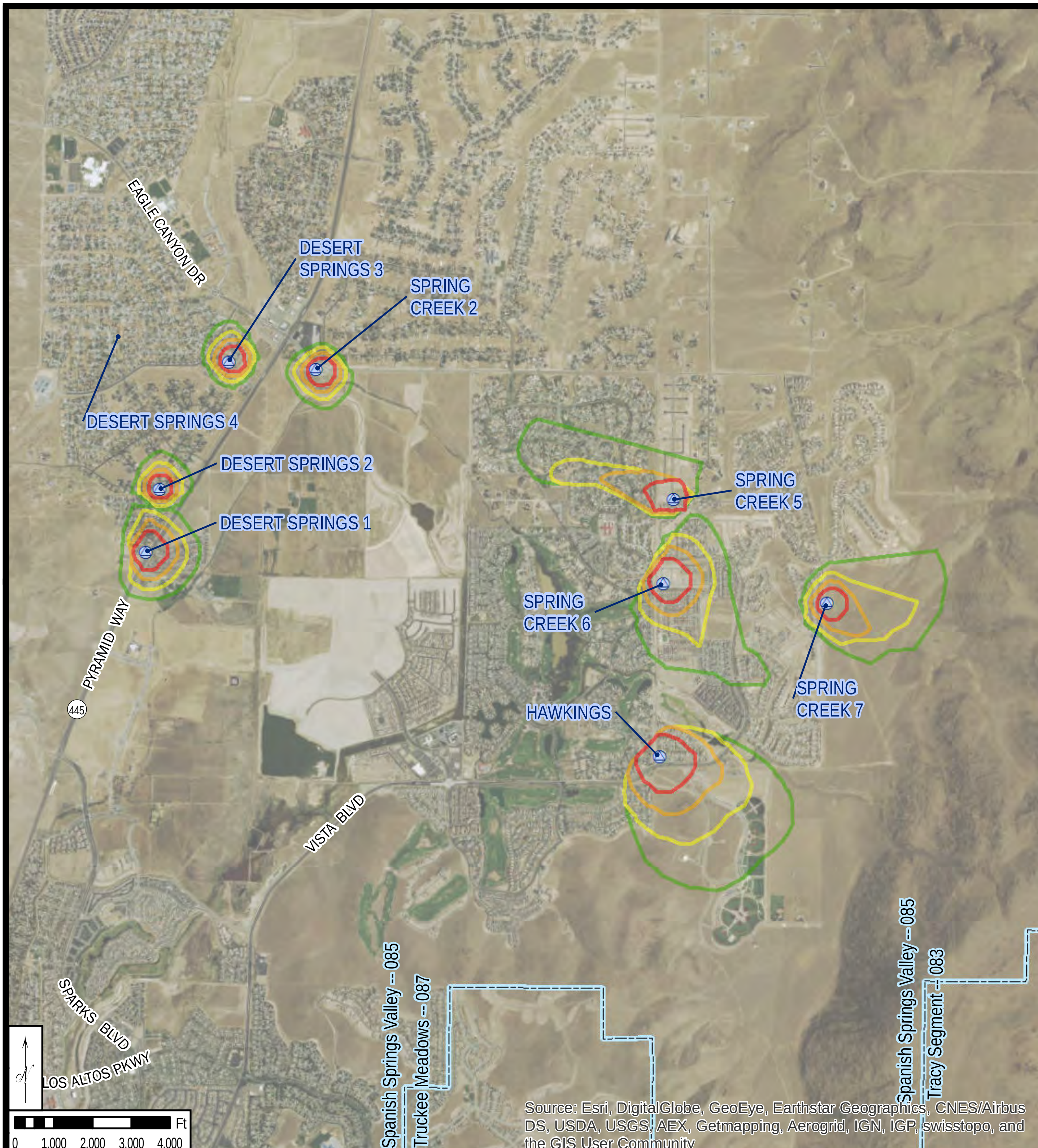
5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELLHEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

SPANISH SPRINGS (BASIN 85) AREA INDEX

TMWA

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

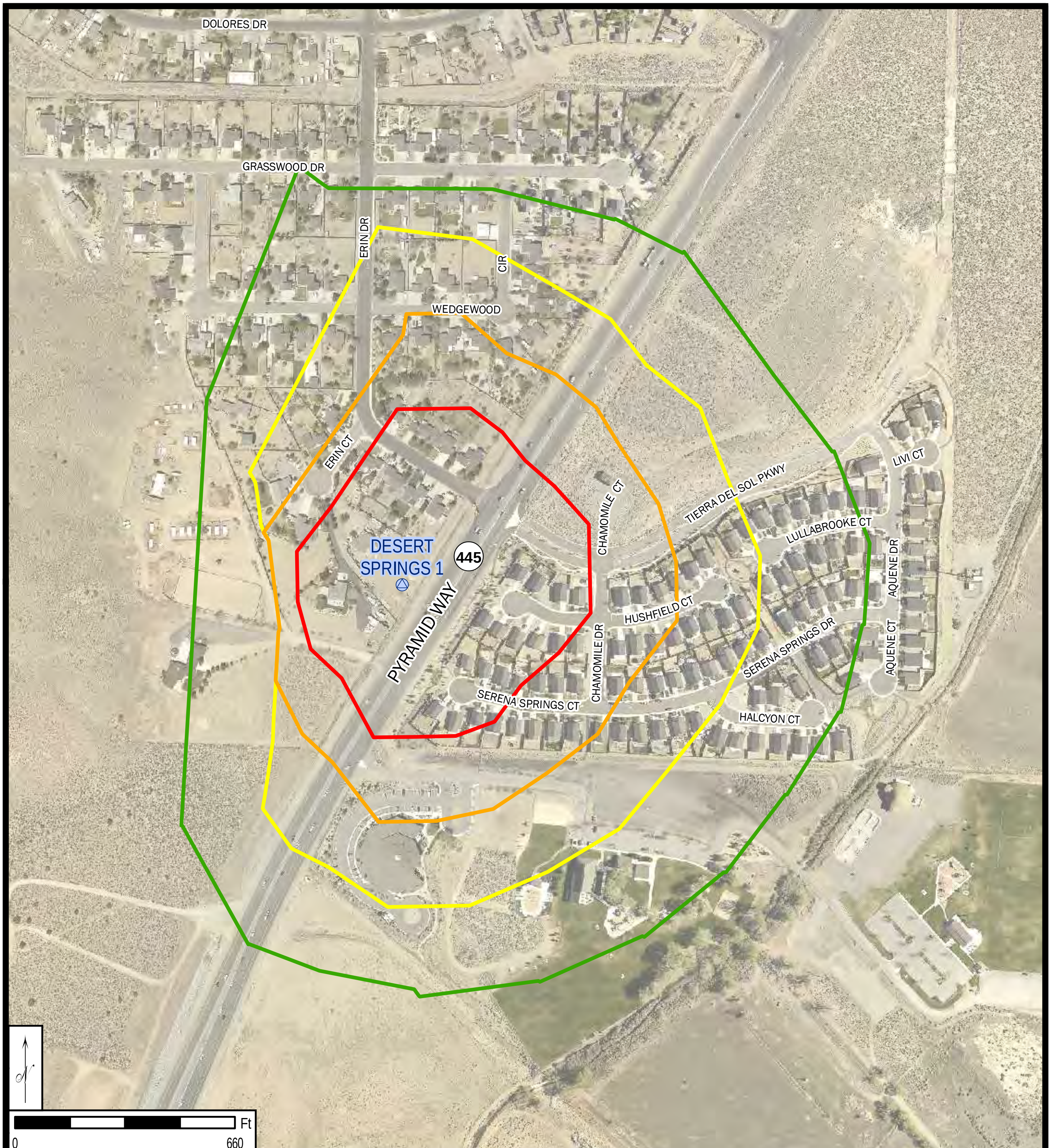
10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NEVADA HYDROBASIN BOUNDARY

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_AreaIndex_DD_8.5X11.mxd, Editor: Michael, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

SPANISH SPRINGS (BASIN 85) -- FIGURE: 1

DESERT SPRINGS 1 WELL SITE

TMWA

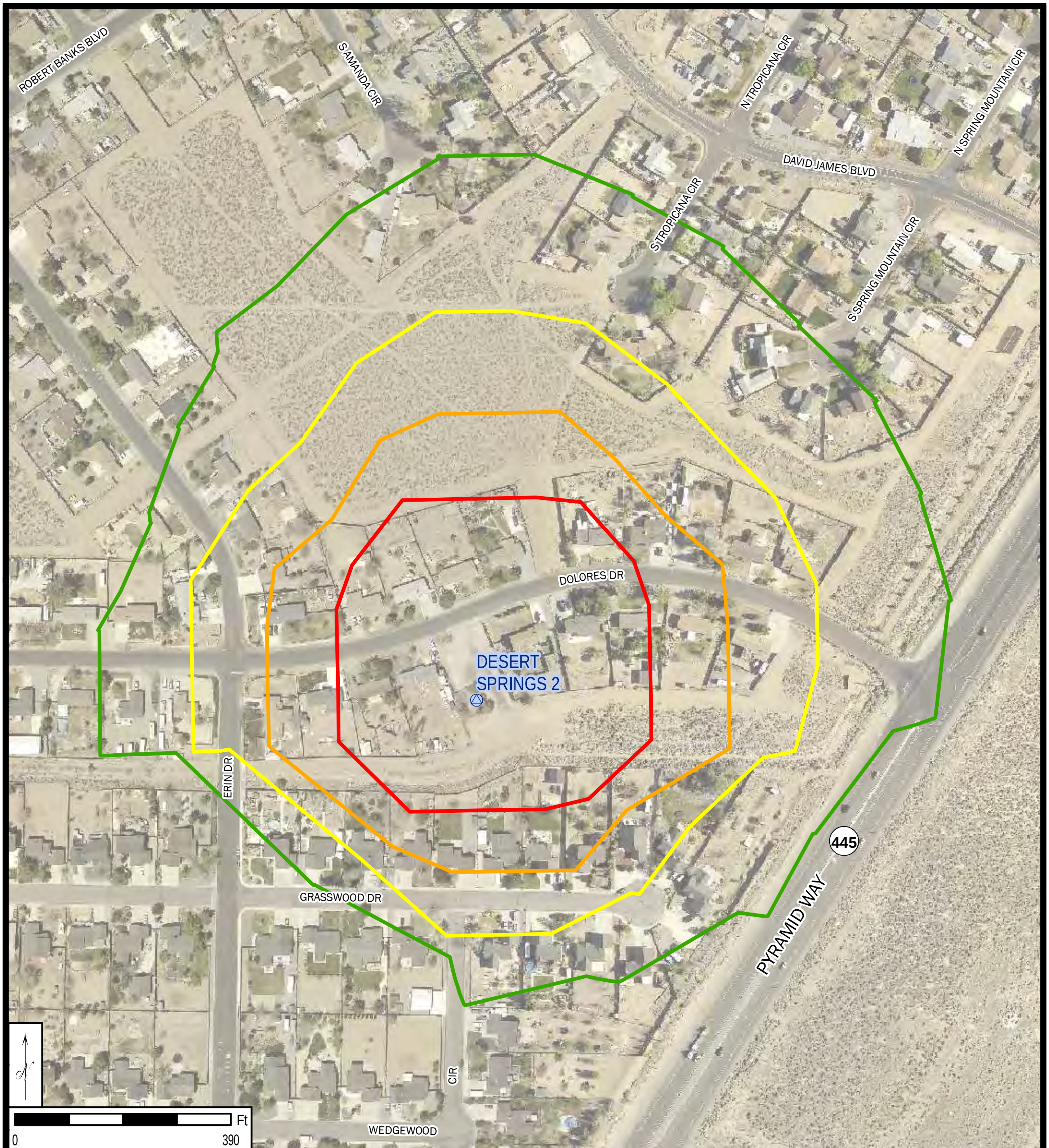
WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

SPANISH SPRINGS (BASIN 85) -- FIGURE: 2

DESERT SPRINGS 2 WELL SITE

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

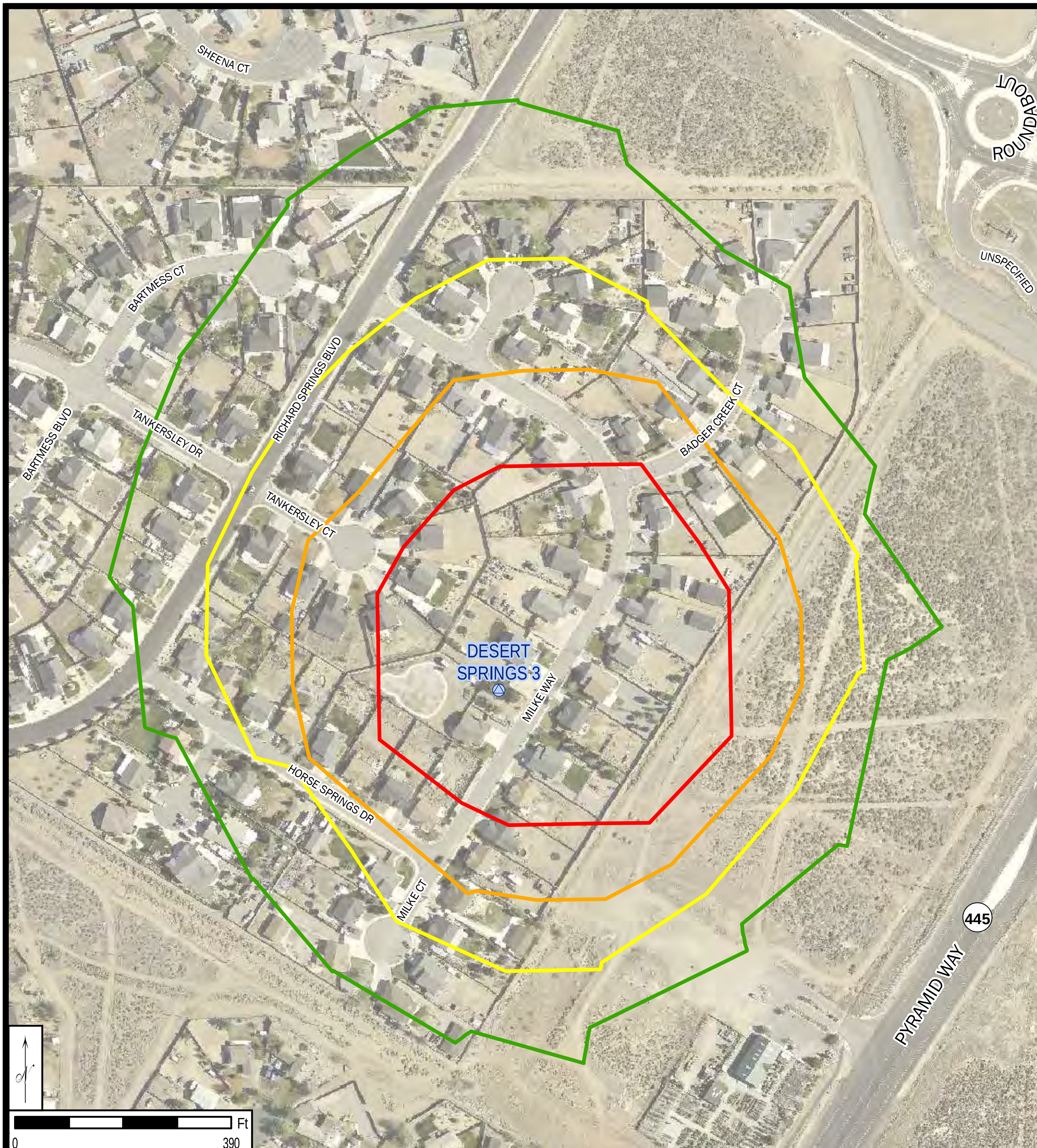
10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

SPANISH SPRINGS (BASIN 85) -- FIGURE: 3

DESERT SPRINGS 3 WELL SITE

TMWA

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

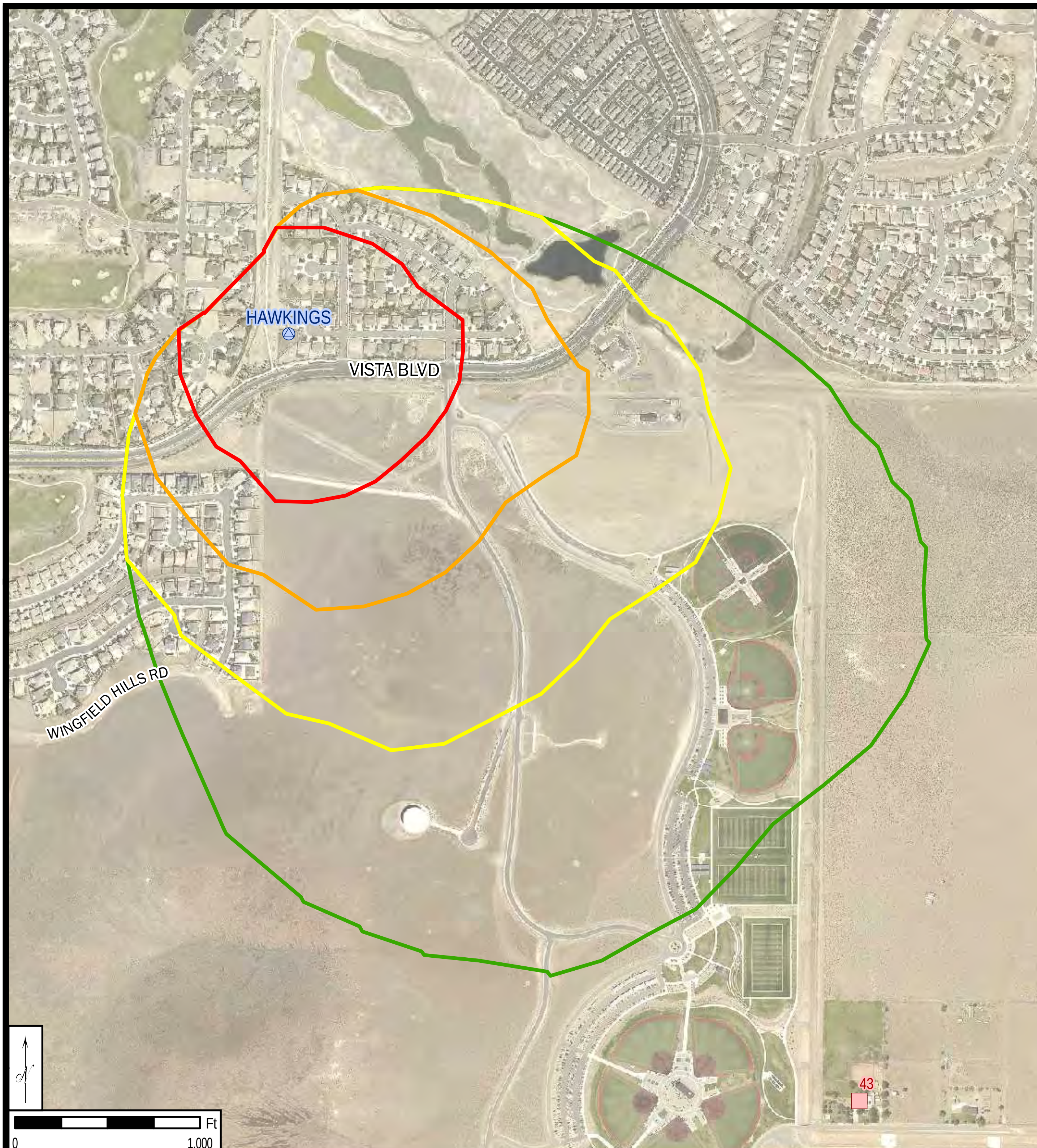
5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

SPANISH SPRINGS (BASIN 85) -- FIGURE: 4

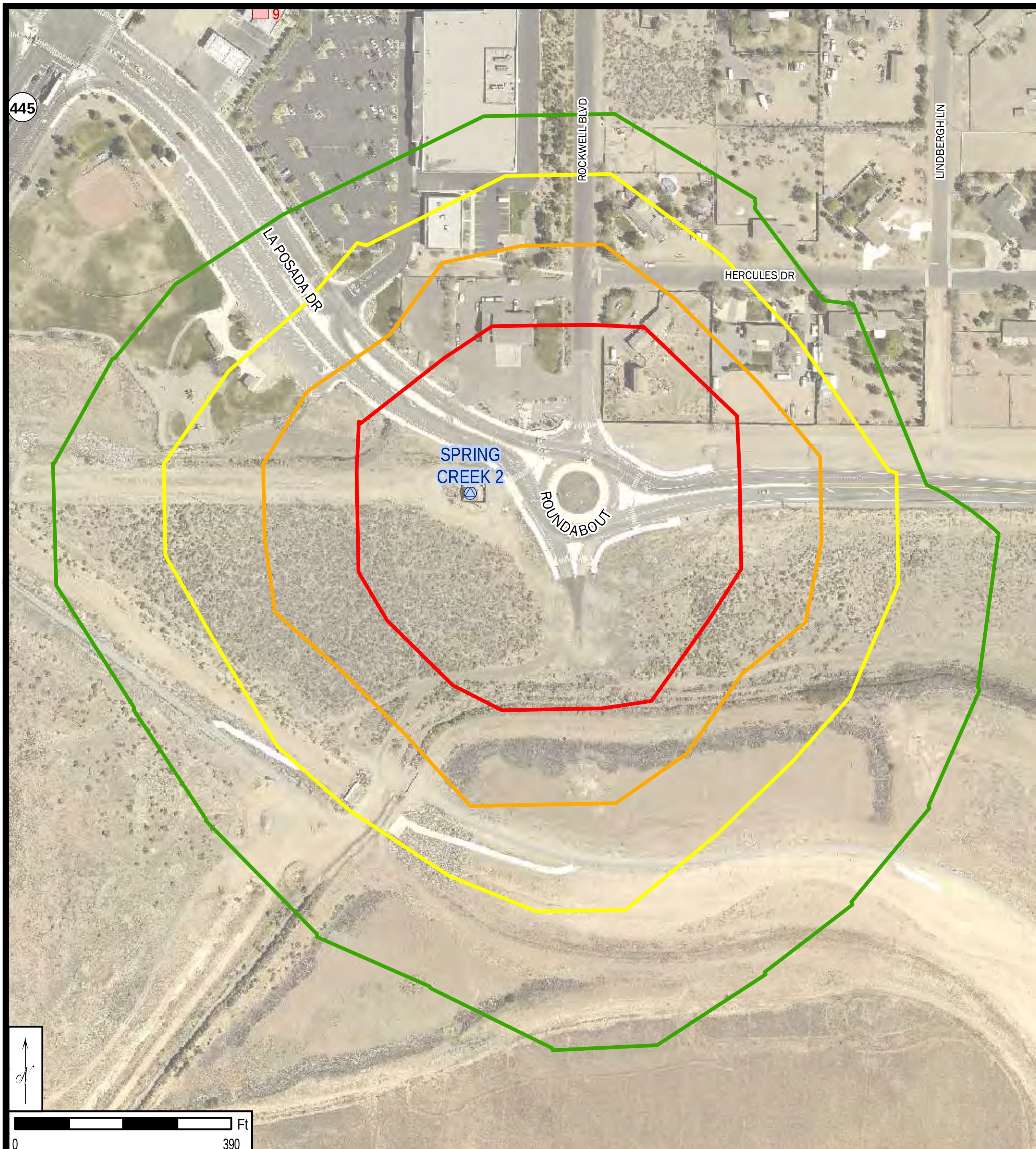
HAWKINGS WELL SITE

- WATER SUPPLY WELL
- CONTAMINANT RELEASE SITE - ACTIVE (NDEP)
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

SPANISH SPRINGS (BASIN 85) -- FIGURE: 5

SPRING CREEK 2 WELL SITE

TMWA

WATER SUPPLY WELL

CONTAMINANT RELEASE SITE - ACTIVE (NDEP)

2 YEAR CAPTURE ZONE

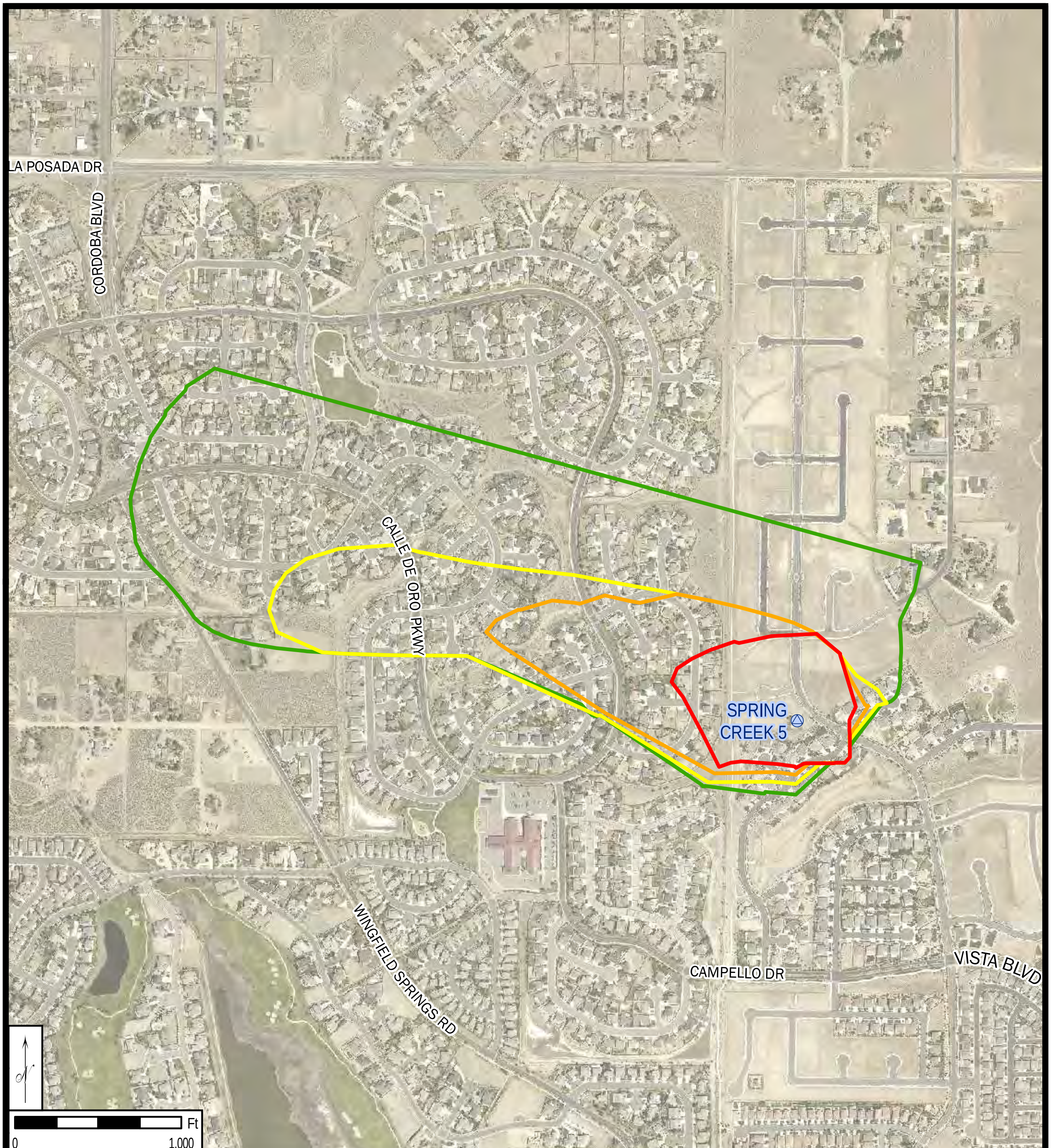
5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

SPANISH SPRINGS (BASIN 85) -- FIGURE: 6

SPRING CREEK 5 WELL SITE

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

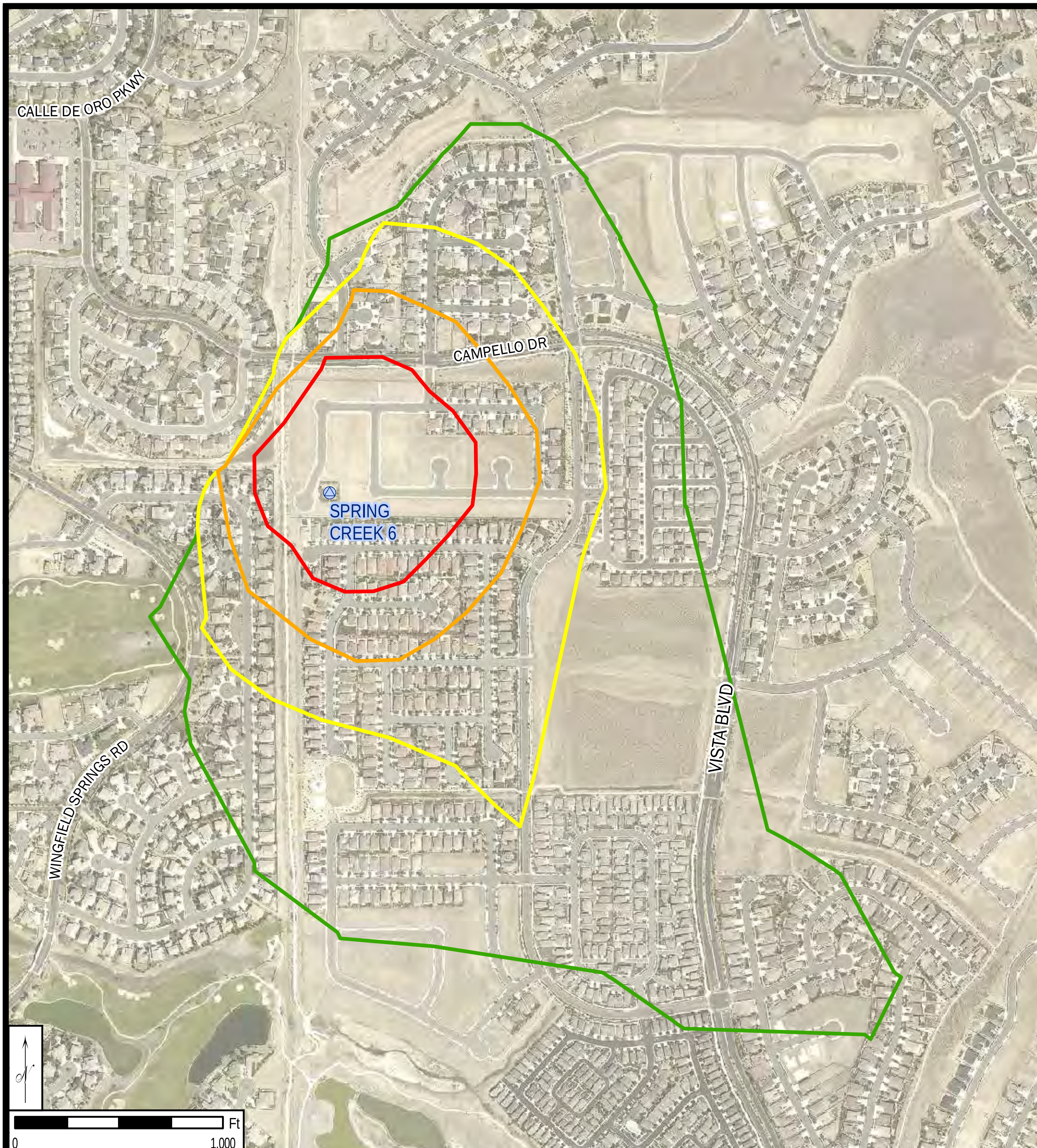
10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

SPANISH SPRINGS (BASIN 85) -- FIGURE: 7

SPRING CREEK 6 WELL SITE

WATER SUPPLY WELL

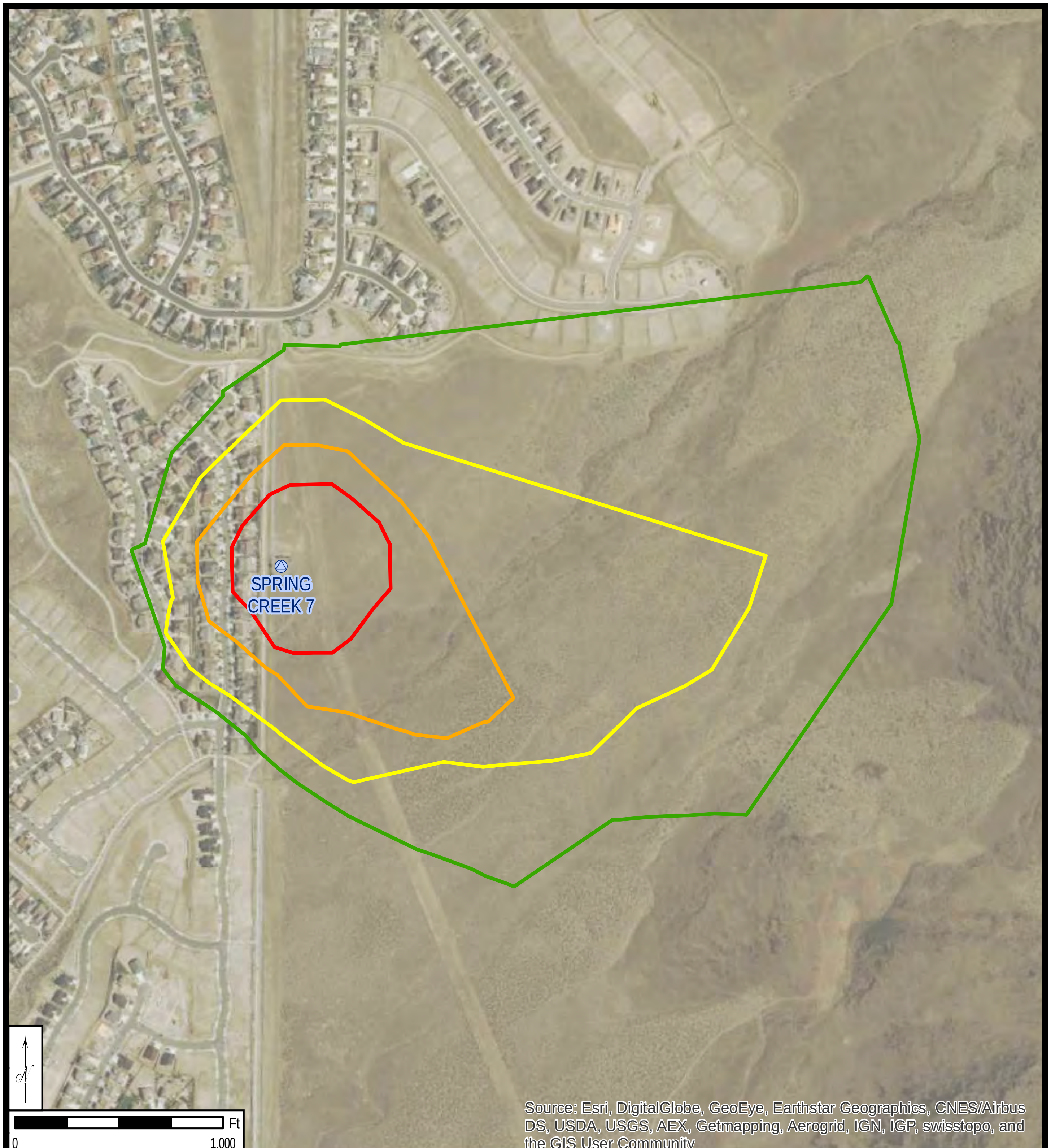
2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

TMWA



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

SPANISH SPRINGS (BASIN 85) -- FIGURE: 8

SPRING CREEK 7 WELL SITE

WATER SUPPLY WELL

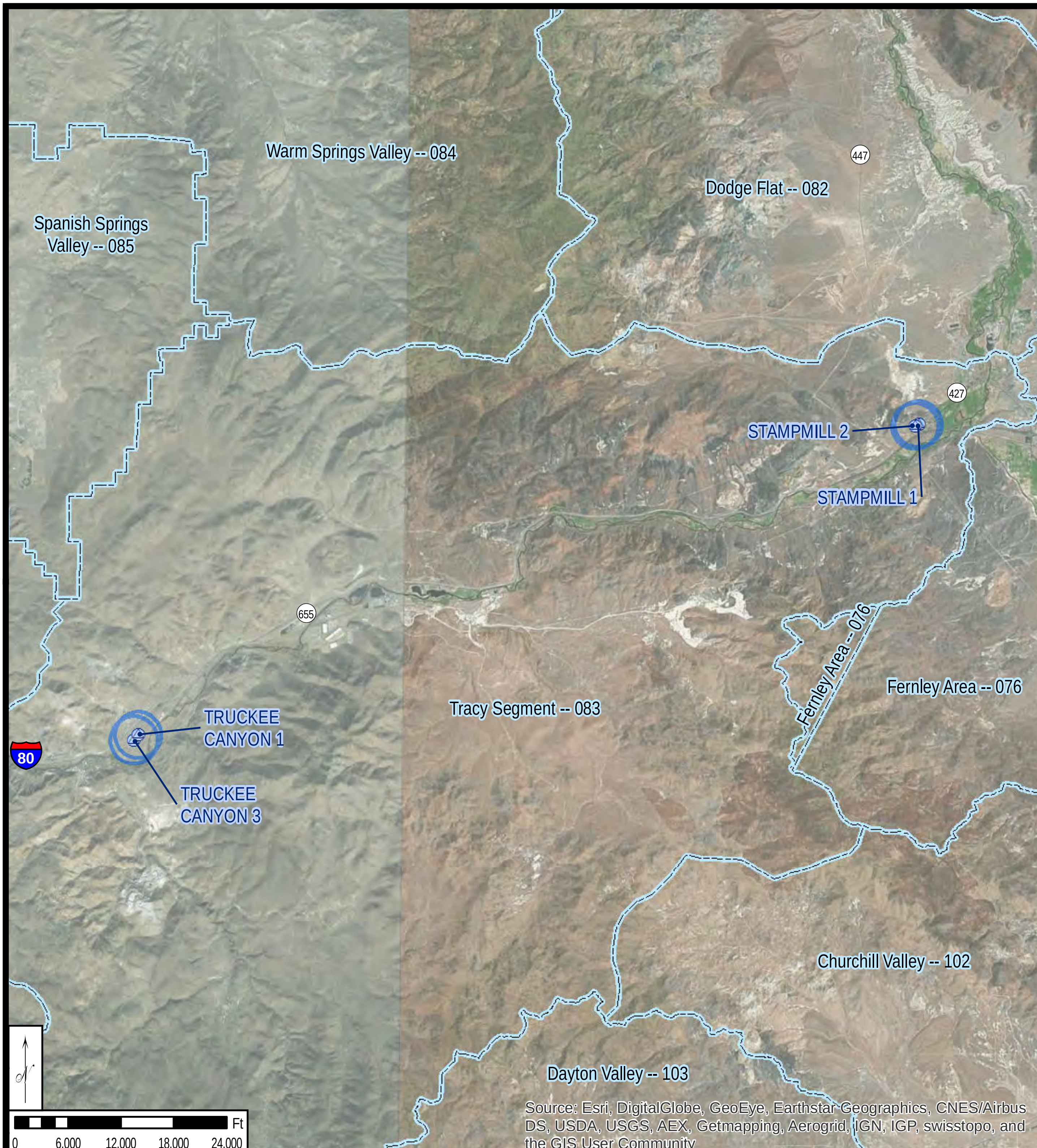
2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

TMWA



WELLHEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRACY SEGMENT (BASIN 83) AREA INDEX

TMWA

WATER SUPPLY WELL

1/2 MILE CAPTURE ZONE

NEVADA HYDROBASIN BOUNDARY

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_AreaIndex_DD_8.5X11.mxd, Editor: Michael, Printed: 9/9/2015

WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRACY SEGMENT (BASIN 83) -- FIGURE: 1

STAMPMILL 1 WELL SITE

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

WATER SUPPLY WELL 1/2 MILE CAPTURE ZONE

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015

WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRACY SEGMENT (BASIN 83) -- FIGURE: 2

STAMPMILL 2 WELL SITE

TMWA

WATER SUPPLY WELL   1/2 MILE CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015

WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRACY SEGMENT (BASIN 83) -- FIGURE: 3

TRUCKEE CANYON 1 WELL SITE

TMWA

WATER SUPPLY WELL

CONTAMINANT RELEASE SITE - ACTIVE (NDEP)

1/2 MILE CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015

WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRACY SEGMENT (BASIN 83) -- FIGURE: 4

TRUCKEE CANYON 3 WELL SITE

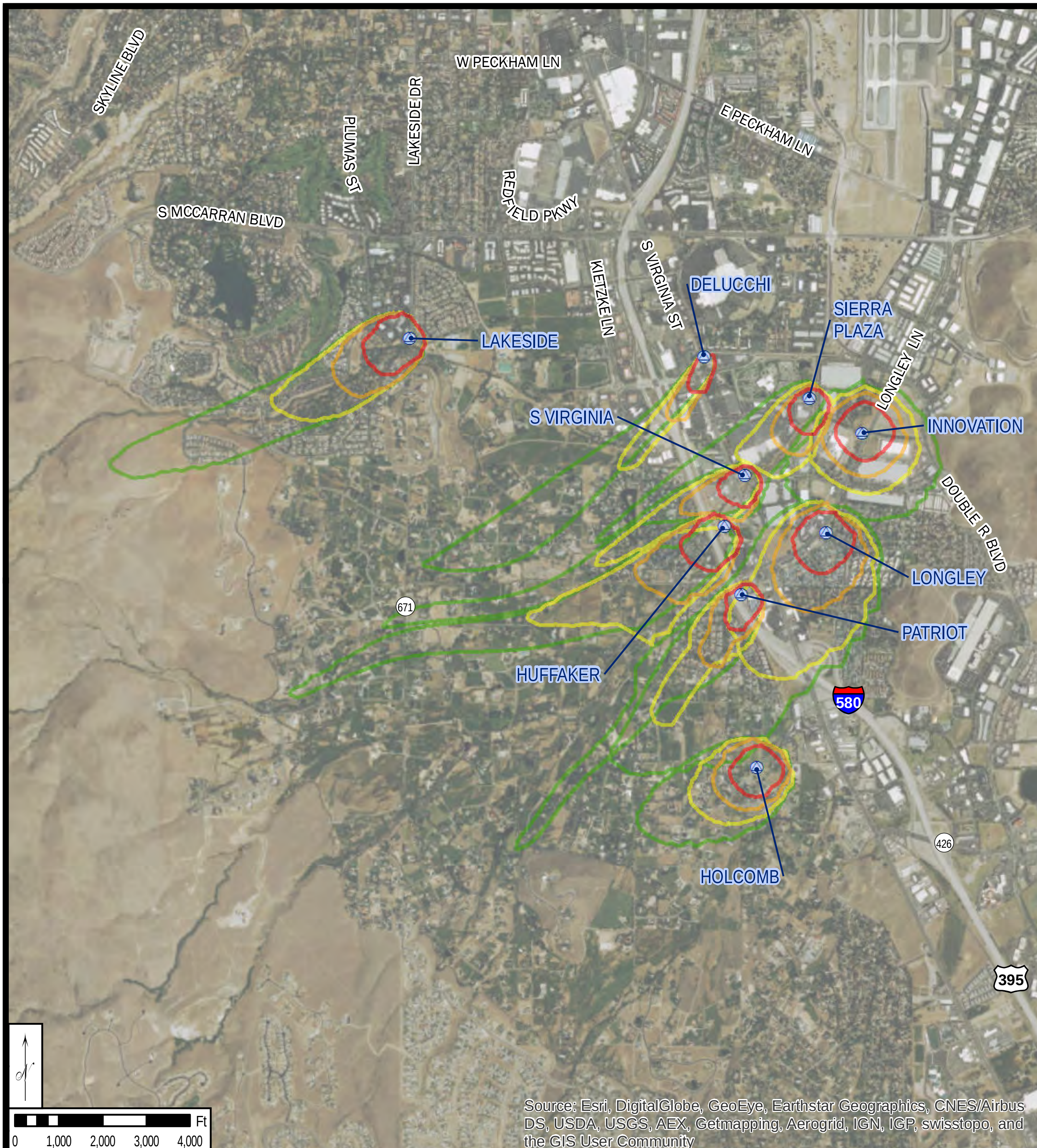
TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

WATER SUPPLY WELL

1/2 MILE CAPTURE ZONE

CONTAMINANT RELEASE SITE - ACTIVE (NDEP)



WELLHEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (CENTRAL) (BASIN 87) AREA INDEX

TMWA

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

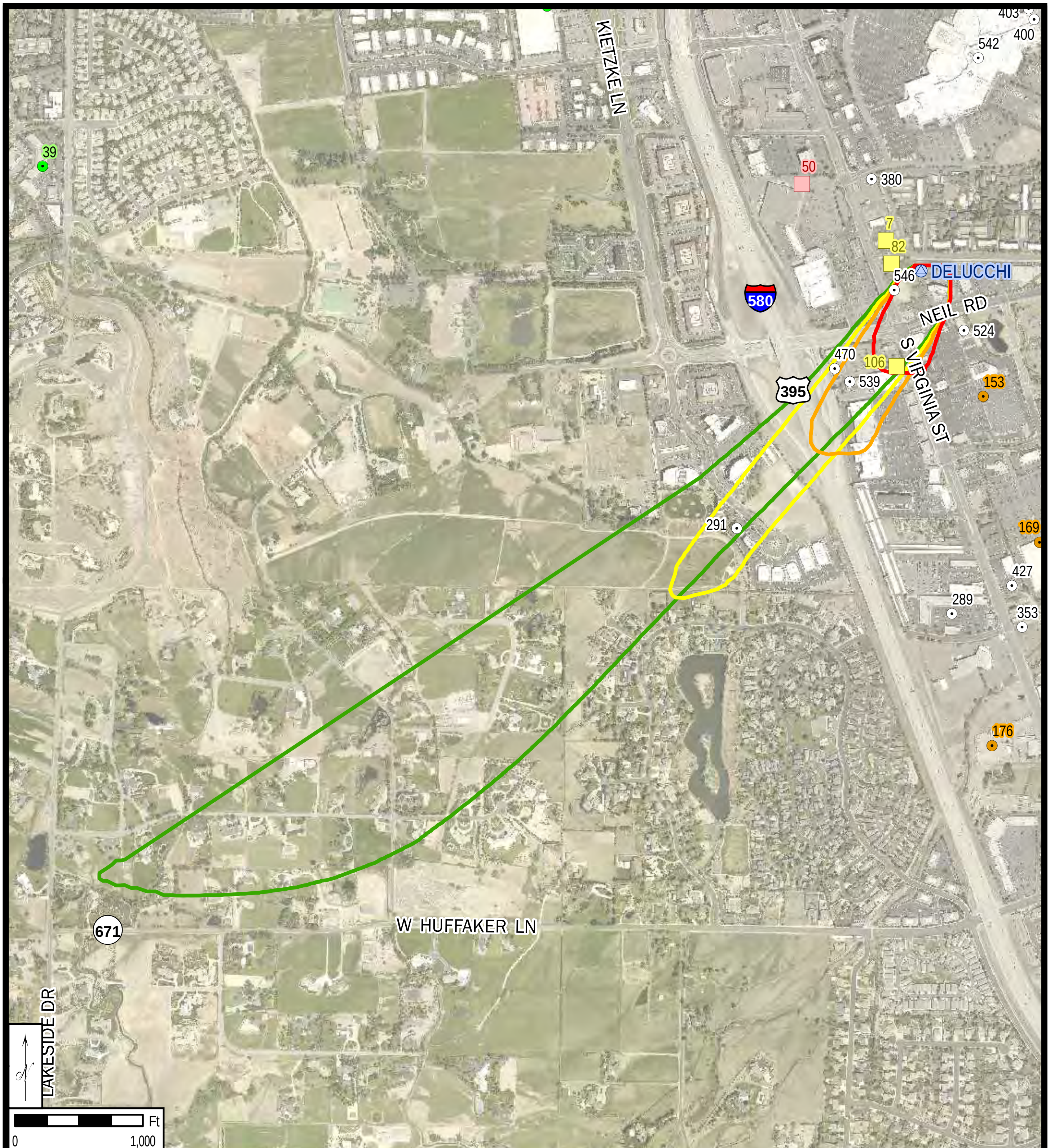
10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NEVADA HYDROBASIN BOUNDARY

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_AreaIndex_DD_8.5X11.mxd, Editor: Michael, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (CENTRAL) (BASIN 87) -- FIGURE: 1

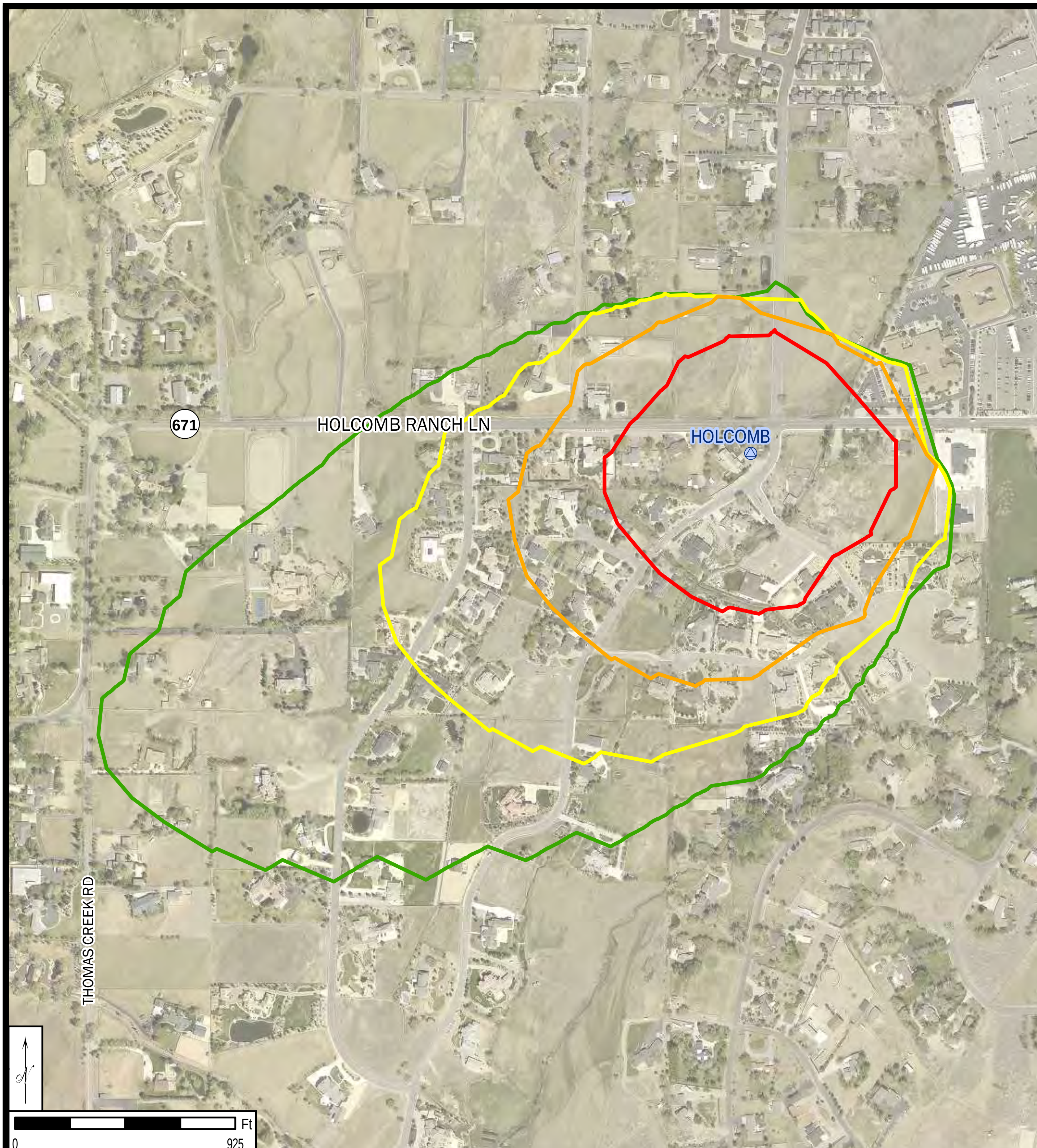
DELUCCHI WELL SITE

TMWA

POTENTIAL CONTAMINANT SOURCE -- SQG (EPA)	2 YEAR CAPTURE ZONE
POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)	5 YEAR CAPTURE ZONE
POTENTIAL CONTAMINANT SOURCE -- (EPA)	10 YEAR CAPTURE ZONE
WATER SUPPLY WELL	20 YEAR CAPTURE ZONE
CONTAMINANT RELEASE SITE - ACTIVE (NDEP)	CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (CENTRAL) (BASIN 87) -- FIGURE: 2

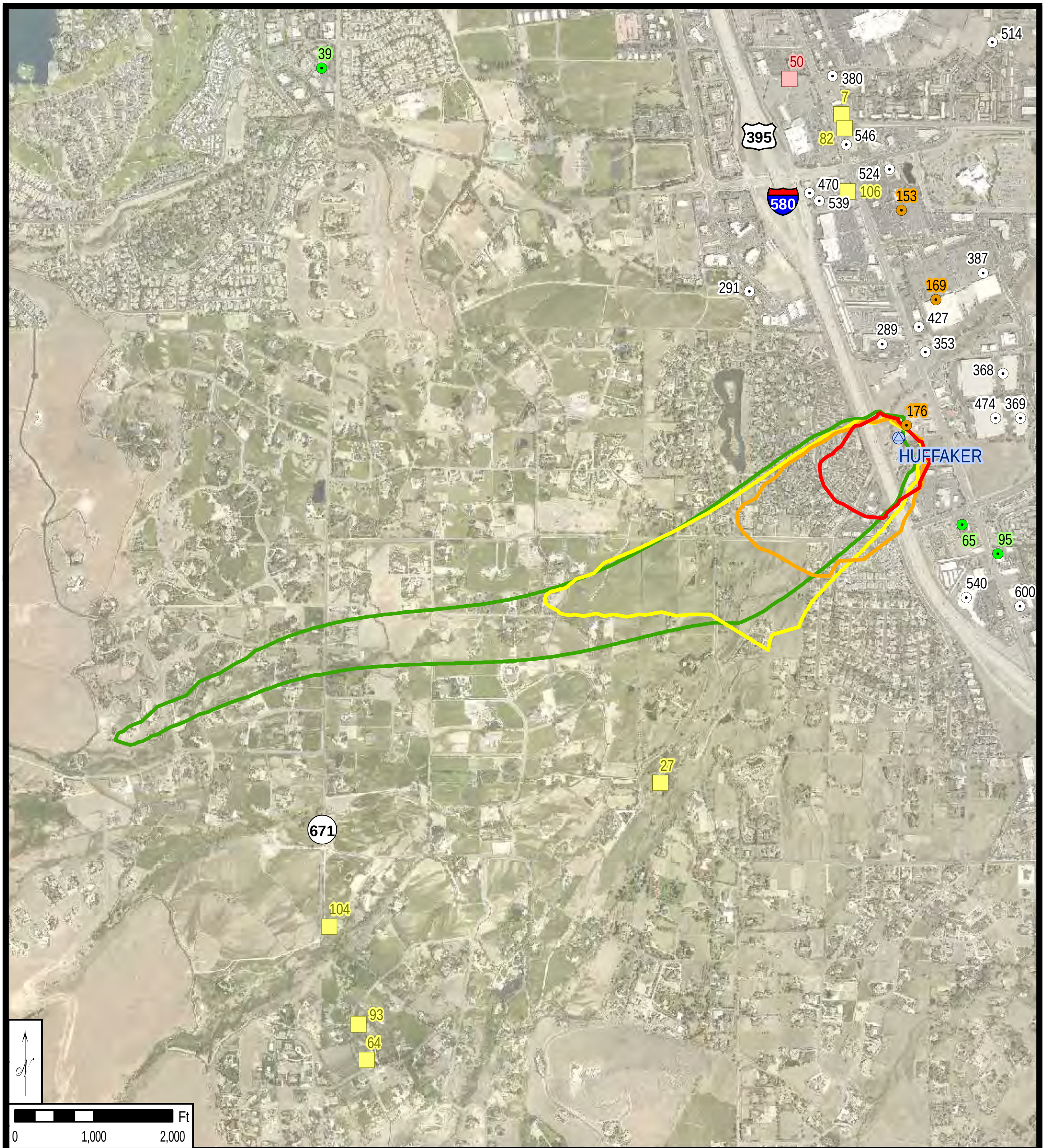
HOLCOMB WELL SITE

TMWA

- POTENTIAL CONTAMINANT SOURCE -- (EPA)
- WATER SUPPLY WELL
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

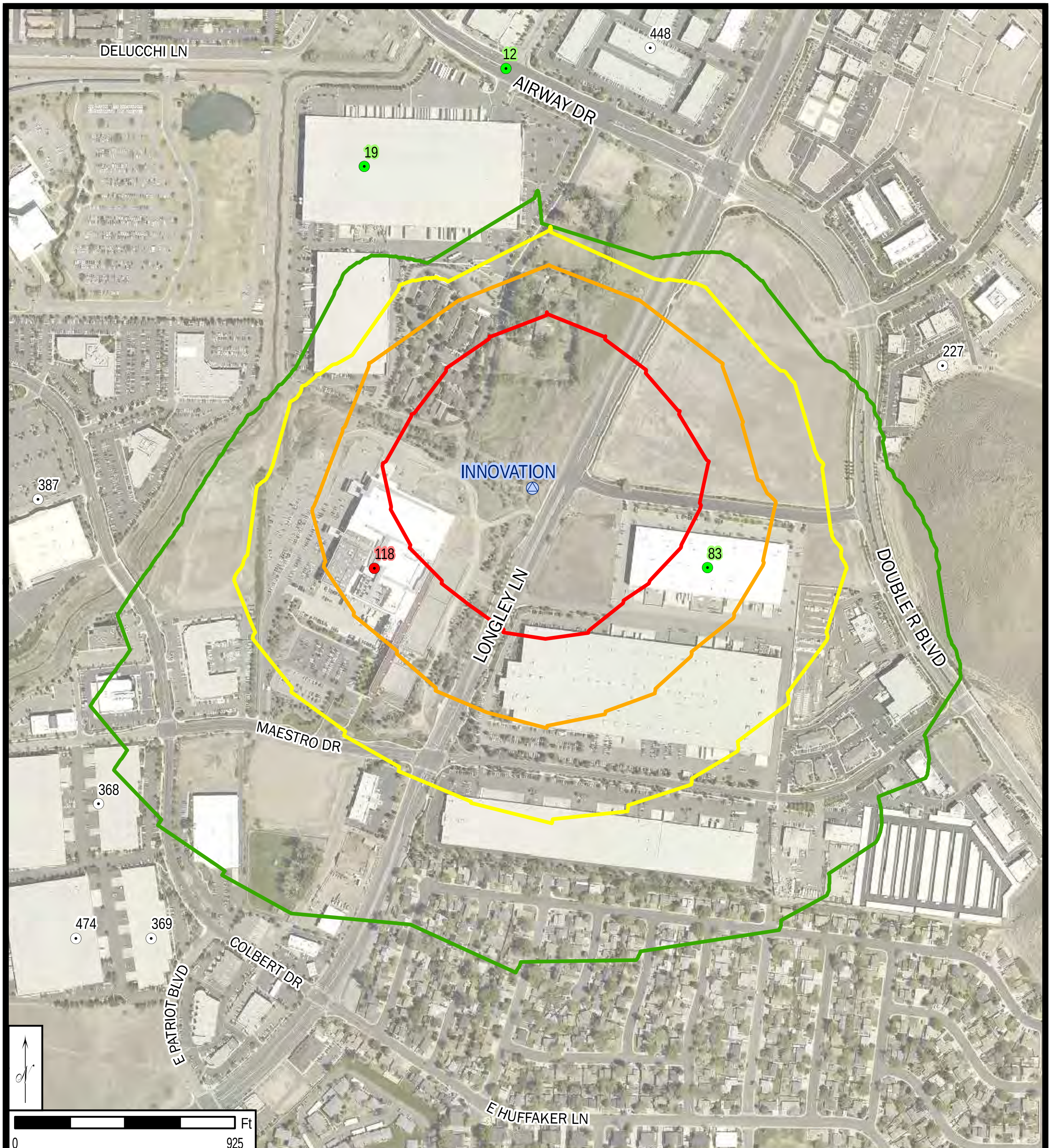
TRUCKEE MEADOWS (CENTRAL) (BASIN 87) -- FIGURE: 3

HUFFAKER WELL SITE

POTENTIAL CONTAMINANT SOURCE -- SQG (EPA)
POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
POTENTIAL CONTAMINANT SOURCE -- (EPA)
WATER SUPPLY WELL
CONTAMINANT RELEASE SITE - ACTIVE (NDEP)

2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE
CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

TMWA



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (CENTRAL) (BASIN 87) -- FIGURE: 4

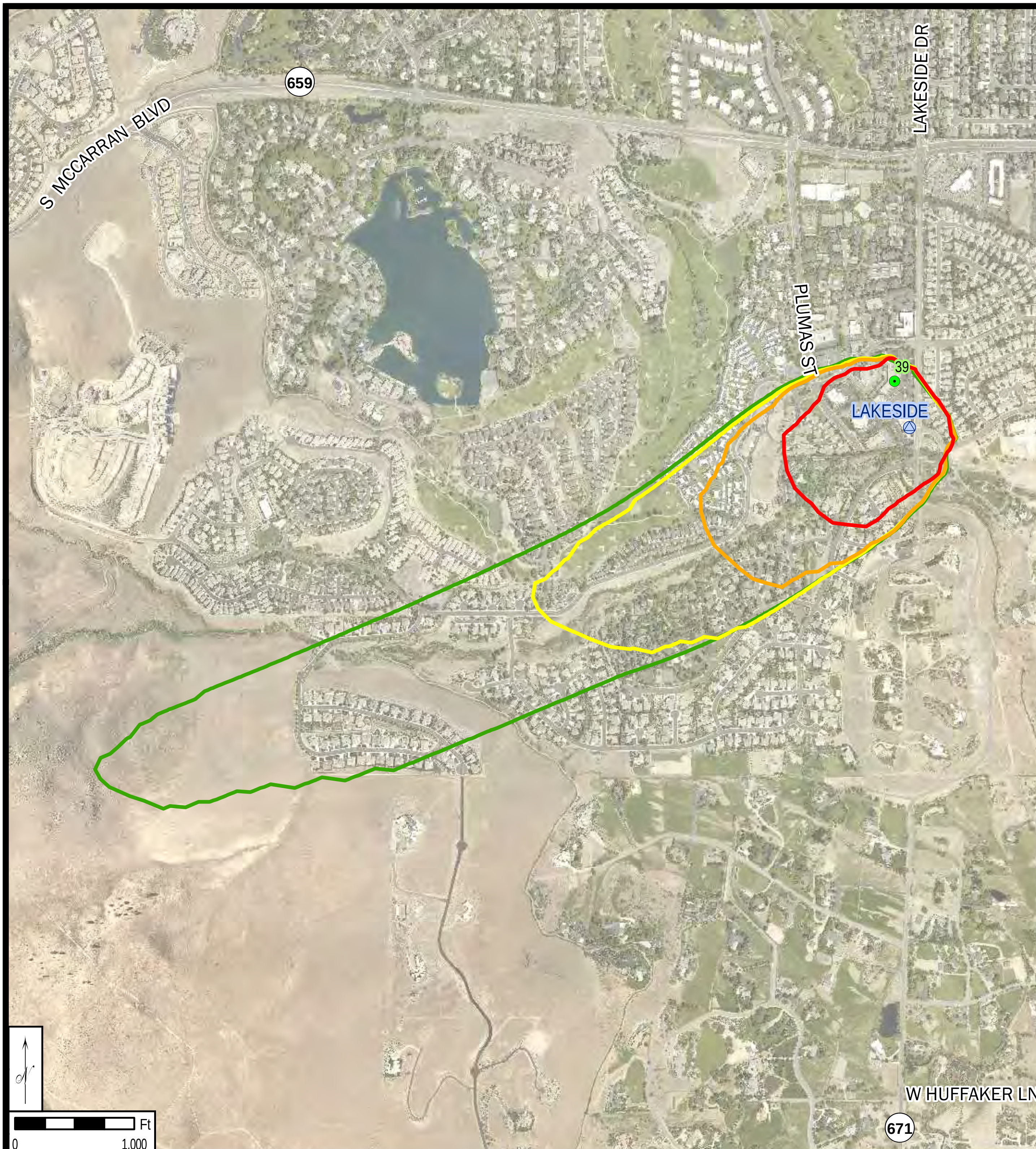
INNOVATION WELL SITE

- POTENTIAL CONTAMINANT SOURCE -- LQG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- (EPA)
- WATER SUPPLY WELL
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (CENTRAL) (BASIN 87) -- FIGURE: 5

LAKESIDE WELL SITE

TMWA

POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

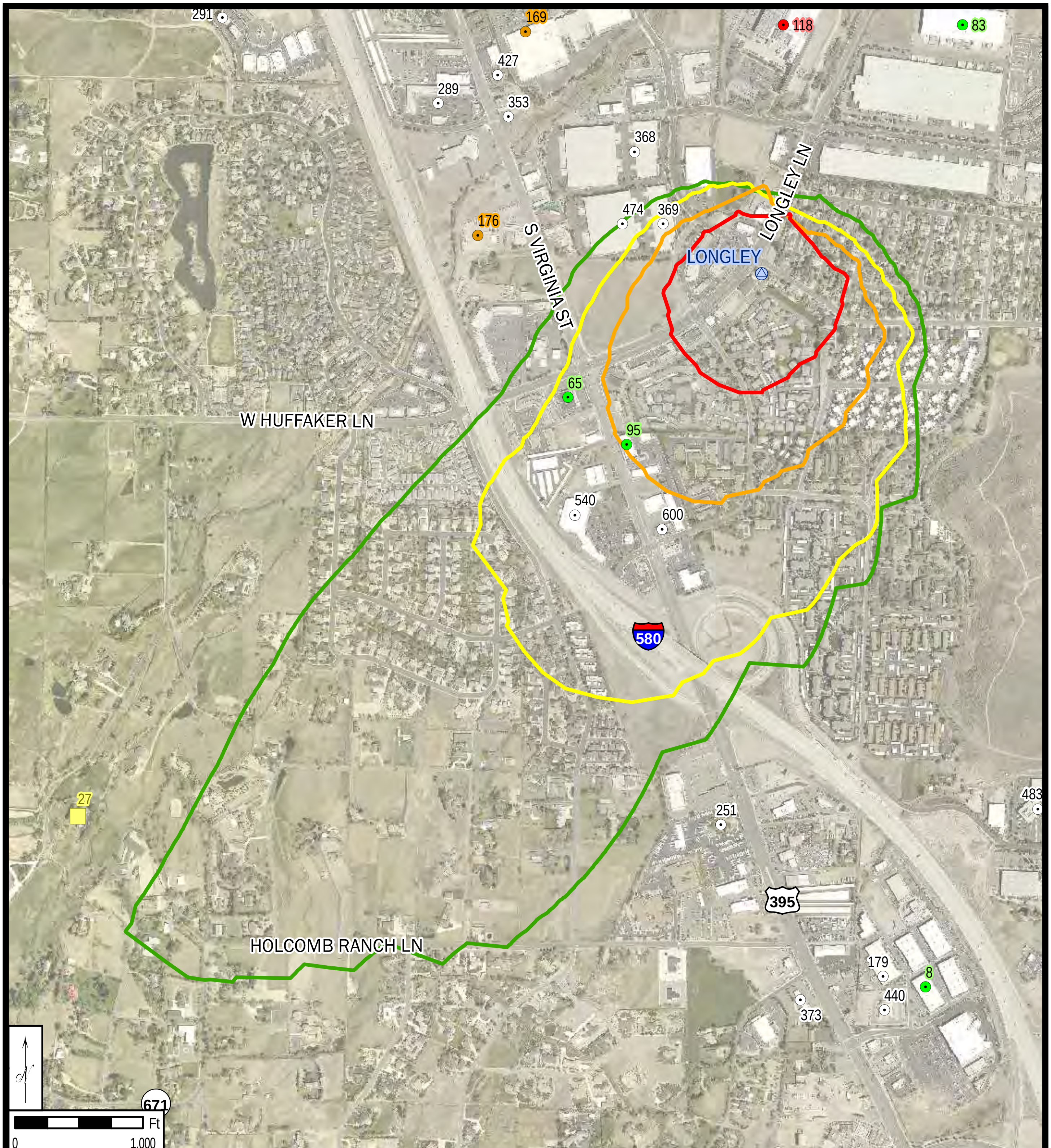
5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (CENTRAL) (BASIN 87) -- FIGURE: 6

LONGLEY WELL SITE

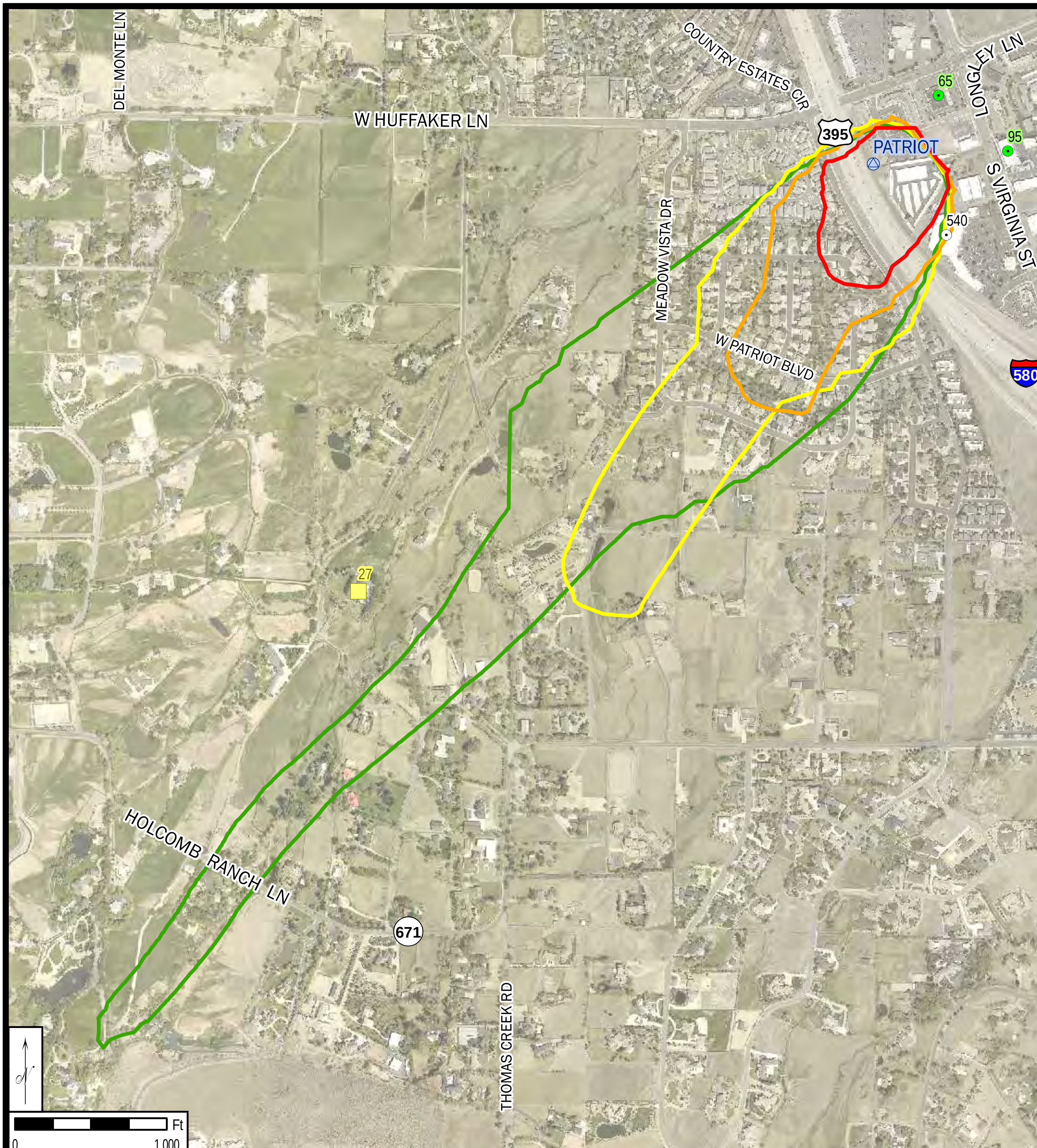
TMWA

POTENTIAL CONTAMINANT SOURCE -- LQG (EPA)
POTENTIAL CONTAMINANT SOURCE -- SQG (EPA)
POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
POTENTIAL CONTAMINANT SOURCE -- (EPA)
WATER SUPPLY WELL

2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE
CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (CENTRAL) (BASIN 87) -- FIGURE: 7

PATRIOT WELL SITE

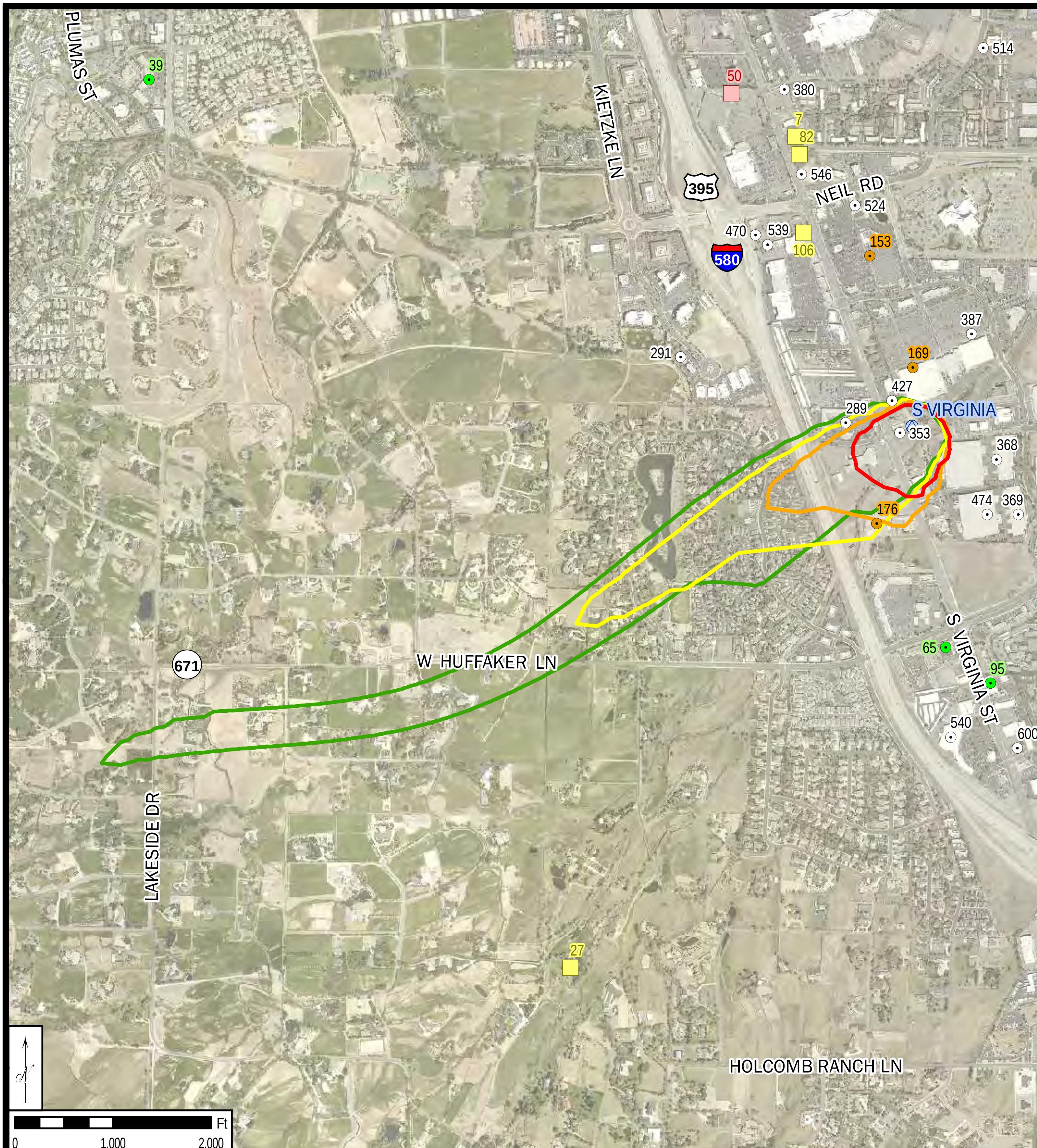
POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
POTENTIAL CONTAMINANT SOURCE -- (EPA)
WATER SUPPLY WELL

2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE
CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (CENTRAL) (BASIN 87) -- FIGURE: 8

S VIRGINIA WELL SITE

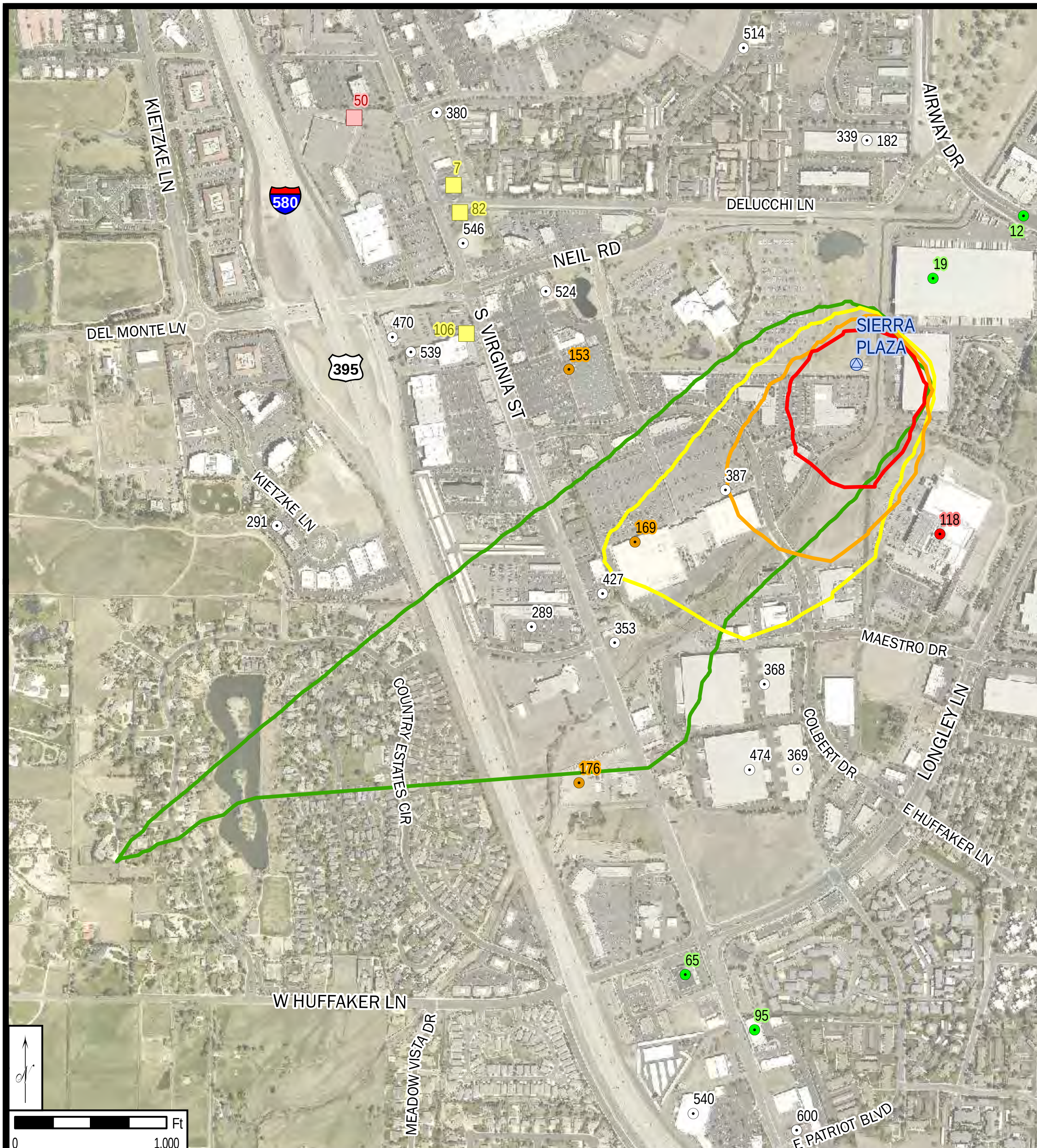
POTENTIAL CONTAMINANT SOURCE -- SQG (EPA)
POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
POTENTIAL CONTAMINANT SOURCE -- (EPA)
WATER SUPPLY WELL
CONTAMINANT RELEASE SITE - ACTIVE (NDEP)

2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE
CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (CENTRAL) (BASIN 87) -- FIGURE: 9

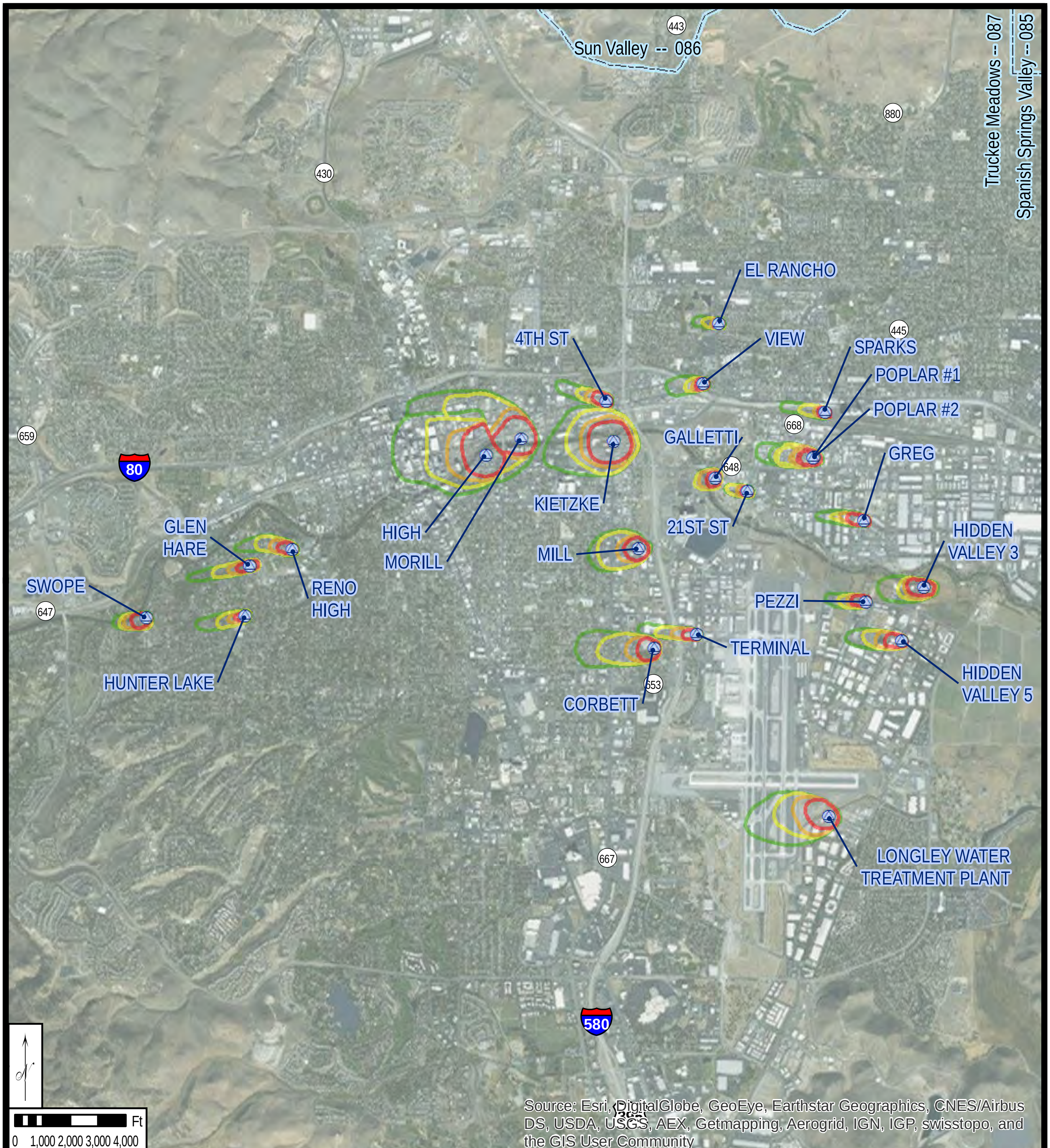
SIERRA PLAZA WELL SITE

- POTENTIAL CONTAMINANT SOURCE -- LQG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- SQG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- (EPA)
- WATER SUPPLY WELL
- CONTAMINANT RELEASE SITE - ACTIVE (NDEP)
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE
- CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELLHEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) AREA INDEX

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NEVADA HYDROBASIN BOUNDARY

TMWA

WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 1

21ST ST WELL SITE

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE

TMWA

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015

WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 2

4TH ST WELL SITE

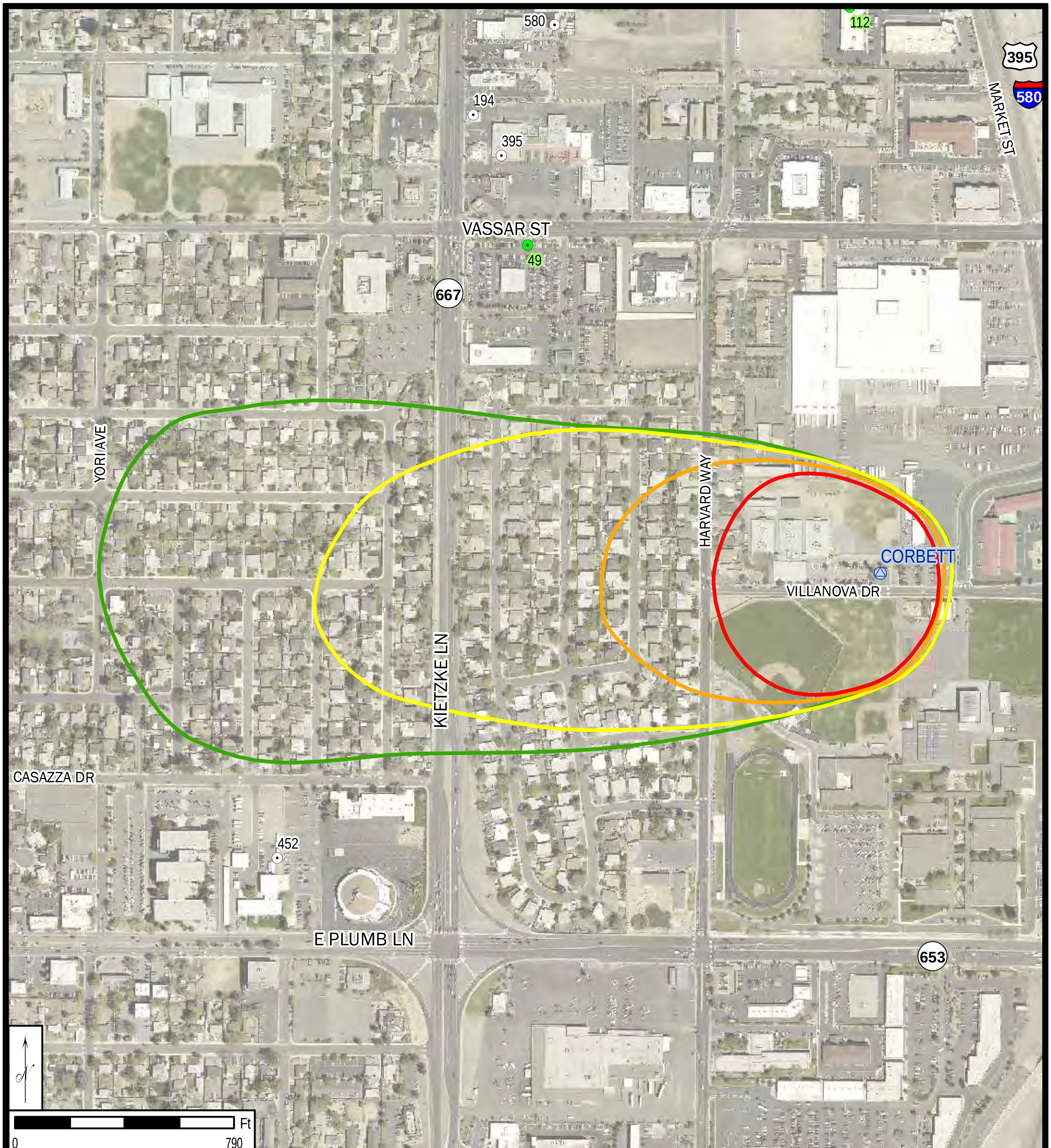
POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
POTENTIAL CONTAMINANT SOURCE -- (EPA)
WATER SUPPLY WELL

2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 3

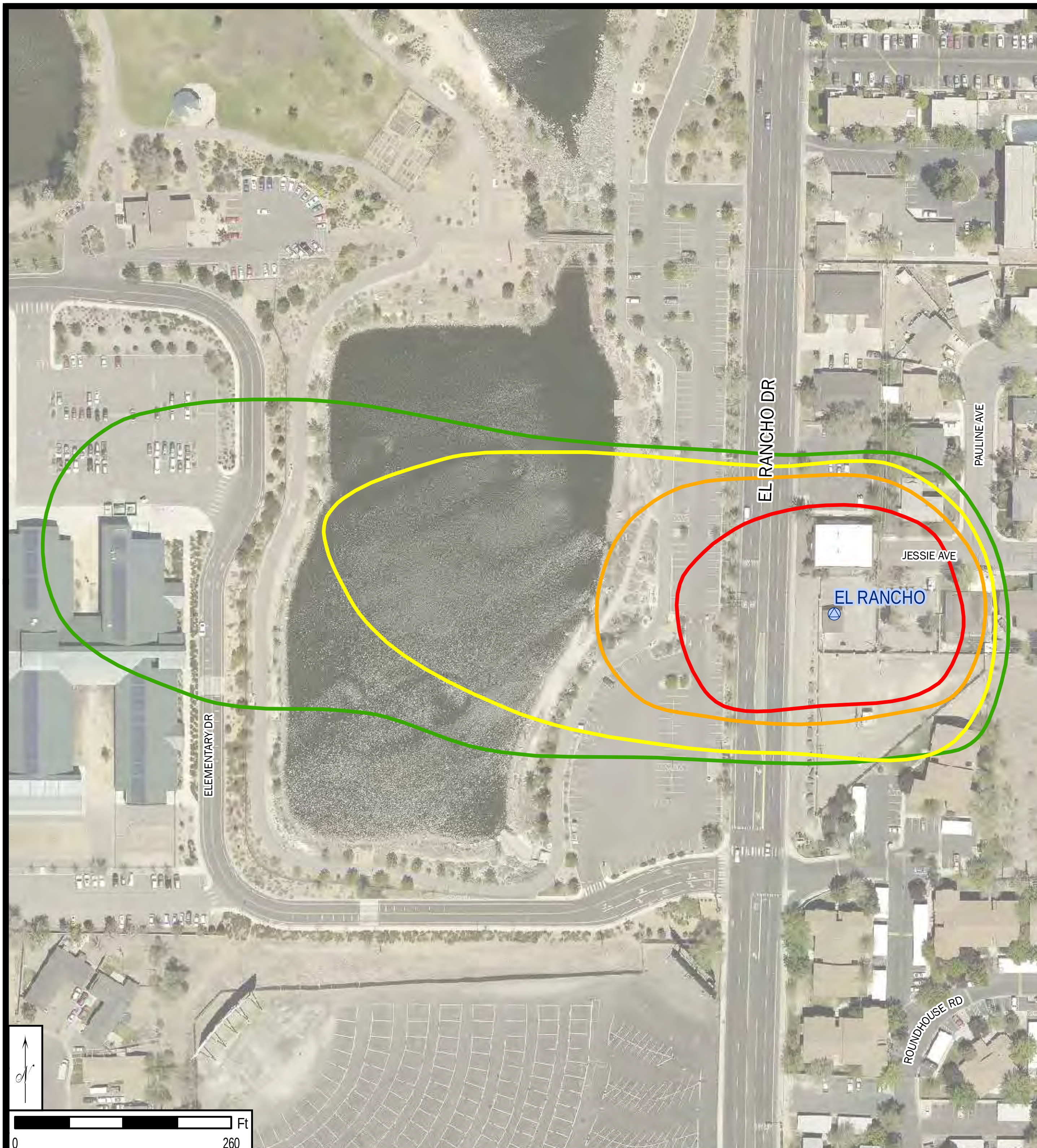
CORBETT WELL SITE

TMWA

POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
POTENTIAL CONTAMINANT SOURCE -- (EPA)
WATER SUPPLY WELL

2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 4

EL RANCHO WELL SITE

TMWA

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015

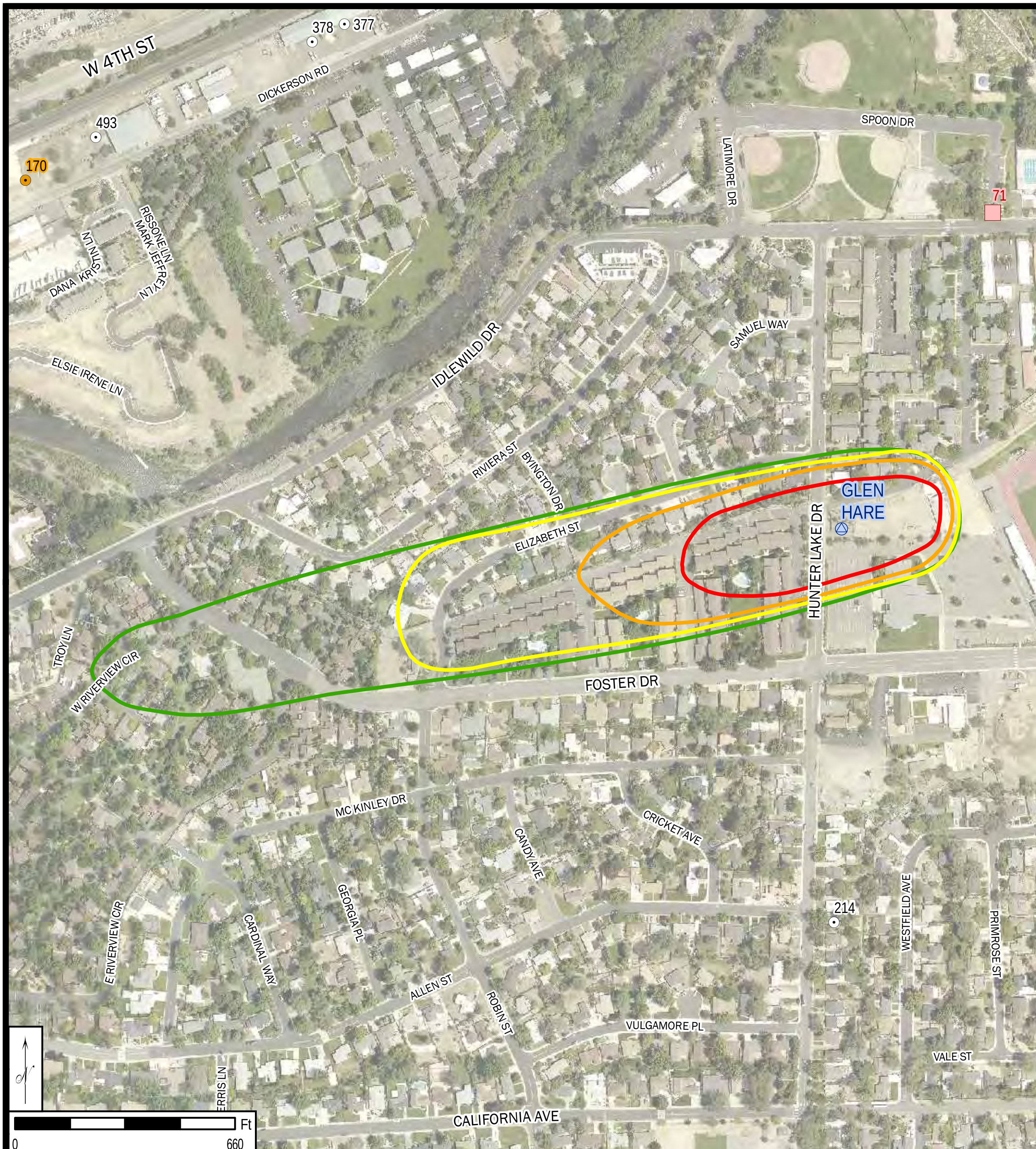
WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 5

GALLETTI WELL SITE

WATER SUPPLY WELL
2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE

TMWA



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 6

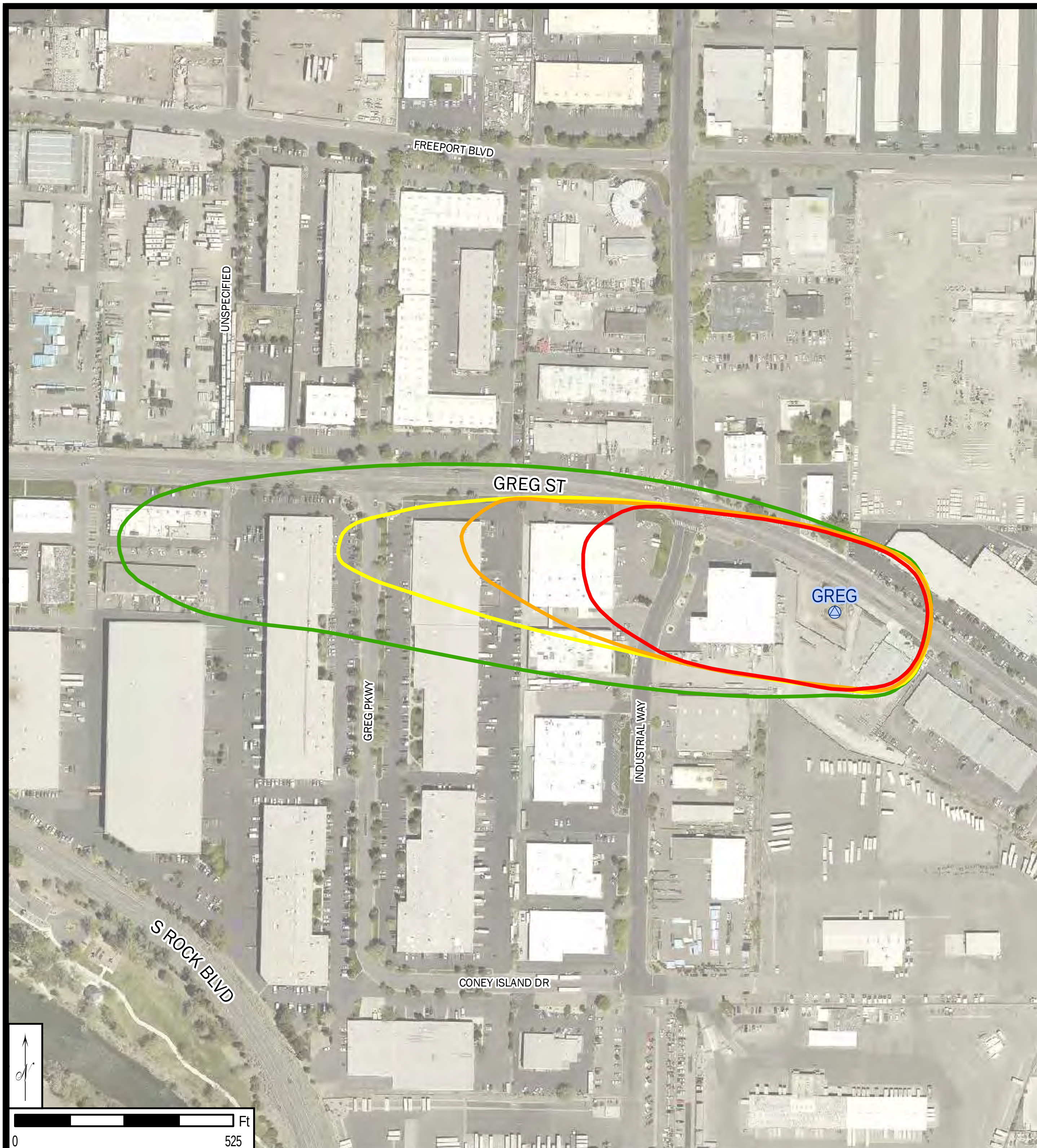
GLEN HARE WELL SITE

TMWA

- POTENTIAL CONTAMINANT SOURCE -- SQG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- (EPA)
- WATER SUPPLY WELL
- CONTAMINANT RELEASE SITE - ACTIVE (NDEP)
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 7

GREG WELL SITE

TMWA

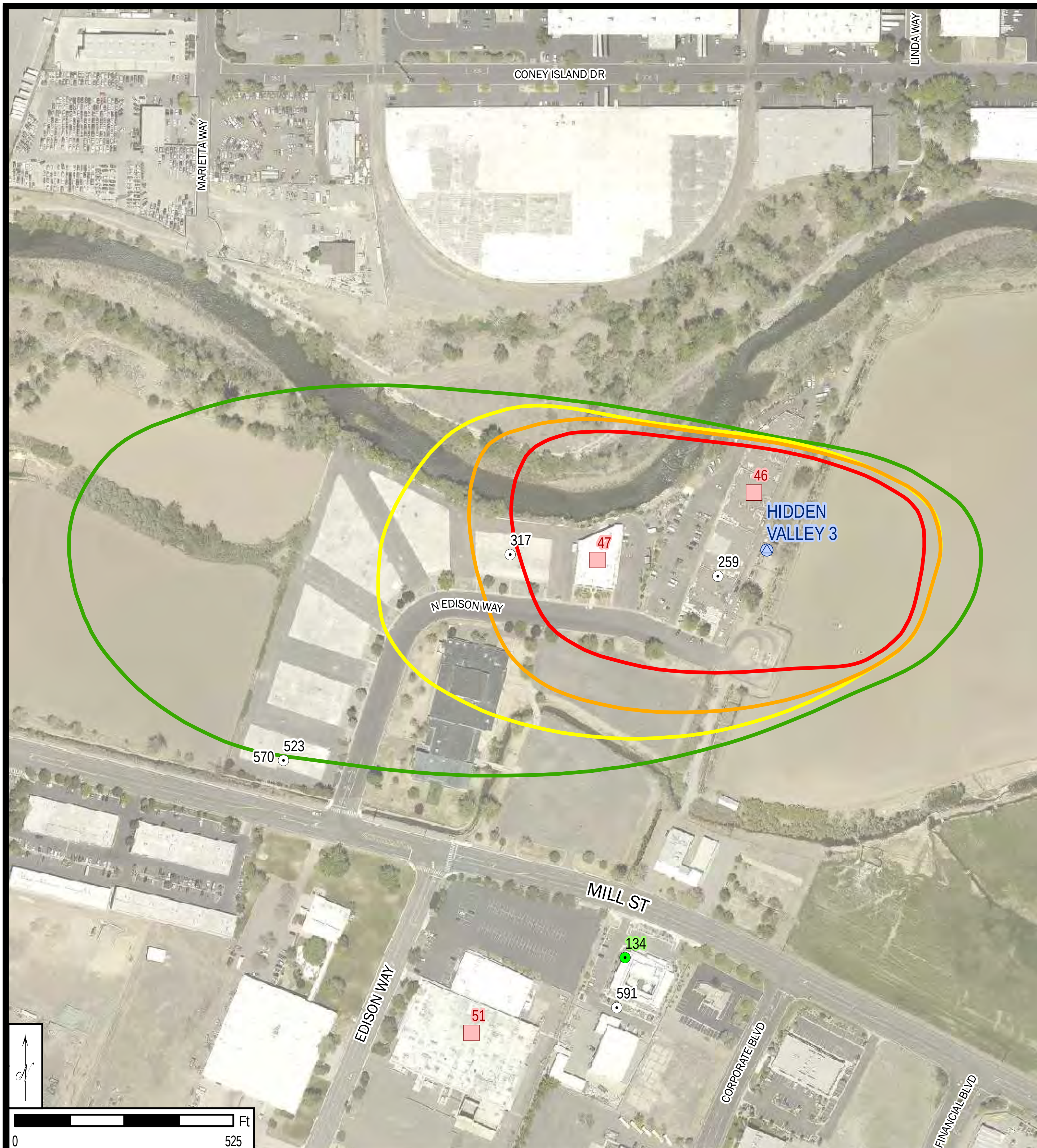
WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

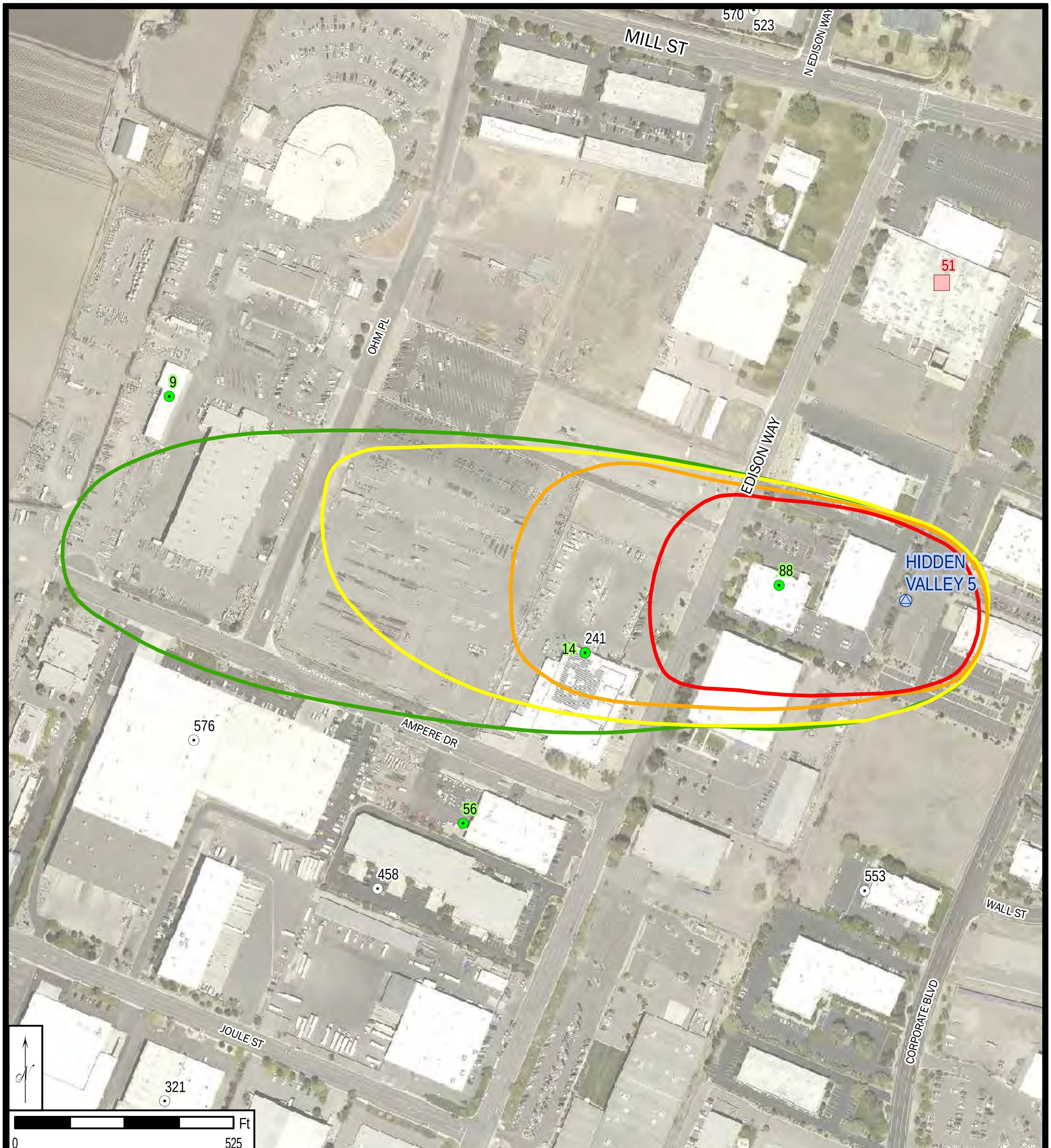
TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 8

HIDDEN VALLEY 3 WELL SITE

TMWA

- POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- (EPA)
- WATER SUPPLY WELL
- CONTAMINANT RELEASE SITE - ACTIVE (NDEP)
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



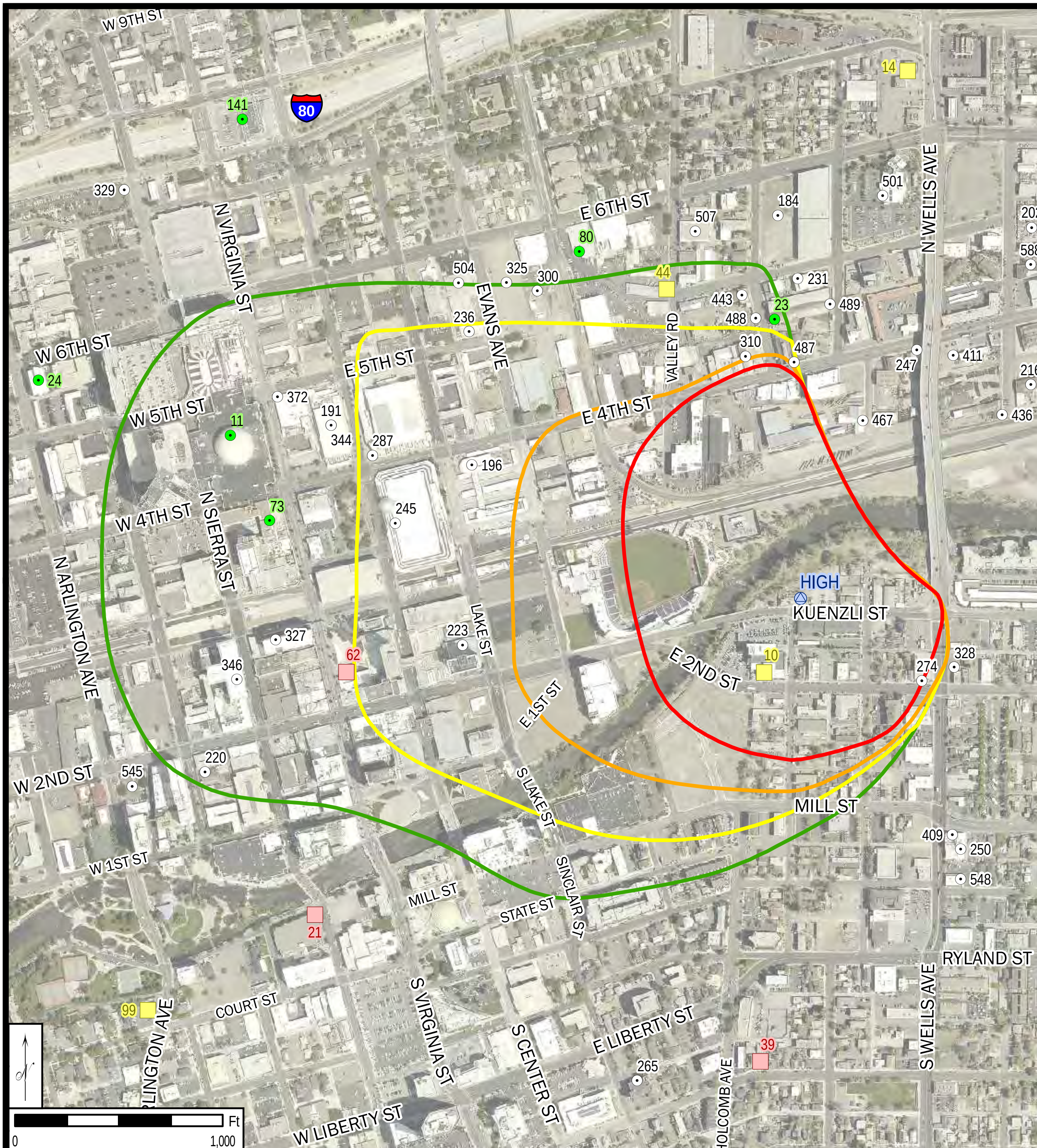
WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 9

HIDDEN VALLEY 5 WELL SITE

TMWA

- POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- (EPA)
- WATER SUPPLY WELL
- CONTAMINANT RELEASE SITE - ACTIVE (NDEP)
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 10

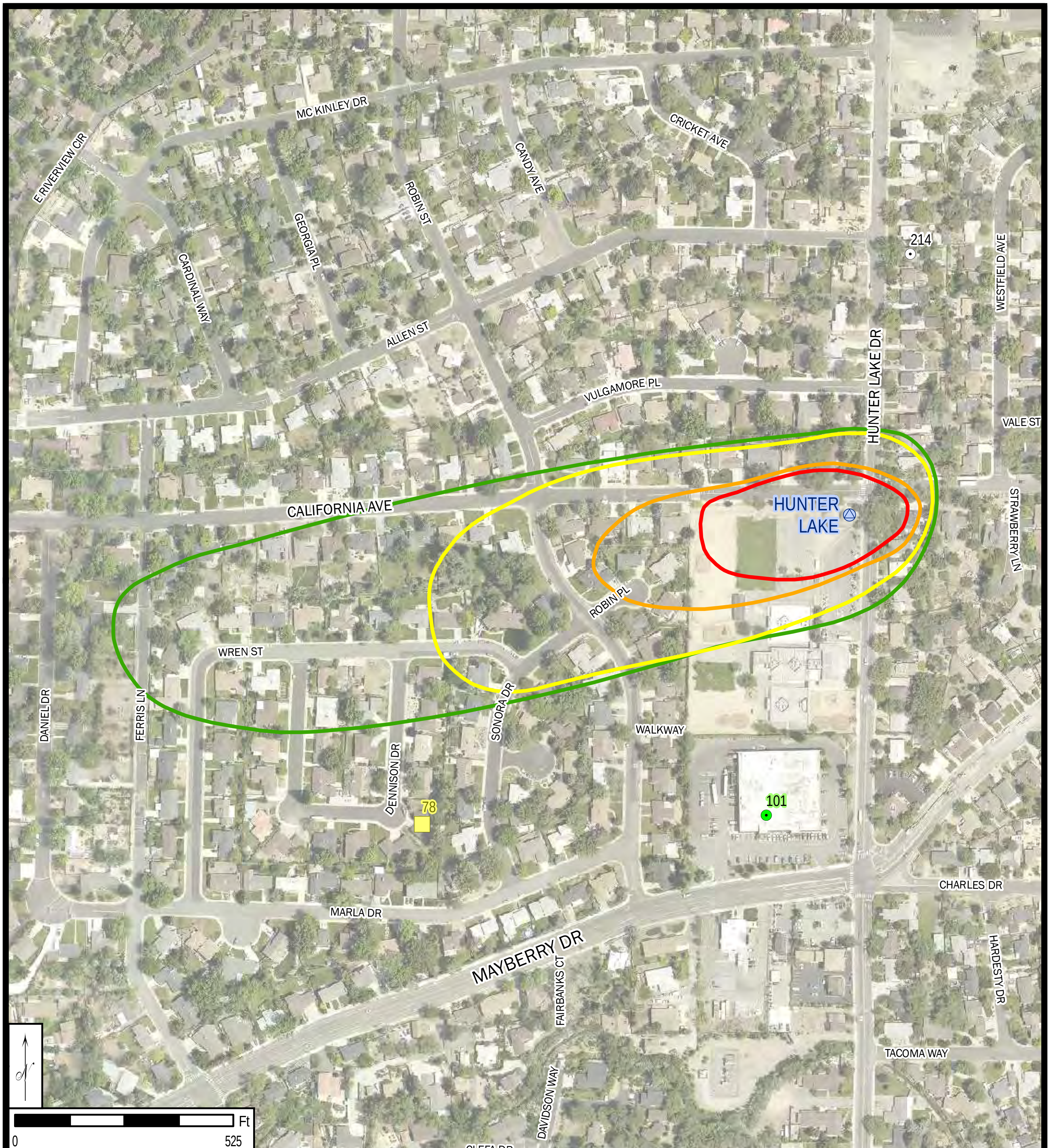
HIGH WELL SITE

POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
POTENTIAL CONTAMINANT SOURCE -- (EPA)
WATER SUPPLY WELL
CONTAMINANT RELEASE SITE - ACTIVE (NDEP)
2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE
CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



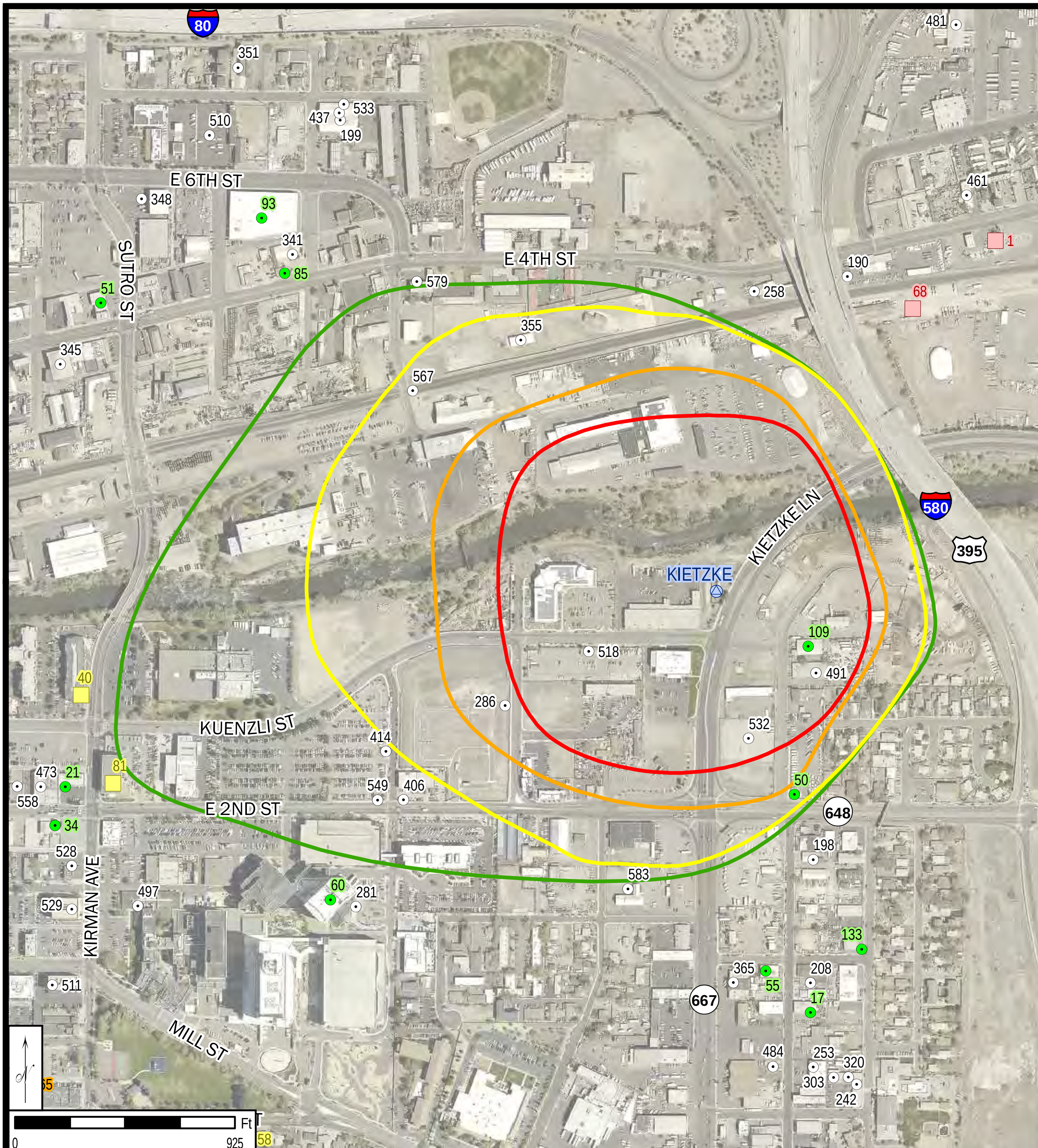
WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 11

HUNTER LAKE WELL SITE

- POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- (EPA)
- WATER SUPPLY WELL
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE
- CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

TMWA



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 12

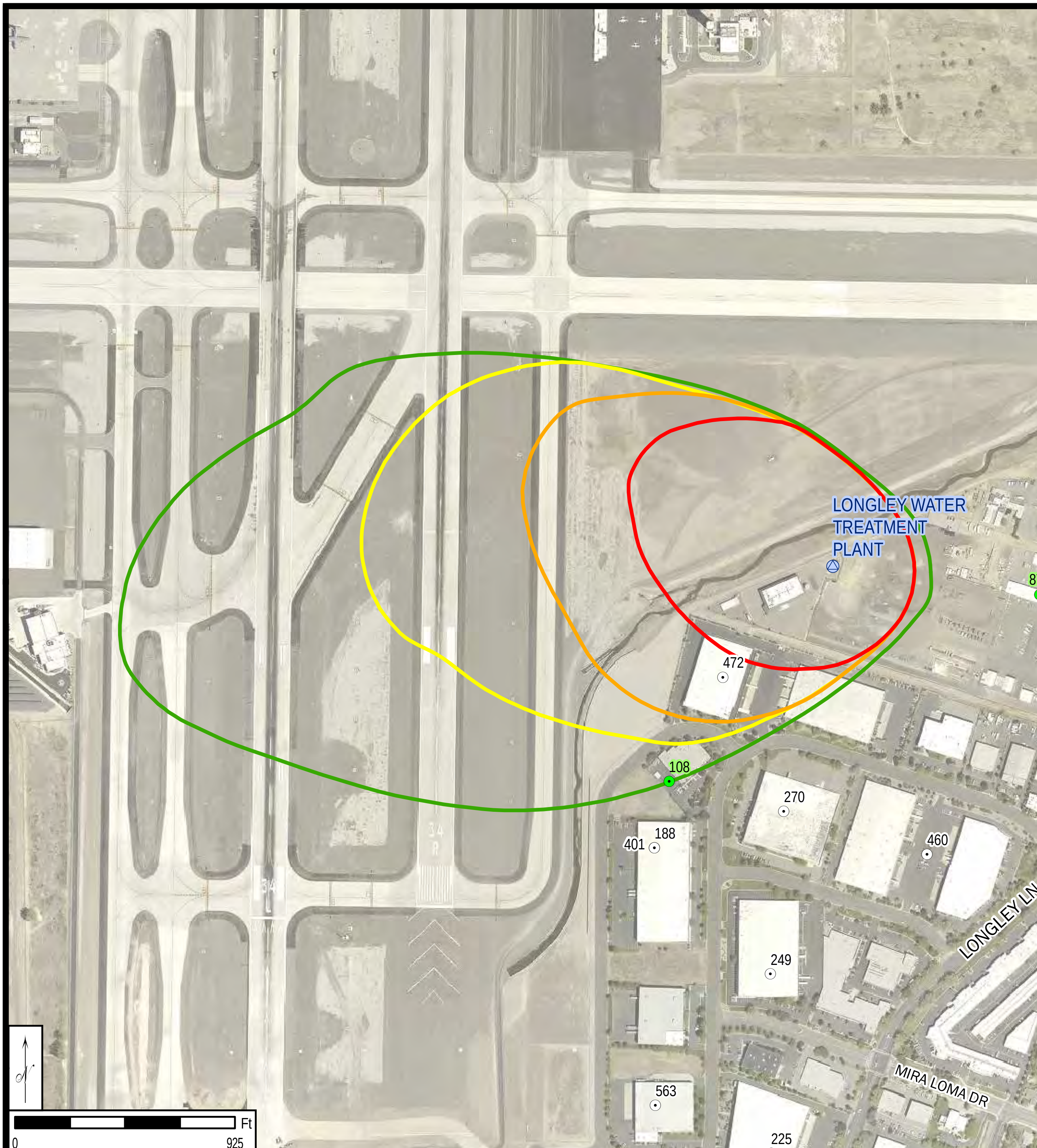
KIETZKE WELL SITE

- POTENTIAL CONTAMINANT SOURCE -- SQG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- (EPA)
- WATER SUPPLY WELL
- CONTAMINANT RELEASE SITE - ACTIVE (NDEP)
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE
- CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 13

LONGLEY WATER TREATMENT PLANT WELL SITE

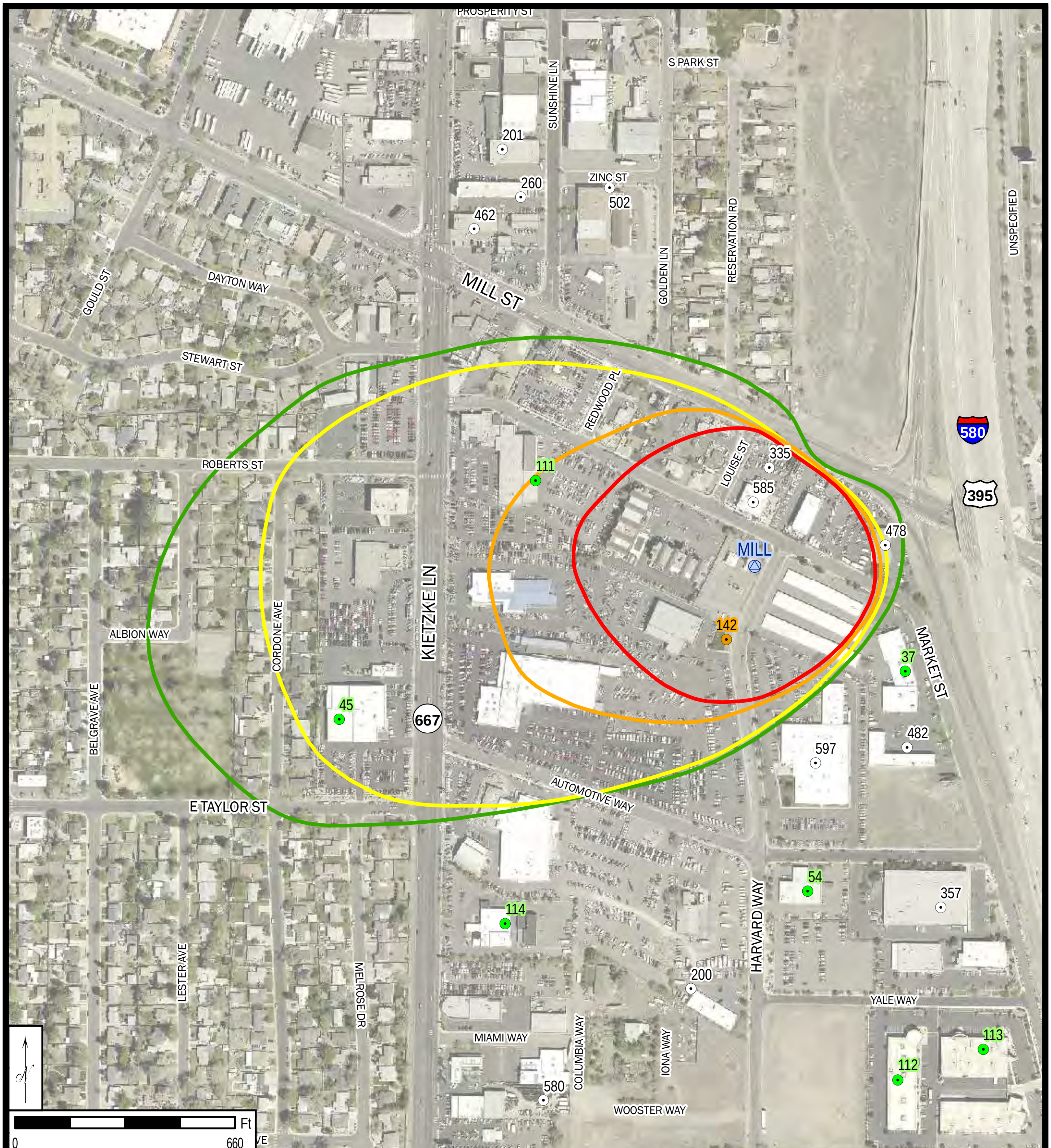
TMWA

POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
POTENTIAL CONTAMINANT SOURCE -- (EPA)
WATER SUPPLY WELL

2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 14

MILL WELL SITE

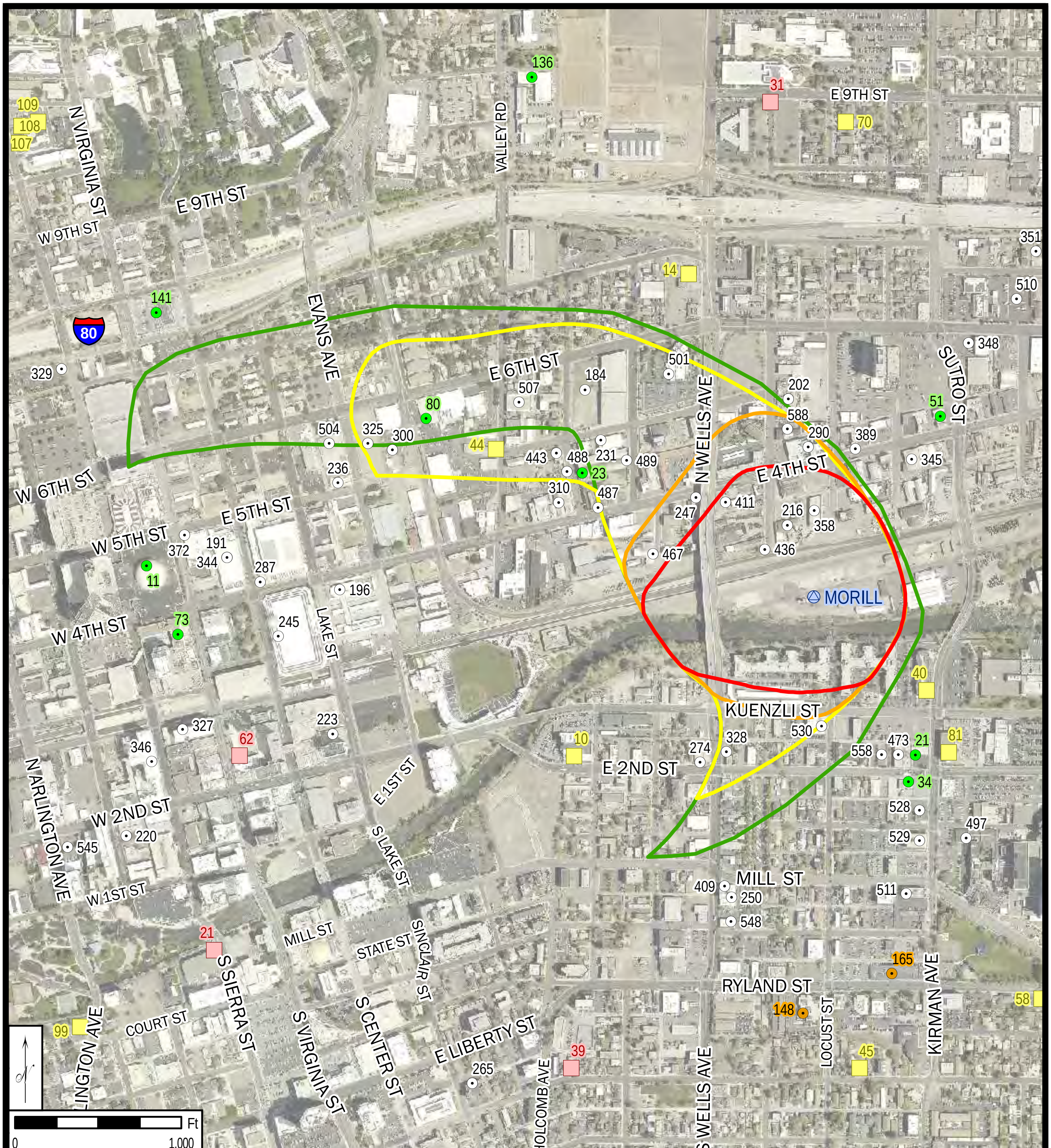
TMWA

- POTENTIAL CONTAMINANT SOURCE -- SQG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- (EPA)
- WATER SUPPLY WELL

- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 15

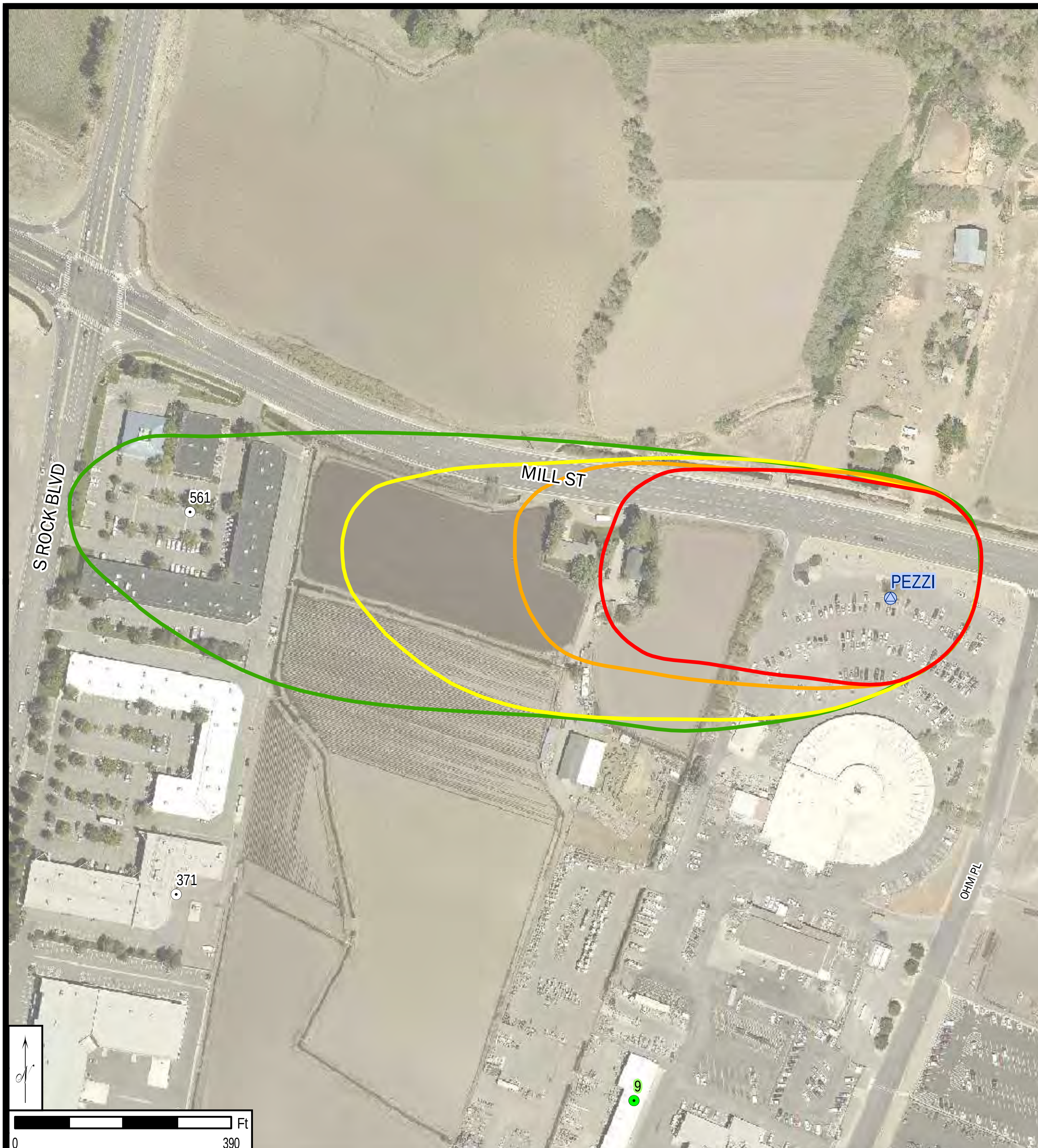
MORILL WELL SITE

- POTENTIAL CONTAMINANT SOURCE -- SQG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- (EPA)
- WATER SUPPLY WELL
- CONTAMINANT RELEASE SITE - ACTIVE (NDEP)
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE
- CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 16

PEZZI WELL SITE

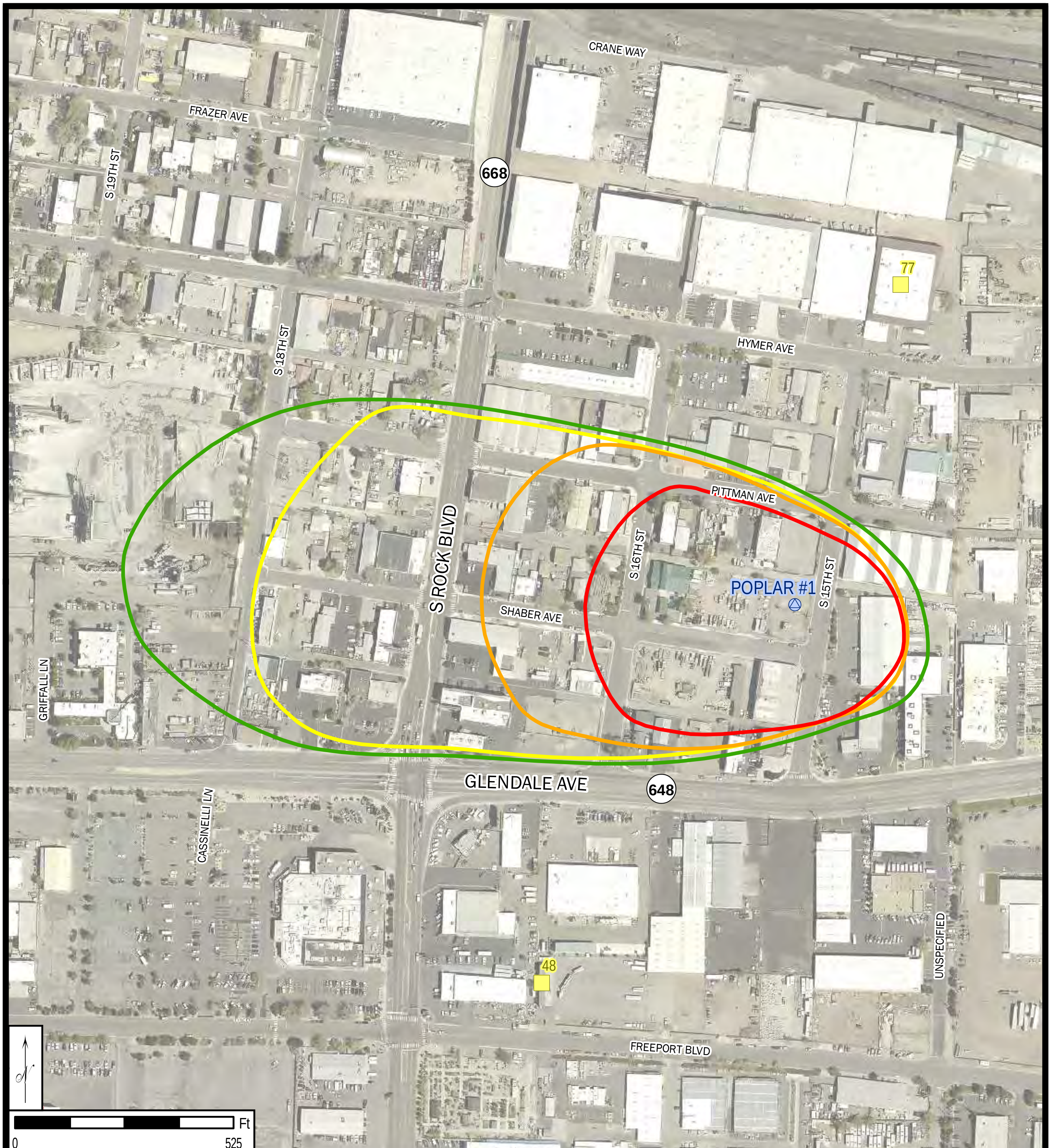
TMWA

POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
POTENTIAL CONTAMINANT SOURCE -- (EPA)
WATER SUPPLY WELL

2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 17

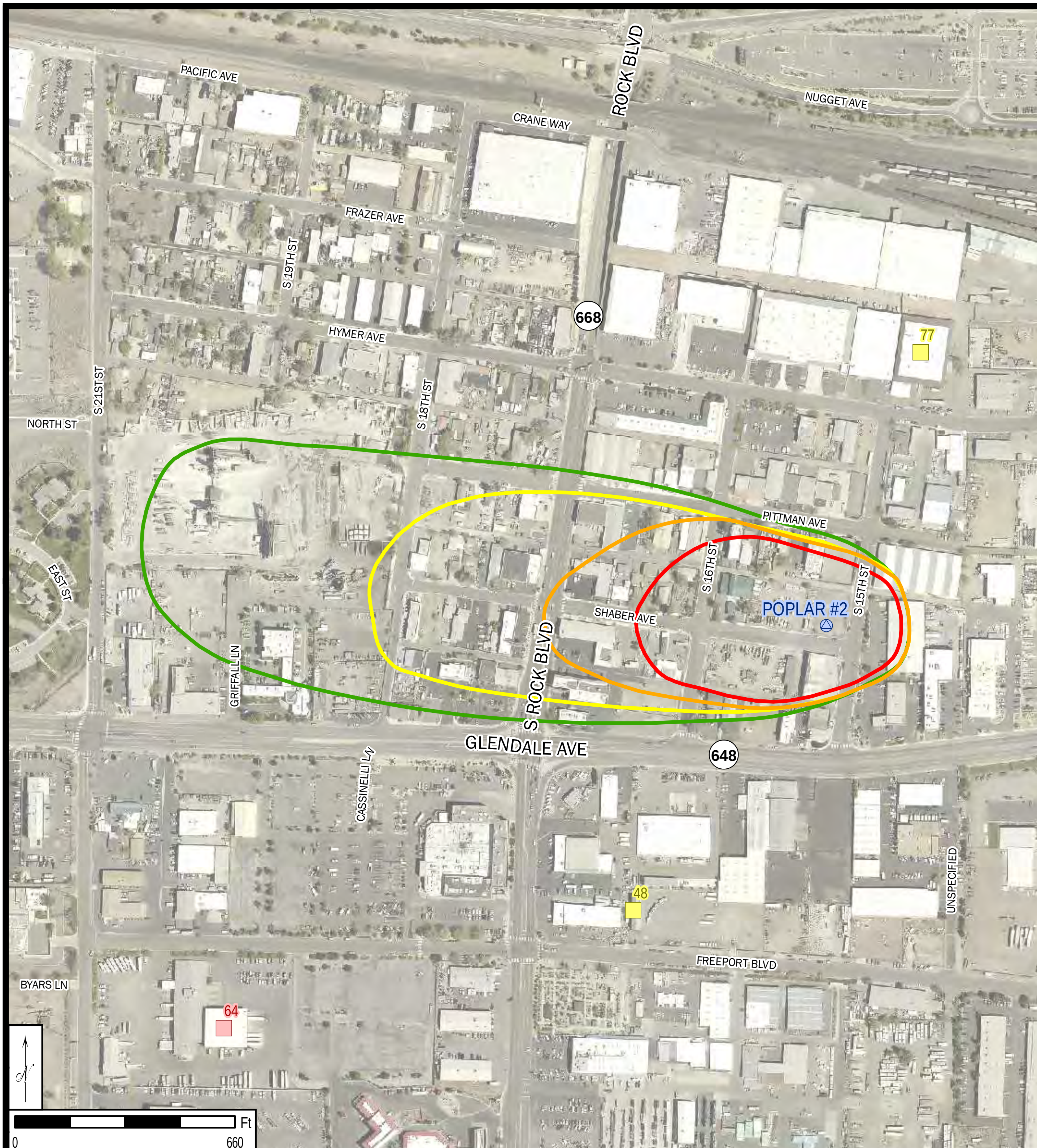
POPLAR #1 WELL SITE

- WATER SUPPLY WELL
- CONTAMINANT RELEASE SITE - ACTIVE (NDEP)
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE
- CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 18

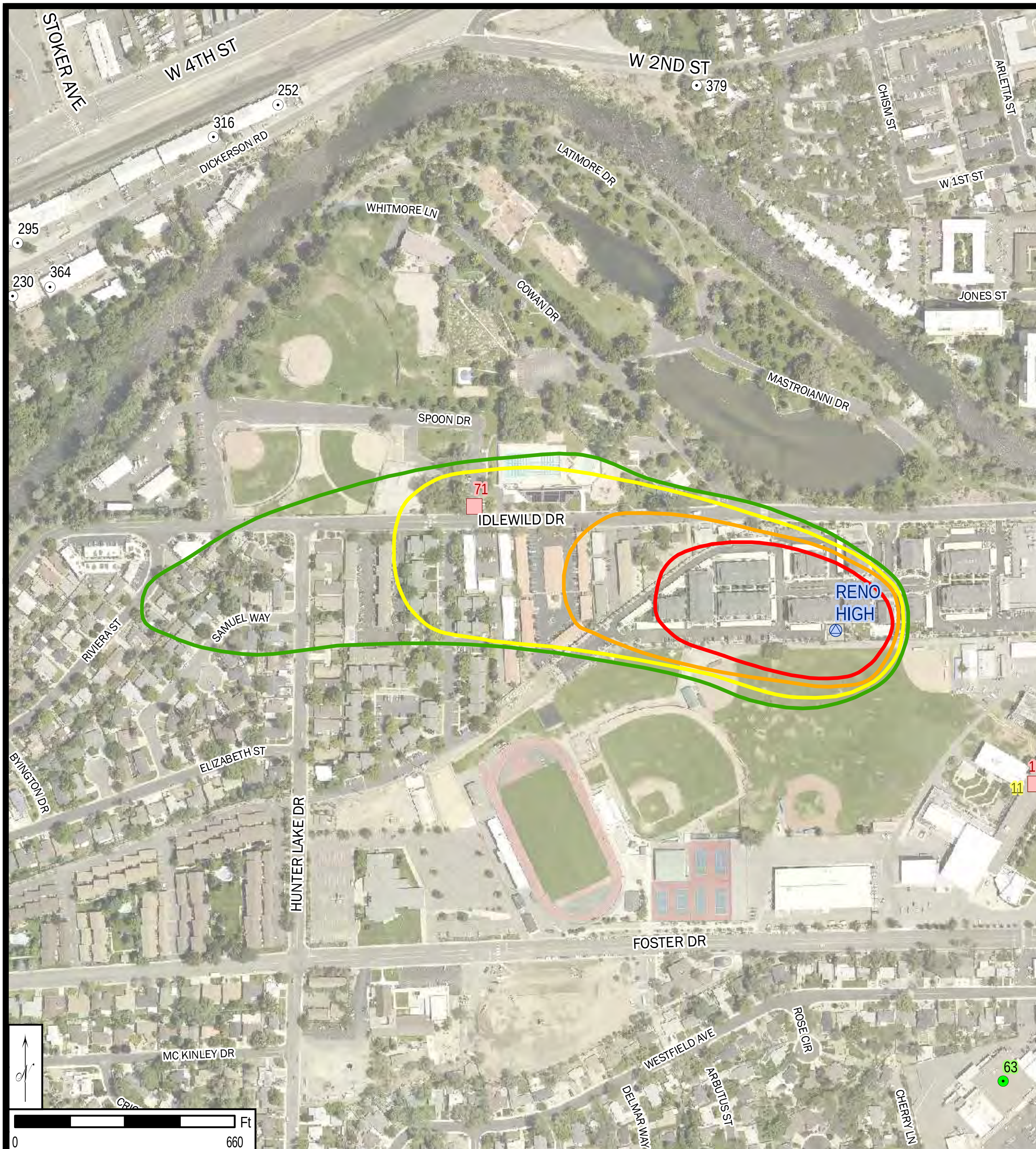
POPLAR #2 WELL SITE

- WATER SUPPLY WELL
- CONTAINMENT RELEASE SITE - ACTIVE (NDEP)
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE
- CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 19

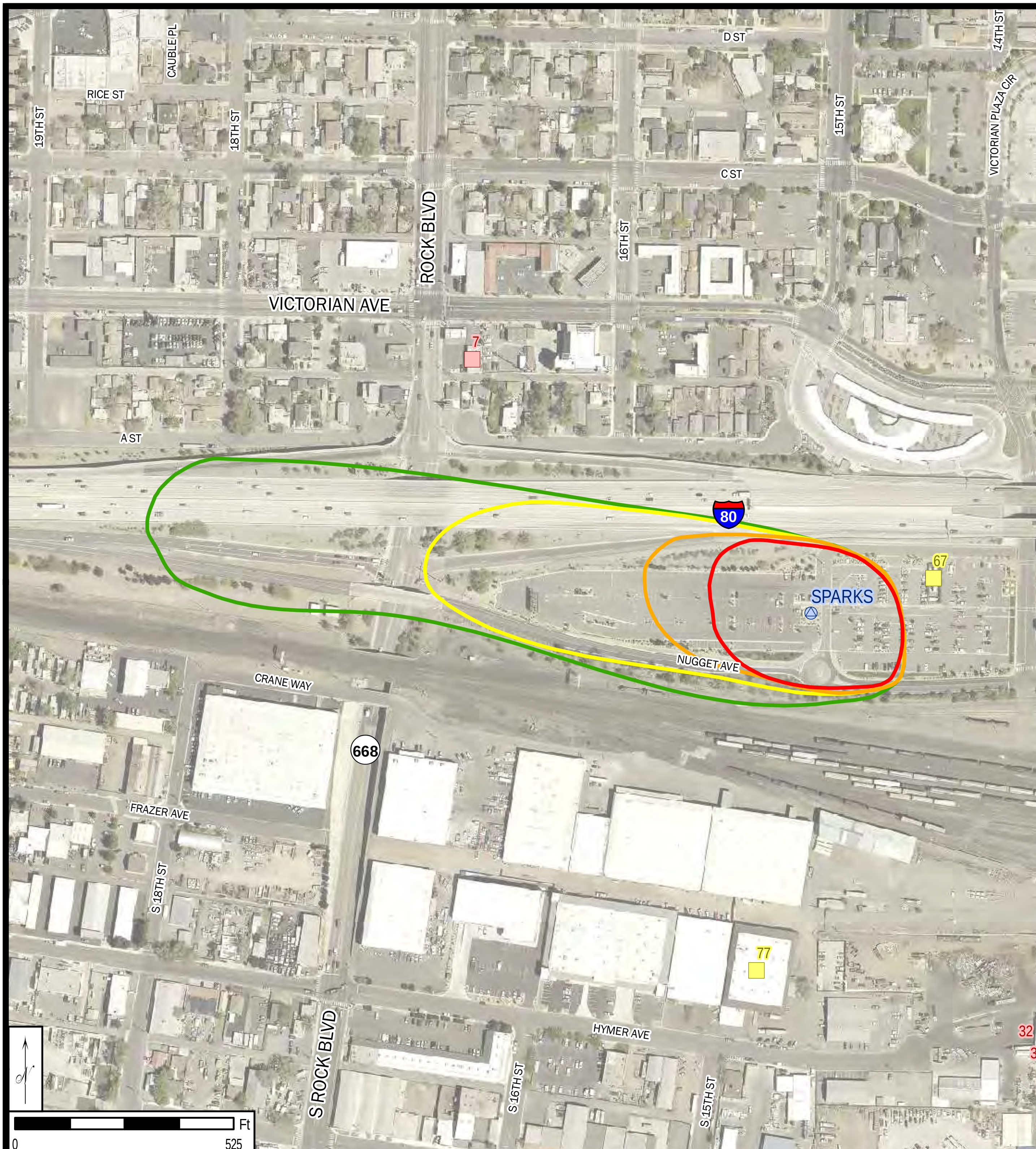
RENO HIGH WELL SITE

- POTENTIAL CONTAMINANT SOURCE -- SQG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- (EPA)
- WATER SUPPLY WELL
- CONTAMINANT RELEASE SITE - ACTIVE (NDEP)
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE
- CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 20

SPARKS WELL SITE

WATER SUPPLY WELL

CONTAMINANT RELEASE SITE - ACTIVE (NDEP)

2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

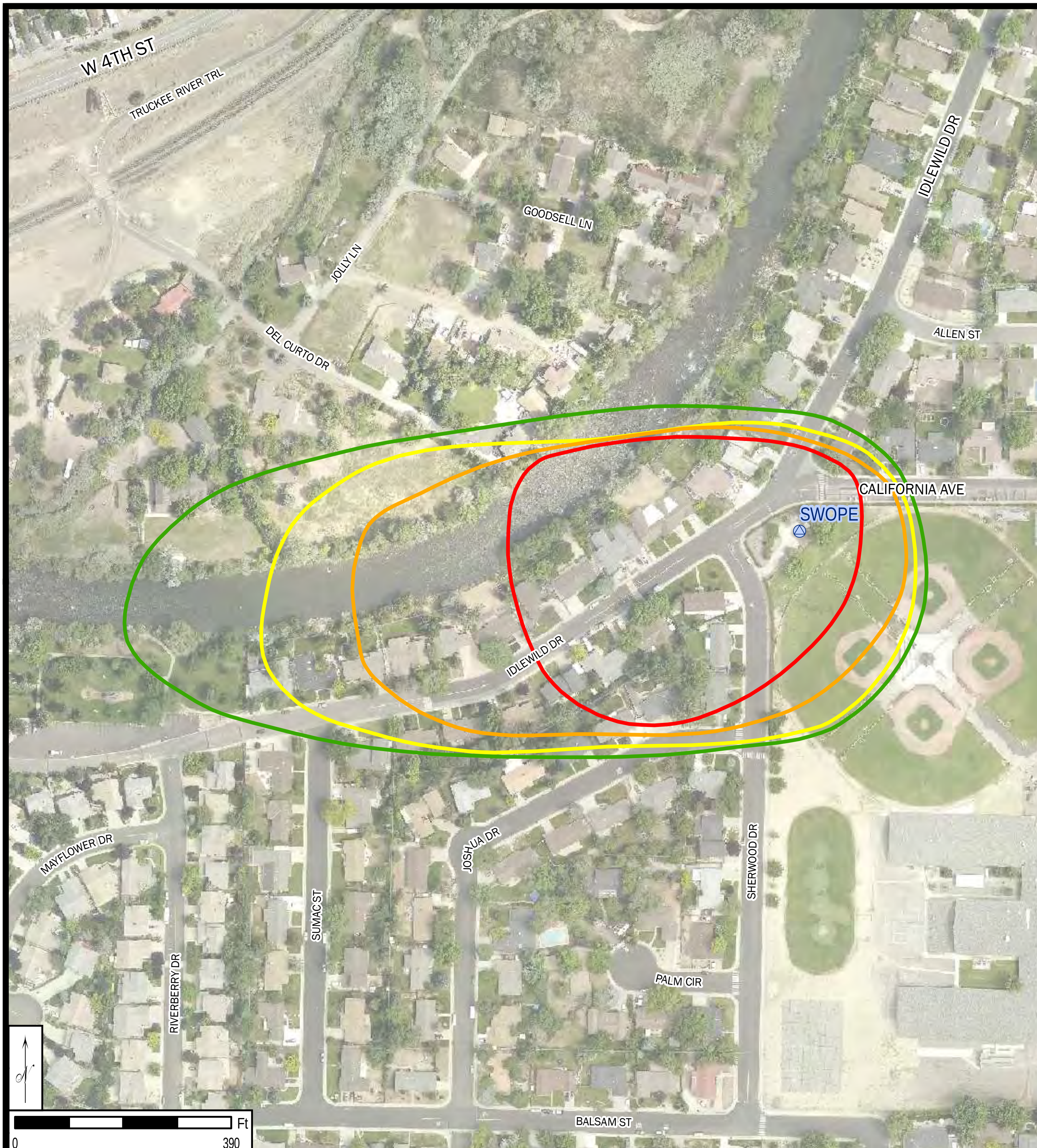
20 YEAR CAPTURE ZONE

CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 21

SWOPE WELL SITE

TMWA

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

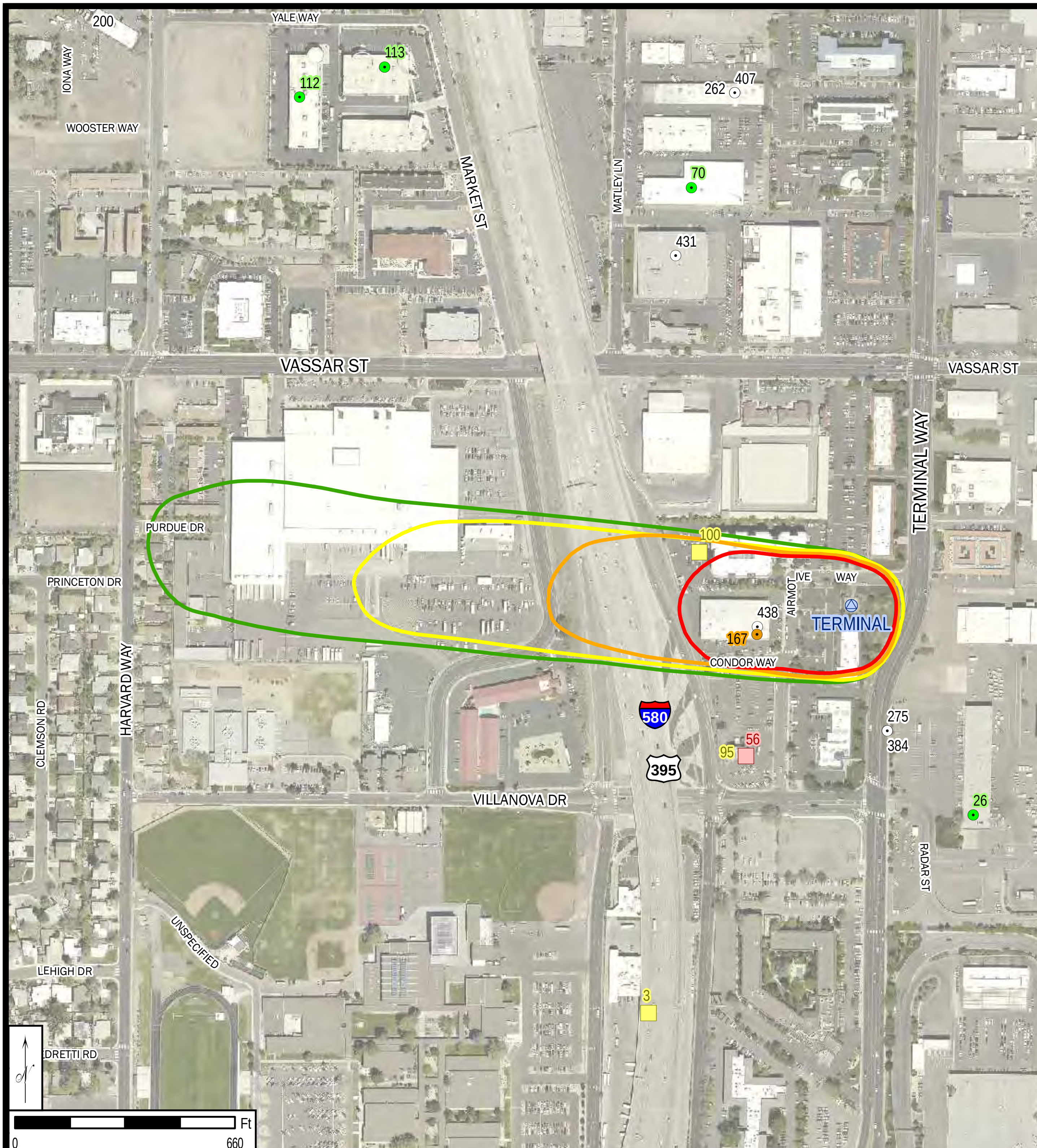
5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

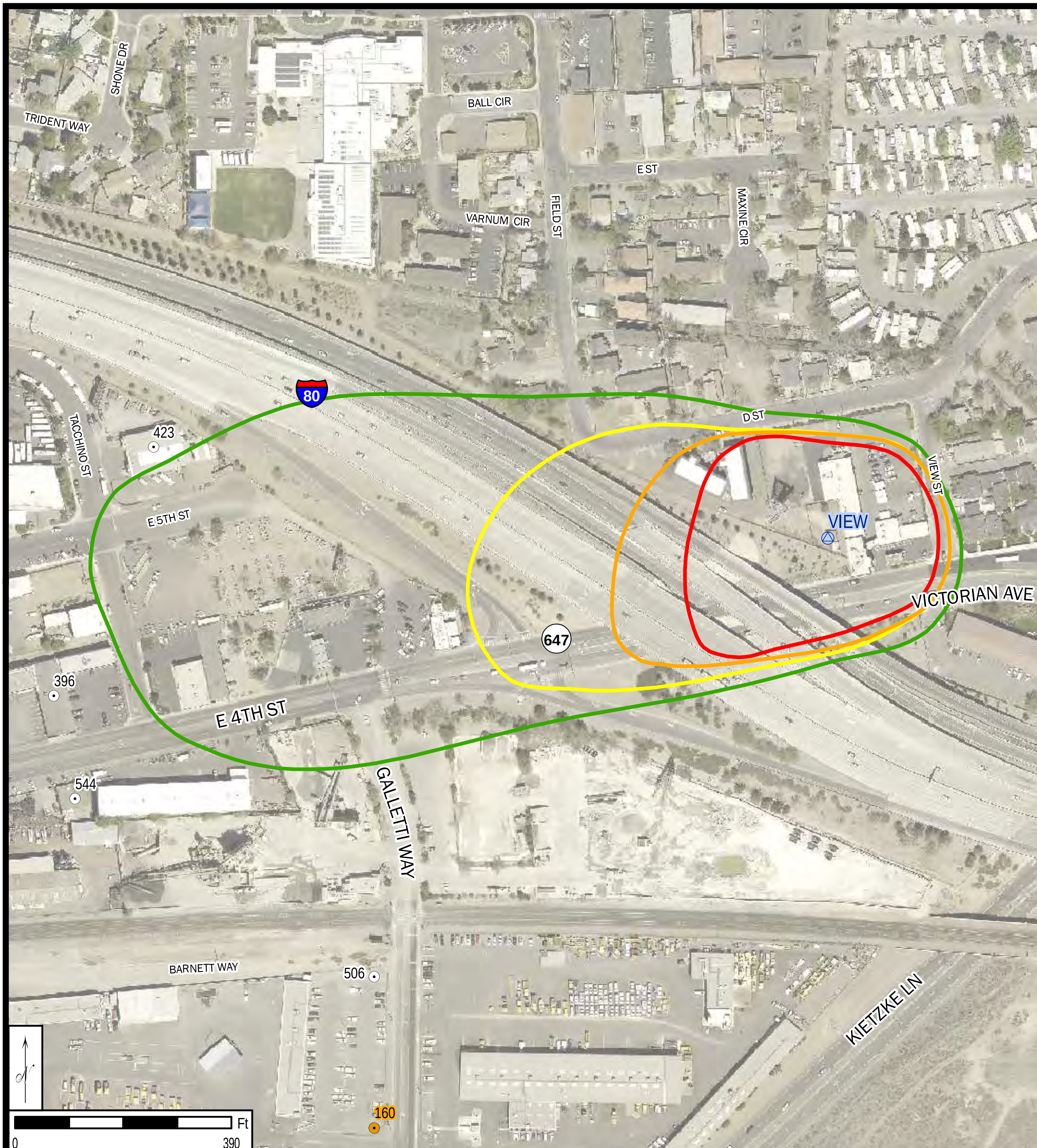
TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 22

TERMINAL WELL SITE

- POTENTIAL CONTAMINANT SOURCE -- SQG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- (EPA)
- WATER SUPPLY WELL
- CONTAMINANT RELEASE SITE - ACTIVE (NDEP)
- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE
- CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

TMWA

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (NORTH) (BASIN 87) -- FIGURE: 23

VIEW WELL SITE

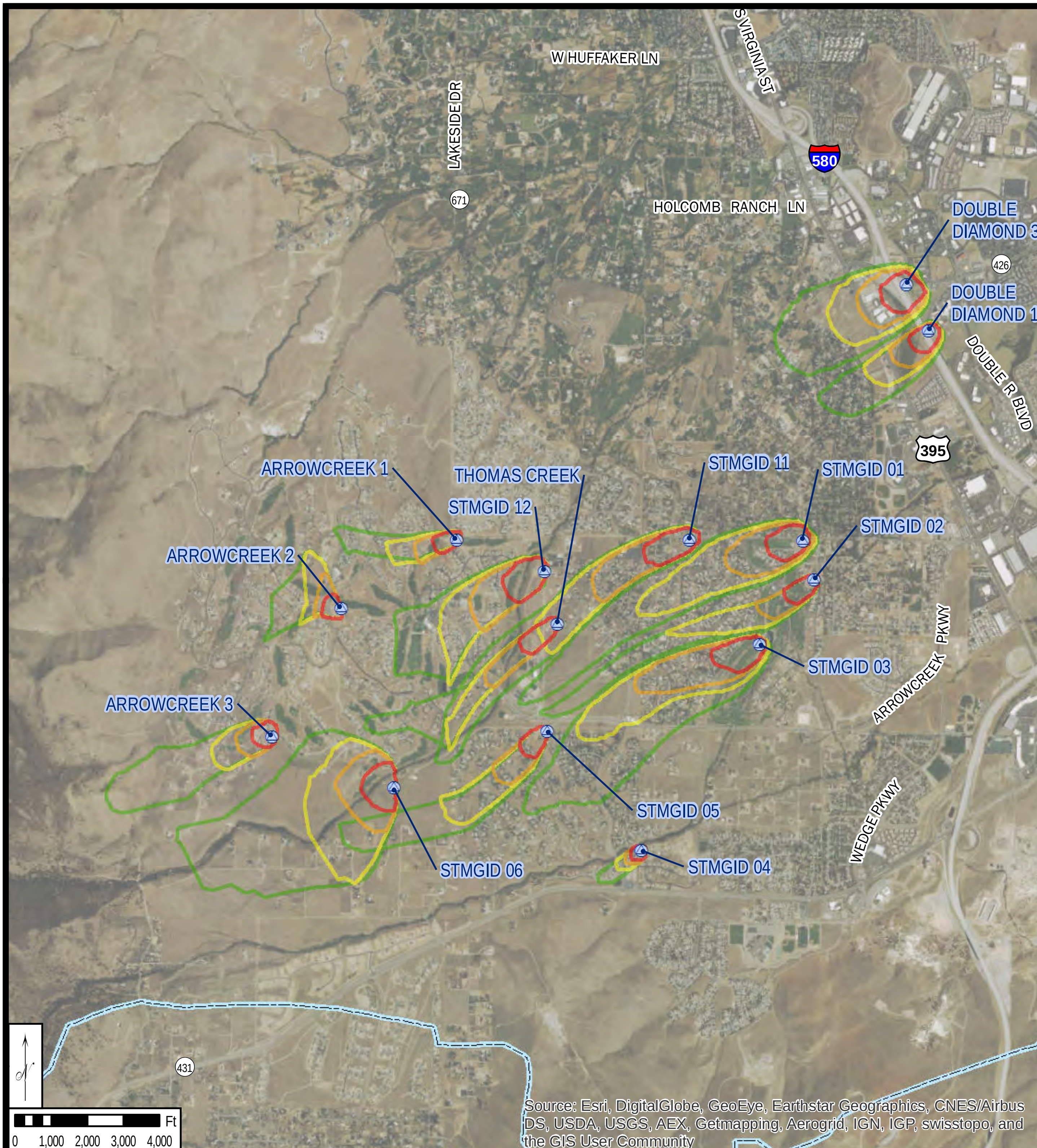
- POTENTIAL CONTAMINANT SOURCE -- SQG (EPA)
- POTENTIAL CONTAMINANT SOURCE -- (EPA)
- WATER SUPPLY WELL

- 2 YEAR CAPTURE ZONE
- 5 YEAR CAPTURE ZONE
- 10 YEAR CAPTURE ZONE
- 20 YEAR CAPTURE ZONE

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELLHEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (SOUTH) (BASIN 87) AREA INDEX

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

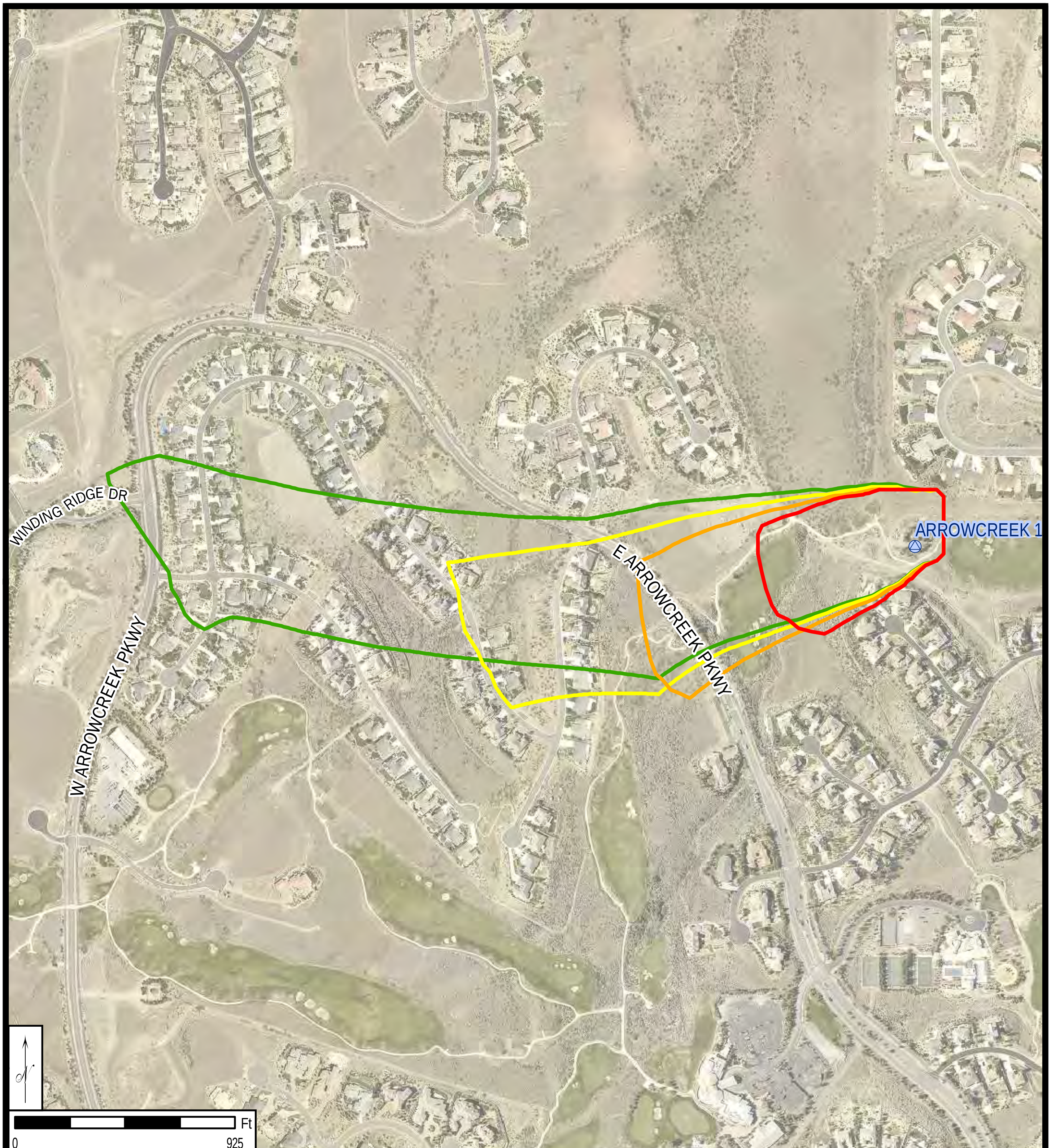
20 YEAR CAPTURE ZONE

NEVADA HYDROBASIN BOUNDARY

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_AreaIndex_DD_8.5X11.mxd, Editor: Michael, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (SOUTH) (BASIN 87) -- FIGURE: 1

ARROWCREEK 1 WELL SITE

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

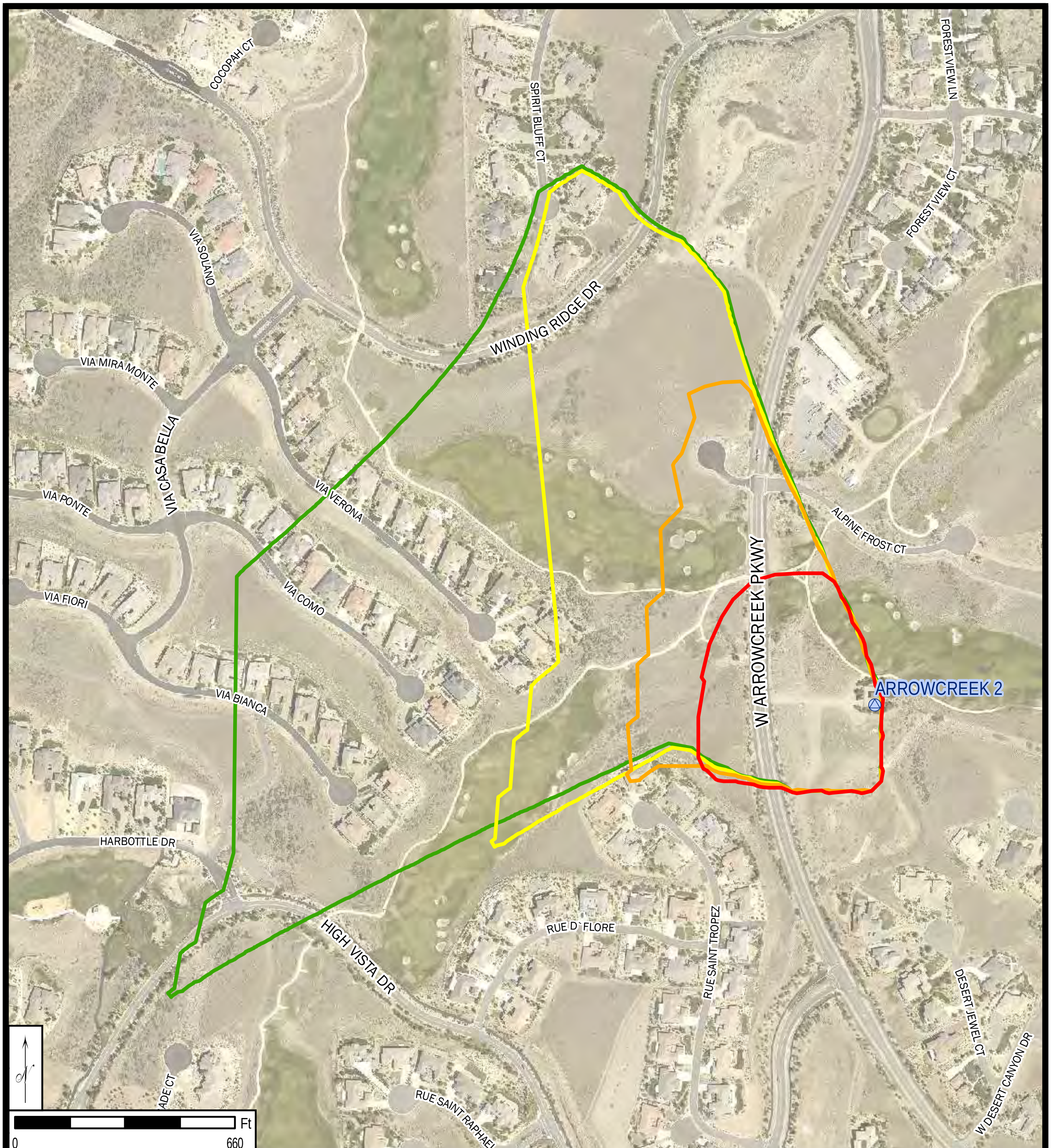
5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

TMWA

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (SOUTH) (BASIN 87) -- FIGURE: 2

ARROWCREEK 2 WELL SITE

WATER SUPPLY WELL

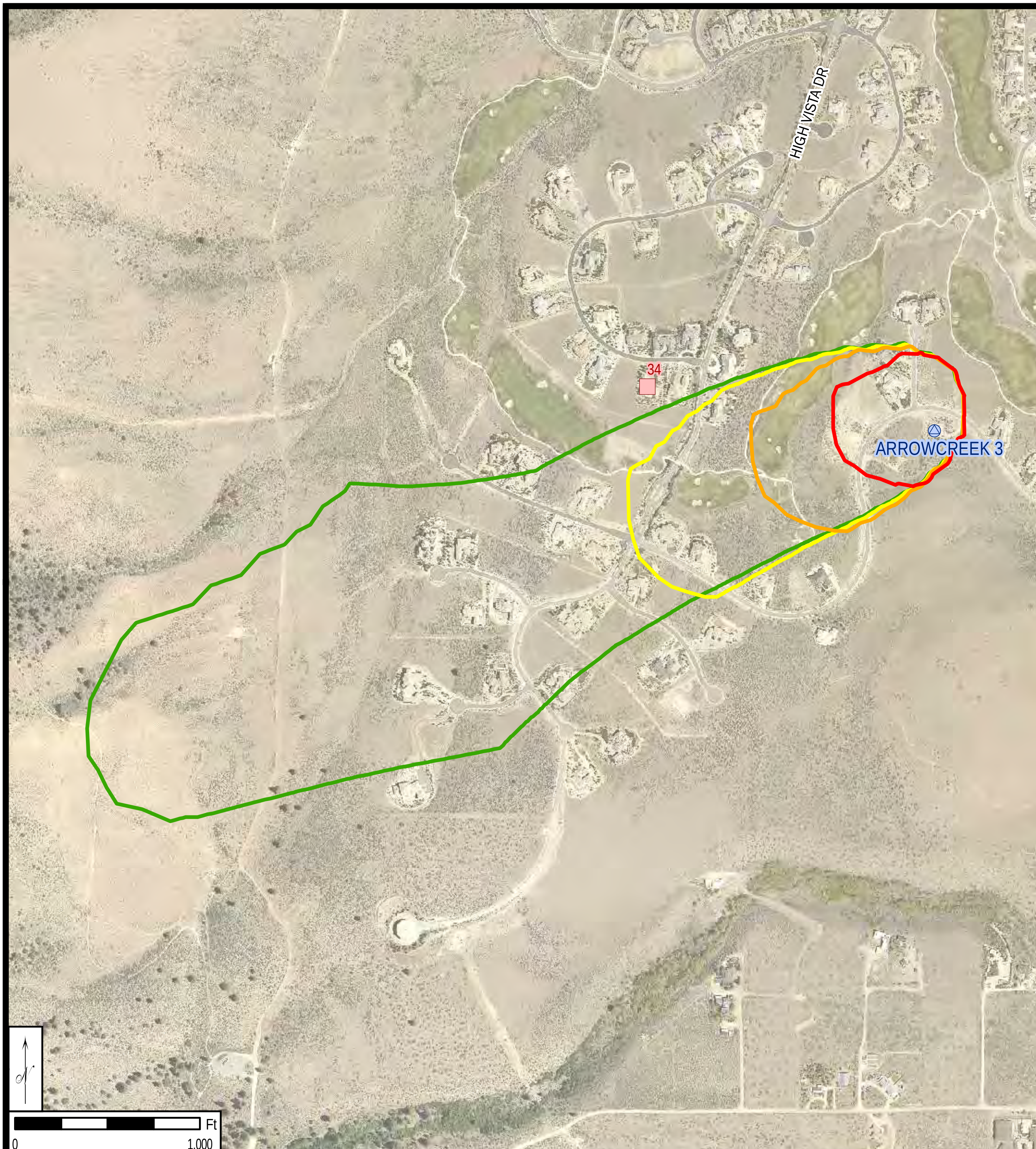
2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

TMWA



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (SOUTH) (BASIN 87) -- FIGURE: 3

ARROWCREEK 3 WELL SITE

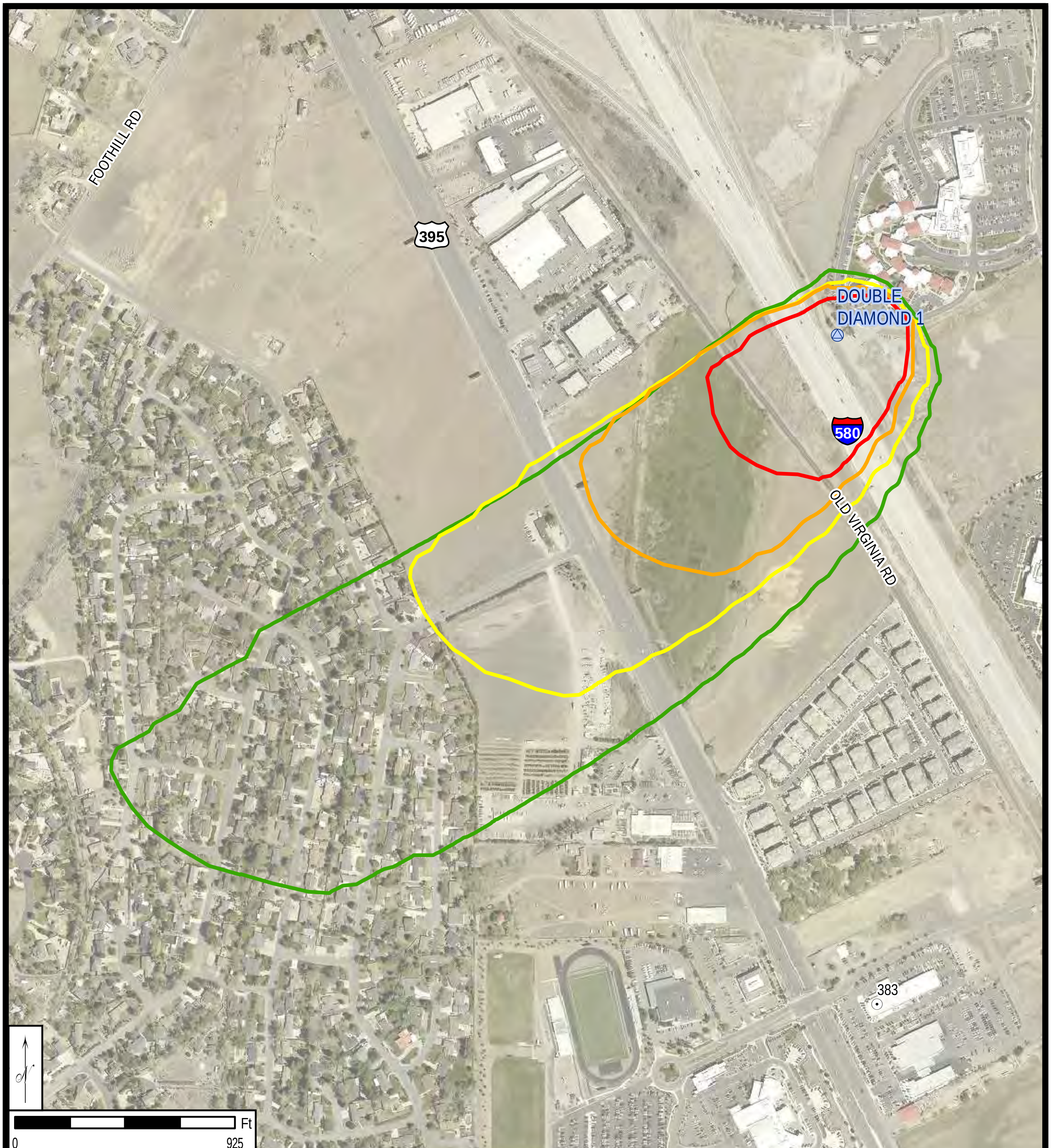
TMWA

WATER SUPPLY WELL
CONTAMINANT RELEASE SITE - ACTIVE (NDEP)

2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (SOUTH) (BASIN 87) -- FIGURE: 4

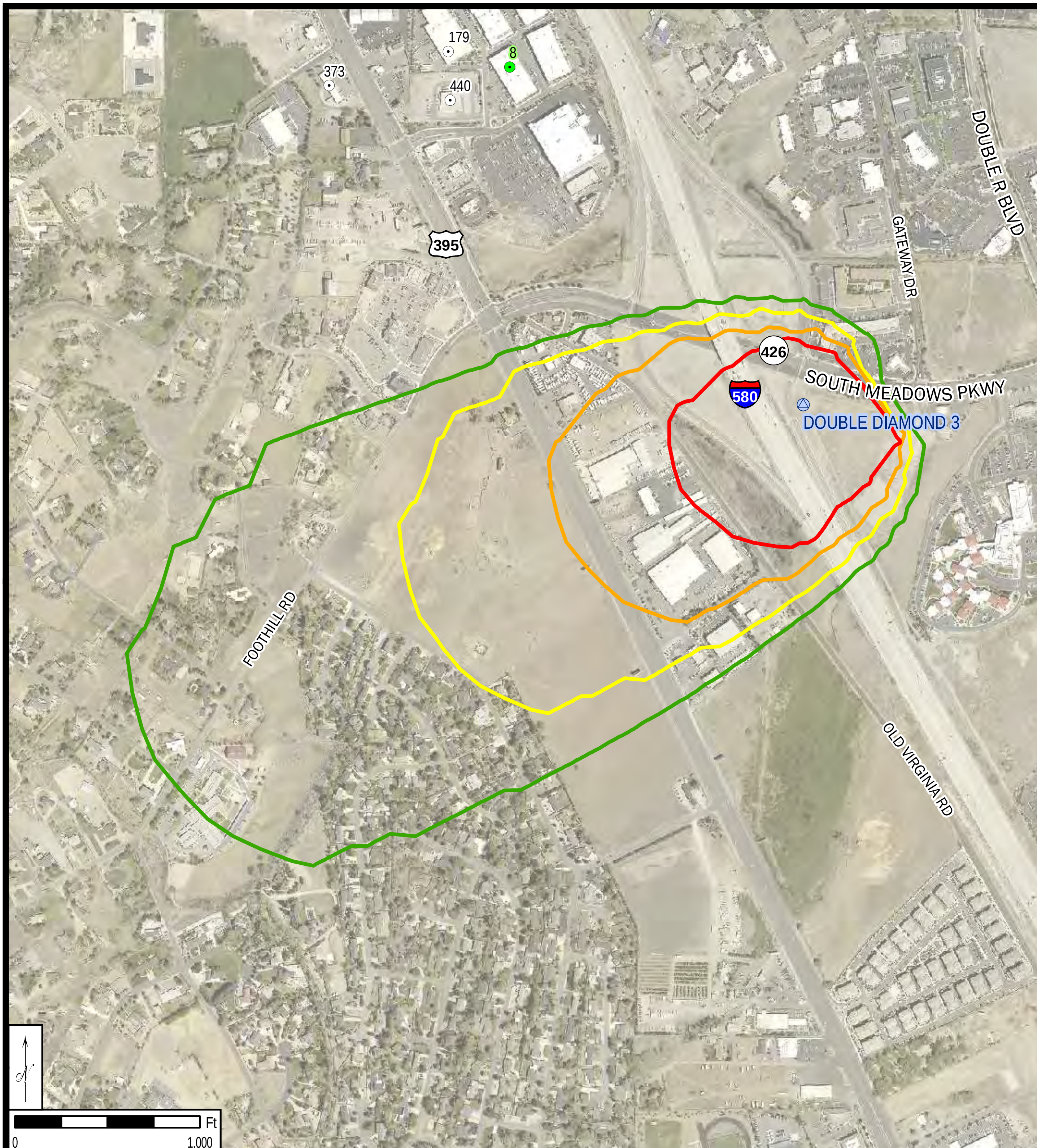
DOUBLE DIAMOND 1 WELL SITE

TMWA

⊙ POTENTIAL CONTAMINANT SOURCE -- (EPA)
WATER SUPPLY WELL

2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

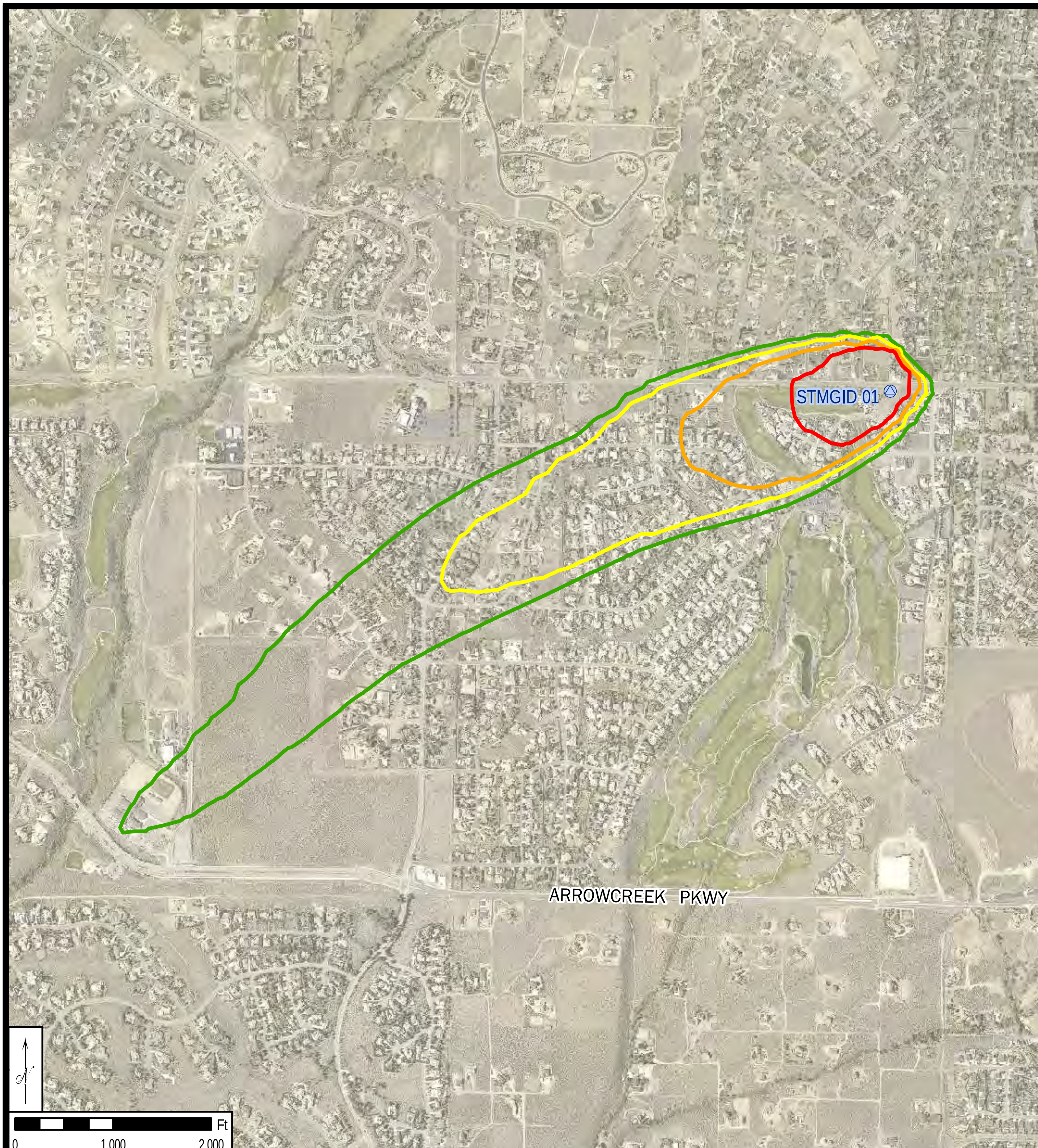
TRUCKEE MEADOWS (SOUTH) (BASIN 87) -- FIGURE: 5

DOUBLE DIAMOND 3 WELL SITE

TMWA

POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)
POTENTIAL CONTAMINANT SOURCE -- (EPA)
WATER SUPPLY WELL

2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (SOUTH) (BASIN 87) -- FIGURE: 6

STMGID 01 WELL SITE

TMWA

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015

WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (SOUTH) (BASIN 87) -- FIGURE: 7

STMGID 02 WELL SITE

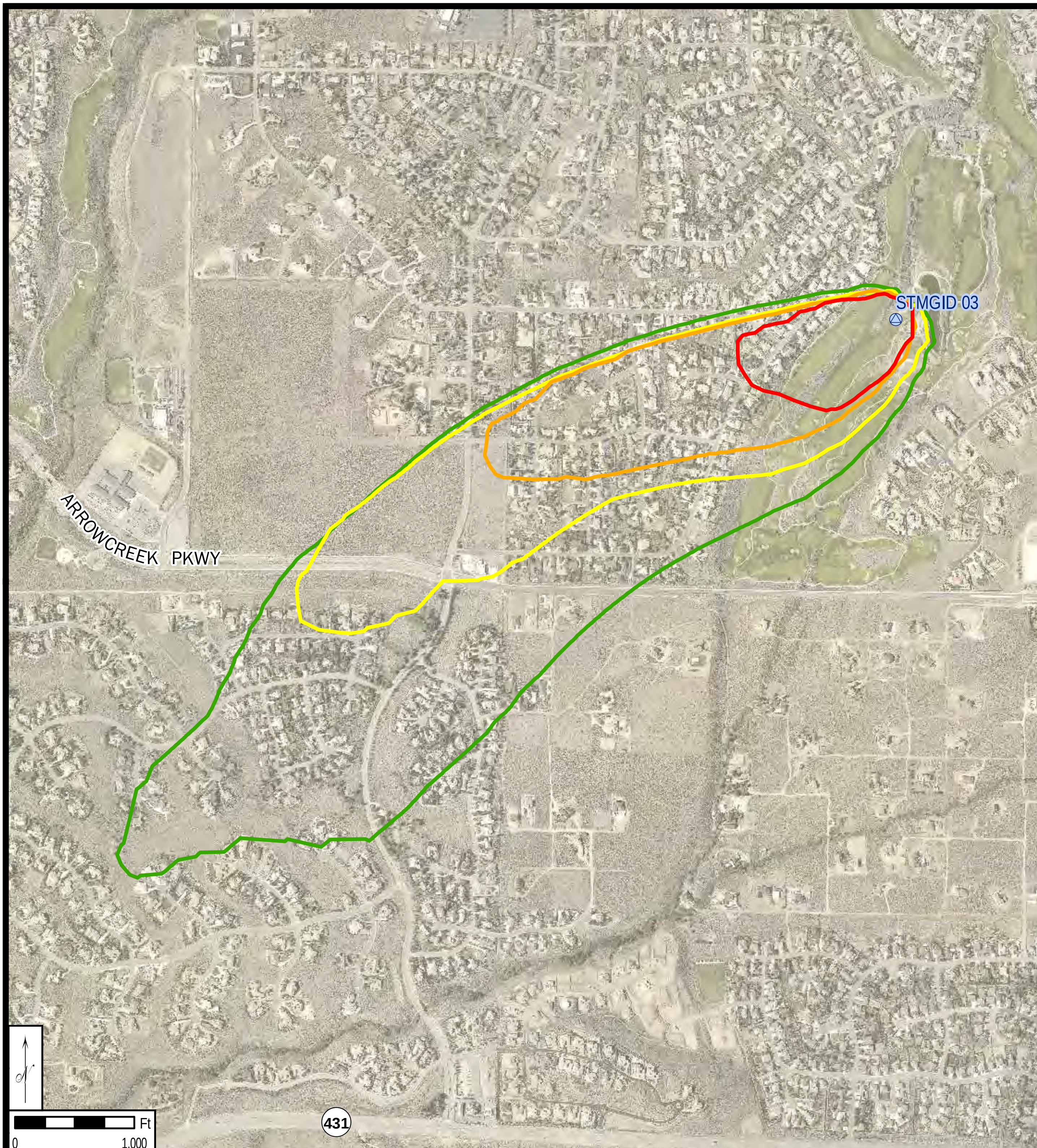
TMWA

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (SOUTH) (BASIN 87) -- FIGURE: 8

STMGID 03 WELL SITE

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

5 YEAR CAPTURE ZONE

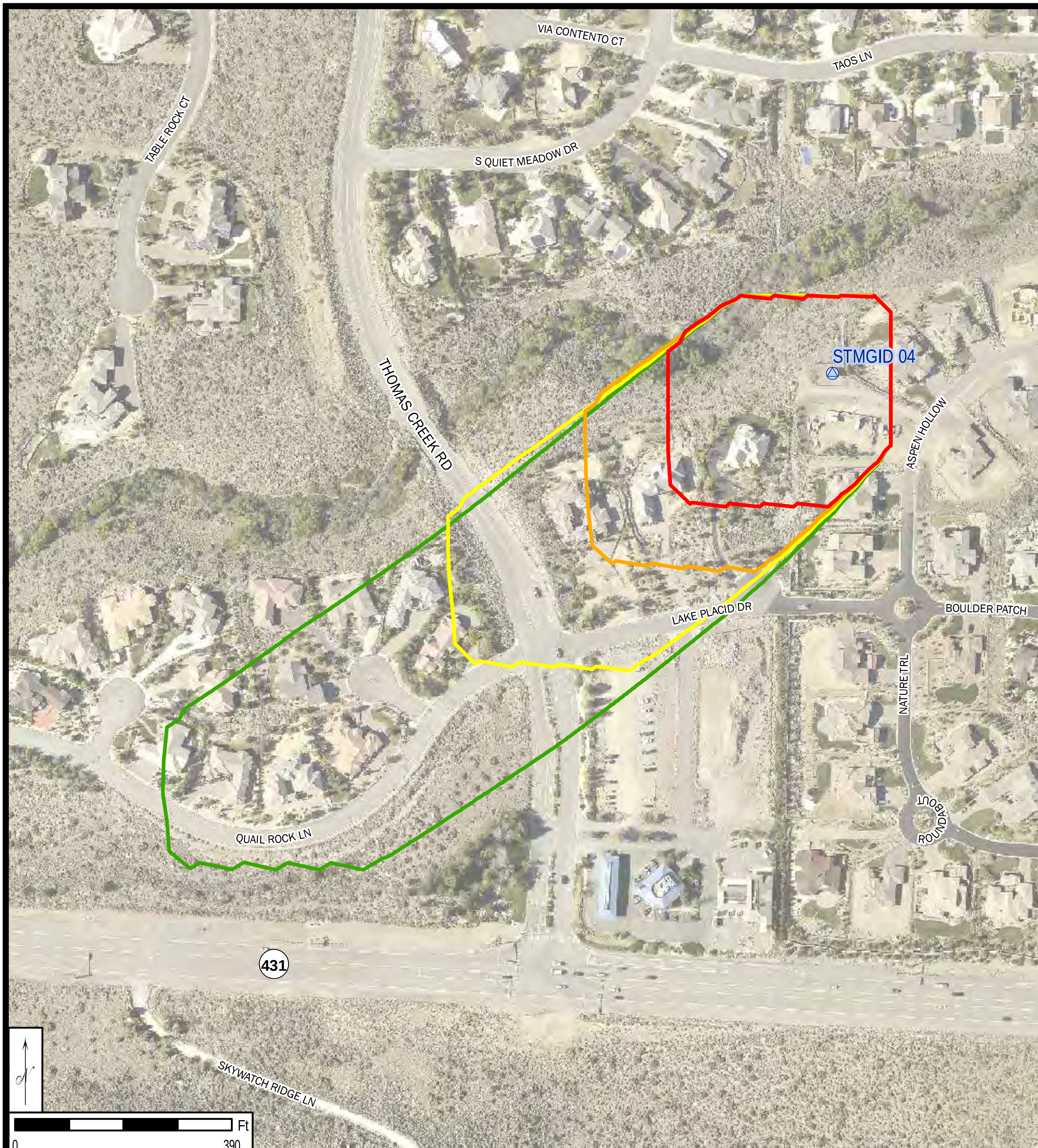
10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (SOUTH) (BASIN 87) -- FIGURE: 9

STMGID 04 WELL SITE

TMWA

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

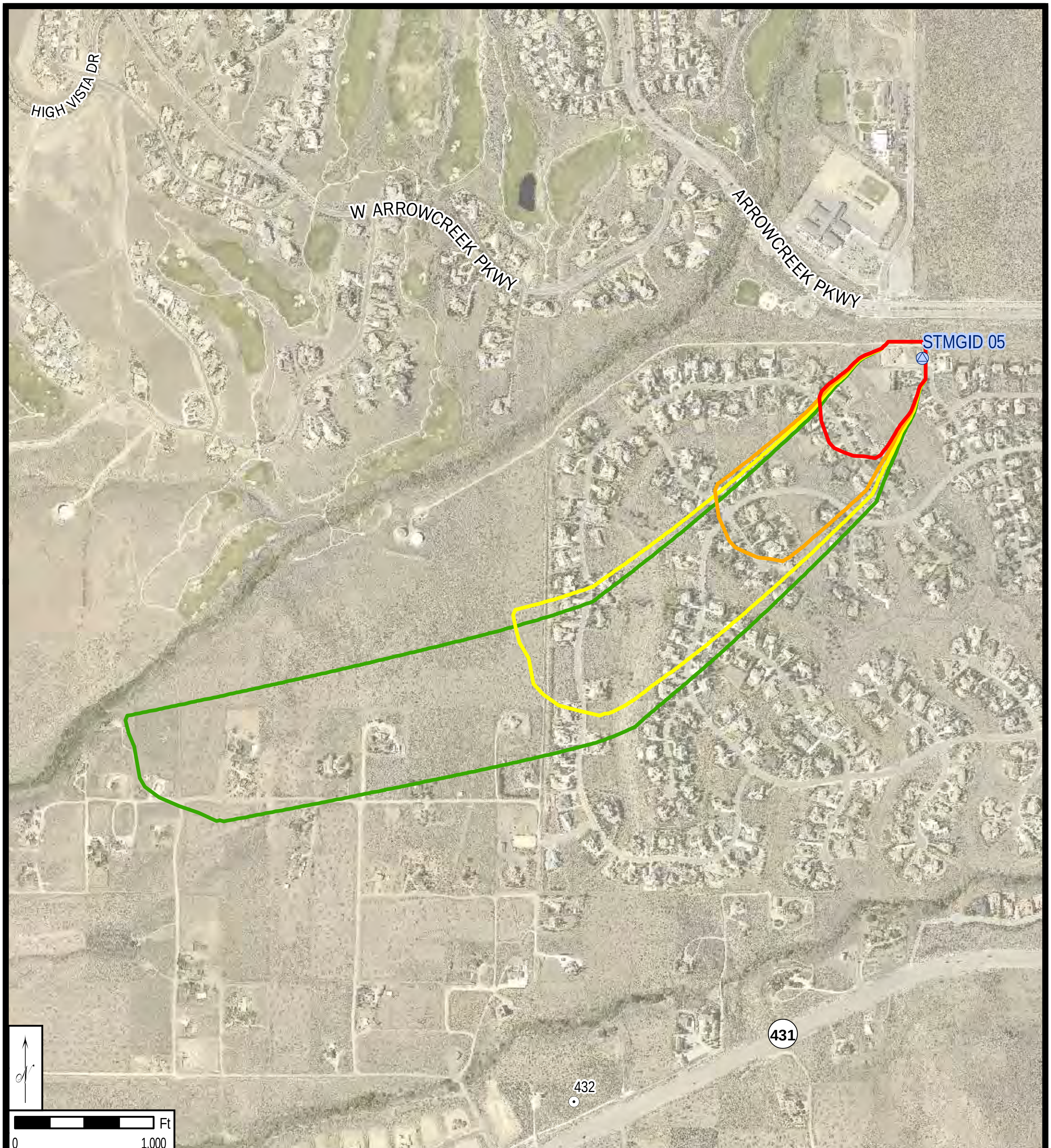
5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

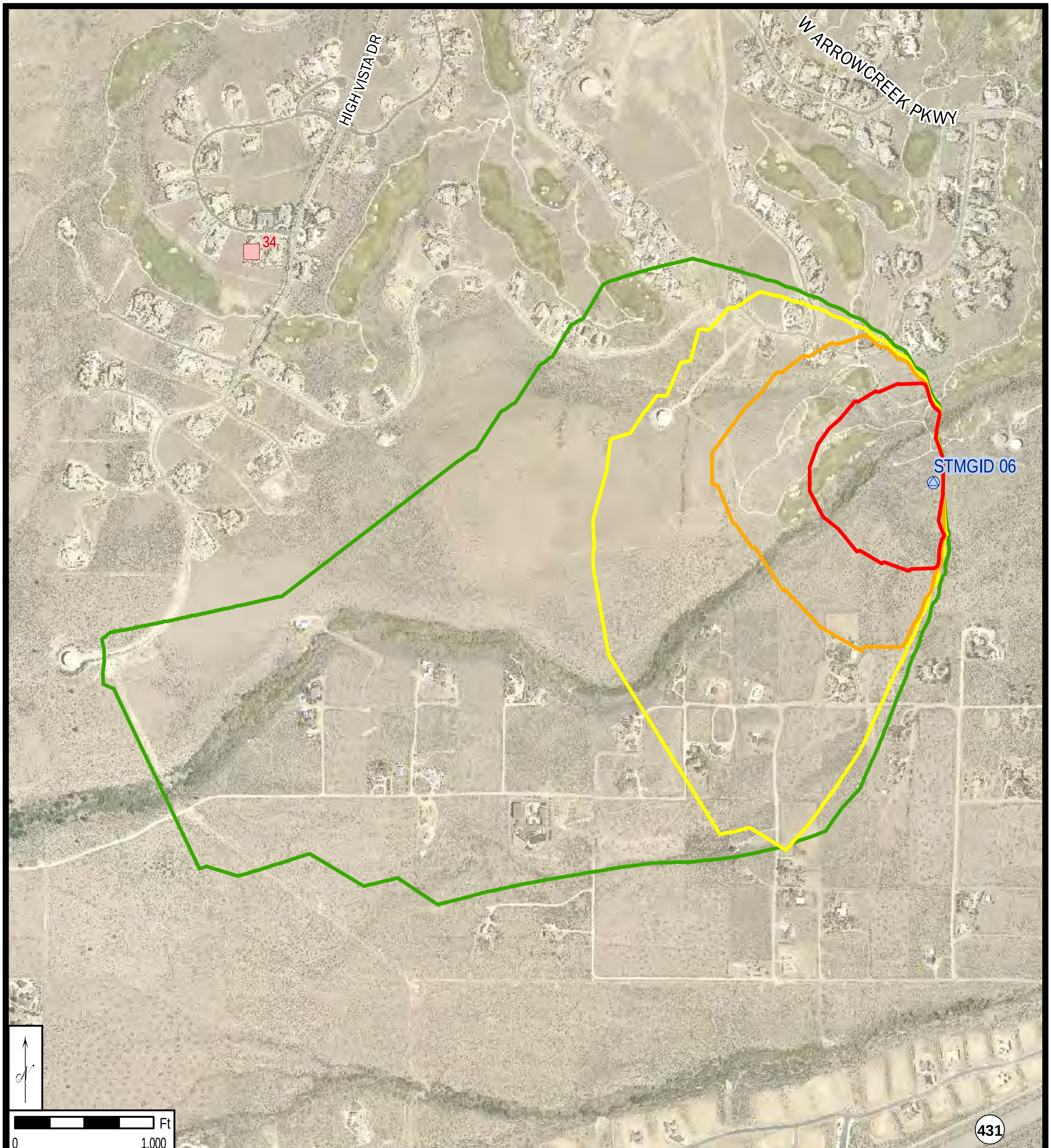
TRUCKEE MEADOWS (SOUTH) (BASIN 87) -- FIGURE: 10

STMGID 05 WELL SITE

TMWA

POTENTIAL CONTAMINANT SOURCE -- (EPA)
WATER SUPPLY WELL

2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (SOUTH) (BASIN 87) -- FIGURE: 11

STMGID 06 WELL SITE

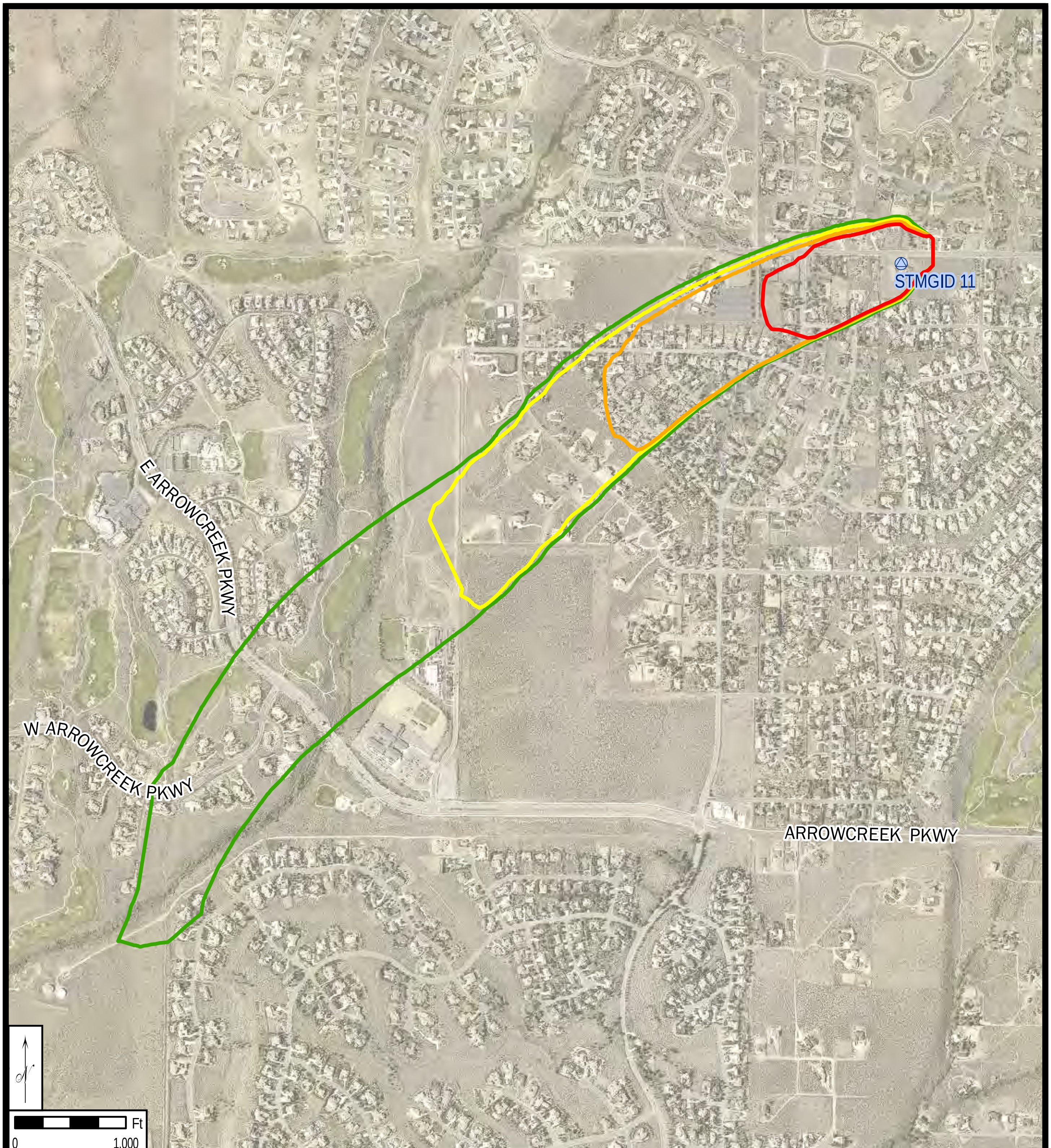
WATER SUPPLY WELL
CONTAMINANT RELEASE SITE - ACTIVE (NDEP)

2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (SOUTH) (BASIN 87) -- FIGURE: 12

STMGID 11 WELL SITE

TMWA

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

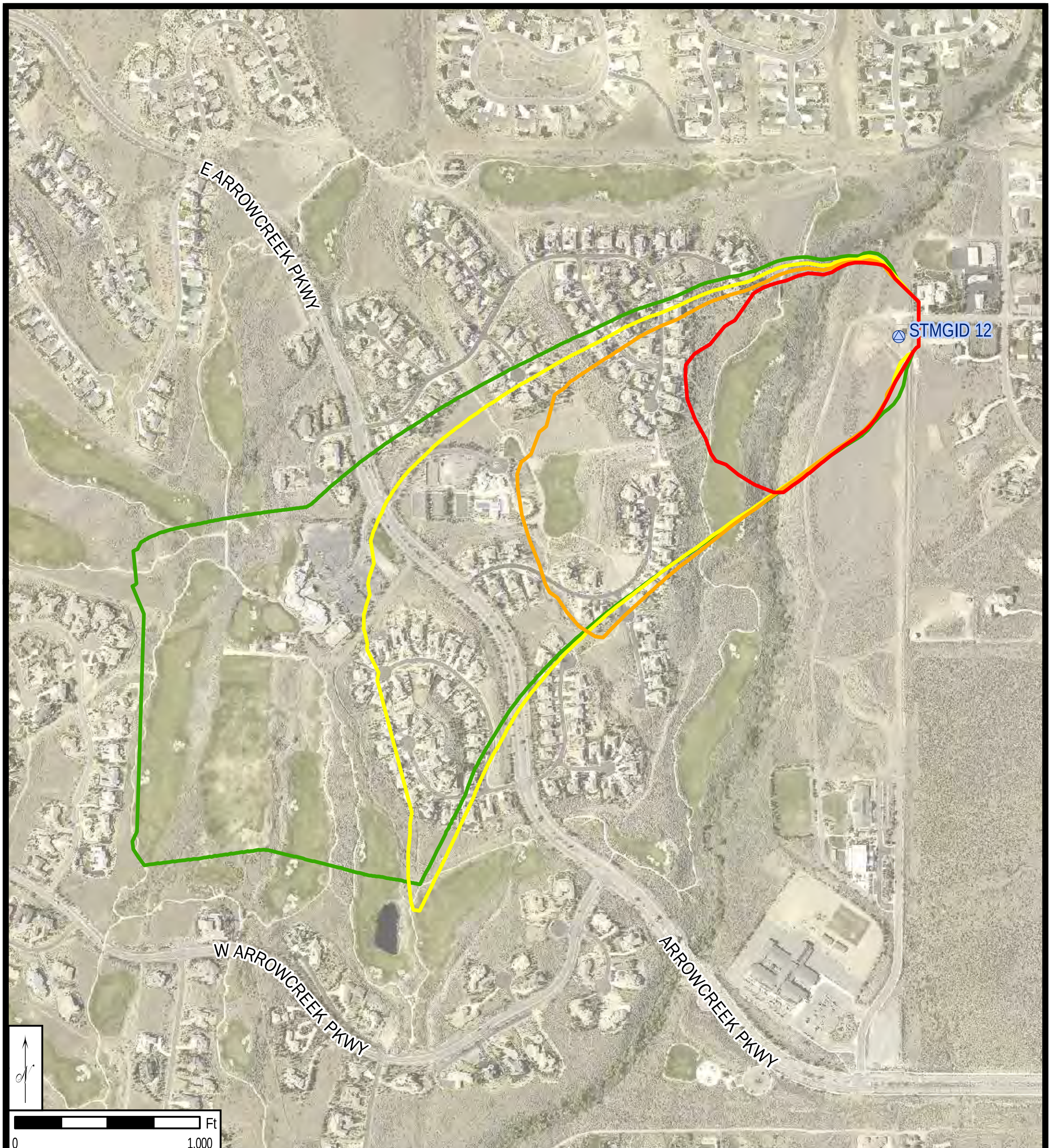
5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (SOUTH) (BASIN 87) -- FIGURE: 13

STMGID 12 WELL SITE

WATER SUPPLY WELL

2 YEAR CAPTURE ZONE

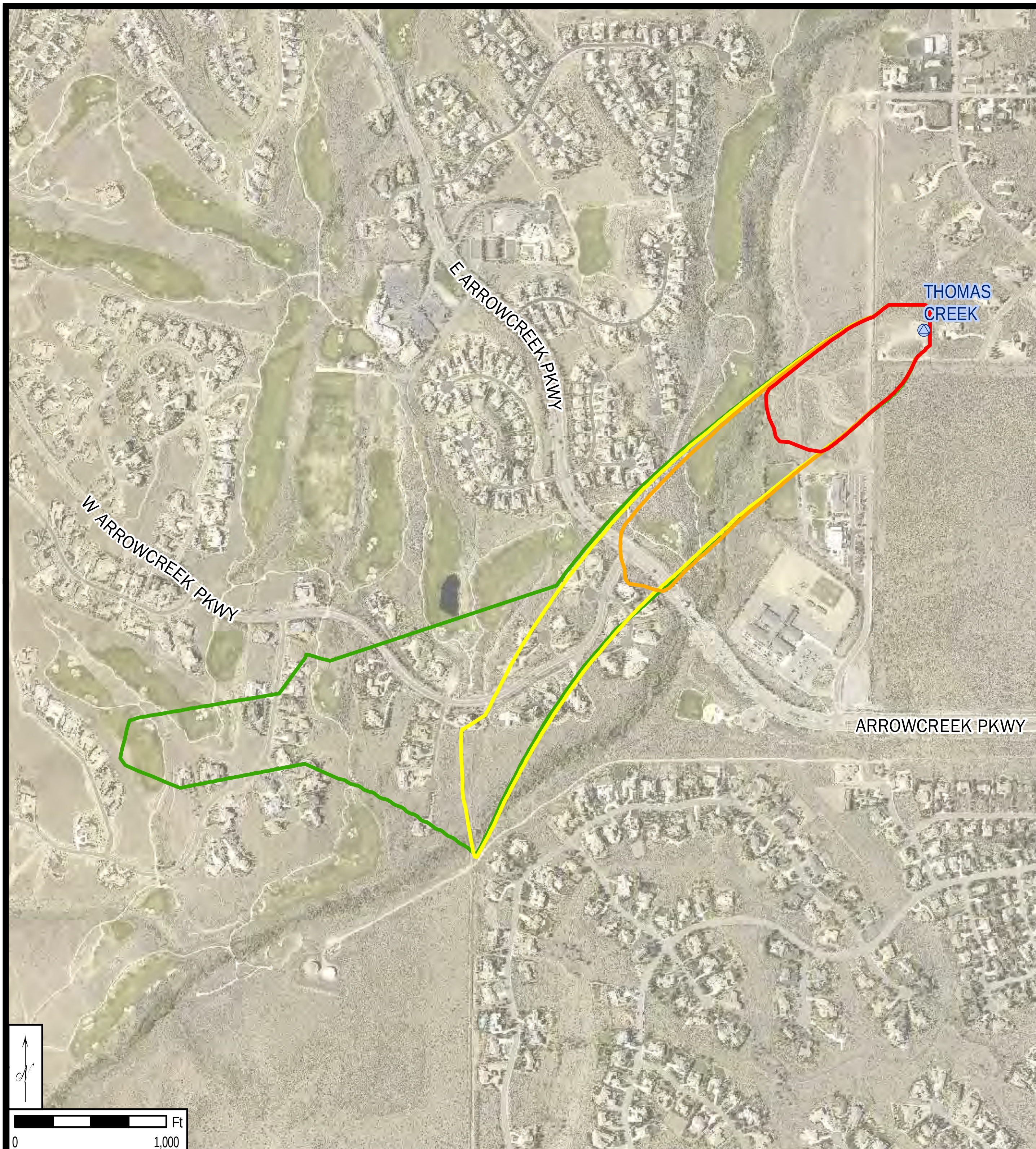
5 YEAR CAPTURE ZONE

10 YEAR CAPTURE ZONE

20 YEAR CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

TRUCKEE MEADOWS (SOUTH) (BASIN 87) -- FIGURE: 14

THOMAS CREEK WELL SITE

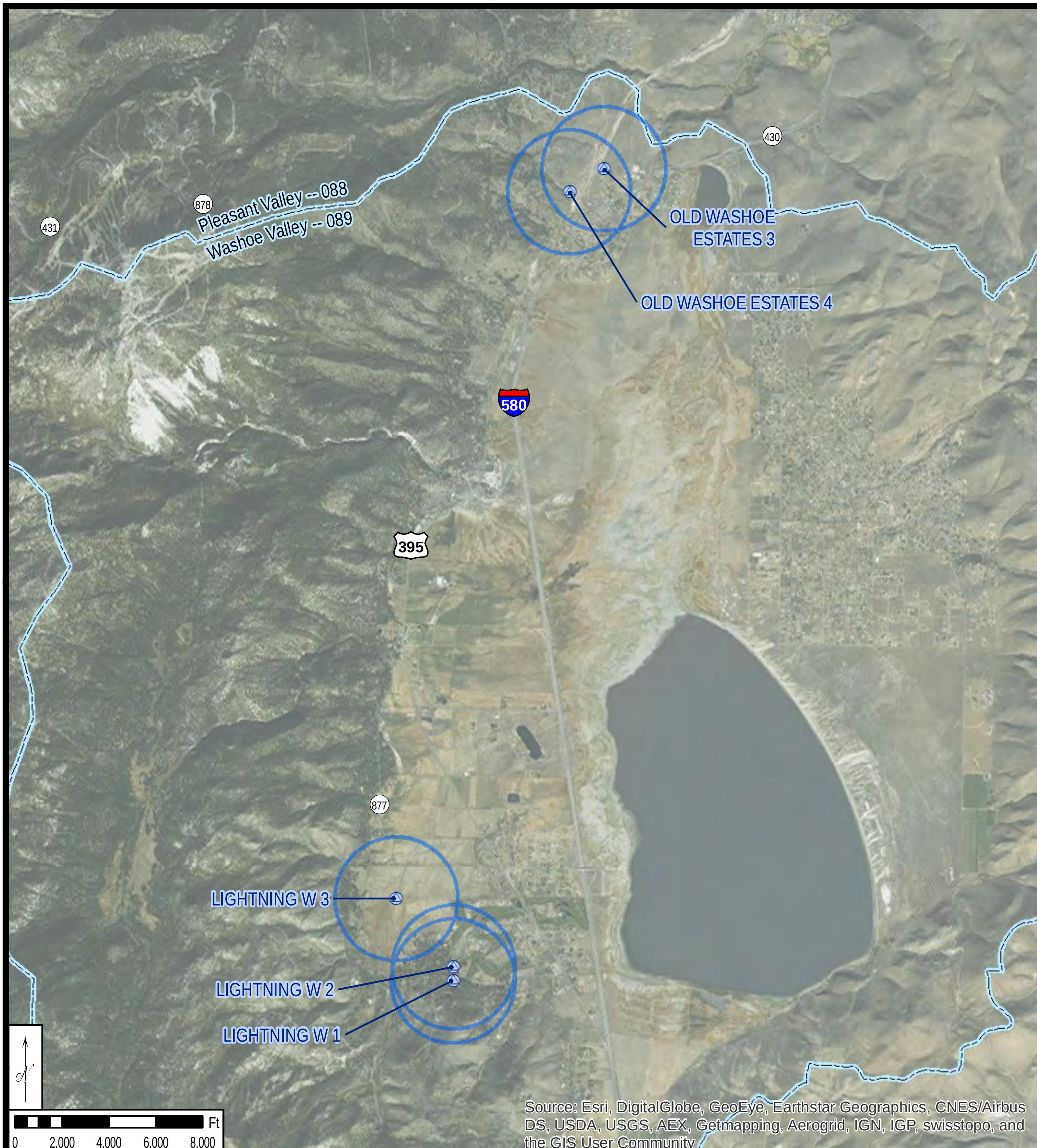
WATER SUPPLY WELL

2 YEAR CAPTURE ZONE
5 YEAR CAPTURE ZONE
10 YEAR CAPTURE ZONE
20 YEAR CAPTURE ZONE

TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELLHEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

WASHOE VALLEY (BASIN 89) AREA INDEX

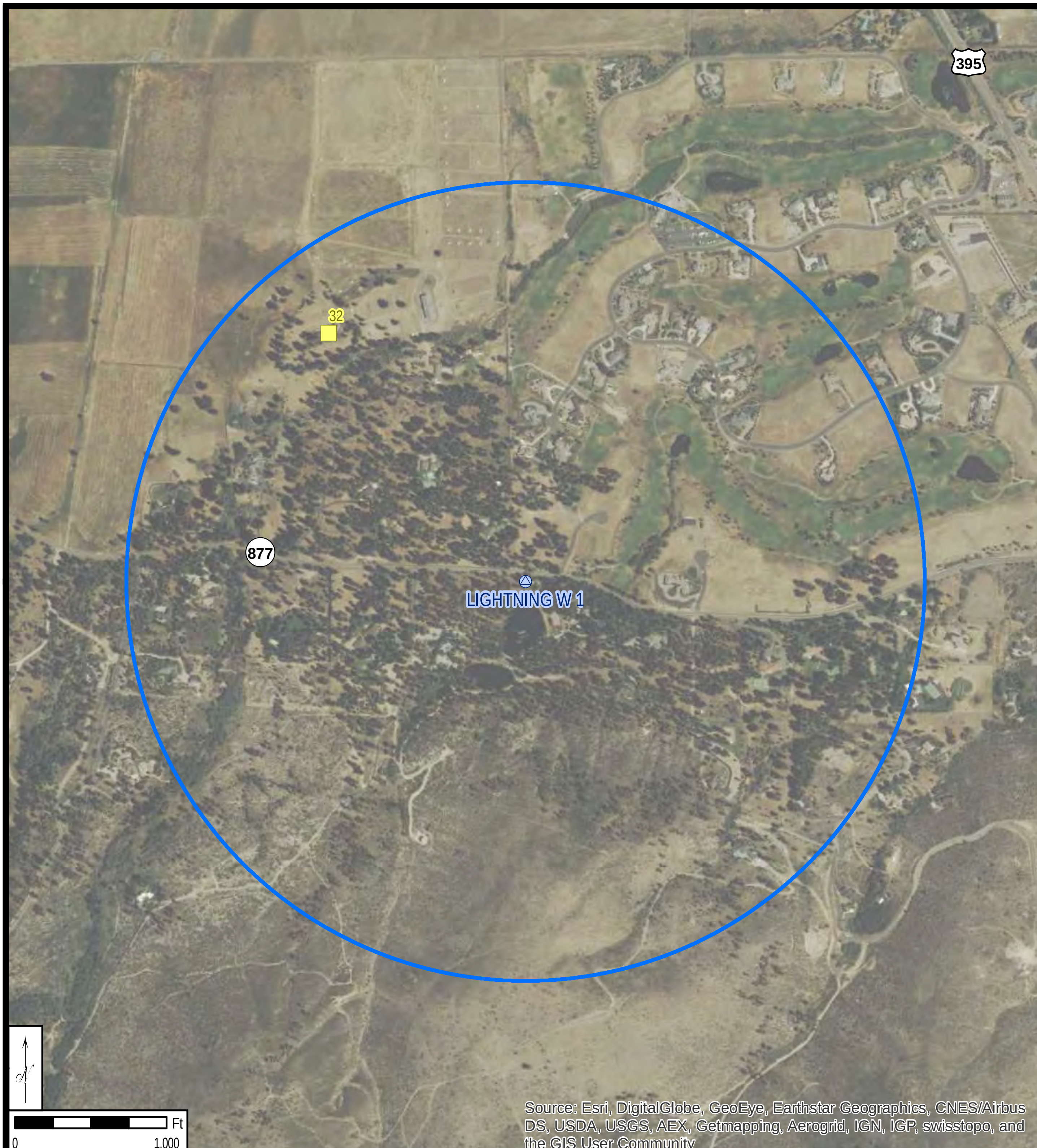
TMWA

WATER SUPPLY WELL

1/2 MILE CAPTURE ZONE

NEVADA HYDROBASIN BOUNDARY

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

WASHOE VALLEY (BASIN 89) -- FIGURE: 1

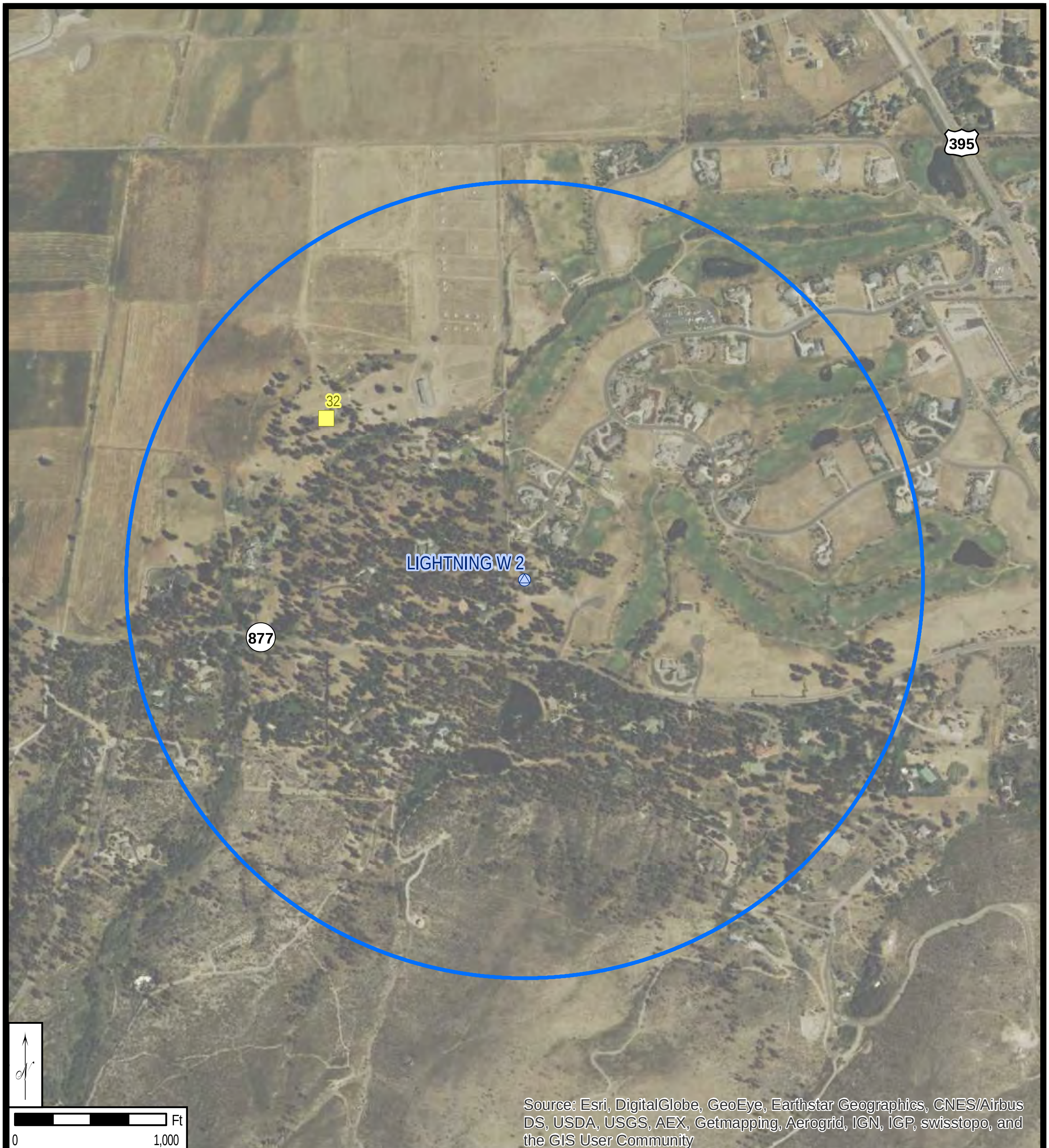
LIGHTNING W 1 WELL SITE

TMWA

WATER SUPPLY WELL

1/2 MILE CAPTURE ZONE

CONTAMINANT RELEASE SITE - INACTIVE (NDEP)



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

WASHOE VALLEY (BASIN 89) -- FIGURE: 2

LIGHTNING W 2 WELL SITE

TMWA

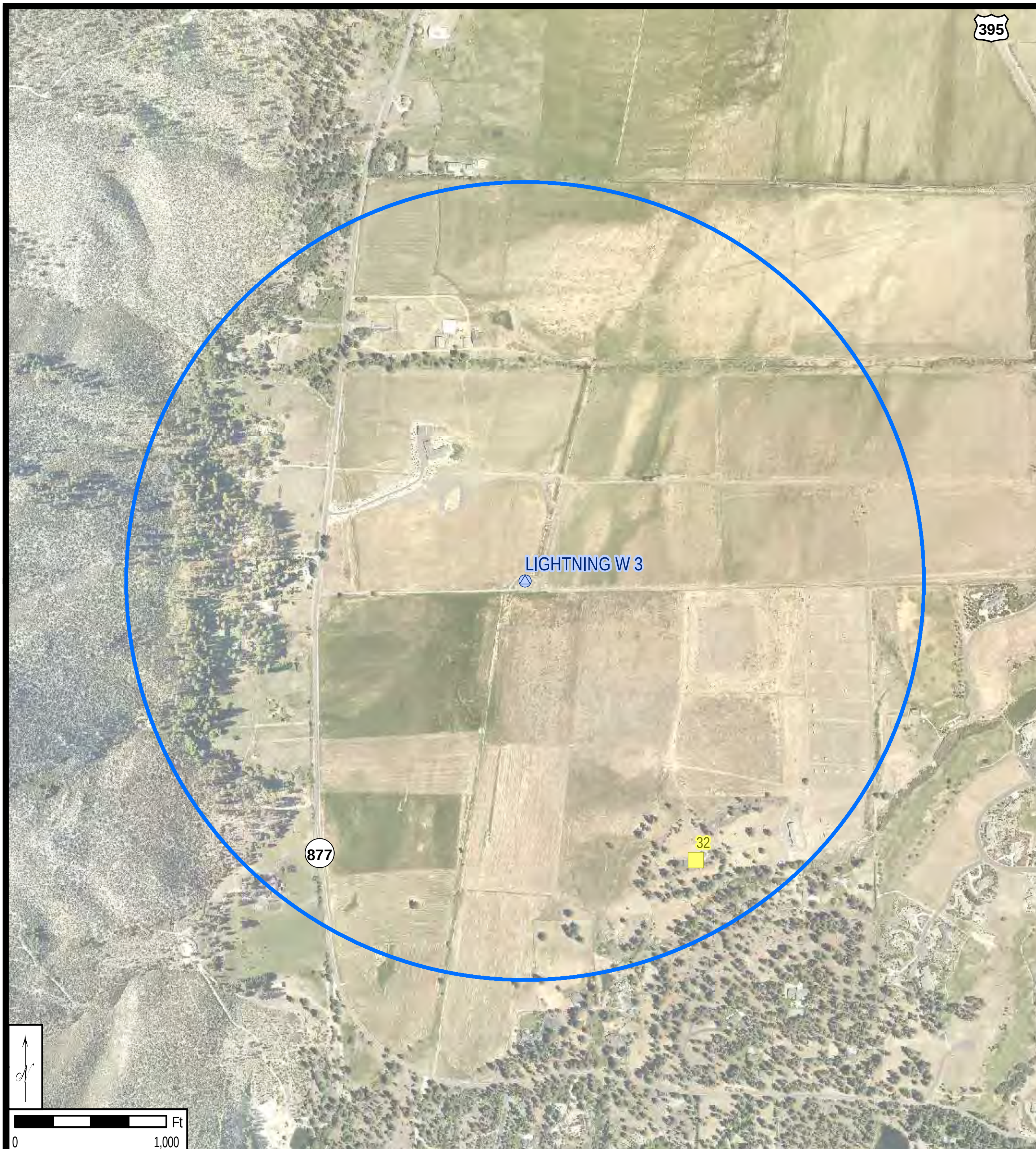
WATER SUPPLY WELL

1/2 MILE CAPTURE ZONE

CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015



WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

WASHOE VALLEY (BASIN 89) -- FIGURE: 3

LIGHTNING W 3 WELL SITE

TMWA

WATER SUPPLY WELL

1/2 MILE CAPTURE ZONE

CONTAMINANT RELEASE SITE - INACTIVE (NDEP)

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015

WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

WASHOE VALLEY (BASIN 89) -- FIGURE: 4

OLD WASHOE ESTATES 3 WELL SITE

TMWA

WATER SUPPLY WELL

1/2 MILE CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015

WELL HEAD PROTECTION PROGRAM CAPTURE ZONE DELINEATION

WASHOE VALLEY (BASIN 89) -- FIGURE: 5

OLD WASHOE ESTATES 4 WELL SITE

TMWA

WATER SUPPLY WELL   1/2 MILE CAPTURE ZONE

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_DD_8.5X11.mxd, Editor: MForrest, Printed: 9/9/2015

APPENDIX C

PCS DATA TABLES

Contaminant Release Sites - Active

ID	Site ID	Facility_Name	Facility_Address	Report_Date	Program	Media	Event	Contaminant
1	4-000003	ALLIED PETROLEUM COMPANY , APN 008-228-01	2500 EAST 4TH STREET, RENO 89512	1/26/1993	LUST	Soil & Ground Water	Confirmed Release	Diesel -- +Gasoline
2	4-000013	ARCO #6017	2240 VICTORIAN AVENUE, SPARKS 89431	1/1/1900	LUST	Ground Water	Confirmed Release	Gasoline
3	4-000053	LUCE & SONS, INC. , APN 003-363-03	2399 VALLEY ROAD, RENO 89512	3/7/2013	LUST	Soil & Ground Water	Confirmed Release	Gasoline
4	4-000061	CHEVRON #94116	947 STATE ROUTE 28, INCLINE VILLAGE 89450	1/1/1900	LUST	Ground Water	Confirmed Release	Gasoline -- Mostly benzene and MtBE
5	4-000135	ALBERS OF NEVADA	755 TIMBER WAY, RENO 89512	11/26/2014	LUST	Soil	Confirmed Release	Diesel
6	4-000185	LAKESHORE ORBIT	560 LAKESHORE BOULEVARD, INCLINE VILLAGE	10/31/2000	LUST	Ground Water	Confirmed Release	Gasoline
7	4-000327	VICTORIAN FOOD MART , APN 032-125-26	1675 VICTORIAN AVENUE, SPARKS 89431	5/7/2009	LUST	Soil	Confirmed Release	Gasoline
8	4-000342	PLUMB LANE SHELL	130 WEST PLUMB LANE, RENO 89509	1/1/1900	LUST	Ground Water	Confirmed Release	Gasoline
9	4-000356	JACKSONS FOOD STORES #145 , APN 534-092-04	8995 LA POSADA DRIVE, SPARKS 89441	1/28/2008	LUST	Soil & Ground Water	Confirmed Release	Gasoline
10	4-000379	7-ELEVEN #15426 , APN 008-073-01	1680 SILVERADA BOULEVARD, RENO 89512	10/21/2010	LUST	Soil & Ground Water	Confirmed Release	Gasoline
11	4-000408	TIME OIL STORE 6-100 , APN 085-851-15	5190 SUN VALLEY BOULEVARD, SUN VALLEY 89433	8/11/2006	LUST	Soil & Ground Water	Confirmed Release	Gasoline
12	4-000475	RANCHO SAN RAFAEL PARK , FORMER LOCATION OF USTS	1502 WASHINGTON STREET, RENO 89503	1/1/1900	LUST	Ground Water	Confirmed Release	Gasoline
13	4-000476	WASHOE COUNTY PUBLIC WORKS DEPARTMENT , APN 021-456-18	3031 LONGLEY LANE, RENO 89502	10/12/2010	non-LUST	Ground Water	Investigation	Solvents -- Trichloroethene
14	4-000502	GO-FER MARKET , APN 003-091-18	4600 NORTH VIRGINIA STREET, RENO 89506	1/1/1900	LUST	Ground Water	Confirmed Release	Gasoline
15	4-000502	GO-FER MARKET	4600 NORTH VIRGINIA STREET, RENO 89506	4/12/2004	LUST	Soil	Investigation	Gasoline
16	4-000503	HERTZ RENT-A-CAR , APN 015-210-34	1551 NATIONAL GUARD WAY, RENO 89502	10/31/2012	LUST	Soil & Ground Water	Confirmed Release	Gasoline
17	4-000519	NATIONAL RENT-A-CAR	1675 NATIONAL GUARD WAY, RENO 89502	1/1/1900	LUST	Ground Water	Confirmed Release	Gasoline
18	4-000594	WASHOE COUNTY SCHOOL DISTRICT , RENO HIGH SCHOOL	395 BOOTH STREET, RENO 89509	6/26/2014	non-LUST	Soil	Confirmed Release	Heating Oil
19	4-000744	CHUCK'S CIRCLE C MARKET , APN 087-283-01	20255 COLD SPRINGS DRIVE, RENO 89508	8/22/2008	LUST	Soil & Ground Water	Confirmed Release	Gasoline
20	4-000830	MAACO AUTO PAINTING & BODY SHOP	2445 EAST 2ND STREET, RENO 89502	4/29/1999	non-LUST	Soil	Investigation	Other -- Diesel, propane, paints, thinners
21	4-000981	MILLS LANE JUSTICE CENTER	1 SOUTH SIERRA STREET, RENO	8/5/2004	non-LUST	Soil & Ground Water	Confirmed Release	TPH
22	4-000984	CONVENIENCE CORNER SHELL , APN 037-030-13	295 SPARKS BOULEVARD, SPARKS 89434	8/7/2008	LUST	Soil & Ground Water	Confirmed Release	Gasoline -- MTBE
23	D-000007	AMERICAN AUTO WRECKING	495 PARR CIRCLE, RENO	7/8/1999	_	Soil	Investigation	Unknown
24	D-000007	AMERICAN AUTO WRECKING	495 PARR CIRCLE, RENO	4/22/2004	non-LUST	Soil	Investigation	Gasoline
25	D-000025	RENO DRAIN OIL SERVICE , APN 084-090-15	11970 I-80 EAST, SPARKS 89434	5/4/2000	Mobile Source	Soil	Confirmed Release	Motor Oil
26	D-000044	SOLARI DECORATING CENTER	1745 WELLS AVENUE, RENO 89505	9/29/1988	non-LUST	Soil & Ground Water	Confirmed Release	Heating Oil
27	D-000086	GLORY TEMPLE CHURCH	16255 SOUTH VIRGINIA STREET, RENO	2/25/2003	_	Soil	Investigation	Other
28	D-000090	GORDON TRUCKING MOBILE SOURCE	HOGE ROAD @ NORTH VIRGINIA STREET, RENO 89506	4/2/2003	_	Soil	Confirmed Release	Diesel
29	D-000092	RYDER TRANSPORTATION MOBILE SOURCE	39 WEBB CIRCLE, RENO 89506	4/30/2003	_	Soil	Confirmed Release	Diesel
30	D-000099	AL EBANS PROPERTY	1629 G STREET, SPARKS	6/2/2003	_	Soil	Investigation	Unknown
31	D-000100	CITY OF RENO REDEVELOPMENT AGENCY	111 MORRILL AVENUE, RENO 89512	4/23/2008	non-LUST	Soil & Ground Water	Confirmed Release	TPH -- oil and tar
32	D-000116	WESTERN NEVADA RECYCLING	1325 HYMER AVENUE, SPARKS	9/15/2003	_	Soil	Confirmed Release	Other -- Non-PCB Mineral Oil
33	D-000116	WESTERN NEVADA RECYCLING	1325 HYMER AVENUE, SPARKS	11/29/2001	non-LUST	Soil	Confirmed Release	TPH -- and Lead
34	D-000142	RENO DISPOSAL/WASTE MANAGEMENT SPILL	5728 RIVER BIRCH DRIVE, RENO 89511	6/2/2004	non-LUST	Soil	Confirmed Release	Diesel
35	D-000561	WELLS MANUFACTURING COMPANY , APN 038-060-09	2 ERIC CIRCLE, VERDI 89439	7/15/1991	non-LUST	Ground Water	Confirmed Release	Solvents -- Trichloroethene and Tetrachloroethene
36	D-000729	ROBERT MCDERMOTT PROPERTY	537 GORDON AVENUE, RENO 89509	10/28/1994	non-LUST	Soil	Confirmed Release	Heating Oil
37	D-000740	RENO OLD TOWN MALL ANNEX	180 WEST PECKHAM LANE, RENO 89509	5/10/2006	non-LUST	Soil & Ground Water	Confirmed Release	Solvents -- Tetrachloroethene
38	D-000749	ARTIST CLEANERS , APN 020-181-10	225 GENTRY WAY, RENO 89502	1/17/2007	non-LUST	Ground Water	Confirmed Release	Solvents -- Tetrachloroethene
39	D-000757	TIMOTHY A. & KRISTINE K. NORTHON PROPERTY	315 STEWART STREET, RENO 89502		_	_	_	_
40	D-000766	RESOLVENT, INC.	831 DEMING WAY, SPARKS 89431	11/15/2007	non-LUST	Ground Water	Confirmed Release	Solvents -- Trichloroethene
41	D-000769	PLUMB LANE PLAZA , RAINBOW CLEANERS	499 EAST PLUMB LANE, RENO 89502	4/13/2004	non-LUST	Ground Water	Investigation	Solvents -- Tetrachloroethene
42	D-000775	ORCHARD PLAZA SHOPPING CENTER , APN 019-160-33	2293 SOUTH VIRGINIA STREET, RENO 89502	9/10/2008	non-LUST	Soil & Ground Water	Confirmed Release	Solvents -- Tetrachloroethene
43	D-000785	THE FOOTHILLS AT WINGFIELD SPRINGS	6500 SPANISH SPRINGS ROAD, SPARKS 89436		_	_	_	_
44	D-000797	FRANKLIN SPARKS, LLC , APN 034-163-03	1300 FRANKLIN WAY, SPARKS 89431	6/19/2009	non-LUST	Soil	Confirmed Release	Other -- Sulfuric Acid
45	D-000807	NEVADA PACIFIC DEVELOPMENT CORPORATION , APN 123-032-01	61 SOMERS LOOP, INCLINE VILLAGE 89451	1/29/2010	non-LUST	Soil	Investigation	Heating Oil
46	D-000808	JOHN DIFRANCESCO PROPERTY , APN 012-272-12	35 NORTH EDISON WAY, RENO 89502	2/17/2010	Brownfields	Unknown	Investigation	Unknown
47	D-000809	JOHN DIFRANCESCO PROPERTY , APN 012-272-10	65 NORTH EDISON WAY, RENO 89502	2/17/2010	Brownfields	Unknown	Investigation	Unknown

48	D-000817	DAVID G. MENCHETTI PROPERTY	1145 LAKESHORE BOULEVARD, INCLINE VILLAGE 89451		_	_	_	_
49	D-000837	DONALD L. SINNAR PROPERTY , APN 011-216-01	604 LANDER STREET, RENO 89509	11/18/2011	non-LUST	Soil	Confirmed Release	Heating Oil
50	D-000852	DEL MONTE PLAZA , APN 040-141-04	6001 SOUTH VIRGINIA STREET, RENO 89502	12/18/2012	non-LUST	_	Confirmed Release	Solvents -- Tetrachloroethene
51	D-000853	ALTAIR NANOTECHNOLOGIES, INC. , APN 012-319-13	204 EDISON WAY, RENO 89502	11/14/2012	non-LUST	Ground Water	Confirmed Release	Solvents -- Trichloroethene, Tetrachloroethene, cis-1,2-Dichloroethene
52	D-000854	ROGER M. MATEOSSIAN RESIDENCE	2245 KOLDEWEY DRIVE, RENO 89509		_	_	_	_
53	D-000857	GARY N. CORNWALL PROPERTY , APN 013-116-10	864 SOUTH WELLS AVENUE, RENO 89502	1/17/2013	non-LUST	Soil	Confirmed Release	Heating Oil
54	D-000862	HAMILTON COMPANY USA	4970 ENERGY WAY, RENO 89502	1/31/2013	non-LUST	Ground Water	Confirmed Release	Solvents -- cis-1,2-Dichloroethene
55	D-000885	BRE/RENO PROPERTY OWNER, LLC , APN 090-051-06	12040 MOYA BOULEVARD, RENO 89506	2/5/2014	non-LUST	Soil	Confirmed Release	TPH -- Transformer Oil
56	D-000891	JON & MICHELLE JENTZ PROPERTY , APN 013-335-04	1395 AIRMOTIVE WAY, RENO 89502	9/11/2014	non-LUST	Soil	Confirmed Release	Motor Oil
57	D-000895	L & G PROPERITES LLC , APN 019-043-30	2044 PLUMAS STREET, RENO 89509	11/19/2014	non-LUST	Soil	Confirmed Release	Heating Oil
58	D-001019	INCLINE DRY CLEANERS , INCLINE VILLAGE	889 TAHOE BOULEVARD, INCLINE VILLAGE	8/6/2013	non-LUST	Ground Water	Confirmed Release	Solvents -- 15 ppb PCE in groundwater
59	D-001120	VIKING METALLURGICAL CORPORATION	1 ERIC CIRCLE, VERDI 89439	12/16/2009	non-LUST	Soil	Confirmed Release	Other -- Hydraulic Oil
60	D-001235	FORMER TEXACO SERVICE STATION , APN 032-065-10	1922 VICTORIAN AVENUE, SPARKS	11/25/1997	non-LUST	Ground Water	Confirmed Release	Gasoline
61	D-001269	TRUCKEE MEADOWS COMMUNITY COLLEGE	7000 DANDINI BOULEVARD, RENO 89512	7/6/1998	_	Soil	Confirmed Release	Other -- transformer oil
62	D-001272	NEVADA CLUB CASINO	224 NORTH VIRGINIA STREET, RENO 89501	7/7/1998	_	Soil	Investigation	15-3700 ppm petroleum product (Phase I)
63	D-001274	ALLIED WASHOE FUEL	2282 LARKIN CIRCLE, SPARKS 89513	7/16/1998	_	_	Confirmed Release	Motor Oil
64	D-001275	BONANZA PRODUCE	1925 FREEPORT BOULEVARD, SPARKS 89431	7/16/1998	_	Soil	Confirmed Release	Gasoline -- Vandalism of company vehicles (Gas & Diesel)
65	D-001277	GIUDICI RESIDENCE	135 CRESTVIEW PLACE, RENO	8/12/1998	_	Soil	Confirmed Release	Heating Oil -- P. Donald monitoring
66	4-000010	SPARKS TERMINAL #1	147 SOUTH STANFORD WAY, SPARKS 89431	12/28/2007	non-LUST	Soil	Confirmed Release	Other -- Ethanol
67	4-000743	UNITED PARCEL SERVICE	369 EAST GLENDALE AVENUE, SPARKS	1/1/1997	non-LUST	Soil	Confirmed Release	Motor Oil
68	4-000917	RMC NEVADA PLANT	2200 BARNETT WAY, RENO	10/13/2004	Mobile Source	Soil & Ground Water	Confirmed Release	Diesel
69	4-001061	EXPRESS SUPERMART #15 , APN 036-540-08	1470 EAST PRATER WAY, SPARKS 89434	6/22/2000	LUST	Soil	Investigation	Gasoline
70	D-000001	COMMERCIAL PROPERTY	9302 PROTOTYPE DRIVE, RENO	4/9/1998	non-LUST	Soil	Confirmed Release	Diesel
71	D-000385	IDLEWILD PARK	1821 IDELWILD DRIVE, RENO 89505	1/1/1900	non-LUST	Soil	Confirmed Release	_

Contaminant Release Sites - Inactive

ID	Site ID	Facility Name	Facility Address	Report Date	Closure Date	Closure Type	Program	Media	Contaminant
1	4-000017	ARCO #0437 , APN 006-121-27	700 Keystone Avenue	5/19/2003	5/31/2013	NAC 445A.22745	LUST	Ground Water	Gasoline
2	4-000046	Budget Car Rental #3801 , APN 015-210-34	1600 National Guard Way	8/9/2005	11/5/2012	Clean w/ Remed	LUST	Ground Water	Gasoline
3	4-000087	Regional Transportation Commission Washoe County	2050 Villanova Drive	2/22/2012	8/9/2013	Clean w/ Remed	non-LUST	Soil	Other
4	4-000340	Shell Service Station	3295 Kietzke Lane	3/24/2003	9/18/2012	NAC 445A.22725 (2)	LUST	Ground Water	Gasoline
5	4-000419	Unocal SS #5614	190 West Plumb Lane	2/15/2005	1/21/2010	NAC 459.9978	LUST	Ground Water	Gasoline
6	4-000476	Washoe County Public Works Department , APN 021-456-18	3031 Longley Lane	6/30/2014	11/10/2014	Petro Constituents	non-LUST	Soil	TPH
7	4-000507	ARCO #4950 , APN 025-290-16	6190 South Virginia Street	1/1/1993	3/6/2013	Clean w/ Remed	LUST	Ground Water	Gasoline
8	4-000512	Buggy Bath Car Wash , APN 019-202-25	2525 South Virginia Street	12/10/2010	2/24/2011	NAC 445A A-K	non-LUST	Soil	Other
9	4-000519	National Rent-A-Car	1675 National Guard Way	1/1/1900	1/23/2015	NAC 445A.22725 (2)	LUST	Ground Water	Gasoline
10	4-000573	City of Reno Police Department	455 East 2nd Street	1/1/1900	3/5/2014	NAC 445A.22725 (2)	LUST	Ground Water	Gasoline
11	4-000594	Washoe County School District , Reno High School	395 Booth Street	6/26/2014	1/16/2015	Petro Constituents	non-LUST	Soil	Heating Oil
12	4-000732	North Valley Satellite Bus Yard , Bus Yard	330 Doubleback Road	1/17/2011	3/22/2011	Clean w/ Remed	Mobile Source	Soil	Diesel
13	4-000826	USA Petroleum Corporation #207	2299 Oddie Boulevard	4/17/2006	3/11/2011	NAC 459.9978	LUST	Soil & Ground Water	Gasoline
14	4-000931	Jacksons Food Stores #19 , APN 008-185-34	695 North Wells Avenue	11/24/2014	12/22/2014	Clean w/ Remed	LUST	Soil	Diesel
15	4-001040	Express Supermart #14 , 021-465-03	4997 Longley Lane	10/4/2004	4/5/2010	NAC 459.9978	LUST	Ground Water	Gasoline
16	D-000117	Union Pacific Railroad Company , Mile Post 245.40	0 Stanford Way	10/27/2010	2/4/2011	NAC 445A A-K	Mobile Source	Soil	Other
17	D-000170	Ormat Technologies, Inc. , Production Well #2-1	1010 Power Plant Road	1/20/2014	4/1/2014	Petro Constituents	non-LUST	Soil	TPH
18	D-000170	Ormat Technologies, Inc. , Production Well #3-3	1010 Power Plant Road	1/6/2014	3/21/2014	Petro Constituents	non-LUST	Soil	TPH
19	D-000170	Ormat Technologies, Inc. , Production Well #3-2	1010 Power Plant Road	2/1/2010	9/2/2010	Clean w/ Remed	non-LUST	Soil	Other
20	D-000170	Ormat Technologies, Inc. , Production Well #1	1010 Power Plant Road	3/15/2013	5/24/2013	Clean w/ Remed	non-LUST	Soil	TPH
21	D-000170	Ormat Technologies, Inc. , Production Well 21-5R	1010 Power Plant Road	11/17/2011	5/25/2012	Clean w/ Remed	non-LUST	Soil	Other
22	D-000170	Ormat Technologies, Inc.	1010 Power Plant Road	7/29/2009	1/6/2010	Clean w/ Remed		Soil	Other
23	D-000207	Sierra Chemical Company , APN 034-171-42	2302 Larkin Circle	12/17/2012	7/15/2013	Clean w/ Remed	non-LUST	Ground Water	Solvents
24	D-000209	John Ascuaga's Nugget , APN 032-172-22	1100 Nugget Avenue	7/16/2010	12/21/2010	Clean w/ Remed	non-LUST	Ground Water	Diesel
25	D-000514	Airport Authority of Washoe County , South end of Runway 14/32 (Near Bravo Ave)	5045 Alpha Avenue	11/1/2013	2/21/2014	Petro Constituents	Mobile Source	Soil	Jet Fuel/Av Gas
27	D-000734	Bruno Benna Residence	8500 Dieringer Road	5/18/2006	9/29/2011	NAC 445A A-K	non-LUST	Soil & Ground Water	Heating Oil
28	D-000759	701 South Virginia LLC , APN 011-232-13	734 South Virginia Street	12/13/2011	1/26/2012	Clean w/ Remed	non-LUST	Soil	Heating Oil
29	D-000759	701 South Virginia LLC , APN 011-232-13	734 South Virginia Street	8/23/2011	10/24/2011	NAC 445A A-K	non-LUST	Soil	Heating Oil
31	D-000791	Cox Enterprises , APN 012-342-18	4920 Brookside Court	5/15/2008	4/23/2010	NAC 445A.22745	non-LUST	Soil & Ground Water	Diesel
32	D-000799	San Antonio Ranch, LLC , APN 005-200-79	7000 Franktown Road	8/18/2009	8/18/2010	NAC 445A A-K	non-LUST	Soil	Heating Oil
33	D-000802	City of Sparks , APN 032-136-06	1212 Victorian Avenue	10/5/2009	3/7/2011	NAC 445A A-K	non-LUST	Soil	Heating Oil
34	D-000804	Lance J. Eklund Property , APN 009-131-52	170 Juniper Hill Road	10/22/2009	3/10/2010	NAC 445A A-K	non-LUST	Soil	Heating Oil
35	D-000810	National Wild Horse and Burro Center , APN 076-251-02	15780 Pyramid Way	2/9/2010	12/8/2010	Clean w/ Remed	non-LUST	Soil	Diesel
36	D-000811	Brian S. Wallace Property , APN 011-265-19	739 Plumas Street	3/25/2010	6/9/2010	Clean w/ Remed	non-LUST	Soil	Heating Oil
37	D-000812	Carol A. Flanagan Residence , APN 011-293-13	1165 Monroe Street	5/19/2010	6/9/2010	Clean w/ Remed	non-LUST	Soil	Heating Oil
38	D-000813	Whitney B. Hackstaff Residence , APN 019-261-05	55 Rancho Manor Drive	6/7/2010	11/5/2010	NAC 445A A-K	non-LUST	Soil	Heating Oil
39	D-000814	Central Oregon Truck Company Mobile Source , APN 037-400-02	1550 East Lincoln Way	5/19/2010	7/13/2010	NAC 445A A-K	Mobile Source	Soil	Diesel
40	D-000815	River Senior Partners , APN 012-051-24	Kuenzli Street @ Sutro Street	7/6/2010	10/21/2010	Clean w/ Remed	non-LUST	Soil	Heating Oil
44	D-000819	Northwest Liquidators Mobile Source , APN 007-303-39	East 5th Street	8/30/2010	2/8/2011	UST Clean Closure	Mobile Source	Soil	Diesel
45	D-000822	Leah C. Silverman Property , APN 013-024-17	759 Stewart Street	12/16/2010	2/14/2011	NAC 445A A-K	non-LUST	Soil	Heating Oil
46	D-000823	Estancia Reno LLC , APN 202-232-11	1424 Hogadon Way	12/28/2010	2/18/2011	Clean w/ Remed	Mobile Source	Soil	Diesel
47	D-000825	Nevada-Utah Conference of Seventh-day Adventists , APN 013-137-10	845 Yori Avenue	6/21/2011	8/12/2011	Clean w/ Remed	non-LUST	Soil	Heating Oil
48	D-000826	Cassinelli Brothers, LLC , APN 034-040-17	1650 Freeport Boulevard	6/29/2011	9/29/2011	Clean w/ Remed	Mobile Source	Soil	Diesel
49	D-000827	Lutheran Church of the Good Shepard , APN 011-152-39	501 California Avenue	7/15/2011	8/3/2011	Clean w/ Remed	non-LUST	Soil	Heating Oil
51	D-000830	Patrick D. Fitzgerald Property , APN 061-090-31	State Route 34	9/6/2011	11/17/2011	Clean w/ Remed	non-LUST	Soil	Diesel
52	D-000830	Patrick D. Fitzgerald Property , APN 061-130-33	State Route 34	9/6/2011	3/14/2012	NAC 445A A-K	non-LUST	Soil	Diesel
53	D-000831	Fort Dearborn Company , APN 037-252-16	295 Lillard Drive	6/21/2011	2/8/2012	Clean w/ Remed	non-LUST	Soil	TPH
54	D-000832	Charles P. Bluth Property , APN 023-121-41	2025 Meadowview Lane	10/11/2011	11/28/2011	Clean w/ Remed	non-LUST	Soil	Heating Oil

55	D-000834	Carl E. Friberg Property , APN 033-042-02	1380 Breaker Way	9/23/2011	10/3/2012	Other	non-LUST	Soil	Heating Oil
57	D-000838	Richard G. Behlmer Residence , APN 018-132-02	1414 Coronet Boulevard	11/29/2011	1/10/2012	NAC 445A A-K	non-LUST	Soil	Heating Oil
58	D-000839	Renown Health , APN 013-031-08	1150 Ryland Street	11/30/2011	11/14/2011	Clean w/ Remed	non-LUST	Soil	Heating Oil
59	D-000840	NV Energy , APN 004-143-02	0 Gaslight Lane	1/26/2012	8/10/2012	Clean w/ Remed	non-LUST	Soil	Diesel
60	D-000841	Nevada Department of Transportation	Interstate 80 @ Vine Street	3/20/2012	6/5/2012	UST Clean Closure	non-LUST	Soil	Heating Oil
61	D-000842	Sylvia Family Properties , APN 088-242-05	0 North Hills Boulevard	5/11/2012	12/6/2012	Clean w/ Remed	Mobile Source	Soil	TPH
62	D-000843	Joseph M. McDonnell Property , APN 019-021-09	1627 Hoyt Street	6/11/2012	8/13/2012	Clean w/ Remed	non-LUST	Soil	Heating Oil
63	D-000844	Lion Mountain Properties, Inc. , APN 020-241-39	1500 Gentry Way	8/1/2012	3/11/2013	NAC 445A A-K	non-LUST	Soil	TPH
64	D-000845	Charles R. Sherven Residence , APN 040-692-09	3705 Lamay Lane	8/13/2012	11/27/2012	Clean w/ Remed	non-LUST	Soil	Heating Oil
66	D-000847	Menachem & Chaya Sara Cunin Residence , APN 023-131-18	3600 Clover Way	10/1/2012	11/27/2012	Clean w/ Remed	non-LUST	Soil	Heating Oil
67	D-000849	North American Van Lines Mobile Source , APN 032-166-14	0 Nugget Avenue	7/12/2012	10/30/2012	Other	Mobile Source	Soil	Diesel
69	D-000851	Rocky Mountain Recycling Mobile Source , APN 026-284-17	2380 Oddie Boulevard	12/3/2012	2/21/2013	Clean w/ Remed	Mobile Source	Soil	Diesel
70	D-000856	Washoe County Public Works Department , APN 008-164-17	842 Spokane Street	1/16/2013	4/29/2013	Clean w/ Remed	non-LUST	Soil	Heating Oil
72	D-000859	NV Energy , APN 021-281-07	4650 Foxfire Drive	4/18/2013	6/21/2013	Clean w/ Remed	non-LUST	Soil	TPH
73	D-000860	Truckee Meadows Business Park , APN 034-410-03	310 Coney Island Drive	4/17/2013	6/21/2013	NAC 445A A-K	non-LUST	Soil	Diesel
74	D-000864	James R. Muff Property , APN 009-111-08	4695 Canyon Drive	5/16/2013	12/6/2013	Clean w/ Remed	non-LUST	Soil	Heating Oil
75	D-000865	Mountain Top Sports	11000 Mount Rose Highway	7/1/2013	7/15/2013	NAC 445A A-K	non-LUST	Soil	Heating Oil
76	D-000866	Blue Crush, LLC , APN 011-212-05	601 South Arlington Avenue	7/30/2013	9/25/2013	Other	non-LUST	Soil	Heating Oil
77	D-000867	Truckee-Tahoe Lumber Company , APN 032-250-30	1550 Hymer Avenue	9/19/2013	10/14/2013	Other	non-LUST	Soil	TPH
78	D-000868	John E. Fitzpatrick Property , APN 010-224-23	1016 Dennison Drive	9/23/2013	10/17/2013	Other	non-LUST	Soil	Heating Oil
79	D-000869	James R. Brown Property , APN 007-111-01 1152 Ralston St.	1152 Ralston Street	10/9/2013	10/29/2013	Clean w/ Remed	non-LUST	Soil	Heating Oil
80	D-000870	Derek Warneke Property , APN 014-211-05	410 West Pueblo Street	10/10/2013	8/19/2014	Petro Constituents	non-LUST	Soil	Heating Oil
81	D-000872	Center for Advanced Medicine , APN 012-371-19	901 East 2nd Street	10/26/2013	12/13/2013	Clean w/ Remed	non-LUST	Soil	TPH
82	D-000873	Sierra View Animal Hospital , APN 025-300-10	6200 South Virginia Street	9/11/2013	11/22/2013	NAC 445A A-K	non-LUST	Soil	Heating Oil
83	D-000874	Washoe County School District , APN 017-011-22	684 State Route 341	11/25/2013	2/20/2014	Petro Constituents	non-LUST	Soil	Diesel
84	D-000875	Arthur L. Farley Property , APN 011-272-19	761 South Virginia Street	12/20/2013	1/13/2014	NAC 445A A-K	non-LUST	Soil	Heating Oil
85	D-000876	U.S. Department of Labor , APN 086-144-01	14175 Mount Charleston Street	12/26/2013	1/30/2014	Clean w/ Remed	non-LUST	Soil	Heating Oil
86	D-000877	JEF Enterprises, LLC , APN 007-011-12	1505 North Virginia Street	1/6/2014	11/14/2014	NAC 445A A-K	non-LUST	Soil	Heating Oil
87	D-000878	Loretta J. Jones Property , APN 016-483-06	14525 Rim Rock Drive	8/9/2013	5/28/2014	Petro Constituents	non-LUST	Soil	Heating Oil
89	D-000882	City of Sparks Redevelopment Agency , APN 037-020-50	550 Marina Gateway Drive	3/6/2014	4/22/2014	Petro Constituents	Brownfields	Soil	Motor Oil
90	D-000883	Landcap Sparks, LLC , APN 037-020-51	650 Marina Gateway Drive	3/6/2014	4/22/2014	Petro Constituents	non-LUST	Soil	Motor Oil
91	D-000884	Jeffrey L. Morby Property , APN 014-204-11	473 West Plumb Lane	3/25/2014	7/9/2014	Petro Constituents	non-LUST	Soil	Heating Oil
92	D-000887	James L. Tuntland Residence , APN 019-261-09	25 Rancho Manor Drive	4/22/2014	7/17/2014	NAC 445A A-K	non-LUST	Soil	Heating Oil
93	D-000888	Daniel G. Buhrmann Residence , APN 040-692-10	4040 Fairview Road	6/24/2014	9/24/2014	Petro Constituents	non-LUST	Soil	Heating Oil
94	D-000890	Charlene M. Herman Property , APN 010-361-42	1785 Adas Street	8/20/2014	9/24/2014	Clean w/ Remed	non-LUST	Soil	Heating Oil
95	D-000891	Jon & Michelle Jentz Property , APN 013-335-04	1395 Airmotive Way	9/11/2014	4/20/2015	Clean w/ Remed	non-LUST	Soil	Motor Oil
96	D-000892	Charlene M. Herman Property , APN 010-361-40	1795 Adas Street	9/23/2014	12/2/2014	Clean w/ Remed	non-LUST	Soil	Heating Oil
97	D-000893	Charles E. Clock Residence , APN 002-344-04	1234 Washington Street	10/15/2014	12/2/2014	Clean w/ Remed	non-LUST	Soil	Heating Oil
98	D-000894	Charles T. Mazza Property , APN 004-233-03	1240 Oliver Avenue	11/13/2014	12/2/2014	Clean w/ Remed	non-LUST	Soil	Heating Oil
99	D-000896	McCarran Mansion LLC , APN 011-101-05	401 Court Street	12/22/2014	1/20/2015	Clean w/ Remed	non-LUST	Soil	Heating Oil
100	D-000898	Airport Gardens Investors, LLC , APN 013-331-15	1325 Airmotive Way	1/8/2015	2/11/2015	Petro Constituents	non-LUST	Soil	Heating Oil
101	D-000899	The Stacie Mathewson Community Wellness Center , APN 007-541-02	580 West 5th Street	1/19/2015	2/5/2015	Clean w/ Remed	non-LUST	Soil	Heating Oil
102	D-000900	Veterans Guest House, Inc. , APN 013-124-19	629 East Taylor Street	1/21/2015	2/11/2015	Petro Constituents	non-LUST	Soil	Heating Oil
103	D-000901	Northern Nevada HOPES , APN 007-541-03	467 Ralston Street	2/3/2015	2/18/2015	Clean w/ Remed	non-LUST	Soil	Heating Oil
104	D-000902	Thomas R. Lamb Property , APN 040-670-11	3600 Holcomb Ranch Lane	2/26/2015	3/31/2015	Petro Constituents	non-LUST	Soil	Heating Oil
105	D-000903	Michael A. Knowles Residence , APN 006-091-16	545 Northstar Drive	2/26/2015	3/31/2015	Petro Constituents	non-LUST	Soil	Heating Oil
106	D-001266	Comp USA Center , Save-on Cleaners	6405 South Virginia Street	3/22/2006	4/30/2013	NAC 445A.22745	non-LUST	Soil & Ground Water	Solvents
107	D-001285	University of Nevada, Reno , 1048 North Sierra Street	Various Locations	4/15/2014	6/19/2014	Petro Constituents	non-LUST	Soil	Heating Oil
108	D-001285	University of Nevada, Reno , 1034 North Sierra Street	Various Locations	2/26/2014	3/25/2014	Petro Constituents	non-LUST	Soil	Heating Oil
109	D-001285	University of Nevada, Reno , 1065 North Sierra Street	Various Locations	2/26/2014	3/26/2014	Petro Constituents	non-LUST	Soil	Heating Oil
110	D-001288	Airport Authority of Washoe County , APN 015-210-34	Various Locations	8/30/2011	12/5/2011	NAC 445A A-K	non-LUST	Soil	TPH

111	D-001288	Airport Authority of Washoe County , SW Cor Mill and S. Rock	Various Locations	10/28/2010	1/24/2011	Invest Closed	non-LUST	Soil	TPH
112	D-001288	Airport Authority of Washoe County , APN 015-210-34	Various Locations	3/19/2013	3/21/2014	NAC 445A A-K	Mobile Source	Soil	Jet Fuel/Av Gas
113	D-001288	Airport Authority of Washoe County	Various Locations	7/26/2011	9/22/2011	Clean w/ Remed	Mobile Source	Soil	Diesel
114	D-001288	Airport Authority of Washoe County , Jet West FBO Center 1880 Gentry Way	Various Locations	7/12/2010	1/21/2011	Clean w/ Remed	non-LUST	Soil	TPH

POTENTIAL CONTAMINANT SOURCE -- CEG (EPA)

ID	Name	Street	CITY	EPA ID
1	LIFETOUCH PORTRAIT STUDIOS	7955 SECURITY CIR	RENO	NVD982041345
2	LITHIA RENO SUBARU DBA LITHIA BODY &	657 GROVE ST	RENO	NVR000078014
3	LITHIA RENO SUBARU	2270 KIETZKE LN	RENO	NVD982461469
4	LOWES H I W INC #321	5075 KIETZKE LN	RENO	NVR000050435
5	MAACO AUTO PAINTING & BODYWORKS	2245 HARVARD WY	RENO	NVR000073775
6	MIDAS MUFFLER	KEYSTONE AVE	RENO	NVR000000927
7	SEPHORA STORE NO.040	13915 S VIRGINIA ST STE 110	RENO	NVR000083402
8	SHERWIN WILLIAMS 8657	9748 S VIRGINIA ST STE G	RENO	NVR000085969
9	SIERRA PACIFIC POWER COMPANY	7 OHM PL	RENO	NVD982373342
10	SILVER STATE AUTOMOTIVE	580 GENTRY WY	RENO	NVD986771707
11	SLIVER LEGACY RESORT CASINO	407 N VIRGINIA ST	RENO	NVR000044982
12	SOUTHGATE CHEVRON AUTOMOTIVE	LOUIE LN STE 5	RENO	NVR000001453
13	SPARKS CITY OF	8500 CLEANWATER WY	RENO	NVD000853465
14	SPPCO - FLEET SERVICES	295 EDISON WY	RENO	NVD047886791
15	STEAMBOAT DEVELOPMENT CORP	1010 POWER PLANT DR	RENO	NVR000083626
16	STEAMBOAT HILLS LLC	20590 WEDGE PKWY	RENO	NVR000084434
17	SUPERGLO AUTO BODY	314 SUNSHINE LANE	RENO	NVR000038588
18	SUREFIRE, LLC	4750 LONGLEY LN, STE 201	RENO	NVR000086686
19	THE AMES COMPANIES INC	3450 AIRWAY DR STE 100	RENO	NVR000089839
20	THE AUTO HOSPITAL	890 GENTRY WAY	RENO	NVD986770410
21	A 1 RADIATOR REPAIR INC	875 E SECOND ST	RENO	NVD981639586
22	A-1 TRANSMISSION INC	670 E GROVE ST	RENO	NVR000078576
23	ADVANCED AUTOMOTIVE	430 ELKO AVE	RENO	NVD986770360
24	ALPINE HEMATOLOGY ONCOLOGY LTD	236 W SIXTH ST STE 400	RENO	NVR000076067
25	AMEC ENVIRONMENT & INFRASTRUCTURE INC	961 MATLEY LANE SUITE 110	RENO	NVR000088237
26	AMERICAN AIRLINES INC	1500 TERMINAL WAY STE I	RENO	NVR000083055
27	ANIXTER INC RENO LOC 333	990 N HILLS BLVD	RENO	NVR000002881
28	ARROW GLOBAL ASSET DISPOSITION INC	9085 MOYA BLVD #100	RENO	NVR000085837
29	AVIATION CLASSICS LTD	4825 TEXAS AVE	RENO	NVD986769016
30	AVIS RENT A CAR	NATL GUARD WY	RENO	NV0000452557
31	HUTCH'S MISSION CAR WASH	6355 S MCCARRAN BLVD	RENO	NVR000076968
32	HV MANUFACTURING	12150 MOYA BLVD	RENO	NVD982436123
33	HVA LLC	12880 MOYA BLVD	RENO	NVR000088484
34	ITAL MOTORS	862 E SECOND ST	RENO	NVD982436321
35	ITRONICS METALLURGICAL INC	14305 MT MCCLELLAN ST	RENO	NVR000043927
36	JOHNS BRITTISH CARS GARAGE	TELEGRAPH UNIT 7	RENO	NVD986776755
37	KELLY MOORE PAINTS	2175 MARKET ST STE A	RENO	NVR000083154
38	KEYSTONE QUALITY PRINTING	W 5TH ST	RENO	NV0000133298
39	LAKERIDGE CLEANERS	6135 LAKESIDE DR SP 107	RENO	NVD982373540
40	TIFFANY CLEANERS	3318 S MCCARRAN BLVD	RENO	NVD982408064
41	TOP HAT CLEANERS	1205 CALIFORNIA AVE	RENO	NVD981673965
42	MOUNT ROSE SKI RESORT	MT ROSE HWY	RENO	NVD986776268
43	NEVADA BELL	1375 CAPITAL BLVD RM 145	RENO	NVD986776904
44	NICKS AUTOMOTIVE	121 LINDEN ST	RENO	NVR000000935

45	NISSAN OF RENO	865 KIETZKE LN	RENO	NVD982477945
46	NORTHWEST TIRE	500 W 4TH ST	RENO	NVD982494122
47	NVARNG HARRY REID COMPLEX	20000 ARMY AVIATION DR	RENO	NVD981575913
48	BARNES DISTRIBUTION	12755 MOYA BLVD	RENO	NVR000081885
49	BARRETT PAINT SUPPLY LTD	1595 VASSAR ST	RENO	NVR000003244
50	BELL LIMOUSINE	1805 E 2ND ST	RENO	NVD986771178
51	BIG O TIRES	1195 E 4TH ST	RENO	NVD986772234
52	BLACK EAGLE CONSULTING INC	1345 CAPITAL BLVD STE A	RENO	NVR000086009
53	BOBS CLEANERS & LAUNDRY	S VIRGINIA ST	RENO	NVD982373433
54	CHAMPION CHEVROLET	2100 AUTOMOTIVE WAY	RENO	NVD986771566
55	CITO AUTO BODY	1890 LEWIS STREET	RENO	NVD982519878
56	CITY OF RENO FIRE DEPARTMENT	315 EDISON WY	RENO	NVD065006058
57	COOPER B-LINE	13755 STEAD BLVD	RENO	NV0000148502
58	CVS PHARMACY #0157	2890 NORTHTOWNE LN	RENO	NVR000085241
59	CVS PHARMACY #6625	1081 STEAMBOAT PKWY	RENO	NVR000086066
60	CVS PHARMACY #7949	75 PRINGLE WY, STE 102	RENO	NVR000086926
61	CVS PHARMACY #8793	285 E PLUMB LN	RENO	NV0000452508
62	CVS PHARMACY #8806	1250 WEST 7TH ST	RENO	NVR000043174
63	CVS PHARMACY #9168	1119 CALIFORNIA AVE	RENO	NVR000073494
64	CVS PHARMACY #9191	5019 S MCCARRAN BLVD	RENO	NVR000038000
65	CVS PHARMACY #9840	8005 S VIRGINIA ST	RENO	NVR000047134
66	CVS PHARMACY #9841	1695 ROBB DR	RENO	NVR000049072
67	CVS PHARMACY #9964	170 LEMMON DR	RENO	NVR000076562
68	CVS PHARMACY #9974	3360 S MCCARRAN BLVD	RENO	NVR000087072
69	DASSAULT AIRCRAFT SERVICES RENO	365 S ROCK BLVD	RENO	NVR000003152
70	DATA FORMS INC	1070 MATLEY LN	RENO	NVD982501835
71	DIPACO DIESEL PARTS USA	E PARR BLVD	RENO	NVR000000083
72	DYNAMIC PAINTERS INC	3550 BARRON WAY STE 6B	RENO	NVR000059030
73	EL DORADO HOTEL CASINO	345 N VIRGINIA	RENO	NVD986769800
74	ELECTRONIC EVOLUTION TECHNOLOGIES, INC	9455 DOUBLE R BLVD	RENO	NVR000074203
75	FAMILY DOLLAR #9174	10525 STEAD BLVD	RENO	NVR000090589
76	FEDERAL EXPRESS	1350 AIR CARGO WY	RENO	NV0000069286
77	FEDERAL EXPRESS - R N O A	1440 CAPITAL BLVD	RENO	NVR000076596
78	FIRESTONE 3581	2515 S VIRGINIA ST	RENO	NVD982445637
79	GENERAL MOTORS LLC	6565 ECHO ST	RENO	NVR000078857
80	GREG'S GARAGE INC	410 E 6TH ST	RENO	NVD986769222
81	H2O ENVIRONMENTAL INC	3510 BARRON WAY STE 200	RENO	NVR000084541
82	HARRAHS RENO HOTEL & CASINO	255 LAKE ST	RENO	NVD982436925
83	HD BUILDER SOLUTIONS GROUP INC FL0065	650 INNOVATION DR STE C	RENO	NVR000080432
84	HERTZ CORP THE	1551 NATIONAL GUARD WAY	RENO	NVD982497612
85	HOGAN'S CARB AND TUNE	1335 E 4TH ST	RENO	NV0000031906
86	WALGREENS STORE NO 4789	3495 S VIRGINIA ST	RENO	NVR000050542
87	WASHOE CNTY - LONGLEY LN SHOPS EQUIPMENT SVCS	3035A LONGLEY LN	RENO	NVR000084814
88	WASHOE COUNTY EDISON COMPLEX	230 EDISON WAY	RENO	NVD986774784
89	WASHOE COUNTY FACILITIES MGMT PAINT SHOP	3021 LONGLEY LN	RENO	NVR000084764
90	WASHOE COUNTY GOLF COURSE	2335 W MOANA LN	RENO	NVD986771632
91	WASHOE COUNTY PARKS & REC	WASHINGTON ST	RENO	NVD982445660

92	WASHOE COUNTY ROAD DEPT	3101 LONGLEY LN	RENO	NVD982497703
93	WEDCO INC	450 TOANO ST	RENO	NVR000086355
94	WEST COAST IMAGING	8985 DOUBLE DIAMOND PKY STE B3	RENO	NVR000081588
95	WESTERN DENTAL	8040 S VIRGINIA ST	RENO	NVR000083410
96	PARAMOUNT AUTO BODY INC	2490 TACCHINO ST	RENO	NVD986770097
97	PENSKE TRUCK LEASING CO LP	14331 LEAR BLVD.	RENO	NVD986771392
98	PLATINUM AVIATION	659 S ROCK BLVD	RENO	NVR000082578
99	PRO LINE PRINTING/RR DONNELLEY	365 PARR CIR	RENO	NVR000079954
100	RALEYS #105	1630 ROBB DR	RENO	NVR000080671
101	RALEYS 103/183	1441 MAYBERRY DR	RENO	NV0000889758
102	RALEYS 104/184	4047 S VIRGINIA	RENO	NV0000895284
103	RALEYS 106/186	701 KEYSTONE AVE	RENO	NVR000000604
104	RALEYS 108/188	18144 WEDGE PARKWAY	RENO	NVR000002501
105	RALEYS 115/195	1075 NORTH HILLS BLVD	RENO	NV0000889741
106	RECREATION PUBLICATIONS	4090 S MC CARRAN BLVD STE E	RENO	NVR000067470
107	REED ELECTRIC	5375 LOUIE LN	RENO	NV0000931907
108	RENO AGRICULTURE AND ELECTRIC	4655 AIRCENTER CIR	RENO	NV0000943894
109	RENO AUTO BODY SHOP INC	1975 KUENZLI LN	RENO	NVD982506446
110	RENO CLEANERS	4910 S VIRGINIA ST	RENO	NVD982373607
111	RENO DODGE SALES INC	700 KIETZKE LN	RENO	NVD981440217
112	RENO HARLELY DAVIDSON - BIG HOUSE	2325 MARKET ST STE C	RENO	NVR000085282
113	RENO HARLEY DAVIDSON	2315 MARKET ST	RENO	NVR000085274
114	SATURN OF RENO	1000 KIETZKE LN	RENO	NVD982436263
115	SEARS A C 1978	MEADOWOOD MALL CIR	RENO	NVR000001388
132	TRUCKEE MEADOWS WTR AUTHORITY - CHALK BLUFF WTF	9605 S MCCARRAN BLVD	RENO	NVR000081075
133	TWO MACS	295 GOLDEN LN	RENO	NVD986771087
134	UNITED CONSTRUCTION CO	MILL ST	RENO	NV0000029298
135	UNIVERSITY OF NEVADA RENO - STEAD	5600 FOX AVE	RENO	NVD982443293
136	UNIVERSITY OF NEVADA RENO - VALLEY	1000 VALLEY RD	RENO	NVD986775039
137	UPS RENO GATEWAY	1395 AIR CARGO WY STE 141	RENO	NVR000082743
138	VEKA WEST INC	14250 LEAR BLVD	RENO	NVR000000711
139	VIEWCREST CLEANERS	3623 KINGS ROW	RENO	NVD982465767
140	VITAL SYSTEMS CORP	4999 AIRCENTER CIR STE 101	RENO	NVR000066001
141	WALGREEN STORE NO. 5295	750 N VIRGINIA ST	RENO	NVR000076984

POTENTIAL CONTAMINANT SOURCE -- SQG (EPA)

ID	Name	Street	CITY	EPAID
131	AMERICAN SIGN & CRANE SERVICE INC	1975 TIMBER WAY	RENO	NVR000084517
142	BILL PEARCE BODY SHOP	745 HARVARD WAY	RENO	NVR000040915
143	BOBBY PAGE'S DRY CLEANERS	1090 SANDHILL RD	RENO	NVR000082297
144	ECO PAK LLC	640 ORRCREST DR	RENO	NVR000088500
145	ENTERPRISE RENO LPG TERMINAL	19975 S RENO PARK BLVD	RENO	NVR000089300
146	FABRIC CARE SPECIALIST	900 W MOANA LN STE 102	RENO	NVD982373508
147	FEDEX SMARTPOST	1175 TRADEMARK DR	RENO	NVR000089383
148	GASTROENTEROLOGY CONSULTANTS PATHOLOGY	880 RYLAND ST	RENO	NVR000085316
149	GGG ENTRP INC DBA CONCOURS BODY SHOP	250 TELEGRAPH ST	RENO	NVD105926539
150	GORDON'S PHOTO SERVICE	5067 S MCCARRAN BLVD	RENO	NVR000053777
151	GORE INDUSTRIES, LLC	4850 JOULE ST STE A2	RENO	NVR000081497
152	HOME DEPOT USA INC HD3304	2955 NORTHTOWNE LN	RENO	NVR000079517
153	HOME DEPOT USA INC HD3310	6590 S VIRGINIA ST	RENO	NVR000000182
154	HOME DEPOT USA INC HD3311	5125 SUMMIT RIDGE CT	RENO	NVR000079525
155	HOME DEPOT USA INC HD8560	1001 STEAMBOAT PKWY	RENO	NVR000080325
156	IGT	9295 PROTOTYPE DR	RENO	NVR000001800
157	KMART DISTRIBUTION CENTER 8272	1402 S MC CARRAN BLVD	RENO	NVR000087528
158	LAWSON PRODUCTS	1381 CAPITAL BLVD	RENO	NVR000085498
159	NCM PAINTING INC	1150 W 1ST ST	RENO	NVR000066019
160	NEVADA AGRICULTURE WAREHOUSE	295 GALLETTI WAY	RENO	NVR000090373
161	NEVADA HISTOLOGY INC	1350 STARDUST ST STE D	RENO	NVR000084707
162	NEVADA SCHOOL & SPORT PHOTOGRAPHY INC	1875 E PECKHAM LANE	RENO	NVR000088450
163	PENTAIR VALVES AND CONTROLS US LP	9025 MOYA BLVD	RENO	NVR000073825
164	PYRAMID LAKE FISHERIES- ADELINE DAVIS RESEARCH LABORATORY	603 SUTCLIFFE DR	RENO	NVR000086330
165	RENOWN FAMILY CARE	975 RYLAND AVE	RENO	NVR000037689
166	RUST BULLET LLC	1186 TELEGRAPH ST UNITS EE2-4	RENO	NVR000089615
167	SHERWIN-WILLIAMS #8645	1375 AIRMOTIVE WY	RENO	NVR000082735
168	SIERRA ENVIRONMENTAL MONITORING INC	1135 FINANCIAL BLVD	RENO	NV0000305649
169	TARGET STORE 1363	6845 SIERRA CENTER PKWY	RENO	NVR000075952
170	UNION PACIFIC RR, MP 238.9 ROSEVILLE SUBDIVISION	2666 DICKERSON RD	RENO	NVR000087395
171	UPS FREIGHT	8900 TERABYTE CT	RENO	NVR000085258
172	WALMART SUPERCENTER 2106	2425 E SECOND ST	RENO	NVR000085670
173	WALMART SUPERCENTER 2189	4855 KIETZKE LN	RENO	NVR000001560
174	WALMART SUPERCENTER 3254	5260 W SEVENTH ST	RENO	NVR000080101
175	WALMART SUPERSTORE 3277	155 DAMONTE RANCH PKWY	RENO	NVR000075887
176	WASHOE COUNTY SCHOOL DISTRICT	7495 S VIRGINIA ST	RENO	NV0000133272

POTENTIAL CONTAMINANT SOURCE -- LQG (EPA)

ID	Name	Street	CITY	EPA ID
116	ALS CHEMEX MINERALS	4977 ENERGY WAY	RENO	NVR000083246
117	CAROLINA LOGISTICS SERVICES LLC	12835 OLD VIRGINA RD	RENO	NVR000076034
118	CHARLES RIVER PRECLINICAL SERVICES NEVADA	6995 LONGLEY LN	RENO	NVR000083097
119	COSTCO NO 25	2200 HARVARD WY	RENO	NVD986776169
120	CVS PHARMACY #9586	55 DAMONTE RANCH PKWY	RENO	NVR000078139
121	DUPONT RENO WESTERN DISTRIBUTI ON CENTER	11535 PRODUCTION DRIVE	RENO	NVR000001495
122	KAPPES CASSIDAY & ASSOCIATES	7950 SECURITY CIRCLE	RENO	NVR000073544
123	LEGACY SUPPLY CHAIN SERVICES	5360 CAPITAL CT STE 100	RENO	NVR000089979
124	MD LOGISTICS	12125 MOYA BLVD	RENO	NVR000089029
125	RR DONNELLEY	14100 LEAR BOULEVARD	RENO	NVD981641434
126	RYDER INTEGRATED LOGISTICS (FOR EASTMAN KODAK AND KODAK ALARIS)	1025 SANDHILL RD #B	RENO	NVR000081471
127	SIERRA PACKAGING AND CONVERTING LLC	11005 STEAD BLVD	RENO	NVR000038869
128	THE SHERIWN-WILLIAMS COMPANY - SIERRA NV DSC	12090 SAGEPOINT CT	RENO	NVR000038737
129	THYSSENKRUPP VDM USA INC RENO	14255 MOUNT BISMARK STREET	RENO	NVD092497999
130	UNIVERSITY OF NEVADA, RENO	1605 EVANS AVE.	RENO	NVD981963549

POTENTIAL CONTAMINANT SOURCE -- (EPA)

ID	Name	Street	CITY	EPA ID
177	AAA AUTO SALES AND SERVICE	5520 SUNVALLEY BLVD	RENO	NV0000039081
178	ABACUS REVIVAL	5350 CAPITAL CT #109	RENO	NVR000076406
179	ABB INC	9716 S VIRGINIA ST	RENO	NVR000085894
180	ADVANCED GRAPHIC DESIGNS	340 WESTERN RD NO 8	RENO	NVR000059667
181	ADVANCED GRAPHICS INC	2890 VASSAR 12B	RENO	NVD982006181
182	ADVANCED IMAGING SYS	5655 RIGGINS CT NO 19	RENO	NVR000001776
183	ADVANCED MOTOR WORKS	2800 WRONDEL WAY	RENO	NVD986769172
184	ADVANCED PETROLEUM RECYCLING	550 ELKO ST	RENO	NV0001037886
185	ADVENT SUPPLY INC	125 CATRON DR	RENO	NVR000002592
186	ADVERTISING SPECIALTY CO	2725 YORI AVE	RENO	NVD986775666
187	AEROLITE PLATING CO	1000 TELEGRAPH ST	RENO	NVD981964596
188	AG SCREEN PRINTING	4673 AIRCENTER CIR	RENO	NVD986769891
189	AIRPORT AUTO BODY	1100 GENTRY WY	RENO	NVR000048215
190	ALCOA RECYCLING CO INC	1970 E 4TH ST	RENO	NVD986776250
191	ALL AUTO AND RV	35 E 4TH ST	RENO	NVD986769941
192	ALL POINTS TOWING	2890 VASSAR STE B11	RENO	NV0000133223
193	ALLSTATE CAR RENTAL AND SALES	3355 KIETZKE LN	RENO	NVD982461295
194	1 HOUR FOTO	1158 KIETZKE LANE	RENO	NVD982411753
195	1 HR FOTO	1085 S VIRGINIA ST	RENO	NVR000042275
196	4TH STREET STATION	200 E. 4TH STREET	RENO	NVR000083634
197	7 TH ST CLEANERS	1265 W 7TH ST	RENO	NVD982373656
198	A & L AUTOMOTIVE	220 SUNSHINE LANE	RENO	NVD986769933
199	A 1 BODY SHOP	680 MONTELLO ST	RENO	NVD981628159
200	A 1 BODY SHOP	935 HARVARD WAY	RENO	NVD982434789
201	A 1 BODY SHOP	591 SUNSHINE LANE	RENO	NVD982496333
202	A ACTION TOW	480 MORRILL AVE	RENO	NVD986777209
203	A 1 BATTERY	2825 2 KIETZKE	RENO	NVD986769008
204	AMERICAN VIDEO	4786 CAUGHLIN PKWY NO 302	RENO	NVD986773299
205	CAROLINA LOGISTICS SERVICES LLC	12835 OLD VIRGINA RD	RENO	NVR000076034
206	CHEVRON USA INC RENO AIRPORT	E PLUMB LN AND TERMINAL WY	RENO	NVT000615500
207	A AND J SERVICES	38 WEBB CIRCLE	RENO	NVR000000166
208	A DELUXE BODY AND FRAME	300 SUNSHINE LN	RENO	NVD982429284
209	A J MCNEIL CO	455 WHISKEY SPRINGS RD	RENO	NVD980889158
210	A M R SERVICES	365 S ROCK BLVD	RENO	NVR000003152
211	A S A P PRINTING AND TYPESETTING	1170 S WELLS AVE UNIT 7	RENO	NVD982446841
212	A SAFE LUBE PLUS	1270 N MCCARRAN BLVD	RENO	NVR000087569
213	A T S INC	5020 TEXAS AVE	RENO	NVD986777217
214	AMALGAMATED RECOVERY SYSTEMS	710 HUNTER LAKE DRIVE	RENO	NVD982321093
215	AMERICAN AIRLINES INC	222 E PLUMB LN	RENO	NVR000063438
216	AMERICAN READY MIX	300 MORRILL ST	RENO	NVR000081026
217	AMERICAN SPEEDY PRINTING CENTERS	5301 LONGLEY LN STE 121	RENO	NV0000148528
218	AMERICAN TIRE	655 VIRGINIA ST	RENO	NVD982428922
219	AMERICAN WATER HEATER CO.	14291 LEAR BLVD.	RENO	NVD009155631
220	COMSTOCK HOTEL CASINO SLOT SHOP	148-1/2 WEST ST	RENO	NV0000269019
221	FASANI PAINTING	1020 LITCH ST	RENO	NVD982429508
222	GREAT BASIN AERIAL SURVEYS	5301 B LONGLEY LANE #52	RENO	NVD982466120
223	HARRAHS RENO HOTEL & CASINO	255 LAKE ST	RENO	NVD982436925
224	ANTENNA SPECIALIST R AND D FACILITY	5401 LONGLEY LN STE B34	RENO	NV0000195933
225	ARMKEL LLC - HOPKINS DISTRIBUTION CENTER	4745 LONGLEY LANE	RENO	NVR000053157
226	ARROW TRANSMISSIONS INCORPORATED	2825 KIETZKE LANE	RENO	NVD982429623

227	ART ASSOCIATES/ELECTROGRAPHICS	5476 RENO CORPORATE DR	RENO	NVR000081216
228	ART CARR PERFORMANCE	14305 MT MCCLELLEN	RENO	NVR000034389
229	AUTO EXPRESS	50 SURGE ST	RENO	NV0000137265
230	AUTO MASTERS	2250 DICKERSON RD	RENO	NVD982461311
231	AUTOMATED REFUSE EQ	650 E FIFTH ST	RENO	NV0000335224
232	AVILAS AUTO AND TRUCK REPAIR	100 GENTRY WY UNIT D12	RENO	NVD982439424
233	B AND B BUS REPAIR	5301 LONGLEY LN UNIT C7	RENO	NVD982466385
234	BAKER & TAYLOR	1160 TRADEMARK DR STE 111	RENO	NVR000073585
235	BALLY DIST OF NEVADA	777 W SECOND	RENO	NVD034954198
236	BARNES AUTO SERVICE	233 E FIFTH ST	RENO	NVD982431587
237	BARRINGER LABORATORIES INC	5301 LONGLEY LN BLDG E	RENO	NVD986769560
238	BAVARIAN AUTO HAUS	2825 KIETZKE LN STE 5	RENO	NVD982437188
239	BEAR REPAIR	572 GENTRY WAY	RENO	NVD986769966
240	BENDER WAREHOUSE	500 PARR BLVD	RENO	NV0000016261
241	BENDIX HVS	295 EDISON WAY	RENO	NVD047886791
242	BILLS QUALITY AUTO SVC	1933 PROSPERITY	RENO	NVD986772416
243	BIOMOLECULAR INC	2325 ROBB DR	RENO	NVD982461998
244	BOBS CLEANERS	1080 SOUTH VIRGINIA ST	RENO	NVU8WC000419
245	BOWLING CONGRESS PHOTOS INC	300 N CENTER ST	RENO	NV0001009927
246	BTS GROUP	4855 LONGLEY LN.	RENO	NVD982479677
247	C AND G AUTO KATZ	385 N WELLS	RENO	NV0000903161
248	C E S MACHINE	7755 SECURITY CIR	RENO	NVR000003145
249	CAL PAK DELIVERY	4674 AIR CTR CIR	RENO	NVD982464174
250	CALLAHANS PRINTING INC	130 S WELLS AVE	RENO	NV0000143859
251	CAMINO CAMPER OF NEVADA INC	9125 S VIRGINIA ST	RENO	NVD982342636
252	CARAVAN CAMPER MFG	1875 DICKERSON RD	RENO	NVD982498354
253	CARLS IMAGING WORKS INC	450 SUNSHINE LN	RENO	NVD982437931
254	CARRIER CORP	121 WOODLAND AVE	RENO	NVR000000067
255	CASE POWER & EQUIPMENT	2620 EAST 5TH ST	RENO	NVD981166549
256	CASINO MOTORS	2890 VASSAR ST NO 10A	RENO	NV0000069294
257	CELESTES ASIAN AUTOMOTIVE REPAIR	1070 GENTRY WY UNIT A	RENO	NVR000001446
258	HOOTEN TIRE	1940 E 4TH	RENO	NVR000000752
259	K TS QUALITY AUTOMOTIVE	35 N EDISON NO 48	RENO	NVR000000539
260	MAJOR AUTO REPAIR	570 A KIETZKE LN	RENO	NVD986770816
261	MERCY AMBULANCE	3010 N SUTRO	RENO	NVD982445678
262	MIRACLE METHOD INC	1040 MATLEY LN NO 11	RENO	NVR000079343
263	CHEVRON PHILLIPS CHEMICAL CO PERFORMANCE PIPE DIV	14381 LEAR BOULEVARD	RENO	NVD982430167
264	CHEVRON USA 9 4323	3499 S VIRGINIA ST	RENO	NVD986775484
265	CITY OF RENO	450 SINCLAIR ST	RENO	NVD986775575
266	KMART SUPERSTORE 4933	4855 SUMMIT RIDGE	RENO	NVR000002287
267	LENNAR HOMES	9603 WESTERN SKIES RD	RENO	NVR000079376
268	RDA INC	2400 TAMPA	RENO	NVD982495210
269	WASHOE KEYSTONE FUEL	1001 W 4TH ST	RENO	NVD986775815
270	CLAIRSON INTERNATIONAL	4660 AIRCENTER CIRCLE	RENO	NVD982017188
271	CLASSIC CLEANERS	190 CALIFORNIA AVE	RENO	NV0000989418
272	CLASSIC CLEANERS	26 CALIFORNIA AVE	RENO	NVD982373458
273	CLASSIC RODS	5325 LOUIE LN STE 10	RENO	NVD986775922
274	CLUTCH HOUSE INC.	645 E. 2ND STREET	RENO	NVD981409444
275	WESTAIR UNITED EXPRESS	1440 TERMINAL WY HGR 10	RENO	NVD986776797
276	JUANS MOBILE AUTO REPAIR	145 HUBBARD WY UNIT C	RENO	NVD986776615
277	KAR PRODUCTS INC DISTRIBUTOR	1085 TELEGRAPH ST	RENO	NVD986776466
278	MAMMOGRAPHY CENTER OF RENO	4600 KIETZKE LN STE E 144	RENO	NV0001025394

279	MASTER-HALCO INC	14331 LEAR BLVD.	RENO	NVD986771392
280	MCCURRYS DISCOUNT CAMERA	1999 S VIRGINIA ST UNIT C	RENO	NVR000001537
281	SIERRA NEVADA LABORATORIES	77 PRINGLE WY LABORATORY	RENO	NVD986776151
282	SOUTH VALLEY TRANSPORTATION	684 HWY 341 GEIGER GRADE	RENO	NVR000002956
283	THE CAMERA BAG	575 E MOANA LN	RENO	NVD986775229
284	COLD CHAIN TECHNOLOGIES	6640 ECHO AVE SUITE E	RENO	NVR000089219
285	COMSTOCK FOREIGN CAR SRV	1070 GENTRY WY	RENO	NVD986770311
286	TONYS SUTRO GARAGE	137 B GIROUX	RENO	NVD986772440
287	UNOCAL SVC STA #0077	103 E 4TH ST	RENO	NVD982042442
288	COPE AND MCPHETRES MARINE	2615 MILL ST	RENO	NVR000000695
289	WINSTON TIRE COMPANY #161	7111 VIRGINIA BLDG B	RENO	NVD981404502
290	CORTESY RADIATOR	945 E 4TH ST	RENO	NVD982415663
291	CREATIVE TOUCH INTERIORS #HDFL0043	5525 KIETZKE LN	RENO	NVR000080341
292	CRESCENT INVESTMENT	485 S ROCK BLVD	RENO	NV0000992990
293	CRUMRINE MANUFACTURING	145 CATRON DR.	RENO	NVD078143377
294	CSAA	199 E MOANA LN	RENO	NV0000561654
295	CUL-MAR PRODUCTS INC	2245 DICKERSON RD	RENO	NVP000073676
296	CUMMINS ALLISON CORP	5301 LONGLEY LN STE B37	RENO	NVD986767317
297	CUSTOM CONCRETE CUTTING SHOP	960 MATLEY	RENO	NV0000939512
298	DAMONTE RANCH HIGH SCHOOL	10500 RIO WRANGLER PKWY	RENO	NVR000079327
299	DEALERS SERVICE DEPT	409 GENTRY WAY	RENO	NVD982477879
300	DESERT MOUNTAIN OIL CO	321 E 5TH	RENO	NVD980892632
301	DOCS SERVICE CENTER	2825 KIETZKE LN #3	RENO	NVD982495228
302	DONREY OUTDOOR ADVERTISING	4945 JOULE ST	RENO	NVD982008534
303	DORANS FOREIGN CAR SERVICE	1921 1921 PROSPERITY	RENO	NVC2WC000330
304	DR BORGMAN REPAIR SERVICE	737 W 3RD ST	RENO	NV0000012146
305	DYNASTY CLEANERS	669 E MOANA LN	RENO	NVD982437154
306	E AND L WELDING DETAIL TRUCK SVC	405 WESTERN RD STE 29	RENO	NVR000000125
307	E T TECHNOLOGIES	750 S ROCK BLVD UNIT B	RENO	NVD982323628
308	E. I. DUPONT DE MEMOURS AND COMPANY	205 PARR BLVD	RENO	NVD980638613
309	EAGLE HARDWARE AND GARDEN NO 475	5075 KIETZKE LANE	RENO	NVR000050435
310	EARL SCHEIB PAINT AND AUTOBODY	559 E 4TH ST	RENO	NVR000078378
311	EATON'S B-LINE BUSINESS	13755 STEAD BLVD	RENO	NV0000148502
312	ECOLAB TEXTILE CARE DIVISION	250 BURGE RD	RENO	NVR000087452
313	ELECTRO GRAPHICS	290 GENTRY WY STE 5	RENO	NVD986774768
314	ELECTROGRAPHICS INC	5450 LOUIE LN	RENO	NVR000048405
315	ELECTRONIC DISPENSERS INTL	400 EDISON WAY	RENO	NVD981989890
316	ELITE CLEANERS	1925 DICKERSON RD	RENO	NVD982510067
317	ELSONS TRANSMISSION	85 N EDISON UNIT 4	RENO	NVD982433930
318	ENVIRONMENTAL MANAGEMENT OF NV INC	9911 N VIRGINIA ST	RENO	NVR000083337
319	ERA HELICOPTER	14505 MT ANDERSON DR	RENO	NVD982318826
320	EXPRESS SMOG	1931 PROSPERITY LN	RENO	NVD981439722
321	FALK DISTRIBUTION CENTER RENO	4970 JOULE ST	RENO	NVD059362723
322	FALLLINE CORP	4802 LONGLEY LANE	RENO	NVD982406134
323	FAST PHOTO	490 E PLUMB LN	RENO	NVD986773679
324	FEDERAL AVIATION ADMINISTRATION	1902 NATIONAL GUARD WAY	RENO	NVR000002261
325	FEDERAL HOSE MFG CORP	550 EVANS ST	RENO	NVD986773638
326	FERRARI COLOR PHOTO IMAGING LLC	333 W MOANA LN	RENO	NVR000032656
327	FITZGERALDS CASINO HOTEL	255 NORTH VIRGINIA ST	RENO	NVD982408056
328	FOOTHILL SALES	40 S WELLS	RENO	NVD986776102
329	FORMER N SIERRA BONUS STATION	707 N SIERRA ST	RENO	NV0000452961
330	FOTO FAST 1 HR	940 W MOANA LN	RENO	NVD982466096

331	FOTO FAST 1HR	5034 S VIRGINIA STREET	RENO	NVD982471682
332	FRAZEE PAINT AND WALLCOVERING #108	4068 KIETZKE LANE	RENO	NVR000081190
333	FRONTIER TOURS RENO	2620 E FIFTH ST	RENO	NVD982433906
334	FUJI PHOTO FILM USA INC	1350 N WELLS AVE	RENO	NVR000078352
335	G K SMOG	2100 MILL ST	RENO	NVD982429300
336	G L J INC DBA SUNNYS MARINE SUPPLY	3771 MILL ST	RENO	NVD986777035
337	GALENA HIGH SCHOOL	3600 BUTCH CASSIDY WY	RENO	NVD986776599
338	GALLI MINERAL ASSOCIATES	940 MATLEY LANE STE 14	RENO	NVD000630319
339	GARDNER MECHANICAL SERVICES	5655 RIGGINS COURT NUMBER 1	RENO	NVD986777019
340	GENERAL TRANSMISSION	2515 SUTRO ST	RENO	NV0000145789
341	GENERATOR EXCHANGE	1395 E 4TH ST	RENO	NVR000000547
342	GLIDDEN CO DBA ICI PAINTS	2600 MILL ST NO 200	RENO	NVR000079905
343	GLOBAL INVESTMENT RECOVERY INC	380 PARR BLVD	RENO	NVR000081893
344	GOLDEN EAGLE AUTOMOTIVE	35 E 4TH STE 9	RENO	NV0000184036
345	GOLDEN EAGLE AUTOMOTIVE	1100 E 4TH ST	RENO	NV0000902734
346	GOLDEN PHOENIX HOTEL	225 N SIERRA ST	RENO	NVR000081125
347	GOODYEAR AUTO SVC CTR	2310 S VIRGINIA	RENO	NVD981665177
348	GOODYEAR TIRE AND RUBBER CO	1250 E 6TH ST	RENO	NVD986770329
349	GORDONS PHOTO SERVICE	180 E PLUMB LANE UNIT A	RENO	NVD986773547
350	GRAND AUTO, INC	4024 KIETZKE LANE	RENO	NVD981398159
351	GREGS GARAGE	1261 E 7TH ST	RENO	NV0000330092
352	GROVE STREET AUTO SERVICE	150 E GROVE ST	RENO	NVD986770071
353	HANNIGAN INC	7250 S VIRGINIA ST	RENO	NVD982445686
354	HANSON INDUSTRIES	750 SOUTH ROCK BLVD	RENO	NVD082108945
355	HARCO	250 1/2 SAGE ST	RENO	NVD982430225
356	HARDING-LAWSON ASSOC	940 MATLEY LN	RENO	NVD067799098
357	HARLEY DAVIDSON OF RENO INC	2295 MARKET ST	RENO	NV0000132647
358	HARNESS PERFORMANCE	315 SPOKANE ST UNIT 5	RENO	NVD986770030
359	HAROLD B CHAPMAN JR IRREVOCABLE TRUST	5600 WHISKEY SPRINGS ROAD	RENO	NVR000083758
360	HARRAHS LAUNDRY	135 LINDEN ST	RENO	NVD981424377
361	HEETRONIX	725 TRADEMARK DR 104	RENO	NVR000079475
362	HERITAGE BANK (FORMERLY NATIONAL STRIPING COMPANY)	9530 N VIRGINIA ST	RENO	NVR000088062
363	HIDDEN VALLEY RANCH FOOD PRODS	12150 MOYA BLVD	RENO	NVD982436123
364	HIGH SIERRA PAINTING AND DECORATING	2220 DICKERSON RD	RENO	NVR000060178
365	HIGHLANDERS GARAGE	300 KIETZKE LN	RENO	NVD986771640
366	HOBBY CORPORATION OF AMERICA	1190 TRADEMARK DR	RENO	NVR000079194
367	HOLIDAY PHOTO	3330 S MCCARRAN BLVD	RENO	NVD986776961
368	HOME DEPOT USA INC HDFL0042	7525 COLBERT LN	RENO	NVR000080333
369	HOME DEPOT USA INC HDFL0048	895 E PATRIOT BLVD SUITES	RENO	NVR000080358
370	HONDAS ETC	3417 MILL ST	RENO	NV0000807271
371	I G T PHOTO LAB	250 SOUTH ROCK BLVD STE 124	RENO	NV0000016253
372	IMPORT TRADING POST INC	490 N VIRGINA ST	RENO	NVD982494106
373	IMPRUVALL TIRE N01	9705 S VIRGINIA ST	RENO	NV0000133314
374	INTERNATIONAL PIPELINE LLC	1000 TELEGRAPH ST UNIT 8	RENO	NVR000083972
375	INTUIT	1225 FINANCIAL BLVD	RENO	NVR000069849
376	J & J VW VANS	260 260 TELEGRAPH STREET	RENO	NVD982431603
377	J J AUTO	2415 DICKERSON RD	RENO	NV0000683219
378	JEFFS MOBILE AUTO RPR	2495 DICKERSON RD	RENO	NV0000039073
379	JEFFS MOBILE REPAIR	1300 W SECOND ST	RENO	NVD982437444
380	JIFFY LUBE	6006 S. VIRGINIA STREET	RENO	NVD982460438
381	JOHNS BRITTISH CARS GARAGE	1000 TELEGRAPH UNIT 7	RENO	NVD986776755
382	MEDCIS	4980 LONGLEY LN #103	RENO	NVR000076513

383	MERCEDES BENZ OF RENO	11500 S VIRGINIA ST	RENO	NVR000082263
384	MERCURY AIR GROUP	1440 TERMINAL WAY	RENO	NVD982439440
385	MERCY AMBULANCE OF RENO	450 EDISON WY	RENO	NV0000137240
386	MERRY X-RAY	295 GENTRY WY STE 24	RENO	NVR000080200
387	MERVYNS STORE	6895 SIERRA CENTER PKWY	RENO	NVR000083824
388	MICHELIN NORTH AMERICA INC	14551 INDUSTRY CIRCLE, SUITE B	RENO	NVR000031575
389	MIDAS MUFFLER	1037 E FOURTH ST	RENO	NVD986771590
390	MIDAS MUFFLER AND BRAKE	3250 S VIRGINIA ST	RENO	NVD986770352
391	MIDTOWN TEXACO XPRESS LUBE	100 GENTRY WY C9	RENO	NVR000080028
392	MIKADO CLEANERS AND LAUNDROMAT	507 WASHINGTON ST	RENO	NVR000040022
393	MIKE MINSCH	8340 CHIPPEWA	RENO	NVD982437162
394	MIKOHN GAMING CORP	4835 LONGLEY LN	RENO	NVR000002394
395	MINUTEMAN PRINTING INC	1535 VASSAR	RENO	NVD986773455
396	MIRACLE AUTO PAINTING	2685 E 4TH ST	RENO	NVD982335762
397	MIRROR IMAGE STUDIOS	4930 ENERGY WY	RENO	NVD986771822
398	KEYSTONE QUALITY PRINTING	890 W 5TH ST	RENO	NV0000133298
399	KIDDIE KANDIDS	4991 S VIRGINIA 104	RENO	NVR000078790
400	KIDDIE KANDIDS	5540 MEADOWOOD MALL CIR #G-112	RENO	NVR000079863
401	KIETCK	4673 AIRCENTER PARKWAY	RENO	NVR000002253
402	KIETEK INTL INC	5325 LOUIE LN NO 7	RENO	NVD986775674
403	KITS CAMERAS 1 HOUR NO 129	5525 MEADOWOOD MALL CIR	RENO	NVR000001081
404	KRAGEN AUTO PARTS 4108	1501 S VIRGINIA	RENO	NVD981398217
405	KRAGEN AUTO PARTS 4113	801 W FIFTH ST	RENO	NVD981639404
406	KROWN RACING	1325 E 2ND ST	RENO	NV0000627927
407	KRUGER PHOTOGRAPHY SVCS	1040 MATLEY LN	RENO	NVD986775443
408	L W AUTOMOTIVE	2415 E 2ND ST	RENO	NVD982433948
409	LABORATORY CORP. OF AMERICA	704 MILL STREET	RENO	NV0000069302
410	LAKESIDE CLEANERS	135 WEST PLUMB LANE	RENO	NVD982373557
411	LANDA MUFFLER	816 E 4TH ST	RENO	NVR000001065
412	LARRYS CAR SERVICE	3413 MILL ST	RENO	NVD986771012
413	LEATHER CONNECTION INC THE	5450 RIGGINS CT NO 5	RENO	NVD986775591
414	LEGEND METALLURGICAL LAB INC	125 MANNEL ST	RENO	NVD982463002
415	LIFESTYLE HOMES INC	6985 PEPPERMINT DR	RENO	NVD986770394
416	LNL PROPERTIES LLC	572 REACTOR WAY	RENO	NVR000083501
417	LUBRICON RENO NEVADA	4795 LONGLEY LANE STE 101	RENO	NVR000000232
418	LUMBERJACK BUILDING MATERIALS	12828 S VIRGINIA	RENO	NVD986774503
419	LUMOS AND ASSOCIATES INC	4200 REWANA WAY #506	RENO	NVD982461287
420	LUMOS AND ASSOCIATES INC	5401 LONGLEY LN STE 13	RENO	NVD986772309
421	LUSTRLUX CLEANERS	454 WASHINGTON	RENO	NVD982373565
422	M AND T GARAGE	208 GENTRY WY	RENO	NVD986776839
423	MAACK DISPOSAL SVC	2695 TACHINNO ST	RENO	NVR000002436
424	MAC BROTHERS AUTOMOTIVE	1520 W 4TH ST	RENO	NVD986775971
425	MAGNUS CORPORATION	475 EDISON WAY	RENO	NVD986774644
426	MOTOR CLASSICS LTD	225 TELEGRAPH #110	RENO	NVD982431629
427	MUSCLE MOTORS A/S	7000 S VIRGINIA ST	RENO	NVR000088633
428	MY MECHANIC	2890 VASSAR ST NO 10 AND 11A	RENO	NV0000071662
429	N C M PAINTING	120 MARY ST	RENO	NVR000057364
430	NATIONAL SEAL CO	525 REACTOR WAY	RENO	NVD982461303
431	NC AUTO PARTS LLC	1150 MATLEY LN	RENO	NVR000085829
432	NEVADA BELL	4940 MT ROSE HWY	RENO	NVT330010422
433	RICH GLO CLEANERS	180 LINDEN ST	RENO	NVD982472482
434	RICKS AUTO REPAIR	128 LINDEN ST	RENO	NVD982494130

435	RITTER PHOTO INC	4830 LONGLEY LN	RENO	NVD986773463
436	WESTERN SEALING & STRIPING	111 MORRILL AVE	RENO	NVR000073957
437	WESTERN X RAY INC	690 MONTELLO ST	RENO	NVD982323610
438	WINDECKER INC	1365 AIRMOTIVE WAY	RENO	NVD982339210
439	NEVADA BELL	3350 LYMBERY	RENO	NVT330010661
440	NEVADA BELL	9700 S VIRGINIA	RENO	NVT330010711
441	NEVADA CARRIAGE COMPANY	205 TELEGRAPH ST	RENO	NVD981967185
442	NEVADA DREAM MACHINE	5301 LONGLEY LN 214 BLDG F	RENO	NVR000002691
443	NEVADA FOREIGN AND DOMESTIC CARS	491 ELKO AVE	RENO	NVD982436305
444	NEVADA TYPESETTING	75 CALIENTE ST	RENO	NVD982486326
445	NEVADA WASTE OIL CO	2005 WATT ST	RENO	NVD981626500
446	NEW FACES CABINETRY	7930 SUGAR PINE CT	RENO	NVR000003111
447	NEW MIKADO CLEANERS	737 WEST FIFTH STREET	RENO	NVD982370157
448	NO NEVADA FLEET SERVICES INC	3555 AIRWAY DR UNIT 310	RENO	NVR000046011
449	NORTH VALLEYS HIGH SCHOOL	1470 E GOLDEN VALLEY RD	RENO	NVR000075903
450	NORTHWEST INC	7900 N VIRGINIA ST #296	RENO	NVD980896203
451	NUGGET 1 HR CLEANERS	237 EAST PLUMB LANE	RENO	NVD982373581
452	NVARNG PLUMB LN ARMORY	685 E PLUMB LN	RENO	NV4210490021
453	OLD TOWN MALL	4001 S VIRGINIA ST	RENO	NVD982007478
454	ORBITBID.COM INC RENO	14551 INDUSTRY CIRCLE STE B	RENO	NVR000085951
455	OUTDOOR POSTERS	2890 VASSAR ST	RENO	NVD982499311
456	P AND L AUTOMOTIVE	2554 WRONDEL ST	RENO	NV0000721555
457	PACE AVIATION LTD	500 EDISON WY	RENO	NVD982350381
458	PALLADIUM ENERGY INC	335 EDISON WY UNIT 9	RENO	NVR000085480
459	PANDA/UPG	2695 MILL ST	RENO	NVD986772044
460	PAP R PRODUCTS COMPANY RENO	3895 CORSAIR ST	RENO	NV0000370205
461	PARAMOUNT AUTO BODY	2375 E 4TH ST	RENO	NVD982411910
462	PARNELLI JONES	590 KIETZKE LN	RENO	NVD986769081
463	PAUL THOMAS ENVIROTRANS INC	3885 BRANT ST	RENO	NVR000046367
464	PAULS AUTOMOTIVE	2552 WRONDEL WY	RENO	NV0000876003
465	PAYLESS CLEANERS	3334 KIETZKE LN	RENO	NVR000082099
466	PERFORMANCE AUTOMOTIVE	555 GENTRY WAY	RENO	NVD982438483
467	PETES AUTO BODY	311 N PARK ST	RENO	NVD986776862
468	PETROSOLUTIONS LLC	14150 MOUNT ANDERSON ST	RENO	NVR000089805
469	PEVCO	9240 PROTOTYPE DR	RENO	NVR000001289
470	PHOTO ONE	6455 S VIRGINIA ST	RENO	NVD986773554
471	PIONEER PHOTO LAB	1715 S WELLS AVE	RENO	NVD982486805
472	PLATINUM AVIATION GROUP INC	4649 AIRCENTER CIR	RENO	NVR000080135
473	PLAZA MACHINE SHOP INC	859 E 2ND ST	RENO	NVD986770402
474	POLYVISION INC DBA POLYCORE OPTICAL	875 E PATRIOT BLVD STE 204	RENO	NVR000003335
475	PORSCHE CARS N AMERICA	1600 HOLCOMB	RENO	NVD982477895
476	POSEIDON TRUCKING INC	10100 DONNAY DR	RENO	NVR000081794
477	PRECISION AUTOMOTIVE INC	1100 W FOURTH ST	RENO	NVD982320947
478	PRECISION TRANSMISSION	2155 MARKET ST	RENO	NVD986770089
479	PRIMARK CORPORATION	4950 JOULE STREET	RENO	NVT330010281
480	PRIMARY IMAGE INC / BML INVESTMENTS	1350 CAPITAL BLVD	RENO	NVR000081430
481	PRIMOS SERVICE	545 DEPAOLI	RENO	NVD982439473
482	PRO AUTO SERVICE	2187 MARKET ST STE F	RENO	NV0001010651
483	PRODUCTION IMAGES INC	9390 GATEWAY DR	RENO	NVR000001016
484	PROSPERITY CLEANERS	401 SUNSHINE LANE	RENO	NVD981982853
485	QUALITY AIR SVCS	5301 LONGLEY LN BLDG B STE 40	RENO	NVR000037085
486	QUICK FIX	700 CASAZZA DR	RENO	NVR000001149

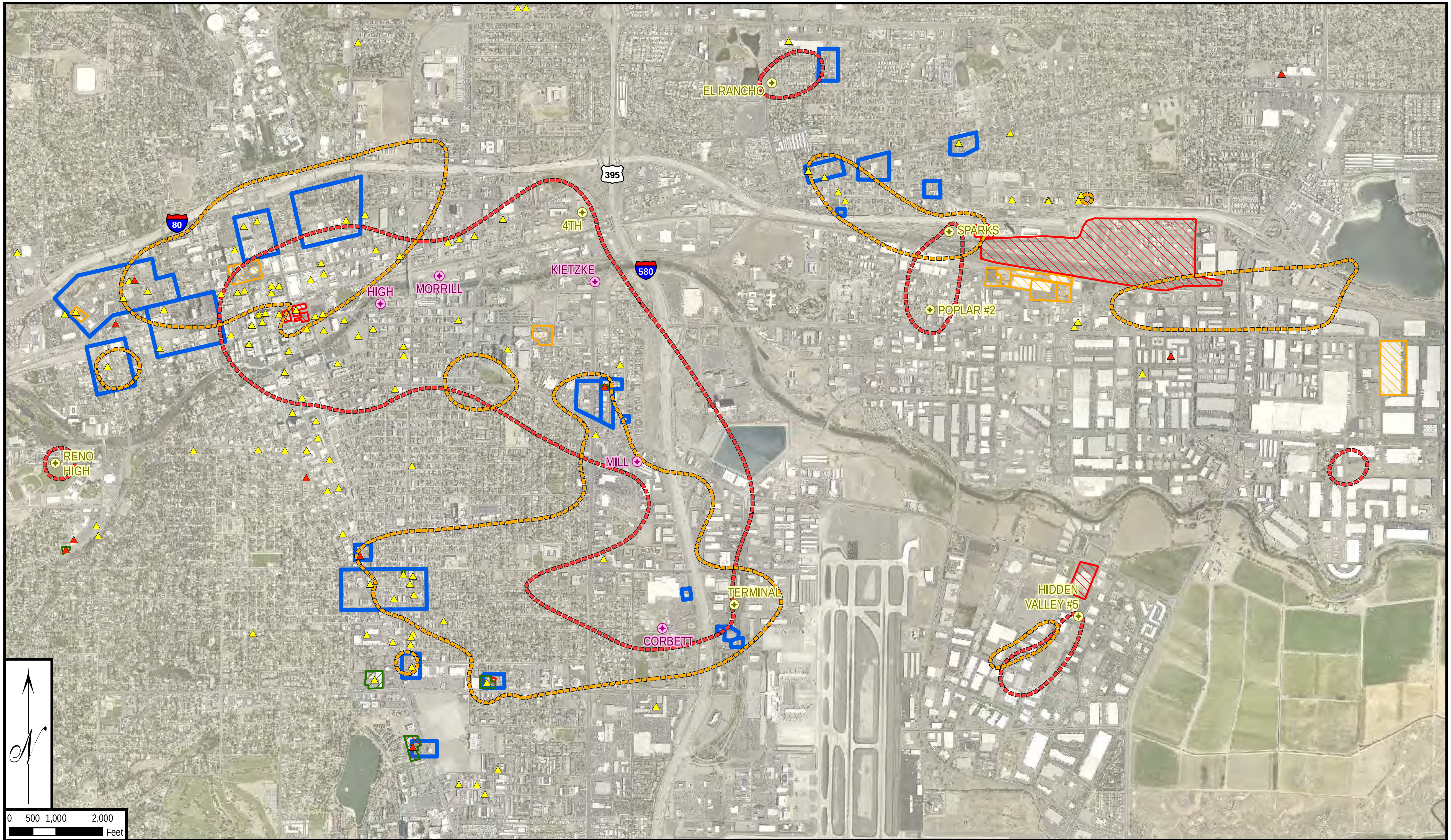
487	R C ENGINES	635 E FOURTH ST	RENO	NVD982461337
488	RAINBO BAKING CO	440 ELKO	RENO	NVD982430712
489	RAINBO BAKING CO	455 EUREKA AVE	RENO	NVD986769958
490	RAINBOW CLEANERS	477 EAST PLUMB LANE	RENO	NVD982413726
491	RALPHS AUTO BODY INC	90 SUNSHINE LN UNIT B	RENO	NVR000000901
492	RECREATION PUBLICATION	2303 KIETZKE LN STE 18	RENO	NVR000001164
493	REDWOOD AUTOBODY NO 2	2625 DICKERSON RD UNIT B	RENO	NVR000000844
494	RELIABLE CLEANERS	727 W 5TH STREET	RENO	NVD982373599
495	REMARC MFG	1995 TAMPA WY	RENO	NV0000069815
496	RENO AUTO SERVICE CENTER	100 GENTRY WY	RENO	NVD986774933
497	RENO BREAST CTR	50 KIRMAN AVE	RENO	NV0000016006
498	RENO COLOR LAB	5401 LONGLEY LN UNIT 12	RENO	NVD986776037
499	RENO COLOR LAB	3330 KIETZKE LN	RENO	NVR000078360
500	RENO CUSTOM CYCLES	3411 MILL ST	RENO	NVD982439465
501	RENO DIAGNOSTIC CENTER	590 EUREKA AVE	RENO	NVD982524308
502	RENO FRAME AND AUTO BODY	1950 ZINC	RENO	NVD986770048
503	RENO PRINTING	940 MATLEY LN STE 3	RENO	NVR000001420
504	RENO REGENCY CONVENTION CENTER	555 EVANS AVE	RENO	NVR000082891
505	RENO SPARKS INDIAN COLONY	2453 E 2ND ST	RENO	NVD986770709
506	RENO SPARKS READY MIX	2200 BARNETT WAY	RENO	NVD986771426
507	RENO TAHOE SPECIALTY INC	550 VALLEY RD	RENO	NVD986770386
508	RENO TYPOGRAPHERS INC	255 BELL ST NO 290	RENO	NVD986773646
509	RENOWN IMAGING @ SOUTH MCCARRAN	6630 S MCCARRAN BLVD STE C27	RENO	NVR000076349
510	RTC ACCESS PARATRANSIT MAINTENANCE FACILITY	600 SUTRO	RENO	NV0000183913
511	RUBENSTEIN RADIOLOGY	890 MILL ST NUMBER 105	RENO	NV0000268961
512	RW STOVALL PRINTING INC	3775 MILL ST	RENO	NV0000133249
513	SPOT CLEANERS	9410 PROTOTYPE DR STE A13	RENO	NVR000034892
514	ST MARYS HEALTHFIRST	5290 NEIL RD	RENO	NVD986774677
515	STAR CLEANERS	2303 S. VIRGINIA ST.	RENO	NVU000085563
516	STRIDE WRITING INSTRUMENTS	1140 CORPORATE BLVD	RENO	NVR000003327
517	SUN CHEMICAL CORP	7970 SECURITY CIRCLE	RENO	NVD981694540
518	SUNSHINE AUTO REPAIR	1670 KUENZLI	RENO	NVR000000315
519	SUPERIOR CLEANERS	18 CHENEY STREET	RENO	NVD982373649
520	SWEDISH AUTO	570-B GENTRY WAY	RENO	NVD986768760
521	RYDER INTEGRATED LOGISTICS/EASTMAN KODAK COMPANY	12035 MOYA BLVD	RENO	NVR000085522
522	VINTAGE SLOT MACHINE AND AMUSEMENT CO	4816 LONGLEY LN	RENO	NVD986769818
523	VITAL SYSTEMS	195 N EDISON WAY UNIT 9	RENO	NVD986771160
524	WALGREENS STORE NO.11446	6450 S VIRGINIA ST	RENO	NVR000082727
525	WALMART 2106	2863 NORTHTOWNE LN	RENO	NV0000593491
526	WASHOE COUNTY SCHOOL DISTRICT	330 DOUBLEBACK RD	RENO	NVD982430910
527	WASHOE IMAGING	350 W SIXTH ST	RENO	NV0000029280
528	WASHOE IMAGING AT 75 KIRMAN	75 KIRMAN AVE	RENO	NV0000026807
529	WASHOE IMAGING AT 85 KIRMAN AVENUE	85 KIRMAN AVENE UNIT 2A	RENO	NV0000029272
530	WASHOE MEDICAL CENTER CLINIC	21 LOCUST ST	RENO	NVR000037697
531	WATERS SEPTIC TANK SERVICE, INC.	4275 REWANA WY	RENO	NV0000123059
532	WEBBS RV	105 SUNSHINE LN	RENO	NV0000133215
533	WEST COAST IMAGING	1400 E 7TH ST	RENO	NVR000076836
534	WINN PRESS	13920 MT MCCLELLAN	RENO	NVD982465528
535	SAV ON DRUG STORE NO 2046	10550 N MCCARRAN	RENO	NVR000001578
536	SAVE MART SUPERMARKETS DBA ALBERTSONS	4995 KIETZKE LN	RENO	NVR000075762
537	SAVE MART SUPERMARKETS DBA ALBERTSONS	195 W PLUMB LN	RENO	NVR000075796
538	SAVE MART SUPERMARKETS DBA ALBERTSONS	525 KEYSTONE AVE	RENO	NVR000075879

539	SAVE ON CLEANERS LLC	6429 S VIRGINIA ST	RENO	NVR000039669
540	SCOLARIS NO 20	8165 S VIRGINIA	RENO	NVR000000596
541	SEARS A C 1978	5400 MEADOWOOD MALL CIR	RENO	NVR000001388
542	SEPHORA STORE 40 MEADOWOOD	5335 MEADOWOOD MALL CIR	RENO	NVR000078519
543	SEVEN DIAMOND CLEANERS	141 E PUEBLO ST	RENO	NVD982373615
544	SHAMROCK AUTO PARTS INC	2560 E 4TH ST	RENO	NVD986770345
545	SHELL OIL CO	280 W 2ND ST	RENO	NVD981685506
546	SHELL SERVICE STATION 138261	6220 S VIRGINIA	RENO	NVD980676324
547	SHERWIN WILLIAMS CO THE	4818 LONGLEY LN	RENO	NV0000921411
548	SHERWIN-WILLIAMS CO THE	196 SO WELLS AVE	RENO	NVD088848692
549	SHOEMANS CYCLE	1291 E 2ND ST	RENO	NVD982437709
550	SIERRA CYLINDERS INC	490 S ROCK BLVD	RENO	NVD981439284
551	SIERRA DYNAMICS	1150 E CRYSTAL CANYON CT	RENO	NVR000000943
552	SIERRA MAINTENANCE INC	2850 WRONDEL WY UNIT H	RENO	NV0000268979
553	SIERRA OFFICE CONCEPTS	1301 CORPORATE BLVD	RENO	NV0000145771
554	SIERRA OFFICE CONCEPTS	955 S VIRGINIA ST	RENO	NVD981962061
555	SIERRA R P R AND SHARPENING	77 W ARROYO ST	RENO	NVD982430233
556	SIERRA STRIPERS & ASPHALT PAINTING INC	296 PARR BLVD	RENO	NV0000002238
557	SIERRA TRANSMISSIONS	100 GENTRY WY STE A1	RENO	NV0000461939
558	SIERRA X RAY SERVICES	845 E SECOND ST	RENO	NVD982524688
559	SILVER STATE AUTO BROKERS SVC	70 W GROVE UNIT 4	RENO	NVD986776128
560	SILVER STATE CAMERA	538 S VIRGINIA	RENO	NVD986768588
561	SIR SPEEDY PRINTING	220 S ROCK BLVD	RENO	NVD986777175
562	SKYLINE NO.1 TANK TMWA	2855 SKYLINE BLVD	RENO	NVR000084897
563	SMARTRIM INC	4750 TURBO CIRCLE	RENO	NVD982466054
564	SMITH FOOD AND DRUG 1 HOUR PHOTO	3600 VIRGINIA ST	RENO	NVD986773372
565	SMITHRIDGE CLEANERS & LAUNDRY	5023 S MCCARRAN BLVD	RENO	NVD982402885
566	SOCIETY DRY CLEANERS	475 KEYSTONE	RENO	NVD982373631
567	SOUTHERN PACIFIC	222 SAGE ST	RENO	NVR000000745
568	SOUTHWEST COLOR INC	5301 LONGLEY LN A 12	RENO	NVR000003020
569	SOUTHWEST TIRE SVC	3075 S VIRGINIA ST	RENO	NVR000000661
570	SPEED AUTO REPAIR	195 N EDISON UNIT 8	RENO	NVD986776078
571	SPEEDEE OIL CHANGE AND TUNE UP	100 GENTRY WAY STE C	RENO	NVR000000273
572	T N T AUTOMOTIVE INC	405 WESTERN RD UNIT 13	RENO	NV0000993006
573	TEDESCO CONSTRUCTION INC	5395 LOUIE LN	RENO	NVR000075416
574	THE BOEING CO FORMER NFL	2550 WHISKEY SPRINGS RD	RENO	NVR000079228
575	THE SHERWIN WILLIAMS COMPANY	8850 DOUBLE DIAMOND PKWY	RENO	NVR000082784
576	THE SHERWIN-WILLIAMS CO. - RENO WAREHOUSE	4900 AMPERE DR.	RENO	NVD096905724
577	THERMAX PARISE AND SONS INC	5385 ALPHA AVE	RENO	NVD986771830
578	TIME FASTENER CO INC	5301 LONGLEY LN STE G	RENO	NVR000040741
579	TIRE CENTERS INC #9861	1500 E 4TH ST	RENO	NVD982430183
580	TIRES UNLIMITED	1120 KIETZKE UNIT A	RENO	NVD986770964
581	TOM JOHNSON INC	300 WESTERN ROAD UNIT NO.3	RENO	NVR000084715
582	TONY HARRAH	11095 THOMAS CREEK RD	RENO	NVD986776995
583	TRAVELERS RV SERVICE DEPT	1765 LEWIS ST	RENO	NVD986776409
584	TRIM LINE OF RENO	240 TELEGRAPH ST	RENO	NVD982403578
585	TRUCKEE MEADOWS PHOTO	790 LOUISE ST	RENO	NVD986772812
586	TRUCKEE PRECISION	110 WOODLAND AVE	RENO	NVR000000570
587	TRUCKEE PRECISION	1045 TELEGRAPH ST	RENO	NVD981973266
588	TWIN CITY DIESEL AND AUTO REPAIR INC	430 MORRILL AVE	RENO	NVD986771095
589	TYCO ELECTRONICS	980 SANDHILL RD STE 100	RENO	NVR000081083
590	UNITED AERIAL	5295 COGGINS DR	RENO	NVR000047571

591	UNITED CONSTRUCTION CO	5320 MILL ST	RENO	NV0000029298
592	UNITED STATES PLAYING CARD CO THE	195 CATRON DR	RENO	NVD982053985
593	UNITED TECHNOLOGIES OTIS ELEVATOR	940 MATLEY ST STE 17	RENO	NVD982434060
594	UNIVERSITY OF NEVADA MAIN FARM	5894 CLEANWATER WAY	RENO	NV0000050815
595	UNOCAL SERVICE STATION #7207	2515 KIETZKE LANE	RENO	NVD982488835
596	UNOCAL SVC STA #6072	300 W 7TH ST	RENO	NVD982057275
597	USDOI BLM RENO	850 HARVARD WAY	RENO	NVD982329138
598	V LINE AUTOMOTIVE	65 WEBB CIR UNIT A	RENO	NVR000000448
599	VENTURA INTERNATIONAL	5325 LOUIE LN STE 14	RENO	NVR000082776
600	XPRESS LUBE AND TUNE	55 E PATRIOT BLVD	RENO	NVR000001735

APPENDIX D

PCE FIGURE



PCE TREATED PRODUCTION - TMWA

PCE IMPACTED PRODUCTION - TMWA

DRY CLEANER (CURRENT)

DRY CLEANER (HISTORICAL)

PCE PLUME CONCENTRATION CONTOURS

SHALLOW ZONE PCE (ESTIMATED)

DEEP ZONE PCE (ESTIMATED)

PCE DETECTED IN SEWER

PCE CORRECTIVE ACTION SITE (CURRENT)

PCE CORRECTIVE ACTION SITE (HISTORICAL)

PCE HIGH MASS AREAS

POTENTIALLY CONTRIBUTORY ACTIVITIES (PCA)
PCE IMPACTED SITES & PCE GROUNDWATER PLUMES

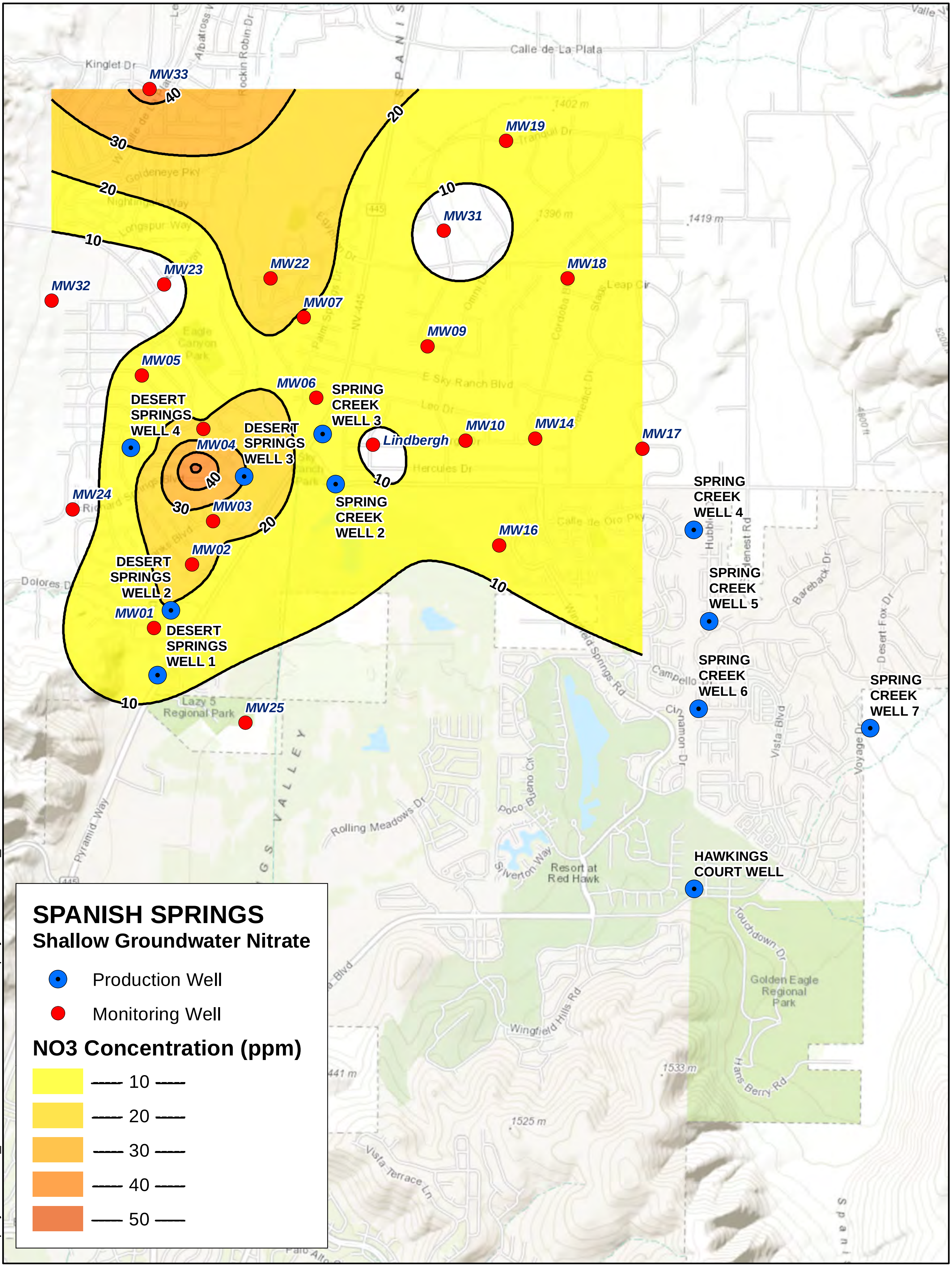
TMWA

NOTE: The scale and configuration of all information shown hereon are approximate only and are not intended as a guide for design or survey work. Reproduction is not permited without prior written permission from Truckee Meadows Water Authority.

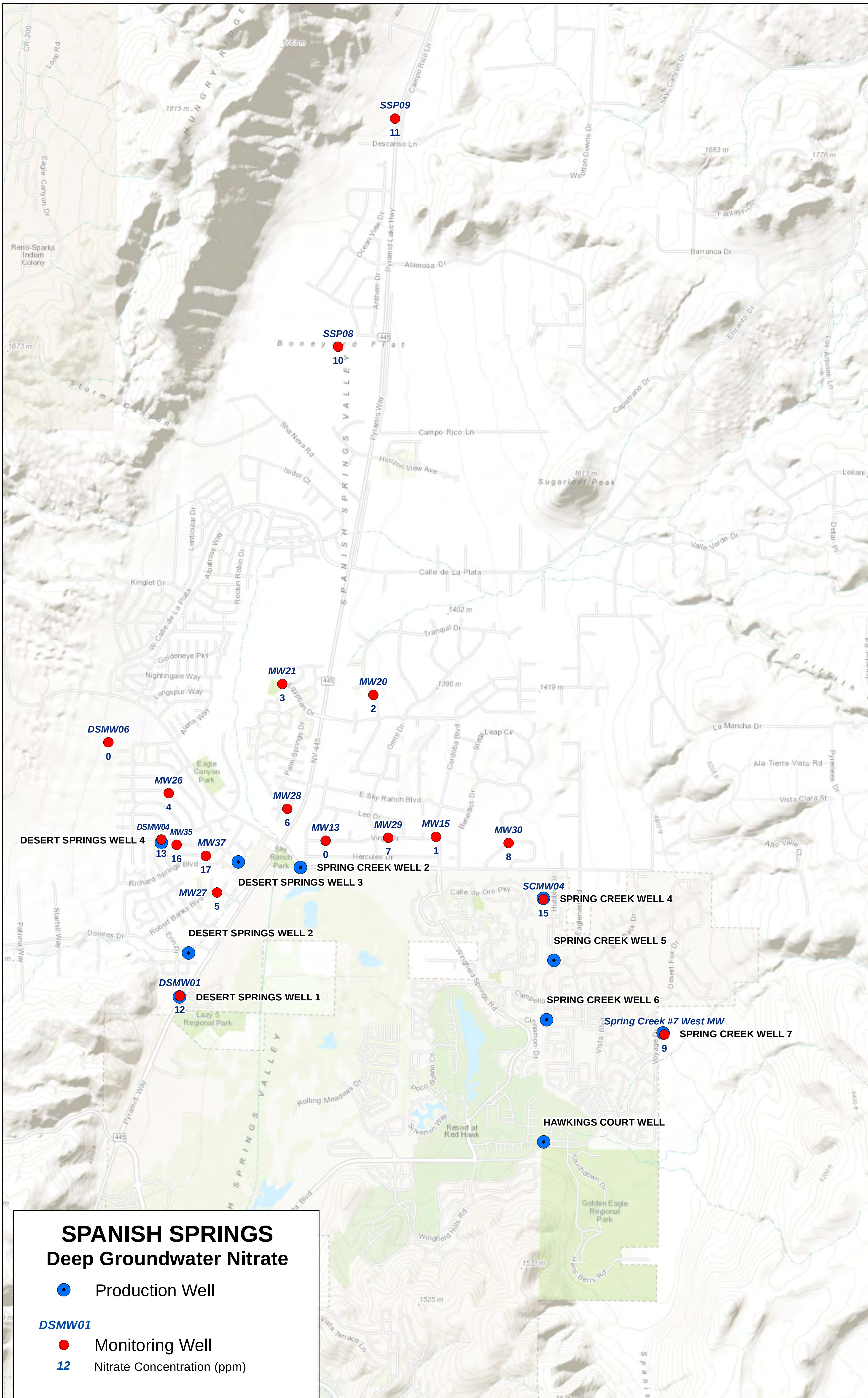
Q:\client\Washoe_County\Maps\TMWA_WellHeadProtection\TMWA_WellHeadProtect_PCE_PCA_ver2_11X17.mxd, Editor: MForrest, Printed: 9/9/2015

APPENDIX E

SPANISH SPRINGS VALLEY NITRATE FIGURES



W:\projects\water_resources\ResourcePlan2016\projects\mxd\SSV_NITRATE85X11.mxd



W:\projects\water_resources\ResourcePlan2016\projects\mxd\SSV_NITRATE_DEEP11X17.mxd