Hydrogeology of Golden Valley, Nevada – A Case Study

Including History of Groundwater Use in Southern Lemmon Valley

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Prepared for

Golden Valley Property Owners Association

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EXECUTIVE SUMMARY

Hydrogeology and groundwater use in Golden Valley, Nevada, have been explored and assessed through a series of investigations, modeling assessments, and feasibility studies to evaluate existing conditions and to identify and assess potential sources of groundwater recharge for domestic water for more than 550 families. The first investigation was based on hydrologic data available in 1971. In the 1980s, a series of studies were conducted to assess the potential for using water resources from Mount Peavine for artificial recharge in Golden Valley. The most recent aquifer recharge assessment was conducted by Terraphase Engineering Inc (Terraphase) to assess hydrogeologic conditions and the evaluate the need for future recharge under the Golden Valley Artificial Recharge Program. Each of these previous studies was conducted with specific scope of work that provided insight into the hydrogeologic framework and/or factors that influence groundwater conditions.

Recognition of declining groundwater levels over multiple years beginning in the 1980s threatened the water supply in Golden Valley for multiple residential users and necessitated the deepening of some domestic wells. The Golden Valley Artificial Groundwater Recharge Program was initiated as a pilot program in 1980s to assess the feasibility of stabilizing groundwater levels. In the 1990s, potable water from the Truckee River was injected and the water supply was monitored for water levels and water quality. Beginning in 2002, under Washoe County Ordinance 1166 and later Ordinance 1548, Washoe County continued recharge until 2016 when injection was suspended due to rising groundwater levels. Terraphase was retained by Washoe County in 2022 to assess hydrogeologic conditions in Golden Valley and evaluate the future need for the Golden Valley Artificial Groundwater Recharge. The Terraphase evaluation included development of a predictive model to identify potential conditions under which the recharge program would be beneficial.

Critically, this Case Study synthesizes previous studies, models, and available data on the hydrogeology, including a chronological assessment reflecting synchronous and sequential interactions of various components that have influenced groundwater conditions within Golden Valley, Nevada, over the past six decades. Data derived from the previous studies is presented in narrative text supported by various charts, graphs, tables, and maps. Tables and Figures are presented following the list of References Cited. Additional data is presented in the Appendices, including a compilation of well logs, precipitation data, and selected references.

This Case Study is structured to address relevant frameworks: Physiographic, Geologic, Cultural, and Hydrologic. Selected professional references and background information are included to provide a foundation for the respective frameworks. The intent is to enrich understanding of the hydrogeology of Golden Valley. The reader is encouraged to pursue other sources that will provide further details and a more in-depth perspective on any given aspect of conditions in Golden Valley and vicinity.

The perspectives on water in Nevada are outlined to illustrate the evolution of thought on use and value of surface water and groundwater resources. Use of water in the State has evolved from take what surface waters you can get to use of ground water based on perennial yield, to use of ground water based on safe yield, and, currently, use based on sustainable yield where surface and ground waters are viewed as an inter-connected entity.

A synoptic analysis is presented on the hydrogeology of Golden Valley. Groundwater conditions, including both confined bedrock fracture system and unconfined phreatic (water table) groundwater, are controlled by the local geology, the bedrock fracture zones, and the overlying valley fill. This synoptic analysis indicates that pumping of municipal wells in excess of safe yield, fluctuations in recharge from precipitation, distribution and timing of artificial injection recharge, location of Medium Density Suburban developments, and surface water runoff interactively impacted groundwater levels across the Golden Valley sub-basin of the Lemmon Valley hydrographic basin. This long-term conceptual understanding of the geohydrology of Golden Valley must continue to be carefully considered and accommodated in any future groundwater modeling.

The geology is the controlling factor when examining the occurrence and movement of water in Golden Valley. Further, the occurrence and movement of groundwater is not confined to the Golden Valley sub-basin watershed that is defined by surface topography. It is integrally linked to the presence and human use of groundwater resources within the adjacent areas of Lemmon Valley East Sub-basin as well as recharge from Mount Peavine that provides groundwater and hydrostatic pressure within the confined bedrock fractures.

The granitic terrains surrounding Golden Valley should be considered critical recharge areas that provide the primary means of replenishing groundwater supplies that are used for potable water, as well as maintaining hydrostatic pressure within the confined bedrock aquifer. These critical recharge areas and the quality of groundwater resources should be the focus of protection from the threat of development that would adversely decrease recharge, decrease hydrostatic pressure within the confined aquifer, or potentially adversely impact groundwater quality.

Since the cessation of excess pumping of several municipal wells, static groundwater levels have risen to near-natural levels, but could be impacted by future natural or human actions. Natural events could include earthquakes, wildfires, or variation in precipitation on either an annual or water-year basis. Human actions could include reactivation of or drilling of new municipal wells, as well as political or policy decisions on land use, particularly within the critical recharge zone.

Golden Valley Artificial Recharge helped mitigate some of the adverse impacts of the excessive pumping of LVP3 from the granitic bedrock fracture system on hydrostatic conditions across much of the northern and eastern portions of Golden Valley. The hydrograph of the Mayo well indicates that even in the southeastern portion of the Valley, excessive drawdown caused significant decline in static groundwater levels for more than 3 decades.

Similarly, excessive pumping of the CMOR and SKY municipal wells primarily from the fractured andesites of Mount Peavine created a cone of depression that intercepted Peavine Inflow recharge beginning in the early 1960s until these municipal wells were abandoned in 2002. These conditions lowered phreatic groundwater levels in Steadfield Estates and along the lower portions of Golden Valley Wash for almost 40 years. As a result, groundwater levels encountered during residential development in these areas were below natural levels.

The Truckee Meadows Water Authority (TMWA) retains water rights to municipal well LVP3. Should pumping of municipal well LVP3 be resumed or if any new municipal wells are drilled in the southern portion of Lemmon Valley East Subbasin, then the rate of pumping should be based on safe yield in accord with the principles of groundwater sustainability. The location of municipal well LVP3 significantly affected the dynamic response of the confined granitic bedrock fracture system aquifer and the rate at which natural discharge could be captured across Golden Valley. Decisions on future municipal well pumping in the southern portion of Lemmon Valley should be consistent with the precepts of sustainable groundwater use, particularly with respect to impacts upon domestic water resources and use in Golden Valley.

Several models have been developed for the Lemmon Valley/Golden Valley. Models are intended to mimic real world conditions. However, no model can capture all the complexities and intricacies of the real-world conditions (e.g., lithologic variations in valley fill, bedrock fracture system, short-term weather, and long-term climate). Synoptic analysis of groundwater conditions over time within Golden Valley confirms groundwater conditions have been influenced by the location of Estates Fault, recharge within the granitic terrain on the margins of the valley and recharge from Mount Peavine. The location and pumping history of municipal wells in the southern portion of Lemmon Valley impacted both piezometric conditions within the bedrock fracture system across the entire valley and phreatic conditions in valley fill in the western portion of the valley. Municipal wells SKY and CMOR extracted groundwater principally from fractures in the andesitic volcanic rocks of Mount Peavine; municipal well LVP3 extracted groundwater from fractures in the granitic bedrock that extends eastward underlying Golden Valley.

But the models can indicate trends that are comparable to historically measured water levels. The added value of the Terraphase modeling is the recognition and incorporation of impacts of the municipal wells in southern Lemmon Valley on static water levels in Golden Valley. These models incorporated hydro-stratigraphic layers, water budgets for the interval 1991 through 2001, and applied finite difference grids within graphical user interface software programs and MODFLOW-2005. These models predicted trends that are generally consistent with time-sequence analysis of hydrographic data based on historically measured water levels. Predicted water levels may differ by several tens of feet from measured values which can be significant depending on well depth.

A number of questions and future uncertainties remain. Would recharge injection into the bedrock fracture zones have resulted in greater benefit? Would an alternative system for recharge (e.g., additional well(s), singular rather than sequenced injection wells, or infiltration gallery) be more effective? Perhaps these questions might be answered with additional groundwater modeling.

Periodic re-evaluation of groundwater resources will be required to assess groundwater levels and groundwater quality within Golden Valley. Groundwater modeling that incorporates this long-term conceptual understanding of both hydrostatic pressure and quantity of groundwater in the confined bedrock aquifer will play an important role in evaluating future conditions and the potential for reactivation of the Golden Valley Artificial Recharge Program to augment groundwater resources. Continued use of groundwater as a resource within Lemmon Valley (and the Golden Valley sub-basin) should prioritize sustainability in terms of groundwater quality and quantity, as well as hydrostatic pressure within the confined bedrock aquifer.

Should similar conditions recur in the future, then the availability of water under existing agreements and permits will need to be considered. There is the potential for another below-average water year such as occurred in the winter of 1993-1994 that limited availability of potable water for diversion to the Golden Valley Recharge Program when only 5 acre-feet of water was injected. Groundwater modeling that incorporates this long-term conceptual understanding will play an important role in evaluating future conditions and the potential for reactivation of the Golden Valley Artificial Recharge Program to augment groundwater resources.

Historical data confirms that the Golden Valley Artificial Recharge Program cannot fully compensate for significant loss of groundwater and hydrostatic pressure in the fractured bedrock aquifer system. And it is unlikely that the Recharge Program could fully compensate for significant loss of groundwater recharge in the local granitic terrain to the bedrock fracture system.

On 14 November 2023, the Washoe County Board of County Commissioners adopted Resolution R23-149 to suspend the Golden Valley Artificial Recharge Program (Program) participant fee collection from January 1, 2024, through December 31, 2033. This Resolution continues Program activities in support of the maintenance of the State of Nevada Division of Water Resources injection permit performed pursuant to Washoe County Ordinance 1548 and requires all Program participants to bring any past due accounts current through the processes identified in Ordinance 1548. This Resolution allows for Washoe County to continue monitoring groundwater conditions and maintain necessary permits and water rights for the Golden Valley Artificial Recharge Program.

The hydrogeology of Golden Valley incorporates complex interactions and consequences of the physical environment and the cultural development of Lemmon Valley over time. Putting the available hydrogeologic data within a broader technical context and chronology is intended for both the technical and lay audience to:

1) help readers understand the complex geologic and hydrologic framework of Golden Valley
2) provide a long-term conceptual understanding to frame future groundwater modeling
3) guide future sustainable use decision-making based on data and the interactions among factors that have and may continue to influence the presence and availability of groundwater resources within Golden Valley

About the Author

Elaine J. Hanford is a Retired Professional Geologist, professionally registered since 1979 and formally retired since 2012. She completed a Master of Science Degree and doctoral program in Geology and later earned an interdisciplinary PhD in environmental hazards and epidemiology. She has more than 45-years of experience as a geologist and environmental scientist consulting for both public and private sectors, as well as university teaching and research. She is currently a Senior Emeritus Member of the Association of Engineering Geologists.

Her work has been honored for more than 4 decades at professional conferences and published in peer-reviewed national and international journals. She has, upon invitation, presented papers at regional, national, and international professional meetings and conferences. Beginning in the mid-1970s, she authored and co-authored papers on the geology, tectonics, geochemistry, and geothermal systems of Western Nevada. She compiles and posts weekly Geoscience, Environmental Science, and Coastal Zone Management Bulletin Boards. Over the past two years, she authored five invited papers for the American Water Resources IMPACT journal, including articles on the pluvial lakes of the Great Basin and the development of the Newlands Project in Western Nevada.

Acknowledgements

No viable work, particularly one that encompasses the scope of this Case Study, is conducted within a vacuum. The efforts of researchers who collected, compiled, and archived data, as well as produced existing documents and reports were invaluable to this effort. Appreciation is extended to Catherine Orpilla, Lemmon Valley Basin Manager with the Nevada State Engineer, for providing hydrologic data and historical outlines for the various municipal wells. The author is appreciative of having had the opportunity to work cooperatively with Washoe County Engineering Staff and is honored to have been a part of the Golden Valley Aquifer Recharge Program Focus Group to identify concerns and provide technical review. The Focus Group provided community perspective during the preparation of the Golden Valley Aquifer Recharge Assessment by Terraphase Engineering Inc. The author provided a technical overview of the Geology and Hydrology of Golden Valley for the Washoe County Board of County Commissioners.

Residents of Golden Valley raised important questions and provided historical insights during Community Meetings that encouraged not only critical thought but were also the impetus for the preparation of this Case Study. Discussions with and review comments from Dr. Greg Pohll, Principal Hydrogeologist and Modeler at Truckee Meadows Water Association, and Tracy Roth, PG, Senior Associate Hydrogeologist at Terraphase, were invaluable in refining the content of this Case Study. My sister, the non-scientist, patiently read the entire document and identified important editorial errors since attention to detail matters. And a final thanks to William J. Elliott, Consulting Engineering Geologist and long-time colleague, for his ever-ready “red pen” and helpful critique.

INTRODUCTION

This Case Study addresses the hydrogeology and chronology of groundwater use in Golden Valley, Nevada **(Figure 1. Golden Valley, Nevada)**. Golden Valley is part of the North Valleys in Washoe County, Nevada. The term "North Valleys" has various meanings and geographic extent depending on whether, for example, one is referring to the North Valleys Planning Unit or the Census County Division as defined by the US Census Bureau **(Figure 2. North Valleys in Washoe County, Nevada).** Therefore, the term "North Valleys" will only be used appropriately in this Case Study.

Since 1971, the hydrogeology and groundwater use in Golden Valley, Nevada, have been investigated and assessed through a series of investigations, modeling assessments and feasibility studies to evaluate existing conditions and to identify and assess potential sources for groundwater recharge for domestic water for more than 550 families. Each of those previous studies was conducted with specific scope of work that provided insight into the hydrogeologic framework and factors that influence groundwater conditions.

Limited residential development in Golden Valley began in the 1960s with the development of Steadfield Estates Subdivision, followed by the platting and development of several developments in the 1970s and 1980s relying on domestic wells and septic systems typically on approximately one-acre parcels. This development paralleled the general growth of southern Washoe County.

Declining groundwater levels over multiple years beginning in the 1980s threatened the water supply in Golden Valley for multiple residential users and necessitated the deepening of some domestic wells. To stabilize declining groundwater levels, a federally funded artificial groundwater recharge pilot project was initiated. Washoe County Department of Water Resources sponsored the program in the early 1990s and continued injection until termination of US Bureau of Reclamation funding in 1998. With the demonstrated success of the pilot program and at the request of Golden Valley residents, the Washoe County Board of County Commissions approved an ordinance in 2002 for the operation of the Golden Valley Artificial Recharge Program, with financial support provided by fees assessed for each parcel within the designated service area. Recharge continued until 2016 when it was suspended due rising groundwater levels within Golden Valley. Groundwater levels and groundwater quality monitoring continued.

In 2022, Washoe County authorized Terraphase to assess the hydrogeologic conditions in Golden Valley and to evaluate whether continued aquifer recharge would be beneficial to domestic well users by examining changes in basin conditions over the decades coinciding with the recharge program and to develop a predictive model under select scenarios to inform decisions for future aquifer recharge. The evaluation included examining the extent to which basin conditions used to originally justify aquifer recharge had changed. A detailed conceptual model of the basin was developed and identified natural recharge and changes in regional municipal pumping as the major drivers influencing groundwater levels in the subbasin. This information was used to build and calibrate a numerical model for use in predictive modeling to simulate select scenarios and inform decisions for future aquifer recharge.

What began as a White Paper has, more appropriately, evolved into this Case Study. Critically, this Case Study synthesizes all previous studies, models, and available data on the hydrogeology, including a chronological assessment reflecting the synchronous and sequential interactions of various components that have influenced groundwater conditions within Golden Valley, Nevada, over the past six decades. The data derived from the previous studies is presented in narrative text supported by various charts, graphs, tables, and maps to explore the physiographic, geologic, cultural, and hydrologic frameworks. Tables and Figures are presented following the list of References Cited. Additional data and selected references are presented in the Appendices.

Using Physiographic, Geologic, Cultural and Hydrologic Frameworks, this Case Study is intended to put the available hydrogeologic data within a broader context and chronology to 1) help both technical and lay readers understand the complex geologic and hydrologic framework of Golden Valley and 2) guide future sustainable decision-making based on factual evidence and the interactions among factors that have, and may continue to influence the presence and availability of groundwater resources within Golden Valley.

The hydrogeology of Golden Valley incorporates complex interactions and consequences of the physical environment and the cultural development of Lemmon Valley over time. Putting the available hydrogeologic data within a broader technical context and chronology as a Case Study is intended for both the technical and lay audience to:

1) help readers understand the complex geologic and hydrologic framework of Golden Valley
2) provide a long-term conceptual understanding to frame future groundwater modeling
3) guide future sustainable use decision-making based on data and the interactions among factors that have and may continue to influence the presence and availability of groundwater resources within Golden Valley

AVAILABLE DATA AND PREVIOUS HYDROLOGICAL STUDIES

Available drillers well logs on file with the State of Nevada were reviewed for each original and deepened domestic well within the delineated Golden Valley surface water drainage basin and vicinity. Tabulation of well logs presented in **Appendix A** includes well log designation, location, year drilled, drillers description from the log including noted fracture zones, static water level (SWL) at time of drilling, and the screened interval. In addition, drillers logs and pumping histories for three commercial wells located closest to the Golden Valley surface drainage basin boundary were also reviewed. Well logs included in the literature (e.g., Harrill 1973) were also reviewed and compared with drillers logs on file with the State of Nevada.

Previous studies include hydrologic assessments of Lemmon Valley and the Golden Valley subbasin. Appraisals and assessments began in 1967 for the Lemmon Valley area. Groundwater flow models have been developed to assess the feasibility of sources for potential groundwater recharge. The previous studies that were identified and reviewed for this Case Study are chronologically listed below with annotated summary of the intent and content of each study. These annotations should not be substituted for reading the original sources. These and other sources noted in this Case Study are listed in the Reference Cited, with respective readily available online links to facilitate access.

Rush FE and Glancy PA. November 1967. Water-Resources Appraisal of the Warm Spring-Lemmon Valley Area, Washoe County, Nevada. Water Resources – Reconnaissance Series Report 43, 70 pages including 1 Figure, 25 Tables and 1 Plate.

A reconnaissance survey of water resources in the Warm Springs-Lemmon Valley area, encompassing roughly 900 square miles within 11 valleys extending from Honey Lake on the north to the Virginia Mountains on the south. Notes roughly 500 acre-feet of water are imported from Truckee River near Reno to Lemmon Valley each year. Available surface waters are diverted from streams for irrigation. Evapotranspiration accounts for most of the natural discharge.

Groundwater can be developed by pumping from wells in or near areas of discharge. Substantial increase in groundwater development in recent years supported rapidly increasing urban population. This report appraised source, occurrence, movement, and chemical quality of water resources, estimated average annual recharge and discharge from groundwater, provided preliminary estimate of perennial yield and transitional storage reserve, and evaluated potential water development.

In general, for Lemmon Valley, the existence of two large faults and gross lithologic variations in the valley fill are noted as probably affecting movement of water in the valley-fill aquifer, but subsurface location, extent and effectiveness cannot be identified from the available information. Springs are noted in Lemmon Valley, but none were identified in Golden Valley. A few wells are noted in Lemmon Valley, but no specifics are given within the Golden Valley sub-basin.

Harrill, JR. 1973. Evaluation of the Water Resources of Lemmon Valley, Washoe County, Nevada, with Emphasis on Effects to Groundwater Development to 1971. Nevada Water Resources Bulletin No. 42. 130 pages including 12 Figures, 27 Tables, and 2 Appendices.

A detailed study to evaluate groundwater recharge, discharge, yield; inventory groundwater pumpage, imported water, and water use; describe the geologic framework as it controls the hydrology; define the extent and magnitude of groundwater storage changes; delineate the extent of poor-quality water; and explore possibilities of artificial recharge and potential effects of sewage effluent on groundwater.

Groundwater quality is generally good, but less than the quality of Truckee River water. Transitional storage reserve is estimated for Golden Valley. Groundwater flows from low mountains toward valley center, then northwestward through the gap to Lemmon Valley. Study focused on Lemmon Valley proper, but also includes limited data on the Golden Valley subbasin.

Soeller SA. May 1978. Quaternary and Environmental Geology of Lemmon Valley, Nevada. Master of Science Thesis in Geology – University of Nevada, Reno. 70 pages including 2 Figures, 1 Plate and 2 Appendices.

Detailed reconnaissance investigation of the Lemmon Valley area in response to needs of Regional Planning Commission, local geological engineering consultants, and the general public. The study identified overall geologic and environmental geological features, with emphasis on the Quaternary geology of Lemmon valley.

Schaefer DH and Maurer DK. 1981. Geophysical Reconnaissance of Lemmon Valley, Washoe County, Nevada. US Geological Survey Water-Resources Investigation Open-file Report 80-1123, 29 pages.

Geophysical reconnaissance included a gravity survey and electrical resistivity survey. Gravity data were used to confirm relative thickness of the valley fill and confirm bedrock structure of Lemmon Valley. Electrical resistivity data reflecting variation in material composition, density, porosity, pore size, water content and water quality. A layer of low resistivity was encountered beneath both Silver Lake and Swan Lake playas. These layers could be interpreted as poor-quality water underlying the playas, with better quality water at depth. Poorer quality water underlies Swan Lake in the eastern portion of the valley at depths of less than 200 feet, but may be as deep as 600 feet. Beneath Silver Lake, better quality water is considerably shallower, with depths of 40 to 80 feet on the west and north sides of the playa likely influenced by recharge from Mount Peavine. East of Silver Lake, better quality water begins at about 490 foot depth.

Cochran GF, Dale MW, and Kemp DW. February 1984. Peavine Mountain Water Harvest: Preliminary Feasibility Report. Desert Research Institute Water Resources Center Publication 41094. Pages including 18 Figures and 7 Tables.

Preliminary study of the feasibility of using salvage runoff from Peavine Mountain with preliminary cost estimates for a harvest/recharge system to offset declining groundwater levels in Golden Valley. Noted 400 homes within Golden Valley relying on domestic wells and septic systems.

The study noted water levels declining in some wells by as much as 10 feet per year; several wells have had to be deepened to maintain access to water. Noted water level drop of about 1 foot per year in 1983, with an observed range up to 10 feet per year decline.

Noted generally good water quality in Golden Valley with mean total dissolved solids of 291 parts per million. Geologic conditions appear favorable to recharge either through infiltration basins or injection wells. Runoff water from Mount Peavine was judged of sufficient quantity and quality as to be suitable for potential groundwater recharge.

Barry JM. 1985. Hydrogeochemistry of Golden Valley, Nevada, and the Chemical Interactions during Artificial Recharge. Master of Science Thesis in Hydrology/Hydrogeology – University of Nevada, Reno. 190 pages including 35 Figures, 11 Tables and 8 Appendices.

Assessed the feasibility of salvaging runoff from nearby Peavie Mountain for diversion to Golden Valley for the purpose of artificially recharging declining groundwater levels. Focused on characterizing the chemical and physical processes controlling groundwater chemistry in Golden Valley prior to any recharge scheme. Predicted kind and extent of any mineral precipitation reactions that may decrease permeability during recharge, determining the extent of mineral dissolution in the aquifer and effects on water quality, and discussing chemical effects of recharging treated Truckee River water as an alternative source.

Cochran GF, Barry JM, Dale MW, and Sones PR. October 1986. Water Harvest from Peavine Mountain with Artificial Recharge in Golden Valley, Nevada: Hydrologic Feasibility and Effects. Desert Research Institute Water Resources Center Publication. With 78 Figures, 26 Tables and 4 Appendices.

Feasibility study of using recharge to offset declining groundwater levels in Golden Valley based on hydrology and water chemistry data collection and monitoring program. Noted average hydraulic

conductivities of 2.94 feet per day in alluvial fill, 2.33 feet per day in bedrock with a high degree of spatial variation.

Noted recharge in highlands surrounding the Valley to the north, east and south. Data collected were used to develop and calibrate conceptual and numerical models of Peavine Mountain and Golden Valley hydrologic and hydrogeochemical systems. Models suggested no adverse impacts would result from injection and that recharge water would improve water quality and decrease the extent of groundwater level declines.

Noted that the rhyolites and metavolcanics in the southeastern corner of Golden Vally are less favorable for the infiltration of water. Also noted that significant quantities of clay are associated with weathered quartz monzonite in the northeast corner of the Valley. Swelling clays would inhibit infiltration.

Without artificial recharge, hydrologic simulation predicted 20-foot decline of groundwater levels under no-growth scenario, 80-foot decline of groundwater levels under constant growth scenario, and greater than 100-foot decline of groundwater levels under instant and total growth scenario. Models suggest that under constant growth scenario, injection of 80 acre-feet per year in 3 wells in the northeast portion of Golden Valley would result in 10 to 20 feet less water level decline than without artificial recharge with the potential greatest benefit in the central portion of Golden Valley.

Dale MW. 1987. Hydrology of the Southern Part of the Peavine Mountain-Silver Lake Sub-basin. Master of Science Thesis in Hydrogeology – University of Nevada, Reno. 124 pages, including 34 Figures, 16 Tables, and Appendix.

Used 24 months of hydrology, water chemistry and isotope data from Peavine Mountain watershed tributaries to Silver Lake to construct a Discrete State Compartment groundwater flow model. Model suggests 200 acre-feet per year could be harvested for use as recharge water within the Golden Valley sub-basin.

Van Hoozer RG. May 1994. Simulating the Effects of Artificial Recharge in Lemmon Valley, Washoe County, Nevada. Master of Science Theis in Hydrology/Hydrogeology - University of Nevada, Reno. 137 pages, including 32 Figures, 3 Tables, and 1 Appendix.

Developed a quasi-three-dimensional finite difference numerical groundwater flow model to simulate the effects of artificial recharge in a topographically-closed basin. The basin was conceptualized as a 2-layer system, with an upper unconfined layer and a lower confined layer.

Stable water levels on an annual basis, along with nearly equal recharge and discharge components suggested the groundwater system was in a quasi-steady-state during the early 1970s. Five-year simulations indicated that artificial recharge (6 months actively injecting followed by 6 months without injection) would add water to aquifer storage and raise groundwater levels by up to 5 feet in Lemmon Valley north of Swan Lake Playa and east of the Airport Fault.

Washoe County. August 1996. High Plains States Groundwater Demonstration Project – Washoe County Recharge Demonstration Study – Summary Report. Report: 2368-00017, 15 pages.

Summarizes the project and findings of the Washoe County Recharge Demonstration Study as one of 13 projects implemented by the US Bureau of Reclamation with local sponsors in cooperation with the Environmental Protection Agency (EPA) and the U. S. Geological Survey (USGS) under the "High Plains States Groundwater Demonstration Program Act of 1983" (Public Law 98-434). The primary purpose of Public Law 98-434 is to advance the state of the art in groundwater recharge techniques. The Project was sponsored by Washoe County, Nevada. Washoe County executed a cooperative agreement with Reclamation in 1990 to conduct artificial groundwater recharge demonstration projects in Lemmon and Golden Valleys.

Project diverted Truckee River Water for delivery to and injection directly into aquifers through injection wells. From diversion to injection the water was treated to municipal water quality standards, pumped through miles of pipeline and "polished" by filtering through activated carbon. Institutional and permitting delays caused several years to pass before Reclamation and the County could sign and implement a cooperative agreement in September 1990. However, delays proved to be beneficial as a drought in the region began in 1987 and influenced project activities through 1993. If the Project had been operational in 1988, virtually no injection could have occurred until 1994 under the conditions agreed upon with various entities. Declining water levels forced homeowners to redrill existing domestic wells.

Project showed that artificial recharge can help mitigate declining water tables and improve management of water resources in Washoe County. Artificial recharge may be an effective tool in offsetting water level declines in over-pumped aquifers, storing water for drought use, and enhancing water quality of ground water supplies. In Golden Valley, deterioration of the aquifer has caused economic hardships related to well deepening or redrilling and has hindered the ability to buy or sell homes in the area. Artificial recharge appears to be the most economic and best solution available to most residents of Golden Valley since construction of a municipal system would be considerably more expense than artificial recharge. Washoe County intends to continue artificial recharge in Golden Valley.

Stone M and Lopez H. July 2006a. Hydrologic Trend Analyses for the Truckee Meadows Region. Appendix 2-1 Basic Summaries in 2016-2035 Water Resources Plan – Lemmon Valley Hydrographic Basin 92A and 92B. 87 pages including 12 Appendices.

Evaluates climate and hydrologic data in Truckee Meadows region to identify potential environmental change that may be consistent with global warming. Analysis of temperature, precipitation, snow water equivalent, streamflow volume and timing, and reservoir volumes showed high annual variability, slight trend toward increased minimum and maximum temperatures, with no consistent trend in streamflow volume. Concluded reservoir volumes were dependent on precipitation.

Stone M and Lopez H. July 2006b. Potential Climate Change and Impacts on Water Resources. Appendix 2-1 Basic Summaries in 2016-2035 Water Resources Plan – Lemmon Valley Hydrographic Basin 92A and 92B. Pages 48-62 of 70.

Evaluation of long-term precipitation data indicated long-term trend slowly increasing levels of precipitation in Lemmon Valley and nearby hydrographic basins. Where groundwater pumping exceeded natural groundwater recharge, water levels declined and had negative impacts on wells that were not screened in deeper parts of the aquifer. In Golden Valley, the artificial recharge program lessened the negative impacts of over-pumping.

Hooper, D. Spring 2007. Groundwater Quality and Supply in Golden Valley, Washoe County, Nevada. Senior Research Project. Washoe County Department of Water Resources. 7 pages and 5 Figures.

Evaluation of water quality within Golden Valley resulting from injection of potable water under the Golden Valley Artificial Recharge Program. Water quality in 2007 was compared to data from 1993, showing improvement in water quality in domestic wells nearest to the injection wells. Noted water levels declined in wells during spring and summer months when domestic use increased for irrigation.

Manhard Consulting Ltd. February 2010. Marlin and Lemmon Channels – Floodplain Analysis & Improvement Alternatives - Final Report. 25 pages plus 8 Appendices.

A hydrologic and hydraulic modeling analysis of the Marlin and Lemmon Channels to investigate potential flood control improvements to develop reliable peak flow rates for the respective surface water channels for a variety of storm return periods to estimate system capacities. Identified potential system improvements capable of conveying stormwater runoff from a 100-year event relative to Federal Emergency Management Agency (FEMA) Flood Hazard Zones.

Davis K and Echeverria J. 2014. Lemmon Valley Hydrographic Basins 7-092A and 7-092B Groundwater Pumpage Inventory Water Year 2014. 23 pages including 5 Figures and 2 Appendices.

Inventory of status and usage of all permitted, certificated and claims of vested groundwater rights for water year 2014 (Oct 2013 through Sep 2014). Golden Valley is a subbasin within Lemmon Valley Eastern Part 7-092B.

Davis K and Echeverria J. 2015. Lemmon Valley Hydrographic Basins 7-092A and 7-092B Groundwater Pumpage Inventory Water Year 2015. State of Nevada Division of Water Resources. 23 pages including 5 Figures and 2 Appendices.

Inventory of status and usage of all permitted, certificated and claims of vested groundwater rights for water year 2015 (October 1, 2014 through September 30, 2015)

Davis K and Echeverria J. 2016. Lemmon Valley Hydrographic Basins 7-092A and 7-092B Groundwater Pumpage Inventory Water Year 2016. State of Nevada Division of Water Resources. 23 pages including 5 Figures, 1 Table and 2 Appendices.

Inventory of status and usage of all permitted, certificated and claims of vested groundwater rights for water year 2016 (October 1, 2015 through September 30, 2016).

McDaniel S and Scott M. 2017. Lemmon Valley Hydrographic Basins 7-092A and 7-092B Groundwater Pumpage Inventory Water Year 2017. State of Nevada Division of Water Resources. 23 pages including 5 Figures, 1 Table and 2 Appendices.

Inventory of status and usage of all permitted, certificated and claims of vested groundwater rights for water year 2017 (October 1, 2016 through September 30, 2017).

Pohll G. 2017. Update to the Golden Valley Groundwater Model. Report to Truckee Meadows Water Authority. 40 pages.

Updated groundwater flow model for Golden Valley in support of managing the aquifer system and administering the Golden Valley Aquifer Recharge Program to address declining water levels. Incorporated pumping and injection data through 2016: included fractured granite and unconsolidated basin-fill in more detailed geological conceptual model, mapped faults, turf irrigation recharge, and detention basin seepage. Developed steady-state model for conditions prior to 1970 and transient model to predict future groundwater level changes following pause in injection program in 2016. Used hydraulic conductivities ranging from 10^{-3} to 10^{-1} meters per day as typical for fractured granite. Pumping history outside the domain boundary was not incorporated into the model (G. Pohll, verbal communication 22 August 2023).

The model captured general water level trends. In a few locations the model simulated a more rapid water level response to changes in fluid injection than was measured. The 2017 model predicted water levels would decline on the order of 2.5 to 3.3 feet per year when the Recharge Program ceased injection of imported water, with localized areas of rising groundwater levels due to seasonal precipitation.

Pohll G. June 2019. Lemmon Valley Groundwater Model. Report to Truckee Meadows Water Authority. 104 pages.

Comprehensive update of groundwater flow models for Lemmon Valley hydrographic sub-basins (092A and 092B), including Golden Valley. Revised model included finite difference grid; updated information on hydro-stratigraphic layers; reconstructed spatial distribution of playa sediments, alluvium, and fractured bedrock; incorporated additional recognized faults as potential horizontal flow barriers; adjusted domestic well pumping and outdoor irrigation in Golden Valley to improve transient calibration; and adjusted model for detention basin and drainage channel seepage in Golden Valley. Generally good agreement between model and measured groundwater levels, except in East Lemmon Valley where simulated levels declined approximately 15 feet from 1970 to 2010, but measured groundwater levels only declined by 1

Terraphase Engineering Inc. April 2023. Golden Valley Aquifer Recharge Assessment. Project number N022-001.001. 28 pages plus 16 Tables, 38 Figures, and 4 Appendices.

Evaluated whether continued use of an aquifer recharge program would be beneficial to domestic well users in Golden Valley. Examined the extent to which basin conditions that were used in the 1980s to originally justify aquifer recharge have changed over the last several decades. A detailed conceptual model was developed to revise and re-calibrate the model of Pohll 2017. Utilized regional geologic reports, drillers well logs, water level data for 60 domestic wells and three monitoring wells, extraction records for municipal wells near Golden Valley basin boundary, injection data from Golden Valley Aquifer Recharge Program, and groundwater modeling for Lemmon Valley (Pohll 2019) and golden Valley (Pohll 2017). Water budget was calculated for the interval 1991 through 2001. Indicated that municipal wells CMOR1, CMOR2, and SKY extracted approximately 42 acre-feet per year in the 1970s, approximately 103 to 126 acre-feet per year from 1980 to 2001, and approximately 32 acre-feet per year beginning in 2002.

Assumed similarity of bedrock conditions in Lemmon Valley and Golden Valley to calculate hydraulic conductivity for valley fill. Calculated a range in hydraulic conductivity from 1.6 to 48 feet per day, with an average of 16 feet per day. Noted that the overlapping of hydraulic conductivity values for bedrock and valley fill indicates heterogeneities in fill materials and variability in fracture characteristics (aperture and inter-connectedness) in bedrock. Depending on porosity and hydraulic conductivity, calculated groundwater travel time across the basin ranged from 13 to 59 years in basin fill and 59 to 491 years in bedrock. Provides for predictive model under select scenarios for aquifer recharge in the future.

Updated the groundwater flow model of Pohll (1027) by refining the bedrock unit from one to three layers, revising the fill-bedrock interface and bedrock hydraulic conductivity based on information from the NDWR database, and updated the model boundary conditions (assigned inflows and outflows) based on calculated water budget. Developed the model using the graphical user interface software program Groundwater Modeling System (GMS) by Aquaveo, Inc., and the MODFLOW-2005 code (Harbaugh 2005) was used to simulate groundwater flow.

The report draws several notable conclusions, including: overall surplus in groundwater storage since 1990 due to decline in municipal well extraction and return of Peavine Inflow; groundwater levels respond to periods of above-average precipitation; and shallow groundwater elevations in the ‘Gun Streets’ (i.e., Steadfield Estates) are likely a function of a mapped fault, bedrock topography and lower transmissivity in basin fill sediments.

PHYSIOGRAPHIC FRAMEWORK

Lemmon Valley

The Nevada State Engineer has designated 14 hydrographic regions and the hydrographic basins/sub-basins within each region, including Region 7 Western Region (**Figure 3. Designated hydrographic regions in Nevada**). Lemmon Valley includes the Western Part (Nevada Hydrographic Basin 7-092A) referred to as the Silver Lake Sub-basin and the Eastern Part (Nevada Hydrographic Basin 7-092B) referred to as East Lemmon Sub-basin as designated in 1973 by the State Engineer (**Figure 4. Designated hydrologic sub-basins within Lemmon Valley**). The boundary of Lemmon Valley is described by Designation Order 391 issued by the Nevada State Engineer on 14 July 1971. Lemmon Valley is bounded to the north by Fred Mountain and Hungry Mountain, to the east by Hungry Ridge, to the south by Mount Peavine, and to the southwest by the Granite Hills.

Lemmon Valley is subdivided into two sub-basins by the Airport Fault that transects the "middle" of Lemmon Valley, essentially underneath Stead Boulevard and acts as a barrier inhibiting groundwater flow. The Airport Fault essentially divides Lemmon Valey into two hydrologic subareas (Harrill 1973). Depths to bedrock in the western part of Lemmon Valley reach maximum depths of about 2,600 feet below the land surface approximately underlying the Silver Lake Playa with a smaller shallower depression reaching depth of about 1,500 feet below the land surface about 2.5 miles north of the playa (Schaefer and Maurer 1980). They also note that east of the Airport Fault, the maximum depth is about 1,000 feet below the land surface with average depth to bedrock of 400 feet or less.

The western segment encompasses roughly 53 square miles and contains Silver Lake which is surrounded by large commercial/industrial properties to the east and northeast and residential properties to the southeast and east. The Truckee Meadows Water Authority (TMWA) serves the developed Silver Lake areas and the historic and newly developed areas in Stead in basin 92B. Washoe County Department of Water Resources (WDWR) serves customers from the north, the east and south of Swan Lake. TMWA uses the West Lemmon Valley sub-basin for groundwater recharge/storage and a program is underway evaluating the feasibility of storing additional water underground beneath Washoe County property north of the airport.

East Lemmon Sub-basin encompasses roughly 40 square miles. This sub-basin contains Swan Lake, with WDWR servicing customers from the north, east and south of Swan Lake, as well as Horizon Hills. No water injection takes place in the East Lemmon Valley sub-basin. A small test well was located near the Reno-Sparks treatment plant.

Golden Valley lies within the southern portion of East Lemmon Sub-basin and encompasses approximately 4 square miles in which older residential properties are reliant upon domestic wells. Newer developments are supplied by TMWA.

Golden Valley Hydrographic Sub-Basin

Definition/delineation of the Golden Valley drainage basin and model domain has been modified somewhat over time by Harrill (1973); Cochran, Barry, Dale and Sones (1986); Pohll (2017); and Terraphase (2023) (**Figure 5. Study area and model domain boundaries**). Harrill (1973) and Cochran, Barry, Dale and Sones (1986) used the boundaries of Golden Valley as defined by the State of Nevada hydrographic drainage basin. This sub-basin of the Lemmon Valley hydrographic basin is defined by topography and surface water drainage, as well as man-made features. Pohll (2017) uses this drainage basin boundary to delineate the model domain. Consistent with the boundary designated for the Golden Valley Aquifer Recharge Program Service Area, Terraphase (2023) used Highway 395 as the western boundary of the drainage basin and refined the delineation of the watershed boundary.

Physiography and Drainage

Lemmon Valley hydrographic basin and the Golden Valley sub-basin lie within the western portion of the Great Basin within the northern portion of the Basin and Range Physiographic Province (**Figure 6. Basin and Range Physiographic Province)**. North-northwesterly trending fault-block mountains bound structurally low-lying closed hydrographic basins filled with alluvial, fluvial, lacustrine and colluvial sediments. Lemmon Valley is a closed inter-montane hydrographic basin with surface runoff discharging into ephemeral playas.

The Sierra Nevada lie within the path of moisture-bearing air masses originating over the Pacific Ocean and driven by westerly winds and the Jet Stream. The topography of the Sierra Nevada causes orographic uplift, cooling the air mass and resulting precipitation on the western slopes. The cooler air masses then descend the eastern slopes of the Sierra Nevada causing an increase in air temperature, increased evaporation, and creating a rain shadow.

This rain shadow effect combined with diurnal winds is enhanced by high summer temperatures, low humidity, and abundant windy days. Regional frontal systems provide the source of all water in Western Nevada primarily in the winter months; winter precipitation is primarily in the form of snowfall. Rain also occurs in association with frontal systems and monsoons primarily during the summer and fall seasons.

Lemmon Valley encompasses approximately 96 square miles in two topographic segments characterized by internal drainage. Adjacent mountains range from 6,000 to 8,300 feet in elevation. Peak elevation of Mount Peavine is 8,266 feet to the west of southernmost Lemmon Valley. The valley floor has an average elevation of 4,900 feet. The elevation of the alluvium-bedrock surface contact ranges from about 5,100 to 5,400 feet. Average maximum relief is about 2,000 feet. Golden Valley is a perched valley, being 100 to 200 feet higher in elevation than adjoining the basin.

All drainage channels are ephemeral (**Figure 7. 2-degree topographic map for Lemmon and Golden Valleys 1890**). Channels and washes carry precipitation, runoff, and meltwater to the north and east from Mount Peavine into Lemmon Valley. The floor of Golden Valley slopes gently westward toward the eastern margins of the alluvial fans of Mount Peavine. Within the sub-basin, Golden Valley Wash accommodates accumulated runoff and flows generally west-northwestward carrying surface waters through "Lemmon Valley Drive Canyon" (aka, Golden Valley outlet channel) toward Swan Lake playa in Lemmon Valley proper.

Topographic elevation ranges from a high of 5,861 feet on the ridgeline northeast of Golden Valley, with ridges typically reaching elevations between roughly 5,200 feet on the east and south and typically exceeding 5,400 feet on the north (**Figure 8. 15-minute topographic map for Golden Valley 1967**). The valley floor generally ranges in elevation from 5,060 to upwards of 5,200 feet on the east. Average elevation of the valley floor west of Estates Drive is about 5,080 feet. The lowest residential elevations lie on the south side of Cactus View Drive and adjacent to Golden Valley Wash at an elevation of approximately 5,052 feet.

Precipitation and Drought

Climate in Lemmon Valley (inclusive of Golden Valley) is semi-arid, being inland and in the rain shadow of the Sierra Nevada, with annual precipitation typically averaging between 6 and 10 inches per year. In portions of Lemmon Valley with higher elevation, annual precipitation may exceed more than 30 inches per year on the upper elevations of Mount Peavine (Cochran, Dale and Kemp 1984). The local climate is strongly controlled by Peavine Mountain to the west. Storms track generally to the east and northeast, spilling over the peak and swirling around its flanks toward Golden Valley. Strong winds often associated with these storms can exceed 70 miles per hour and increase evapotranspiration.

Annual variability is reflected in the precipitation record at Reno International Airport for the period 1937 through March 2023 **(Figure 9. Precipitation Record for Reno International Airport 1937-Aug 2023** and **Appendix B)**. Average annual precipitation in Reno was 7.31 inches for the period 1937 to 2023. Average annual precipitation was 7.47 inches for the period 1980 to 2023.

This arid to semi-arid climate supports greasewood, rabbitbrush, sagebrush, juniper and pinyon pine vegetation augmented by native grasses and forbs. Cheatgrass is a dominant invasive species. Vegetation cover and the associated leaf litter temporarily captures precipitation which decreases runoff and soil erosion by as much as 50 percent and allows for increased infiltration.

Precipitation tends to be seasonal, with most rain and/or snow falling from November through April, followed by drier summers. Precipitation may accumulate as snowfall and snow melt may be hastened by rains. Short-term intense rainfall/hail may occur during thunderstorms **(Figure 10. Thunderstorms have produced quarter-sized hail).** As a result, most recharge occurs during the autumnal through spring months which comprise the water year from October 1st through May 3rd. By the beginning of May 2023, 12.53 inches of water-equivalent precipitation were recorded in Reno, making 2022/2023 the second wettest water year on record compared to 2016/2017 in which 14.90 inches of water-equivalent precipitation were recorded.

The Washoe County Rain Gauge Network (WCRGN) includes 78 rain gauges that were installed between 1998 and 2009 (McEvoy and McCurdy 2018). The gauges were deployed in under-gauged regions of central and northern Washoe County across 7 hydrographic basins, including 9 gauges within the western and northern portions of Lemmon Valley installed in 1998. The purpose of the WCRGN is to provide data to validate and potentially improve existing groundwater recharge estimates.

No designated recording stations exist within Golden Valley to provide historic annual precipitation data. Isohyets for average annual precipitation indicate a range of 10 inches per year in the western portion of Golden Valley increasing to 12 to 14 inches per year, and more with higher elevation around the northern and eastern margins of the Valley (Barry 1985) (**Figure 11. Isohyets of average inches precipitation per year).**

Stone and Lopez (2006a) evaluated historical climatic and hydrologic data and found high year to year variability in temperature, precipitation, snow water equivalent, hydrograph volume and reservoir storage volumes throughout the greater Reno-Tahoe area. Further, they found relationships between variables remained consistent over time, with no clear evidence of global warming or associated changes in volume or timing of hydrologic variables.

Stone and Lopez (2006b) noted that precipitation data indicate a long-term trend of slowly increasing levels of precipitation in Lemmon Valley and nearby hydrographic basins. Where groundwater pumping exceeded natural groundwater recharge, water levels declined and had negative impacts on wells that were not screened in deeper parts of the aquifer. They noted that in Golden Valley the artificial recharge program lessened the negative impacts of over-pumping.

Commonly used terms to identify drought include meteorological drought, hydrologic drought, and induced drought. Meteorological drought is often defined by a period of well-below-normal precipitation, with duration generally on the order of months or years. Hydrologic drought reflects periods of depleted reservoir/aquifer storage. Induced drought results from over-drafting (production exceeds natural recharge) of the water supply for consumptive use, often aggravated by less than average precipitation that results in below average aquifer recharge.

Based on the annual precipitation record for the Reno International Airport since 1937, meteorological drought, by definition, is noticeably absent. However, annual precipitation ranged from 58% to 89% of average for 8 years during the interval from 1984 through 1994, ranged from 59% to 77% of average for 5 years during the interval from 1999 through 2003, and ranged from 54.7% to 68% of average for four years during the interval from 2011 through 2014. Hydrologic/induced drought in Golden Valley was evidenced by declining groundwater levels that were noted beginning in the early 1980s.

Geologic Framework

The North Valleys (including Lemmon Valley and Golden Valley) are typical of basins within the Basin and Range Province. Generally north-northeast trending, fault-bounded alluvial basins lie between bedrock ranges. Geological mapping of this area was conducted by Bonham and Bingler (1973) and by Cordy (1985). **Figure 12. Geologic Map of Golden Valley and immediate vicinity** depicts the pertinent portions of the Reno NE and Reno Quadrangles; the approximate location of a bedrock fault that transects Golden Valley has been added to the map. Soeller (1978) mapped Lemmon Valley proper in greater detail, focusing on the exposed Quaternary deposits. Geologic units mapped in Golden Valley are identified in the geologic map legend (**Figure 13. Geologic map legend**). Mapping of Golden Valley was later updated by Ramelli, Henry and Walker (2011).

These units can generally be correlated with the available well logs. However, caution must be exercised in interpreting drillers logs that often report the drillers assessment of the materials drilled rather than their true geologic nature. For example, the drillers well log 42159 describes "tan & light brown shail" from 1 foot to 65 feet and "brown shail" from 65 feet to 89 feet (**Figure 14. Comparison of drill log and geologic map**). The geologic map for Golden Valley confirms this well is drilled in an outcrop of the volcanics mapped by Bonham and Bingler (1973) as Hartford Hill Formation (aka Tuffs of Campbell Creek).

Similarly, the drillers log for well 18587 on Golden Valley Road describes thick layers of light brown clay, blue gray clay, purple clay, and blue gray clay to a depth of 215 feet before describing purple rock from 215 to 260 feet. What are described on various drillers logs as "soft zones" are likely fracture zones within the bedrock. The meaning of "consolidated fractured granite" is uncertain. Well log 19523 describes "sandstone" from a depth of 30 to 170 feet. Geological interpretation of the drillers logs is necessary to delineate basin stratigraphy and depth to bedrock, although deciphering drillers logs is, in some instances, rather challenging.

Bedrock Geology and Faults

The predominant bedrock in Golden Valley is Cretaceous intrusive granodiorites that outcrop along the northern, eastern, and southwestern margins of the valley. The rock is typically light to medium gray in color reflecting its composition as a biotite-hornblende granodiorite. Margins of these intrusive bodies may be greenish in color due to deuteric alteration which resulted in the alteration of micaceous minerals to chlorite. This deuterically altered granite is described in drillers well logs as "green granite" and is typically distinguished from the underlying "hard rock." These coarse-grained rock masses are highly fractured with no uniform fracture pattern; however, in outcrops, both weaker near-vertical joints and stronger exfoliation planes can be observed (**Figure 15. Outcrop of granodiorite in northern Golden Valley)**.

These intrusive granodiorites are associated with the Sierra Nevada uplift. Outcrops are rugged, resistant to erosion, and display joints and fractures that are close to widely spaced and of varying density. Many of these fractures may be attributed to exfoliation and unloading. The granodiorites have been intruded by aplite dikes that may be similar in mineral composition, but are fine to very-fine grained and are much more resistant (i.e., harder) than granodiorite.

The quartz monzonite in the eastern portion of the Valley is the youngest intrusive rock type, bounded on the east by a north-south trending fault. This distinctive rock is highly weathered and more friable than the granodiorites and is exposed as a grussy colluvium that has been mined for decomposed granite (dg) for construction and landscaping. Originally known as the Echeverria Pit, the Golden Valley Aggregate Pit located in Section 17 of Township 19 North, Range 21 East has been operated by A&K Earth Movers under Special Use Permit No. SW01-015 issued on 3 April 2002 (Washoe County, 2016). Material is not currently being mined from the pit and reclamation of a portion of the pit is ongoing (**Figure 16. Golden Valley Aggregate Pit**). A&K Earth Movers submitted a mineral material exploration application on 14 July 2022. The US Bureau of Land Management issued authorization on 30 May 2023 for mineral material exploration assigned serial number NVN-101419 to provide one year for conduct by A&K Earth Movers to sample and test mineral materials in T20N, R19E, Section 12 as a basis for application to potentially extend the pit boundary. Cochran, Barry, Dale and Sones (1986) suggest that clays associated with this weathered quartz monzonite may inhibit infiltration and movement of groundwater. Local drillers often refer to this weathered quartz monzonite as "sponge rock."

Unconformably overlying the granodiorites in the southeastern corner of the Golden Valley are buff colored quartz latite to rhyolitic ash flow tuffs and mudflow breccias of the Tertiary (Oligocene) Hartford Hill formation which was later renamed as the Tuff of Campbell Creek (Ramelli, Henry and Walker 2011). In outcrop exposures these volcanics exhibit a range of colors varying from cream to brown to dark purple or red, with a slaky appearance on cut slopes that have longer-term exposure to weathering (**Figure 17. Outcrop of Hartford Hill/Tuff of Cambell Creek volcanics)**. These tuffs mark the beginnings of the Basin and Range structural character about 23 million years ago (Henry, Hinz, Faulds, Cogan, et al 2012). The Tuffs of Campbell Creek erupted from a caldera in north-central Nevada and spread as welded ash flows through generally westward trending paleo-valleys across northern Nevada and the Sierra Nevada. Secondary hydrothermal alteration and limited disseminated mineralization has occurred over time (Hudson 1977).

In drillers well logs, these volcanics are typically described as rock or clays of varying colors: gray, brown, blue, yellow, red, or purple. In well 50044, yellow volcanic rock to a depth of 111 feet overlies clay layers varying from brown to gray and extending to a depth of 242 feet overlying granitic material. In well 11735, "red rhyolite" is identified at a depth of 112 to 150 feet. In well 18587, light brown to blue gray and purple clay overlies "purple fractured rock" to a depth of 260 feet. In well 73431, gray and purple clay are described from a depth of 61 feet to a depth of 188 feet. In Well 16808, these tuffs are described as "sticky clay" of brown to white color within a depth interval of 42 to 170 feet. In well 24998, red volcanic rock overlies purple rock to a depth of 90 feet.

Locally, these volcanics are tightly fractured and the hydrothermally altered rhyolitic mineralogy leads to minimal percolation rates and expansive character (Bell, Louisell and Vestbie 1986). Cochran, Barry, Dale and Sones (1986) noted the mineralogy of these rhyolites and altered volcanics would inhibit infiltration and the movement of groundwater. Consequently, the distribution of these tuffs correlates with the locations of engineered septic systems (i.e., typically mound systems) in the Sun Cloud Circle-Golden Valley Road portion of Golden Valley (**Figure 18. Engineered septic systems in volcanic terrain**). This mineralogy also results in slaky weathering where the volcanic bedrock is exposed in road cuts.

In contrast, the volcanics of Peavine, mapped as andesite by Ramelli, Henry and Walker (2011) show significant fracturing (**Figure 19. Outcrop of Peavine volcanics**). The andesite is light brown to pale reddish brown on weathered surfaces where iron staining has occurred. It is very hard, very slightly weathered with closely-spaced fractures that allow movement of groundwater. These volcanics may be equivalent to the Alta or Kate Peak formations of hornblende/pyroxene andesites, flow breccias and pyroclastic rocks.

Numerous faults have been mapped along the boundaries of the basin (Bonham and Bingler 1973, Cordy 1987). Bell and Pease (1980) showed that soil profile development could be used to determine general age of Quaternary deposits and the recency of fault movement. Some faults are buried beneath the valley sediments. Well logs indicate that a fault extends from the southern margin of Golden Valley northwestward beyond Golden Valley Road and then transects beneath Estates Drive (Harrill 1973, Cochran Dale and Kemp 1984, Pohll 2019, Terraphase 2023). This fault is herein named the Estates Fault which has created a bedrock ridge with sediment thickness increasing with distance on either side of the buried ridge. Estates Fault is a high-angle dip-slip fault down-dropped to the east.

Quaternary Geology

During each of the sequential Pleistocene Ice Ages, much of the Great Basin was dominated by a series of pluvial lakes (Reheis 1999) with lake levels as much as 270 feet higher than those of the well-documented Late Pleistocene pluvial lakes (e.g., Lake Bonneville and Lake Lahontan). Evidence of the history of the pluvial lakes is derived from outcrops, geomorphology, soil stratigraphy, core samples, pollen, and isotopic studies (Hanford 2022a, Appendix C). Direct evidence of lake levels, changes in lake margins, and geologic events such as catastrophic floods, drainage-basin changes (due, for example, to stream capture), and isostatic rebound are combined with proxies for changes in lake level, water temperature and chemistry, and ecological conditions. Many pre-Late Pleistocene lakes in the western Great Basin were significantly larger and record wetter conditions compared to younger pluvial lakes (Reheis, Adams, Oviatt and Bacon 2014).

Basins occupied by the pluvial lakes were formed by strike-slip and extensional faulting caused by tectonic interactions between the North American and Pacific Plates (Stewart 1978, Kreemer and Hammond 2007). The existence and fluctuations of these pluvial lakes were driven by a combination of increased precipitation rates due to changes in atmospheric dynamics and decreased evaporation rates resulting from temperature depression and summer insolation changes.

In Western Nevada, the most recent Pleistocene pluvial lake was Lake Lahontan (Russell 1885) which occupied at least three major subbasins roughly between 45,000- and 16,500-years BP: Smoke Creek-Black Rock Desert subbasin, Pyramid Lake subbasin, and Winnemucca Dry Lake subbasin (**Figure 20. Pluvial Lake Lahontan as delineated by Russell 1885**). Detailed soil and stratigraphic relationships within Lake Lahontan sediments were identified by Morrison (1964), with age dating and correlation based on tephrochronology and stratigraphic evidence (Davis 1978), and the high stand marked by surficial characteristics and soil development that facilitate regional shoreline correlation (Adams and Wesnousky 1999).

Lake levels fluctuated with high stands recorded in beach morphology in the respective basins. The lake reached it last brief highstand about 15,700 years ago and had a consistent shoreline at 4,121-foot elevation. Lake level rose rapidly from about 15,000 to 13,500 years BP so that Lake Lahontan became a single body of water that persisted until about 12,500 years BP. At its largest, Lake Lahontan covered more than 8,500 square miles, with maximum depth of about 886 feet at present-day Pyramid Lake. High stands were probably a combination of increased effective moisture and changes in the areal extent of Lake Lahontan drainage basin (Reheis 1999).

By about 13,250 years ago, lake level had fallen to 3,957-foot elevation and, as the lake receded, its waters were limited primarily to the Pyramid and Winnemucca Subbasins. Modern remnants include Walker Lake, Pyramid Lake, Honey Lake, and the Carson and Humboldt Sinks. Winnemucca Lake has been a dry lake bed since the 1930s, and Honey Lake periodically dries out. The decline of Pyramid Lake and Winnemucca Lake was exacerbated by diversions of irrigation water from the Truckee River starting in the early 1900s (Hanford 2022a, b).

Coincident with climatic change in the Late Pleistocene, lake levels continued to decline resulting in the formation of numerous smaller lakes within many subbasins. During the Holocene (the last 10,000 years), these smaller lakes have been subject to one or more major periods of desiccation during various recognized climatic optima (**Figure 21. Average Holocene near-surface temperatures in Northern Hemisphere**). Past changes in the hydrologic balance were large in magnitude and took place in a rapid step-like manner. Smaller isolated and semi-isolated lakes may have developed in response to these same conditions during the Pleistocene and Holocene, including Lake Lemmon.

Pluvial Lake Lemmon

Late Pleistocene Lake Lemmon was first named by Hubbs and Miller (1948) and described in greater detail by Soeller (1978). Lake Lemmon encompassed roughly 13 square miles within central Lemmon Valley (Mifflin and Wheat 1979). Lake Lemmon has been added to Russell's 1885 map of Lake Lahontan to show its relative location. Lacustrine deposits were subsequently mapped within Lemmon Valley (Cordy 1987) indicating the lake reached an elevation of 4,984 feet which is below the sill elevation of 5,055 feet at the lowest outlet of the basin. A highstand of Lake Lemmon is recorded by prominent a beach bar set in east Lemmon Valley with shorelines at 4,970 feet in elevation. Cordy (1985) reported a Carbon-14 age of 10,440 BP from a mammoth bone in this deposit. Shoreline deposits (including beach, fore-beach and lacustrine deposits) are also present in the eastern portion of Lemmon Valley (Cordy 1987). Any Lake Lemmon waters that exceeded the sill level would have overflowed via Hungry Valley to Lake Lahontan.

Recessional highstands of Lake Lemmon are evidenced by roughly concentric shorelines visible in aerial photography from 1946 (**Figure 22. Aerial photograph of Lake Lemmon and vicinity 1946**). Much of the geomorphic evidence of these shorelines has been masked by more recent development (**Figure 23. Aerial photography of Lake Lemmon and vicinity 2020-newer)**.

Paleo-seismic trenching and shoreline mapping by Dee, Ramelli and Koehler (2018) indicate Lake Lemmon likely overtopped the 5055-foot sill elevation. Lidar allowed for identification of additional shoreline remnants of the Lake Lemmon highstand. Spillover at the sill would have resulted in limited late Pleistocene hydrologic drainage via Hungry Valley to the northeast to Lake Lahontan. The age of Lake Lemmon highstand is unknown but it is reasonable that the lake may have reached maximum elevation synchronous with the late-Pleistocene Seehoo high stand of Lake Lahontan at 13,000 C-14 BP (~15,300 cal BP) (Adams and Wesnousky 1999; Adams, Goebbel, Graf, Smith, et al 2008). Lacustrine sediments were also identified beneath alluvial fan deposits, with a shoreline eroded into that fan surface. This relationship suggests the fan is older than the most recent lake highstand and the underlying lacustrine sediments may be part of an earlier Pleistocene pluvial lake.

Over the ensuing 10,000 years, Lake Lemmon continued to decline, with Silver Lake and Swan Lake remaining as ephemeral playa remnants occupying the lowest elevations within the eastern portion of Lemmon Valley. These playas likely were desiccated during the various Holocene climate optima. These playas receive annual surface runoff, including runoff from Mount Peavine into Silver Lake and runoff from Golden Valley into Swan Lake. The playas retain runoff waters following years of above-average precipitation. When dry, the surfaces of these playas are a source area for wind-blown dust and sand. When the next ice age occurs, these playa surfaces will once again become flooded as a new pluvial lake.

Basin Stratigraphy

Widmer (2000) used gravity and magnetic data to estimate thickness of basin-fill sediments, estimating a maximum thickness of 2,200 feet in West Lemmon Valley and 1,000 feet in East Lemmon Valley roughly centered beneath Swan Lake. Playa lake deposits and older pluvial lake deposits are mostly clay and silt with fine-grained sand. Playa sediments are interstratified with fine-grained to coarser-grained alluvial and colluvial sediments derived from the surrounding foothills and mountains.

Within Golden Valley, depth to bedrock can be assessed by interpreting available well logs. In general, bedrock appears to dip to the east from the subsurface bedrock ridge associated with Estates Fault, reaching maximum depth beneath the area between Spearhead Drive and Wigwam Way **(Figure 24. Isopach map of valley fill in Golden Valley (i.e., depth to bedrock)**. Westward from the bedrock ridge, sediment thickness increases from about 10 feet to roughly 100 feet. Coarse-grained sediments derived from local granitic bedrock become inter-stratified with distal margin alluvial fan deposits from Peavine Mountain. The Peavine fan deposits are semi-lithified, poorly bedded and poorly sorted, silty-sandy pebble to cobble gravel with a fine-grained matrix. This stratigraphy is reflected in the drillers well logs from Steadfield Estates and further west.

Valley fill across most of Golden Valley east and north of Estates Fault is comprised of weathered material from the surrounding volcanic and granitic ridges with interstratified layers of clay, silt, fine-grained to coarse-grained sand, and some gravel. Generally, valley fill is coarser near the mountain ridges and becomes finer-grained toward the center of the valley. Observations of sediments exposed in drainage ditches and road cuts, as well as in Golden Valley Wash indicate that the silt and clay fraction in typically less than about 10 percent. In eastern Golden Valley, the valley fill sediments include layers and lenses of clay-rich sediments that may have been deposited in isolated small pluvial lakes within the valley that were contemporaneous with, but geographically isolated from Lake Lemmon and older pluvial lakes (see logs for wells on Indian Lane, Warpaint Circle, and Wigwam Way). Clay-rich lenses and layers are characterized by low permeability and tend to restrict movement of groundwater. Hard pans (typically caliche) which also inhibit infiltration and movement of groundwater are noted in several wells (e.g., log 28771, log 13582, and log 13562).

Pohll (2017) developed a generalized geologic cross section of Golden Valley **(Figure 25. Generalized east-west geologic cross-section of Golden Valley**). This cross-section is in good overall agreement with the lithologic materials cited in the referenced drillers well logs. Description of the sedimentary units has been modified on this geologic cross section to note the occurrence of clay lenses and layers within the sedimentary sequence, particularly in the area east of Estates Fault.

Terraphase (2023) utilized approximately 100 well logs for domestic, monitoring, and municipal wells to develop five well log profiles that depict depth to bedrock with generalized lithologies encountered in each well (**Figure**

26. Terraphase profile locations) but do not infer stratigraphic correlations within the valley fill. Locations of identified wells are indicated on these five profiles and are generally shown relative to the respective topographic profiles (**Figure 27. Terraphase profile A-A', Figure 28. Terraphase profile B-B', Figure 29. Terraphase profile C-C', Figure 30. Terraphase profile D-D', and Figure 31. Terraphase profile E-E'**).

The well logs were used to identify basin fill thickness and depth to bedrock. Lithology from the well logs was simplified and designated as sand/gravel, clay, decomposed granite, granite, decomposed andesite, andesite, or rhyolite. Locations of known and inferred faults are indicated but without structural orientation. The aquifer system was conceptualized by Terraphase as two hydro-stratigraphic units: 1) basin fill and 2) bedrock. These units were characterized by differences in geologic character, hydraulic parameters, and water yield.

In general, valley fill sediments within the eastern portion of Golden Valley (i.e., east of Estates Fault) are not saturated. However, precipitation does infiltrate the sedimentary sequence and fractured bedrock and moves downward to the deeper fracture flow system. Therefore, most wells drilled in Golden Valley obtain water within intervals that are screened across fracture zones within the granitic bedrock.

Other unrecognized buried faults likely exist as suggested by well log data. For example, in well 13738, 77 feet of sediments overly a 27-foot thickness of hard volcanic rocks unconformably overlying granitic materials, suggesting an unrecognized fault between this well and the exposed volcanics in the vicinity of Sun Cloud Circle.

Seismicity and Faulting

Southern Washoe County forms a significant structural link between some of the most active faults in the Western Basin and Range: the north-south trending normal (dip-slip) Carson Range fault system to the south and the northwest-trending strike-slip faults of the northern Walker Lane (e.g., Honey Lake, Warm Springs Valley, and Pyramid Lake fault zones). The main uplift of the Sierra Nevada-Walker Lane Region began about 17 million years ago with slow uplift of the central Sierra Nevada. Many older faults of the Foothills fault system were re-activated and continue to be active with slow slip rates. The area between the Sierra Nevada and the Walker Lane is a complex zone of irregular patterns of horst and graben blocks and conjugate normal and right- and left-slip faults of NW and NE trend, respectively. (Slemmons, Van Wormer, Bell and Silberman 1979).

As documented by the seismic history **(Figure 32. Seismicity of the Western US since 1850),** this area retains a high risk for seismic shaking as measured by the Modified Mercalli Intensity Scale and Richter Magnitude (**Table 1. Modified Mercalli Intensity Scale & Richter Magnitude**). Twenty-three earthquakes of magnitude 6 or greater have been documented in Nevada since the 1840s. Ground surface rupture has occurred in association with several historic earthquakes in western Nevada **(Table 2. Notable Historic Earthquakes Impacting Western Nevada)**.

The largest earthquake in Nevada history occurred on 2 October 1915 in Pleasant Valley, approximately 50 miles south of Winnemucca. Over the course of about 7 hours, three strong earthquakes shook this area. The strongest third shock with M7.3 shook most of northern Nevada with damaging ground motion **(Figure 33. Modified Mercalli Intensity map for 1915 Pleasant Valley Earthquake).** The frequency of such notable earthquakes can be interpreted as the recurrence interval, or return time, defined as the average time between past events. Long-term predictions are largely based on identification of fault characteristics such as segmentation, recurrence interval, and the time of the last earthquake interpreted from soil profile, tephrochronology, carbon-14 dating, or other methodology. Active faults in the Basin and Range commonly have calculated earthquake recurrence intervals within the range of 1,000 to 10,000 years.

But geological conditions are not constrained by the human propensity to impose statistically calculated averages. The intervals between events have been measured in years, months, or minutes; for example, the 1954 M7.1 Fairview Peak earthquake was followed 4 minutes and 20 seconds later by the M6.9 Dixie Valley earthquake. These earthquakes partially define the Central Nevada Seismic Belt (CNSB) which is characterized by surface faulting that extends nearly 190 miles with multiple surface rupturing Holocene seismic events (Bell Caskey Ramelli and Guerrieri 2004).

The Olinghouse fault (Sanders and Slemmons 1979) is a northeast trending left-lateral strike-slip fault located in the Truckee River Canyon between Reno and Fernley. Paleoseismic trending and fault trace analysis indicate this fault has been a source of multiple latest Pleistocene and Holocene surface-rupturing earthquakes (Briggs and Wesnousky 2004). The Olinghouse fault is among the most active faults including north-trending normal frontal faults of the Carson Range (Ramelli, Bell, DePolo and Yount 1999) and the conjugate northwest-trending right-lateral strike-slip faults of the Pyramid Lake fault zone (Hanford and Slemmons 1979) that accommodate shear across the northern Walker Lane (**Figure 34. Quaternary fault map of Western Nevada).** The Olinghouse fault has accumulated 2.5 to 3 km of left-lateral offset at an overage rate of 0.3 to 0.6 mm/yr (Sturmer and Faulds 2018).

Paleoseismic analysis of these fault zones indicates two to three major surface-rupturing earthquakes in the last 4,500 years (Briggs and Wesnousky 2005). Comparison of paleoseismic records for these fault zones suggests that triggered slip may have occurred, particularly near fault zone junctures. A prominent bedrock scarp of approximately 8 km minimal length, with maximum normal offset of about 3 feet suggests an earthquake of M6.7 in the mid-Holocene; several older scarp segments have cumulative offsets of 2.5 to 4.8 meters (Sanders and Slemmons 1996). Earthquakes that occurred in western Nevada in 1860 (M 6.3–7.0) have been linked to the Olinghouse fault based on eyewitness account of surface cracks that formed sometime in the 1860s (Slemmons 1977). Historical accounts and geomorphic evidence of young left-slip offsets of up to 3.6 meters reflect an earthquake of M7.1 at the east end of the Olinghouse fault zone (Sanders and Slemmons 1996). Isoseismal maps place this 1860 event near Pyramid Lake (Toppozada, Real and Parke 1981).

Naming of the Pyramid Lake fault zone is attributed to Bell and Slemmons (1979) by Haller and Adams (2016). This northwest trending fault zone is manifested by springs, vegetation and tonal lineaments, tufa deposits, scarps, linear bedrock and alluvial ridges, and sag ponds paralleling the lower Truckee River south of and adjacent to Pyramid Lake. Offsets of post-Lake Lahontan alluvium range from 26 to 69 feet right-lateral displacement, with a smaller vertical component. Historic seismic activity along the Pyramid Lake fault zone includes microseismic events and may include the earthquake of about 1851 reported for the Pyramid Lake area with an estimated Richter magnitude of 7.0 on the fault zone that is inferred capable of generating a 7.0 to 7.5 magnitude event (Bell and Slemmons 1979). Newspaper accounts in the Virginia City Territorial Enterprise following an 1865 earthquake referenced an earlier earthquake that was marked by ground cracks, water spouts up to 100 feet high, ground shaking and large landslides.

At least four major earthquakes have occurred on the Pyramid Lake fault zone over the last 15,000 years since the desiccation of Lake Lahontan, with a minimum of two earthquakes since the deposition of Mount Mazama tephra (Briggs and Wesnousky 2004) and the most recent earthquake occurring in the last 1700 years. Paleoseismic investigation indicates four and possibly five Holocene faulting events in this fault zone (Anderson and Hawkins 1984) displacing Mount Mazama tephra, with the most recent surface rupture occurring within the last few hundred years. Alluvial, eolian and lacustrine deposits are displaced by this fault zone.

The principal named Quaternary faults in Lemmon Valley include Peavine Peak fault, Petersen Mountain fault (north of Cold Springs Valley), Freds Mountain fault (north of Swan Lake), and Lemmon Valley-Golden Valley fault zone, and Spanish Springs Valley fault (Dee, Ramelli and Koehler 2008), with discontinuous fault traces in both Cold Springs and Lemmon Valleys including the Airport Fault (**Figure 35. Geologic map & faults in Lemmon Valley**). These faults are identified as seismic sources (Peterson, Mosschetti, Powers, Mueller, et al 2014; Koehler 2018). This area is an important tectonic link between fault zones within the Walker Lane (Honey Lake, Warms Springs Valley, and Pyramid Lake fault zones) and the Carson Range fault system that fronts the Sierra Nevada (Dee, Ramelli and Koehler 2008) with evidence of four or five surface-rupturing events over the past 7,000 years. These Quaternary faults may facilitate or inhibit movement of groundwater.

Older faults are recognized in Golden Valley with displacements apparent in bedrock outcrops and in subsurface bedrock structure. Principal among these is the Estates Fault that transects Golden Valley from the southern margin south of the North Valleys High School and trending generally northwestward beneath Estates Road. Estates Fault forms the eastern boundary of an associated granitic bedrock ridge. Older faults may also facilitate or inhibit movement of groundwater.

Golden Valley has been subjected to seismic shaking, although the observable impacts have generally not been significant based on the Modified Mercalli Intensity Scale. Bell, Broadbent and Szumigala (1977) used

Modified Mercalli Intensity mapping and travel-time comparison to locate the potential epicenter for the 1948 Verdi earthquake that was accompanied by “mysterious rumbles” heard in Verdi and Reno.

Local soils and bedrock, including basin geometry, will influence the duration of seismic shaking and peak ground acceleration. Seismic energy may either be attenuated or amplified. But it is likely that Golden Valley will experience seismic shaking comparable to that experienced during several historic earthquakes **(Figure 36. Modified Mercalli Intensity maps for selected historic earthquakes)**. Within Golden Valley, local site conditions are not generally amenable to the development of liquefaction (shear strength failure). Slope instability could occur. Depending on the intensity of seismic shaking, infrastructure could be impacted. Historically, the 1915 Pleasant Valley earthquake impacted groundwater resources across much of northern Nevada. It is not possible to predict exact site response or damages that might occur in Golden Valley from a future moderate or major earthquake. The intensity of seismic shaking will be dependent on earthquake magnitude, distance to and directional orientation to the causative fault, and the energy transmissive nature of the intervening geologic materials.

CULTURAL FRAMEWORK

There is no question that Native Americans have a long-established presence in the Western Great Basin. Significant archeological evidence of the Western Pluvial Lakes Tradition has been identified at numerous sites and localities in Western Nevada, including Washoe Lake, the Carson Sink, the Coleman Site, and the Dansie Site. These attest to the presence of Native Americans in the vicinity of Lemmon Valley beginning at least 10,000 years ago (Hester 1973) based on lithic assemblages associated with pluvial lake shorelines. Paleoindians often concentrated their activities adjacent to pluvial lakes and wetland resources as Late Pleistocene and Holocene lake-level fluctuations occurred (Adams, Goebbel, Graf, Smith, et al 2008); sites were abandoned during intervals in which lakes were completely desiccated.

The Paiutes are part of the Numic speaking peoples of the Uto-Aztecan language family. The Northern Numic peoples either displaced or absorbed the pre-existing Fremont culture and became the dominant group by around 1,000 A.D when they began moving into the Great Basin. They lived a semi-nomadic lifestyle with frequent moves according to the seasons, plant harvests, and animal migration patterns.

Prior to the mid-1800s, Paiutes encountered Euro-American traders, travelers, and trappers, but did not have to cope with white settlement on their lands. McBride (2002) characterizes three phases of interaction. The first phase was with “Fur Trappers and Caravanners” who explored the area for natural resources from 1826 to 1833. The second phase of “Sponsored Explorations” from 1834 to 1853 included the arrival of explorers seeking to claim the area for the government, the railroad, and the Mormon Church. The final phase of “Emigration” between 1844 and 1859 saw Euro-American settlers-colonizers emigrate across the state to reach the gold fields of California.

In the 1850s, members of the Mormon Church began colonization efforts. Mormon Station (later named Genoa) is the oldest permanent settlement in Western Nevada that was founded in 1851 as a trading post and provisioning station for wagon trains along the Emigrant Trail. The discovery of silver in the Comstock Lode in 1859 resulted in reverse migration from California to Western Nevada, along with enticing fortune seekers from the East. In general, Euro-American settlers enjoyed amicable relations with Native Americans in Nevada except for small conflicts with larger volumes of travelers on the emigrant trails in northern Nevada (McBride 2002). The Pyramid Lake Paiute and the Walker River Paiute Reservations were established in 1859. Battles at Pyramid Lake in 1860 between Paiutes and Euro-Americans likely resulted from hordes of permanent settlers rushing to the Comstock, disrupting Paiute, Washoe, and Shoshone traditional culture and economics.

In 1861, Fielding Lemmon established Peavine Ranch in his namesake Lemmon Valley. The ranch was located near several springs and served as an overnight stage stop for travelers and teamsters in transit through the Nevada Territory between the Truckee River and ranches near Honey Lake. Peavine Ranch encompassed more than 5,280 acres that extended from the slopes of Mount Peavine all the way to the “Old Pyramid Road.”

The Nevada California and Oregon (NCO) Railroad was a narrow-gauge track that was constructed in 1881 through Lemmon Valley, crossed the current location of Stead Airport, and exited through Cold Spring Valley to the north. Passenger service began in 1882 and continued until the financially strained Company sold the southernmost 64 miles of track from Reno to Herlong, California, to the Western Pacific Railroad. In 1918, Western Pacific moved the railroad grade westward to the slopes of Peavine Mountain. Despite more recent development, remnants of the old NCO railroad grade persist in limited areas.

In the early 1920s, the Nevada Highway Department built a gravel road from Reno to the Nevada-California state line. This road was paved and became 2-lane Highway 95 in 1933. The southern portion of the highway was not widened to become a 4-lane highway until 1976.

In 1941, an Air Transport Command ferry and training base was built in Lemmon Valley to support the military in transit to the Pacific Theater during World War II. The base was used for survival training by the Strategic Air Command, as a helicopter pilot school by the US Air Force, and by the Nevada Air Guard before being deactivated in June of 1966. The base became known as Stead Air Base in honor of Croston Stead, a pilot who died when his P-51 fighter crashed during a mock dog fight on 11 December 1949. Since 1968, when the land was incorporated into the City of Reno, the facility has functioned as an uncontrolled non-commercial municipal airport.

In the 1940s and 1950s, development focused on the Stead Air Force Base and surrounding military residents. Residential development relying upon domestic wells was focused in the northeast portion of Lemmon Valley in the 1960s through the 1970s. Utility-supplied developments focused on Silver Lake, Horizon Hills, and east Lemmon Valley.

In 1964, Bill Stead (brother of Croston) organized the first Reno Air Races at Sky Ranch airfield in Spanish Springs Valley before moving the races to Stead in 1966. The 2023 Reno National Air Races will be remembered as the last held in Reno (and probably the State of Nevada) due primarily to safety concerns resulting from significant development in Lemmon Valley.

Beginning in 1944, water was imported by pipeline from the Truckee River to serve the Stead Air Force Base. In the 1960s, importation of Truckee River water was expanded to serve Raleigh Heights on the flanks of Mount Peavine. TMWA is the major water purveyor of water derived from groundwater within Lemmon Valley, surface water imported from the Truckee River, and more recently, groundwater imported from Honey Lake Valley.

Lemmon Valley Development 1970s to Present

Prior to 1960, development and the associated number of domestic wells drilled in Lemmon Valley Sub-basins 7-092A and 7-092B were limited (**Figure 37. Domestic wells in Lemmon Valley Sub-basins**). A total of 32 municipal wells were drilled in Lemmon Valley (**Figure 38. Municipal wells in Lemmon Valley**), including those wells later drilled for the Golden Valley Artificial Recharge Program. Most of these wells (17) are owned by small private water companies. TMWA owns 8 production wells and 3 injection wells in West Lemmon Valley.

Washoe County population was 122,142 in 1970. Lemmon Valley experienced rapid development beginning in the mid-1970s, with a coincident increase in demand for water reflected by the increase in net annual groundwater production from roughly 1,000 acre-feet per year to roughly 2,000 acre-feet per year by the mid-1980s (**Figure 39. Net annual groundwater pumping in Lemmon Valley).** With commitment of existing groundwater resources in Lemmon Valley, little to no development occurred in the basin until additional Truckee River water rights were dedicated to Lemmon Valley. This level of total annual net production was sustained until the early 2000s when the importation of water began.

Since the 1970s, the number of domestic wells has increased as residential development increased. Areas with higher densities of domestic wells include Silver Knolls west of Stead Airport, Heppner subdivision located north and east of Swan Lake Playa, and Golden Valley. Domestic well owners also utilize septic systems.

The municipal wells in Lemmon Valley include several wells in the southern portion of the valley that were drilled on the west side of US Highway 395 on the flank of Mount Peavine and one well drilled in the outlet channel from Golden Valley to Lemmon Valley. For roughly four decades these wells provided water for residential and commercial developments. These wells extracted water primarily from the bedrock fracture zones, some in the andesitic volcanics of Mount Peavine and others in the granitic bedrock. In 2002 pumping of the Peavine flank wells was significantly offset (i.e., reduced) as water was imported to service Lemmon Valley residents (Pohll 2019). Production from the outlet channel municipal well was suspended in 2005 due to increased use of imported water in Lemmon Valley (Terraphase 2023).

Groundwater production in Lemmon Valley has declined overall since 2002 with importation of water from the Truckee River to meet a continuing demand due to further residential and commercial property development. With the dedication of the Vidler Importation Project in 2007, an additional 8,000 acre-feet of water can be delivered from the Honey Lake area for future development projects in the basin. Although the Vidler Project was dedicated in 2007, TMWA did not pump any water from those wells until 2019 (G. Pohll, personal communication, September 2023).

Washoe County population grew from 122,142 in 1970 to 195,372 in 1980 to 256,643 in 1990 and 341,389 by 2000. Further population growth has occurred in the County from 373,233 in 2003 to 501,653 in 2022. As the total population increased, the average annual population growth rate has decreased from 4.69% in the 1970s to 2.87% in the 1980s, to 2.98% in the 1990s, to 2.30% in the 2000s, to 1.43% in the 2010s, to 1.23% from 2020 through 2021 (Nevada Real Economic Analysis Project 2022). Lemmon Valley has played a substantial role in that growth and is once again experiencing significant residential and commercial development. Residential and commercial development within Lemmon Valley has replaced native vegetative cover with more impermeable surfaces, thus increasing runoff and limiting net infiltration into the soil/bedrock.

Golden Valley Development 1970s to Present

Prior to 1950, settlement in Golden Valley was limited (**Figure 40. Topographic map of Golden Valley 1950).** Only 42 domestic wells had been drilled in Golden Valley prior to 1970. Steadfield Estates became the first platted subdivision in 1962. During the 1970s and 1980s, several additional subdivisions were platted in Golden Valley and the adjacent acreages were developed as single-family home sites **(Figure 41. Platted subdivisions and home sites**). Domestic wells were drilled to support residential development generally on 1-acre parcels across most of Golden Valley **(Figure 42. Residential well and septic system installations by decade**). Records of the Nevada State Engineer indicate 362 wells were drilled in the 1970s, with most of those wells drilled between 1975 and 1980. From 1980 to 1990, an additional 104 domestic wells were drilled. Only 33 wells were drilled in the 1990s and an additional 15 wells were drilled between 2000 and 2015. In February 2001, application was made to the Public Utilities Commission of Nevada to expand water service to include Lots 1 and 4 of Steadfield Estates Subdivision No. 1 for annexation to the approved water service to the new North Valleys High School main along Golden Valley Road for domestic water service; approval was not confirmed.

In the 1970s and 1980s, Golden Valley was considered prime horse property. Corrals on individual lots were constructed to house one or more horses. Each horse can consume, on average, between 5 and 25 gallons of water per day depending on temperature. During cooler weather, water consumption is typically between 5 and 10 gallons per day. In the hotter summer months, each horse can consume 20 to 25 gallons per day or more. With the generational change in property ownership over the past two to three decades, the majority of corrals no longer house horses but rather serve as parking lots for recreational vehicles (e.g., trailers, campers, boats), contributing to a small decrease in domestic water use particularly during summer months.

Medium Density Suburban (MDS) developments and the North Valleys High School (**Figure 43. Medium Density Suburban (MDS) developments)** were approved beginning about 2000 for construction in the southern and western portions of Golden Valley **(Figure 44. Distribution of Medium Density Subdivision (MDS) developments**). Medium Density Suburban developments encompass 0.25 to 0.33 acre lots allowing for 4 or 3 dwelling units per acre in accord with Washoe County Chapter 18.02 Zoning Districts and Development Code Articles 402, 404 and 406. These MDS developments were connected to the sanitary sewer system with water supplied by TMWA. Construction and building of MDS developments have replaced native vegetative cover with more impermeable surfaces. With appropriate permits and approvals, natural grade was altered by placement of engineered fill to rise above the pre-existing floodplain level in Wild Stallion Estates in the western portion of Golden Valley.

The North Valleys High School is connected to the sanitary sewer system and water is supplied by TMWA. On a portion of the North Valley High School property, native vegetative cover was replaced with more impermeable surfaces including buildings and pavement areas. Turf grass of the athletic fields has replaced native vegetation and likely results in increased groundwater recharge when those fields are irrigated. North Valleys High School also includes a detention pond on the northwest corner of the property.

The most recently approved development is Golden Mesa. This development is to be constructed in two phases on approximately 1-acre parcels in keeping with the character of the surrounding properties. Zimmerman (2019) conceived of developing this property as Golden Valley Estates with 200 medium density housing units in what is now Golden Mesa South and future expansion into the proposed Golden Mesa North with an additional 100 plus medium density housing units along with open space. Among other limitations, the Zimmerman conceptual design did not provide for the existence of a FEMA designated flood zone across the southern property. The Zimmerman conceptual design was an academic exercise that was not submitted for, nor given, permits and approvals.

Golden Mesa South is currently under construction following the scarification of native vegetative cover across the roughly 50 acres encompassed by this development. These homes will be connected to the sanitary sewer system with domestic water supplied by TMWA. A detention channel is under construction across Golden Mesa South coincident with the FEMA designated flood zone. With appropriate permits and approvals, natural grade was altered by placement of engineered fill to rise above the pre-existing floodplain level in Golden Mesa South. Construction of Golden Mesa North (north of Indian Lane) is pending permit approvals.

Golden Mesa is likely the last major residential development that will be approved for Golden Valley and, if completed, will encompass roughly 50 single-family residential properties between Indian Lane and Golden Valley Road with 30 homesites in Golden Mesa South and 20 homesites in Golden Mesa North Phase I, with additional single-family residences proposed for Golden Mesa North Phase II, north of Indian Lane, pending approvals.

There are also a limited number of individual property parcels that could be developed in the future at various locations throughout Golden Valley. These properties would likely be supported by domestic water wells and septic systems depending on location and the potential to connect to existing water system infrastructure.

Hydrologic Framework

Perspectives on Water Resources in Nevada

Surface Waters in Nevada

The following discussion of surface waters as a resource in Territorial and then State of Nevada is extracted from Hanford (2022b; Appendix C).

In June 1859, the first major discovery of silver ore in the United States occurred near Virginia City, Nevada, and drew fortune seekers and miners from the goldfields of California and the East to the Comstock Lode, as well as providing the impetus for the creation of the Nevada Territory in 1861 and statehood in 1864. Mining practices and the clearing of forests for timber for use in the mines initiated a long period of declining surface water quality. In heavily logged areas, increased runoff over bare earth caused soil erosion and a high sediment load in local streams. Consequently, both the Truckee and Carson Rivers fluctuated between droughts and floods.

Beginning in the 1860s, many settlers turned to agriculture, for which they needed a stable water supply. A haphazard system of diversion canals was dug to control flooding and direct river waters. But potential was limited by the few settlers and cattlemen who controlled much of the land around surface water sources. In 1888, John Wesley Powell, director of the US Geological Survey, submitted a plan for an irrigation survey to assess the water resources of the Far West. The 1888–1890 Powell Irrigation Survey encompassed three parts: topographic determination of drainage areas to locate lands most suitable for irrigated agriculture and reservoirs; hydrographic determination of available water supplies, principally through stream gauging; and engineering to plan irrigation and design dams, canals, and other necessary structures.

The Powell Irrigation Survey was significant in transferring reclamation of arid lands from the local level to the federal government, initiating political squabbling between East and West that dominated the issue until the early 1900s (and still continues today). In the arid West, lack of precipitation required settlers to divert water from streams, but demand outstripped supply. Settlers wanted to increase supply by storing "wasted" runoff from rains and snowmelt. Private and state-sponsored ventures mostly failed because of lack of funding and engineering skill. Since Congress had already invested in roads, river navigation, harbors, canals, and railroads in other parts of the country, Westerners demanded that the federal government invest in irrigation projects. Despite the findings of the Powell survey, no viable action was immediately taken.

Francis Griffith Newlands, a trustee of extensive landholdings in Nevada, moved to Carson City in 1888 and began acquiring his own land along the Truckee River. As he expanded his holdings, he commissioned surveying and engineering parties to examine potential reservoir and canal sites. Newlands used reclamation as an issue in his successful bid for political office, serving as a U.S. Representative from 1893 to 1903 and as a Senator from 1903 to 1917. Though his proposed reclamation legislation was turned down by the Nevada Legislature and later brushed aside by President William McKinley, President Theodore Roosevelt embraced the project. Roosevelt believed that land should be usable and settled by farming families and that water in western rivers, if not being used to help people, was wasted.

On June 17, 1902, the U.S. Congress passed the Reclamation Act. This moment marked the start of a new era in the American West, when millions of acres of arid land would be "reclaimed" for use by farmers, ranchers, and cities and towns. One of the first federally legislated outcomes was the Newlands Project, a complex of dams and canals in west-central Nevada that has helped provide livelihoods for generations of farmers and ranchers.

The Newlands Reclamation Act authorized the federal government to commission water diversion, retention, and transmission projects in arid lands in 16 arid and semi-arid states. Within a year, five projects were authorized, with an additional 20 projects authorized over the next five years.

Ground Waters of Nevada

The first US Geological Survey groundwater investigation in Nevada was conducted by Carpenter (1915) in the southeastern part of the State from Las Vegas northward to Lund, incorporating significant portions of Clark and Lincoln Counties, as well as limited portions of White Pine and Nye Counties. Enlargement of agricultural communities and nearly complete utilization of stream waters prompted consideration of the possible development of underground water supplies for irrigation.

As outlined by Allander and Berger (2015), the cooperative water program began in 1938, followed by systematic investigations of groundwater in 1944, with the beginning of publication of the Water Resources Bulletin Series in 1946 and the Groundwater Resources Reconnaissance Series in 1960. Discharge was based on mapping the discharge area and assigning estimated evapotranspiration rates; estimates had a high degree of uncertainty. Recharge was initially assumed equal to discharge. Maxey and Eakin (1949) utilized precipitation maps for estimating ground-water recharge; this technique was gradually refined to address valley-specific conditions (Donovan, Katzer and Brothers 2009).

Very little groundwater development occurred in Nevada prior to the late 1950s. The amount of groundwater available for use after that time was based on the Perennial Yield Concept. Perennial yield is defined as the maximum amount of ground water that can be salvaged each year over the long term without depleting the ground water reservoir (King 2016). Perennial yield cannot be more than natural recharge, with the goal of not allowing consumptive use to exceed the perennial yield. Under ideal conditions, perennial yield is an effective concept and has constrained over-development of groundwater resources in Nevada (Allander and Berger 2016). However, groundwater may discharge to streams, springs, and wetlands that may be allocated for human use or support critical habitat. Ground and surface waters were not recognized as a single resource. Therefore, the concept of perennial yield is limited.

Donovan, Katzer and Brothers (2009) note that recharge estimates are less important than perennial yield or safe yield, which vary over time, as do actual recharge and evapotranspiration. Recharge estimates can provide a first approximation of perennial yield, but safe yield is only determined over time using pumping stresses in conjunction with monitoring and basin management.

Safe yield is defined as the amount of water that can be withdrawn from an aquifer without producing adverse impacts on water quantity and/or water quality. Safe yield is variable and depends on management strategies.

More recent understanding of changing climatic conditions emphasizes sustainability defined by the potential of the resource and the ability of resource managers to continue to meet the demand for water resources for human use and critical habitats. Sustainability recognizes the inter-relation of ground and surface water, as well as understanding the effects of pumping on time, rates, and location of depletions (Allander and Berger 2016).

As outlined by Allander and Berger (2016) the following information is needed for making sustainable decisions and identifying sustainable strategies, including (but not limited to):

- Decisions
  - Water budgets that recognize interaction between groundwater and surface water
  - Identifying acceptable changes with regard to stream/spring depletion, habitat reduction, water level changes, stakeholder values, and mitigation to offset impacts
  - Transmissivity (permeability) and aquifer storage properties
  - Estimating impacts using analytical solutions or groundwater models

- Strategies
  - Artificial recharge
  - Conservation
  - Optimizing pumping locations or schedules
  - Monitoring
  - Adaptive management
  - Mitigation

Groundwater budgets are estimated by comparison of discharge and recharge as a basis for evaluating the potential for groundwater development in basins. But water budgets should not be used to determine the magnitude of possible groundwater development (Theis 1940; Bredehoeft, Papadopulos and Cooper 1982; Bredehoeft 2002). And, as noted by Devlin and Sophocleous (2005), the water budget is important in assessing sustainability with respect to the broader issues of the ecology, water quality, and human and environmental welfare. They further note that recharge is not necessarily the factor that limits sustainable pumping rates; this is of particular importance with respect to confined aquifers. Bredehoeft, Papadopulos and Cooper (1982) make several important points, including:

- The magnitude of groundwater development depends on the effects deemed tolerable.
- The magnitude of sustained groundwater pumpage generally depends on how much natural discharge can be captured and whether recharge can be increased.
- The placement of wells significantly affects the dynamic response of the aquifer and the rate at which natural discharge can be captured.

Surface Water Hydrology

Several surface water hydrology components are present in Golden Valley **(Figure 45. Surface water components and groundwater flow directions).** Surface water drainage is facilitated by the network of roadside drainage ditches toward the center of Golden Valley where it accumulates in a limited floodplain before flowing westward through the Marlin Ditch into Golden Valley Wash. Golden Valley Wash is the primary natural ephemeral drainage channel that conveys runoff toward the outlet channel and eventually to Swan Lake in Lemmon Valley.

Steadfield Estates was recognized as a business entity in Reno, Nevada, on 22 May 1962, as they began selling lots for residential construction. It is likely that the Marlin Ditch was excavated prior to May of 1962 in preparation for sale of properties and development of Steadfield Estates. The ditch is clearly visible on aerial photography from 21 May 1966, extending straight westward from Estates Road, passing beneath Remington Road and Marlin Drive, and ending at Golden Valley Wash west of Marlin Drive (**Figure 46. Trace of Marlin Ditch - May 1966**). The Marlin Ditch is an unlined earth ditch with culverts beneath roads to facilitate surface water flow across this western portion of Golden Valley **(Figure 47. Views of Marlin Ditch – September 2023**).

Two detention ponds provide interim surface water storage to facilitate infiltration and evapo-transpiration. A system of roadside drainage ditches is maintained by Washoe County to facilitate local runoff and reduce the potential for flooding **(Figure 48. Roadside ditches & culverts)**. During storms that produce high amounts of runoff, these ditches transmit turbid waters with high levels of kinetic energy that can erode ditches or undercut driveways that are not protected. Residents have used a variety of methods (e.g., rip rap, landscape blocks, concrete) to protect the culverts and minimize undercutting. The County has similarly protected the ends of culverts that transmit runoff beneath roadways.

Surface runoff from Mount Peavine is concentrated by the alignment of US Highway 395 and the Western Pacific Railroad further to the west. All surface water from Mount Peavine that is not lost to infiltration, evaporation, or evapotranspiration is directed through a series of culverts and flows toward Silver Lake playa.

Surface water runoff within the Golden Valley watershed is controlled by topography, timing and amount of precipitation, character of land surface cover, and human impacts. Any disturbance of the natural vegetative cover (e.g., scarification or wildfire) will increase runoff and consequent erosion. Modification of surface topography (e.g., increasing or decreasing grade or relief) will impact both the amount and rate of runoff. Replacing natural vegetative cover with either bare ground or impermeable surfaces (e.g., roofs or pavement) can increase runoff by as much as 50 percent. Increased runoff results in decreased infiltration and recharge.

No springs have been mapped within Golden Valley. However, residents note that water periodically trickles from bedrock fractures exposed in road cuts along Tamra Drive, particularly during wetter water years or following heavy rain storms (M. Rodriguez, personal communication, June 2023).

Detention Basins

Two surface water detention basins are located within Golden Valley. One basin, located northeast of Alice Smith Elementary School adjacent to Beckwourth Drive, collects runoff from the adjacent subdivision (**Figure 49. Detention basin adjacent to Beckwourth Drive**). This detention pond is approximately 0.2 acres and was constructed in the mid- to late 1990s.

A second detention basin located west of the North Valleys High School, just south of Golden Valley Road **(Figure 50. North Valleys High School detention basin),** collects runoff from the high school and upgradient areas further south. This roughly 1.9-acre detention pond was built on the northwest corner of the school property in 2005. The deepest portions of this detention pond are toward the north and east margins where soil moisture supports denser vegetation growth.

The function of these two detention basins is to facilitate infiltration, but each of the basins has accumulated a lining of fine-grained sediment that retards infiltration when water accumulates within the detention basin. The periodic presence of hydrophilic vegetation within the two detention basins suggests standing water and loss of water through evapotranspiration.

FEMA Flood Zone & Golden Mesa South Detention Channel

The State of Nevada Division of Water Resources is the Floodplain Administrator and reports to FEMA on matters related to designated flood zones (http://water.nv.gov/FloodHazard.aspx). A FEMA Flood Zone has been designated across Golden Valley in association with drainages that lead to Golden Valley Wash **(Figure 51. FEMA designated flood zone**).

Floodplains provide important surface water functions:

- Abatement of kinetic energy of floodwaters to enhance infiltration and recharge
- Filtration of sediment, contaminants, and transported nutrients
- Reduction of flooding and flood-related damages through their floodwater conveyance and storage functions to keep erosion and siltation from occurring in the waterway
- Reduction of downstream and peak flooding

Applications for a Letter of Map Amendment (LOMA) or a Letter of Map Revision (LOMR) are submitted to the Floodplain Administrator and FEMA for review and approval. Five LOMA and one LOMR **(Table 3. LOMA & LOMR for Golden Valley)** have been approved by FEMA for the central portion of Golden Valley associated with the Flood Hazard Zone (**Figure 52. LOMA & LOMR approved in Flood Hazard Zone).** Any interpretation of a parcel of property relative to the Flood Hazard Zone must incorporate approved LOMA and/or LOMR, as well as implemented grading elevations.

FEMA (https://www.fema.gov/glossary/letter-map-amendment-loma) defines a Letter of Map Amendment (LOMA) as:

> An official amendment, by letter, to an effective National Flood Insurance Program (NFIP). A LOMA establishes a property's location in relation to the Special Flood Hazard Area (SFHA). LOMAs are usually issued because a property has been inadvertently mapped as being in the floodplain, but is actually on natural high ground above the base flood elevation. Because a LOMA officially amends the effective NFIP map, it is a public record that the community must maintain. Any LOMA should be noted on the community's master flood map and filed by panel number in an accessible location.

FEMA (https://www.fema.gov/glossary/letter-map-revision-lomr) defines a Letter of Map Revision (LOMR) as:

> A modification to an effective Flood Insurance Rate Map (FIRM), or Flood Boundary and Floodway Map (FBFM), or both. Letter of Map Revisions are generally based on the implementation of physical measures that affect the hydrologic or hydraulic characteristics of a flooding source and thus result in the modification of the existing regulatory floodway, the effective Base Flood Elevations (BFEs), or the

Special Flood Hazard Area (SFHA). The LOMR officially revises the Flood Insurance Rate Map (FIRM) or Flood Boundary and Floodway Map (FBFM), and sometimes the Flood Insurance Study (FIS) report, and when appropriate, includes a description of the modifications. The LOMR is generally accompanied by an annotated copy of the affected portions of the FIRM, FBFM, or FIS report. All requests for changes to effective maps, other than those initiated by FEMA, must be made in writing by the Chief Executive Officer (CEO) of the community or an official designated by the CEO. Because a LOMR officially revises the effective NFIP map, it is a public record that the community must maintain. Any LOMR should be noted on the community's master flood map and filed by panel number in an accessible location.

A detention channel is integrated into the construction plans for Golden Mesa South (DEW Hydrology 2019) and represents a modification to the FEMA Floodplain Hazard Zone. In the adjacent lots of Golden Mesa South, engineered fill was place to raise natural grade by 10 or more feet above the floodplain.

During construction of this detention channel, a rain/snow melt event occurred. From 9 March 2023 through 12 March 2023, an estimated 2 to 3 inches of rain fell, melting much of the heavy wet snow cover (up to 1.5 feet thick layer of snow) across the Valley. Runoff across the central portion of Golden Valley was primarily confined to road-side ditches flowing toward the detention channel where floodwaters displaced an existing culvert and eroded engineered fill that had been placed on lots just east of Estates Road **(Figure 53. Golden Mesa South detention channel flooded by rain/snow melt**). Remedial work on 14 March 2023 included replacement of the eroded engineered fill and at least one of the onsite culverts within the detention channel **(Figure 54. Golden Mesa South detention channel - reconstructed**). Subsequently, the roadside ditches surrounding the development, but not the detention channel, were riprapped to provide protection from erosion. Currently this detention channel is undergoing redesign to minimize the potential for groundwater discharge into the channel.

Municipal Well Production History

Basin fill and underlying fractured or deuterically altered granitic bedrock are considered groundwater aquifers with the ability to yield adequate quantity of water to wells for domestic purposes. Municipal water supply wells exist throughout Lemmon Valley. Several domestic wells have been drilled in the southernmost portion of Lemmon Valley but exhibited limited drawdown and therefore were deemed to have lesser potential for influencing groundwater in Golden Valley. No municipal wells have been drilled within Golden Valley. Of particular interest are the municipal wells that have been drilled in the southern portion of the Lemmon Valley East Sub-basin.

Within the Lemmon Valley Basin, the four municipal wells with a history of significant drawdown were identified as having potential for influencing groundwater in Golden Valley. The SKY, CMOR1 and CMOR2 wells were drilled in the southern portion of East Lemmon Valley Sub-basin to the west and upgradient of Golden Valley and municipal well LVP3 located approximately 2000 feet downgradient of the Lemmon Valley outflow boundary (**Figure 55. Municipal well logs - SKY, CMOR and LVP3**).

SKY Wells

Nevada State Engineer records for the SKY wells indicate on log 17563 that a replacement well was drilled in 1977 through sediments to a depth of 110 feet, through fractured volcanic bedrock (Andesites of Peavine Mountain) to a depth of 253 feet, and terminating at a depth of 277 feet in fractured granite. The well was perforated from a depth of 116 feet to a depth of 275 feet in both fractured andesite and underlying granitic bedrock. Static water level was noted at a depth of 97 feet. 24-hour pump test data from 1977 indicated 72 gallons per minute at 114-foot depth, 98 gallons per minute at 115-foot depth, 125 gallons per minute at 132-foot depth, and 150 gallons per minute at 145-foot depth within the fractured volcanics; no drawdown data are recorded on the well log.

Under permit 31287 (log 24310), a domestic/municipal well was drilled (noted as a redrill on the well log) in 1982 to a depth of 351 feet through sediments to a depth of 138 feet and then through fractured volcanic rock to a depth of 193 feet and then into fractured granite. The well was screened from a depth of 307 to 351 feet within the granitic bedrock. 24-hour pump test noted a drawdown of 126 feet was noted at a pumping rate of 320 gallons per minute in December 1982. Static water level was recorded at a depth of 215 feet and production was noted to range from 300 to 500 gallons per minute. This well was abandoned in October 1998 (log 76656); when abandoned, static water level was noted at a depth of 348 feet.

Per well log 73427, the Skyline Mobile Home Park drilled a replacement municipal well in October 1998 to a depth of 601 feet. The drillers log indicates primarily sand and clay layers with gravel to a depth of 115 feet, overlying hard andesite and fractured volcanic rock to total depth of 601. This well was screened from a depth of 320 feet to total depth of 600 feet with the fractured andesite. Drawdown of 50 feet was noted at a pumping rate of 100 gallons per minute in October 1998. Static water level was recorded at a depth of 320 feet. Log 87892 (Permit 31287) indicates this well was abandoned in April of 2002; measured static water level depth was 170 feet prior to abandonment

The SKY wells produced an average of 55 acre-feet per year from 1970-2000, with an average of 71 acre-feet per year from 1980 through 1994 and 93.95 acre-feet per year from 1995 through 2000 when pumping was suspended. The SKY wells produced water from fracture zones in volcanic and granitic rock prior to 1998. From October 1998 until abandonment in 2000, the SKY well produced water from fractured andesitic rock.

CMOR1 and CMOR2

Records of the Nevada State Engineer indicate the CMOR well history is complicated. It began with permit 17229 dated April 1957 to enlarge an existing well to provide up to 3 second-feet water service to about 100 individual trailers with completion of the work filed 4 September 1959 (certificate 5792). Log 7534 (well no. 27687, permit 17229/428) indicates the well was drilled to a total depth of 408 feet, encountering first water at a depth of 158 feet, with the chief water-bearing zone from 360 to 402 feet. Application permit 27687 filed 14 August 1973 replaced application 17229 to change the point of diversion to commercial (trailer park) and domestic use, noting that the well drilled at the original point of diversion was inadequate. Work under permit 27687 was completed 15 December 1975. Permit 72723 limited the amount of water to be appropriated for municipal use to not exceed 0.56 cubic feet per second or 16.23 acre-feet annually. Permit 72723 was later abrogated.

Municipal wells CMOR1 and CMOR2 were drilled to depths of 217 and 408 feet, respectively (**Table 4. Municipal Well Data**) and were designated as 20/19-15bcdc and 20/19-15cbac (Harrill 1973). CMOR2 (log 7534) was drilled through layers of varying amounts of "clay, sand & broken rock forms" to a depth of 360 feet, overlying a "water bearing" zone from 360 to 402 feet, and hard rock from 402 to 408 feet; the well casing was perforated from a depth of 200 to 400 feet. The CMOR well produced water from fractures within the andesitic bedrock. Pump test data indicated 200 gallons per minute at 160-foot depth and 300 gallons per minute at 192-foot depth.

CMOR1 yielded 60 gallons per minute which produced a drawdown of 113 feet in 1961. CMOR2 yielded 300 gallons per minute which produced a drawdown of 67 feet. Pumping of CMOR2 between August 1963 and November 1971 lowered the groundwater level from a depth of 125 feet to a depth of 166.19 feet. CMOR1 was abandoned in July 1995 (log 49053); the well was reported as dry to a depth of 167 feet prior to abandonment. Pumping of CMOR2 was likely terminated about 2002 or 2003. CMOR2 was abandoned in May 2004 (log 93741); static water level at the time of abandonment was at a depth of 54 feet.

No production data is on file with the Nevada State Engineer for the CMOR wells (C. Ophilla, personal communication, 30 August 2023). Permit 72723 limited the amount of water to be appropriated for municipal use to not exceed 0.56 cubic feet per second or 16.23 acre-feet annually. However, drawdown indicates that production exceeded natural recharge rates.

Historically, production from the CMOR wells exceeded the perennial yield and resulted in drawdown of static water levels sustaining a significant cone of depression that was enlarged between Spring 1971 and November 1971 by pumping during the summer dry season. Harrill (1973) reported more than 40 feet decline in the groundwater level in CMOR2 between 1963 and 1971.

Pohll (2017) and Terraphase (2023) estimated 42 acre-feet per year in the 1970s and approximately 103 to 126 acre-feet/year from 1980 to 2001 for the CMOR and SKY wells extracting groundwater from fractured volcanic bedrock on the flank of Mount Peavine.

LVP3

Records on file with the Nevada State Engineer indicate that well log 84990 was originally associated with Permit 26172 (well log 7830). This permit was filed in 1971 by Valley Water Company for quasi-municipal purposes. This permit was changed by Permit 27236 in 1975 by Valley Water Company, expanding the place of use but the point of diversion remained the same. In 1984, Valley Water Company filed Permit 48652 to change Permit 27236 to expand the place of use but the location of the well was unchanged. Title was updated from Valley Water Company to Washoe County for this water right. Washoe County filed Permit 55938 to expand the place of use from Permit 48652; location of the point of diversion was not changed with this permit. Title was changed from Washoe County to Truckee Meadows Water Authority in 2015. Permit 55938 is still an active water right in the office of the Nevada State Engineer. Municipal well LVP3 has not been abandoned/plugged because there are active water rights under Permits 55938, 66853, 66956, and 6701 that are owned by TMWA for quasi-municipal or municipal purposes.

Municipal well LVP3 is located approximately 2000 feet downgradient of the Lemmon Valley Outflow Boundary in the outlet channel and was designated as 20/19-4ddac (Harrill 1973). This well was drilled in 1963 (well log 84990) to a depth of 296 feet **(Table 4. Municipal Well Data)**. The drillers log indicates sand was encountered to a depth of 63 feet overlying hard rock with fractured intervals to total depth. The well log lists the chief aquifer from 63 to 187 feet deep and other aquifers (water-bearing zones) in the interval from 188 to total depth of 296 feet within fractures in the bedrock.

This well was screened across bedrock fracture zones from a depth of 140 feet to 180 feet. In 1963 this well yielded 440 gallons per minute with static water level listed at a depth of 60 feet below ground surface elevation of 4,882 feet (4862-foot groundwater elevation). Permit 26172 applied for 3 cubic feet per second, but not to exceed 1,917.0 million gallons annually.

Municipal well LVP3 annual production was metered and data are available for the period 1970 through 2006 **(Figure 56. Annual production of municipal well LVP3 1970 – 2006)**. Well LVP3 produced water from fractures within the granitic bedrock. A maximum of 141.9 acre-feet was extracted in 1973, with average annual production of 88.1 acre-feet/year in the 1970s, 77.2 acre-feet/year in the 1980s, 66.8 acre-feet/year in the 1990s, and 71.7 acre-feet/year from 2000 through 2002. Production was significantly decreased to 32 acre-feet/year in 2003, 12.7 acre-feet/year in 2004, and then suspended in 2005 due to the increased use of imported water in Lemmon Valley.

Historically, rates of extraction from LVP3 exceeded perennial yield and induced a relatively steep gradient of static water levels through the Lemmon Valley outflow boundary and depressed static ground water levels within the outflow area (Harrill 1973). Static water level in LVP3 declined from a depth of 60 feet in 1963 to a depth of more than 100 feet in 1982, with a maximum static water level depth of about 205 feet in 2002 (**Table 5. Static Water Levels LVP3).**

Groundwater Recharge Zones

Groundwater recharge is dependent upon precipitation in the topographically closed basins in the Great Basin (Stone and Lopez 2006a). Terraphase (2023) water budget calculations indicate that approximately 82 percent of groundwater recharge in Golden Valley over the 30-year period from 1991 through 2021 is derived from precipitation, which is consistent with estimates for Basin and Range precipitation-based recharge (Neff, Meixner and De La Cruz 2014). The remaining 18 percent is comprised of a combination of the Golden Valley Artificial Recharge Program (1991-2001) injection waters, redistribution of surface water drainage (1970s – present), and irrigation in new developments (calculated based on water use and irrigation assumptions) and the North Valleys High School supplied by the school irrigation records (2001-present).

Variable rates of groundwater movement exist within the basin fill and the bedrock fracture system, with direction of flow generally west and northwest across the basin from higher elevations along the eastern valley margin (**Figure 57. Groundwater Recharge zones)**. The Estates Fault transecting the west-central portion of the Golden Valley created a subsurface bedrock ridge that differentiates the “gun streets” (i.e., Steadfield Estates) and lower elevation areas along the west side of Cactus View Drive adjacent to Golden Valley Wash from the remainder of the Valley.

The 30-year water budget prepared by Terraphase (2023) calculates that roughly 50% of recharge is from Peavine Inflow and roughly 41% is from infiltration of precipitation over the land surface and into the deeper fractured bedrock that occurs along the margins of the subbasin, with new developments constructed after 2000 contributing less than 5% of recharge due to irrigation. The new housing developments have impermeable surfaces (e.g., roofs and pavement) that reduce infiltration and increase runoff.

During the periods of operation, the Golden Valley Artificial Recharge Program contributed approximately 7% of total recharge. Critical recharge occurs in the granitic terrain along the northern and eastern margins of Golden Valley **(Figure 58. Critical recharge zone on northern & eastern Golden Valley margins).** Reduced recharge occurs in the less permeable volcanic outcrops. Along the southern & western margins of Golden Valley, Medium Density Suburban developments have reduced infiltration and increased surface runoff **(Figure 59. Zones of reduced recharge on western & southern Golden Valley margins**). Very low percolation rates in volcanic bedrock, particularly in the area from Sun Cloud Circle to Golden Valley Road, necessitated construction of engineered septic systems.

Seasonally, critical groundwater recharge occurs during the water year from October 1 through the beginning of May (**Figure 60. Annual versus Water-Year precipitation**). Winter precipitation is the source of 79% to 90% of groundwater recharge in the northern Basin and Range (Neff, Meixner and De La Cruz 2014). Groundwater levels typically rise during the water year interval and then decline when domestic water is extracted during the drier summer months. Precipitation during the summer months may evaporate, be evapo-transpired, or become surface runoff with only limited infiltration. Domestic lifestyles also increase the demand for water during the summer months when water use may exceed recharge. Consequently, ground water levels may vary seasonally by up to several tens of feet dependent on variations in annual water year recharge, dryness of the summer months, and domestic use (**Figure 61. Hydrograph of seasonal groundwater levels)**.

Hydrogeochemistry

Groundwater quality (i.e., hydrogeochemistry) is influenced by a number of factors, including: composition of the aquifer, soluble minerals present and their concentration, flow paths of groundwater through the aquifer, contact or residence time, and recharge rates. Other factors include well depth, use, and construction.

Chemical quality of the groundwater across Golden Valley varies with local geology. Historical data indicated that groundwater quality is generally good, with mean total dissolved solids (TDS) of roughly 200 parts per million (ppm). Cochran, Dale and Kemp (1984) reported typical water chemistry statistics for the interval 1980 to 1983 for 60 samples with constituent concentrations within Nevada State water quality standards, except for higher iron and manganese levels and for nitrates which slightly exceed the current water quality standard of 10 ppm. The variability of water quality from well to well is reflected in the Standard Deviation values and reflects the variations in local geology and groundwater flow. These data are comparable to the water chemistry reported by Barry (1985) and monitoring well water quality analyses reported for 1998, for 2001, and for 2021 as part of the Golden Valley Artificial Recharge Project (**Table 6. Groundwater Chemistry 1980-1983, 1998, 2001, and 2021**).

Golden Valley Artificial Recharge Project

Beginning in the 1970s groundwater withdrawals exceeded the natural groundwater recharge. In the 1980s residents experienced declining groundwater levels. One well was deemed improperly constructed on the drillers well log (11354) and necessitated well replacement. Other wells primarily in the northern and eastern portions of Golden Valley needed to be deepened to access adequate water supplies within the confined bedrock fracture system aquifer. In addition to having to deepen some existing wells, new wells had static water levels that were up to several tens of feet lower than expected compared to groundwater levels in 1971.

To alleviate declining groundwater levels in Golden Valley, application was made for an artificial recharge program to augment the water supply through artificial recharge using Truckee River water. The pilot study was designed to address three principal issues:

1. water quantity and source
2. hydraulic characteristics of the aquifer
3. resultant quality of the mixed water

If successful, the artificial recharge project would provide the aquifer with an acceptable amount of water with no or minimal adverse hydraulic or chemical effects.

Washoe County had determined that recharge was hydrologically technically feasible (Harrill 1973; Cochran, Dale and Kemp 1984; Barry 1985; Cochran, Barry, Dale and Sones 1986; Dale 1987), but was concerned with two issues (Katzer, Morros and Quinn 1988):

1. public acceptance of the practicality and potential for success of a recharge project
2. the legal aspects of defining the water right applied to artificially recharged water

The pilot program in Golden Valley initially considered artificial recharge of about 250 acre-feet of potable Truckee River water to the groundwater system, with the potential of increasing that amount to about 1,000 acre-feet per year (Katzer, Morros and Quinn 1988).

The Golden Valley Artificial Groundwater Recharge Program was one of 13 projects implemented by the US Bureau of Reclamation and local sponsors in cooperation with the US Environmental Protection Agency and the US Geological Survey under the "High Plains States Groundwater Demonstration Program Act of 1983" (Public Law 98-434). The primary purpose of Public Law 98-434 is to advance the state-of-the-art in groundwater recharge techniques.

The project was sponsored by Washoe County under an executed cooperative agreement with the US Bureau of Reclamation to conduct an artificial groundwater recharge demonstration project. Truckee River water meeting municipal water quality standards was to be delivered and injected into the aquifers. Permitting, monitoring, acquiring water rights, and gaining public acceptance required extensive effort giving due consideration to the management of Truckee River waters. Though not legally required under the granted water right permit (Washoe County 1996), diversion timings were successfully negotiated with the US Fish & Wildlife Service with respect for the ecological sensitivity of Pyramid Lake.

Institutional and permitting delays caused several years to pass before the US Bureau of Reclamation and Washoe County could sign and implement a cooperative agreement in September 1990. Construction and implementation of the project was delayed due to institutional constraints and a coincident drought period between 1986 and 1993. If the Project had been operational in 1988, virtually no injection could have occurred until 1994 under the conditions agreed upon among the various entities (Washoe County 1996).

Infrastructure included three 8-inch diameter injection wells (GVI-1, GVI-2, and GVI-3 sequenced from south to north), three 2-inch monitoring wells (MW3, MW-4 and MW-5), approximately 10,500 feet of 6-inch diameter water line, the filter house and carbon filter, and all necessary valves, meters and electrical equipment to operate the facilities (**Figure 62. Golden Valley Groundwater Recharge System**). Well GVI-3 was originally installed to a depth of 250 feet and screened across 70 feet of granitic sand and 45 feet of granitic bedrock, then later deepened to a total depth of 450 feet. The Recharge Program included water meter, pipeline and four injection wells, and used domestic and monitoring wells for assessing groundwater levels and for measuring injection water quality.

Construction of the facilities necessary to deliver treated drinking water to the recharge sites was completed in October of 1992. Injection wells were screened in coarse-grained granitic sediments and granitic bedrock (**Figure 63. Golden Valley injection well logs & screened intervals**). The Golden Valley Artificial Recharge Pilot Program began operation in January 1993 under the direction of the Washoe County Department of Water Resources. In response to project start up delays (resulting from drought conditions), Washoe County was granted a two-year extension by the US Bureau of Reclamation, extending the project through 1997 to allow for the requisite period of monitoring to assess the efficacy of the pilot program.

Above-average precipitation beginning in December 1992 allowed injection to begin in January 1993. Initially injection was under gravity feed. But after several months, injection under pressure was utilized to negate negative pressure at above-ground connections and fittings to eliminate leaks, and to allow an increase in the rates of injection. Potable water was injected into the ground and the water supply was continuously monitored for water levels and water quality. Total injection for Golden Valley was roughly half of the 50 acre-feet goal; repairs to the injection wells and booster pump were conducted as needed **(Figure 64. Injection volumes 1993-1994**).

The winter of 1993-1994 experienced below-average precipitation. By late summer of 1994, the Truckee River "ran dry" as surface flow ceased in East Reno and Sparks, limiting the availability of waters for diversion for recharge. Only 5 acre-feet of water was injected in Golden Valley. Because of lower-than-expected injection capacities, Washoe County sought to extend the original injection period from September through January of each year to September through June of each year. In August 1994, the US Fish & Wildlife Service granted extensions to the injection intervals based on predictions of Truckee River flow.

The winter of 1994-1995 resulted in snow pack in the Sierra Nevada approaching 200 percent of average. Based on higher-than-average streamflow predictions for the Truckee River, recharge began in February and continued throughout the year except for July and August.

A total of 40 acre-feet was injected in Golden Valley in 1995. Injection well GVI-2 developed a leak around the sanitary seal and had to be abandoned. Washoe County requested and was granted addition funds to drill a replacement well (GVI-4) adjacent to the abandoned GVI-2 (**Figure 65. Injection volumes and replacement well 1995-1996)**.

The winter of 1995-1996 experienced above-average snow pack and high runoff predictions. Recharge began in February and by July, 31 acre-feet had been injected in Golden Valley, progressing toward a goal of 50 acre-feet. This injection goal was again met in 1997.

From 1993 through 1998, a total of 202.99 acre-feet of water had been injected, with an annual average of 33.832 acre-feet and a maximum annual of 62.89 acre-feet in 1996 (**Table 7. Volumes of Injected Water .** Federal funding for the Golden Valley Artificial Groundwater Recharge Program ended in 1998.

The pilot study confirmed that artificial recharge could offset at least some of declining groundwater levels without degrading groundwater quality. Because of this successful demonstration, the Community requested that Washoe County create and operate a recharge program. This request led to Washoe County Ordinance 1166 dated 25 June 2002 which defined the Service Area for the Golden Valley Artificial Recharge Program (Washoe County 2002). The Golden Valley Artificial Recharge service area included 596 residential lots and two commercial facilities (**Figure 66. Golden Valley Artificial Recharge Program Service Area – 2002**).

Washoe County Ordinance 1166 was superseded by Ordinance 1548, authorized on 21 November 2014 that confirmed the Golden Valley Artificial Recharge Program Service Area (**Figure 67. Golden Valley Artificial Recharge Program Service Area – 2014)**. Program elements included management and field work to monitor water levels and water quality of both injected water and groundwater. Permits were obtained from the Nevada Department of Environmental Protection and the Nevada Division of Water Resources for water rights and water credits. Cooperative agreements were established with NV Energy and TMWA.

Initially, recharge water was provided under agreement with the Washoe County Department of Water Resources Water Utility. In January 2015, the Washoe County Water Utility was merged into TMWA. On 31 December 2014, TMWA acquired the water distribution system in connection with the merger agreement. TMWA agreed to provide water service for the Golden Valley Artificial Recharge Program beginning on 16 December 2015.

The Program infrastucture included 4 injection wells, 3 monitoring wells, a carbon-vessel treatment system for injection water, and a contractually uninterruptable water service. Washoe County continued a monitoring program for both groundwater levels and quality. Previously drilled GVI-1, GVI-3 and GVI-4 were used when the injection program resumed. Well GVI-5 was drilled and became operational in 2003. With the addition of GVI-5, the injection wells were sequenced from south to north as GVI-1, GVI-4, GVI-3, and GVI-5.

From 2002 through 2016, a total of 873 acre-feet of water was injected, ranging from an annual low of 12.26 acre-feet in 2002 to a maximum of 81 acre-feet in 2013, with an annual average of 58 acre-feet (**Figure 68. Artificial recharge volumes 1993-2016)**. For comparison, the North Valleys High School uses between 21 and 87.5 acre-feet of TMWA-supplied water per year to irrigate athletic fields and landscaping, which either evapotranspires almost completely or contributes up to 2 acre-feet per year to groundwater recharge.

Beginning in the early 2000s, groundwater levels in portions of Golden Valley began rising. As a result, water injection was reduced to approximately 20 acre-feet in 2016 and then suspended. Washoe County continued to monitor groundwater levels and water quality.

In 2022, Washoe County initiated a hydrogeological study to attempt to answer, at a minimum, the following questions:

- Why are there significant differences in groundwater levels within Golden Valley: i.e., shallow groundwater beneath the ground surface of Steadfield Estate Subdivision (colloqually known as the "Gun Streets") versus deeper groundwater levels elsewhere in the Valley that locally are increasing and/or declining?
- What is the source(s) of groundwater within the Valley?
- What role, if any, did the Recharge Program or new developments play in observed groundwater level increases?
- Will artiticial recharge be needed in the near future?

Terraphase Engineering Inc. was retained by Washoe County in 2022 to assess hydrogeologic conditions in Golden Valley and evaluate whether continued aquifer recharge would be beneficial to domestic well users. The evaluation included examining the extent to which basin conditions used to originally justify aquifer recharge had changed. A detailed conceptual model of the basin was developed and identified natural recharge and changes in regional municipal pumping as the major drivers influencing groundwater levels in the subbasin. This information was used to build and calibrate a numerical model of 30 years of water level measurements that was then used as a predictive model to simulate select scenarios and inform decisions for future aquifer recharge.

The Terraphase (2023) analysis included geologic review and analysis of precipitation data, recharge and discharge of groundwater considering natural and man-made influences on the aquifer since the 1970s (infiltration from precipitation, regional municipal well pumping influence, septic system return flow, landscape watering at new housing developments, high school irrigation, surface water drainage, and the injection program). Terraphase prepared a 30-year water budget with these inflows and outflows from 1990 to 2020 that was used to calibrate the model to seasonally fluctuating conditions.

Washoe County continued to implement the various Program elements, including management, field work to monitor water levels, and testing quality of both injected water and groundwater. Terraphase submitted their final report in April 2023. The technical study indicated that there is a low likelihood that artificial recharge will be needed during the next few decades

Washoe County worked together with experts and Golden Valley residents through a series of Community and Focus Group meetings to provide for public input and to conduct a technical review of hydrogeologic conditions impacting Golden Valley. Since it is impossible to fully predict the future, residents are aware that natural events (e.g., major earthquake, significant wildfire, and/or drought) or programmatic/political events may trigger conditions under which resumption of groundwater recharge may be advisable. The majority of Golden Valley residents supported maintaining the Golden Valley Artificial Recharge Program, continuing to monitor groundwater levels and water quality and having the infrastructure to resume injection should the need arise.

On 14 November 2023, the Washoe County Commissioners approved Resolution R23-149 to suspend the Golden Valley Artificial Recharge Program (Program) participant fee collection from January 1, 2024, through December 31, 2033, while continuing Program activities in support of the maintenance of the State of Nevada Division of Water Resources injection permit performed pursuant to Washoe County Ordinance 1548, at an estimated annual cost of $30,000.00 with all efforts utilizing existing fund balance (Fund 566), estimated to be $684,000.00 as of September 30, 2023, and to require all Program participants to bring any past due accounts current through the processes identified in Ordinance 1548. Monitoring of groundwater levels and water quality continues.

Groundwater Hydrology

The groundwater flow system in Golden Valley includes flow through alluvium (phreatic water levels) and groundwater in the confined fracture systems of the underlying granitic bedrock (piezometric water levels resulting from hydrostatic pressure). Sausse and Genter (2023) provide some insight into the nature of fractures in granite, including small aperture fractures as well as more isolated permeable fractures that allow hydraulic connection for injection and production of groundwater.

Water level measurements indicate that groundwater flows generally from east to west from the valley margins toward US Highway 395, and exits the valley through "Lemmon Valley Drive Canyon" (outlet channel) to the north. The depth to which fractures penetrate the granitic rocks is unknown, but well logs indicate fracture zones are present to a depth of 300 feet or more and include both water-bearing and non-water-bearing fracture zones. Transmissivity of groundwater through these materials and fracture ranges from 90 gallons per day per foot (gpd/ft) to 5,700 gpd/ft (Cochran, Dale and Kemp 1984; Terraphase 2023), being greatest in wells intersecting fractured granitic rock. Terraphase (2023) noted that water moves slowly through the system, and depending on porosity and hydraulic conductivity, calculated groundwater travel times across the basin that ranged from 13 to 59 years in basin fill and 59 to 491 years in bedrock. Wells in areas of phreatic water may exhibit more rapid response times due to the influx of recharge during periods of precipitation and infiltration of runoff, as well as greater porosity/permeability. Wells may exhibit response times for changes in hydrostatic pressure within the confined bedrock fracture system that may be more rapid than groundwater travel times.

Municipal wells were drilled west of what is designated as the Peavine Inflow Boundary and north of the Lemmon Valley Outflow Boundary (i.e., within the outflow boundary channel) in the early 1960s and continued to extract groundwater over the next several decades. From 1970 through 2015, a total of 550 individual domestic wells were drilled for domestic water resources for individual residences within Golden Valley. Of critical importance to the residents of Golden Valley are changes in groundwater levels and/or groundwater quality.

Harrill (1973) conducted the first hydrologic study of Lemmon Valley, including the Golden Valley sub-basin. His data provides a baseline, augmented by water levels previously recorded for individual wells, to assess the changes that have occurred in groundwater levels in Golden Valley over the ensuing decades. Harrill noted the impact of the commercial wells on static groundwater levels in Golden Valley by 1971 (**Figure 69. Groundwater levels – Natural conditions and Spring 1971**).

Pumping of LVP3 had resulted in declining static water levels by Spring 1971 with further lowering by November 1971 (**Figure 70. Groundwater levels November 1971).** Historically, high rates of extraction from LVP3 exceeded natural yield, inducing a relatively steep groundwater gradient through the Lemmon Valley Outflow Boundary (outlet channel) and depressing static ground water levels within the outflow area. Harrill (1973) further indicated approximate water levels in the outlet ranging from 4,940 to 5,020 feet within the outlet channel under natural conditions by 1971, suggesting a drawdown of 60 or more feet within the cone of depression. Under natural conditions, aquifers are in a state of dynamic equilibrium with the volume of recharge equal to the volume of groundwater discharge. However, these rates will vary in response to climatic changes and may vary seasonally.

Groundwater levels were further impacted by the development of 362 domestic wells within Golden Valley during the late 1970s and by lower-than-average precipitation in 1976-1977 which reduced recharge. Cochran, Dale and Kemp (1984) calculated an average groundwater decline of about 1.4 feet per year for the periods 1972 to 1975 and 1978 to 1980. They calculated an average rate of decline of nearly 2.8 feet per year during the short-term drought of 1976 to 1977. Declining piezometric groundwater levels necessitated deepening of a number of domestic wells across the northern and eastern portions of Golden Valley (**Figure 71. Groundwater levels April-June 1984**).

In response to declining groundwater levels, the Washoe County Recharge Demonstration Study pilot program began injecting potable water in 1994 on the eastern margin of Golden Valley, continuing until federal funding ended in 1998. Some increase in groundwater levels was noted during the interval 1993 to 1996 in the easternmost portion of Golden Valley while groundwater levels continued to decline in the area generally between Estates Road and the central portion of Spearhead Way (**Figure 72. Differences in groundwater levels 1993-1996).**

Terraphase (2023) developed groundwater contour maps for 1991 (**Figure 73. Groundwater levels 1991**), for summer of 2005 (**Figure 74. Groundwater levels 2005),** for summer of 2015 (**Figure 75. Groundwater levels 2015**), and for March of 2021 **(Figure 76. Groundwater levels 2021**). In general, the groundwater contour map for 1991 shows lowering of static groundwater across Golden Valley as indicated by the eastward shift in groundwater contour elevations compared to 1971 (Harrill 1973) and 1984 (Barry 19855). In 2005, groundwater contours begin shifting westward in the eastern half of Golden Valley indicating that static groundwater elevations are beginning to rise, but with an area of static water level depression in the vicinity of the Johnson-Walsh-Schoensky wells in the eastern portion of the valley. A "bull's eye" contour is indicated in Steadfield Estates showing static water levels exceeding 5040-foot elevation. The groundwater contours for summer of 2015 shifted further westward indicating continued rise in static groundwater levels, along with a significant enlargement of the bull's eye in Steadfield Estates. Continued rise in static groundwater levels is indicated by March of 2021, with contours of static water levels continuing to shift to the west. The 2005 and 2015 contour maps reflect, in part, the increased use of groundwater by residents during the summer season. The March 2021 contour map reflects, in part, the water year recharge prior to more intense summer use of water by residents. These groundwater contour maps do not reflect the impacts of Estates Fault.

Terraphase (2022) illustrated groundwater levels across Golden Valley (**Figure 77. Groundwater levels North Valleys HS to Steadfield Estates 2002-2021**) but did not distinguish between piezometric and phreatic water levels. This profile does not include the location of a drainage divide to the west of the "gun streets area" that would mark the transition from Mount Peavine Inflow from the west into Golden Valley. And this profile does not reflect the influence of Estates Fault and the associated buried bedrock ridge on groundwater levels.

Synoptic Analysis of Hydrogeologic Data

Without benefit of understanding the hydrogeology of Golden Valley, erroneous conclusions were previously drawn and shared by rumor, for example:

- Wells in Golden Valley needed to be deepened because they were not originally properly drilled
- Golden Valley Artificial Recharge Program caused very shallow groundwater levels in Steadfield Estates over the past two decades
- Municipal well production outside the Golden Valley Artificial Recharge Program domain did not have significant impact on groundwater resources within Golden Valley

The deepened wells were a consequence of the decline in static water levels in the 1980s and 1990s. And, as noted by Stone and Lopez (2006b), in Golden Valley, the artificial recharge program lessened the negative impacts of over-pumping.

In Golden Valley, two conditions need to be considered: confined fractured bedrock and unconfined (water table) aquifers. Piezometric (i.e., induce by confined hydrostatic pressure within the bedrock fracture system) and phreatic (i.e., water table at upper limit of saturated sediments) groundwater levels can be recognized within Golden Valley.

Water levels in wells in confined aquifers cannot necessarily be correlated to changes in volume of aquifer storage. In confined aquifers, pumping causes a decrease in water pressure (hydrostatic pressure) in the aquifer but does not necessitate a significant change in the quantity of water in storage within the confined aquifer. The distance from the well over which hydrostatic pressure varies will depend on the physical characteristics of the confined aquifer (i.e., structural configuration of the fracture zones) and regional geology. A variety of hydrogeological contexts may exist within bedrock fracture systems (**Figure 78. Confined conditions in fractured bedrock**). Changes in hydrostatic pressure may be rapid, while travel times for groundwater flow through the fracture system may range upwards of hundreds of years or more. Regional precipitation is the predominant source of water recharging confined bedrock fracture systems. A small portion of such precipitation may infiltrate the overlying valley fill, be pulled downward by gravity through the valley fill sediments, and then leak into the bedrock fracture system.

In contrast, in unconfined aquifers, water levels in wells are direct indicators of the amount of groundwater in storage in the aquifer that can fluctuate over both the short- and long-term. Changes in water levels in wells result from the interaction between groundwater recharge and discharge to and from the aquifer. In general, water levels in wells decline due to increased groundwater withdrawal (discharge) and/or reduced aquifer recharge. Conversely, reduced discharge and/or increased recharge will cause water levels in wells to rise as more water is stored in the aquifer. Groundwater generally flows in arcuate pathways (Darcy's Law) with travel times increasing with depth (**Figure 79. Groundwater movement and travel times in unconfined aquifers**). Regional precipitation and surface runoff typically recharge the unconfined aquifer, although upward movement of water from bedrock fractures may also provide recharge.

Groundwater Conditions – Confined Fracture Flow in Bedrock

Characterizing the flow regime and hydrogeological parameters in fractured bedrock aquifers poses challenges due to the heterogeneous and anisotropic variations across different scales of observation (Ofterdinger, MacDonald, Comte and Young 1989). Despite the commonly encountered low yields of fractured bedrock aquifers, these complex bedrock aquifers play an important role in water resource management and are key to understanding the potential impacts of competing demands. At shallow to intermediate depth, fractured bedrock aquifers are confined systems that help to sustain surface-water base flows and groundwater-dependent ecosystems, provide local groundwater supplies, and impact contaminant transfers on a catchment scale. Changes in water levels in confined aquifers should not automatically be interpreted as changes in aquifer storage. Water is extracted from the saturated space within fractures. Pumping can, therefore, cause a decrease in water pressure and, as pressure is reduced, water levels can decline. In Golden Valley, characterization of fracture flow can initially be based on traditional hydrogeological techniques, such as well hydrograph monitoring and time-series analysis.

The predominant groundwater condition throughout most of Golden Valley involves groundwater flow through the fracture system of the underlying bedrock (**Figure 80. Schematic cross-section of southern Lemmon Valley**). The bedrock is primarily granitic, but on Mount Peavine the granitic bedrock is locally overlain by andesite flows which are also fractured. Municipal wells SKY and CMOR produced water primarily from the fractured andesite; municipal well LPV3 produced water from the fractured granite. Movement of water within a fracture system depends on a variety of factors, including fracture orientation, length, density, spacing and infilling, connectivity of the fractures, and surface roughness of the fracture planes. Field observations suggest that, fractures in the andesites yield water more freely than fractures in the granitic rocks; this is confirmed by pump test data. No preferred orientation of fractures was identified in bedrock outcrops in Golden Valley (Cochran, Barry, Dale and Sones 1986).

Fracture flow aquifers typically have low specific yields, but may be responsive to changes in hydrostatic pressure and/or recharge. Recharge is primarily from precipitation that infiltrates into exposed bedrock fractures in areas of higher elevation. Deeper flow originating from upper elevations on Peavine Mountain may move through connected fractures into Golden Valley, and upward flow gradients observed within the basin may also suggest influence from a more localized fracture flow system originating from outcrops of decomposed and fractured granites in the surrounding uplands on the northern and eastern valley margins (Barry 1985). Movement of recharge through the bedrock fracture system is the source not only of groundwater but is also the source of hydrostatic pressure in the confined aquifer. With higher elevation and greater amounts of precipitation, it is reasonable to assume that Mount Peavine inflow significantly contributes to recharge and hydrostatic pressure in Golden Valley.

Calculated hydraulic conductivities within the bedrock range from 0.32 to 20 feet per day, or 22 to 181 feet per year, with associated travel times across the basin of 59 to 491 years (Terraphase 2023). These rates reflect variability in fracture characteristics and hydraulic gradient across the basin. Field observations of the fractured andesites of Mount Peavine and the fractured granodiorite exposed in Golden Valley, along with pump test data, suggest that the fractured andesites are characterized by higher transmissivity.

In Golden Valley, most domestic wells derive water by intercepting water-bearing fracture zones with screened intervals at depths generally greater than 100 feet within the granitic bedrock as indicated by drillers well logs. These conditions exist primarily east and north of Estates Fault and the associated subsurface bedrock ridge. Similar to the role of the Airport Fault in subdividing the Lemmon Valley hydrographic basin into Western and Eastern sub-basins, Estates Fault subdivides Golden Valley into two areas. The eastern portion of Golden Valley has the thickest sequence of valley fill sediments, but the valley fill generally does not yield sufficient quantity of water for domestic use.

Hydrostatic pressure within the confined bedrock fracture system causes water levels in wells to rise above water-bearing zones to a piezometric (pressure) surface **(Figure 81. Piezometric water level in bedrock fracture system).** If the piezometric pressure were great enough to induce wells to flow unaided at the ground surface, then the systems would be described as artesian. Reduced hydrostatic pressure within the confined bedrock fracture system will result in lowering of the static water level and wells may go dry.

Groundwater Conditions – Phreatic Water Levels

Surface topography and subsurface bedrock configurations play important roles in delineating areas of phreatic (water table) groundwater levels in portions of Golden Valley (**Figure 82. Phreatic groundwater conditions in valley fill).** West of Estates Fault (and the associated bedrock ridge), the predominant groundwater condition involves fracture flow and the relatively uninhibited movement of groundwater through the overlying porous sediments that vary in thickness from about 10 feet to as much as 100 feet. Subsurface flow of groundwater in the saturated zone toward the eastern portion of Golden Valley is inhibited by the subsurface bedrock ridge associated with Estates Fault.

Calculated hydraulic conductivities within the valley fill ranging from 1.6 to 48 feet per day, or 181 to 849 feet per year, with associated travel times across the basin of 13 to 59 years (Terraphase 2023). These rates reflect heterogeneity within the sediments, with clay layers and lenses tending to inhibit the rate of groundwater movement.

Similar phreatic conditions exist further west adjacent to Golden Valley Wash and immediately south of the lower end of Cactus View Drive. Surface relief was increased by grading for the adjacent Medium Density Suburban development of Wild Stallion Estates which included placement of engineered fill to raise natural grade by 10 or more feet.

Recharge in these areas of phreatic groundwater is partially dependent upon Peavine Inflow, as well as infiltration of surface runoff from the Marlin Ditch and Golden Valley Wash. Groundwater flows through fractures in the underlying bedrock and is inter-connected with the overlying coarse-grained valley fill sediments. Well logs for homes in these areas indicate that these wells derive sufficient domestic water from both bedrock fractures and saturated overlying valley fill sediments.

Hydrogeologic Analysis

Well LVP3 was drilled in 1963 (log 84990) to a depth of 296 feet (**Table 4. Municipal Well Data**). In 1963 this well yielded 440 gallons per minute with static water level at a depth of 60 feet below ground surface elevation of 4,882 feet (4862-foot static groundwater elevation. Static water level in 1963 rose 3 feet above the contact between sandy sediments and the underlying fractured granitic bedrock that extended to total depth of the well.

Pumping of LVP3 had resulted in declining static water levels by Spring 1971 with further lowering by November 1971. Historically, high rates of extraction from LVP3 exceeded natural yield, inducing a relatively steep groundwater gradient through the Lemmon Valley Outflow Boundary (outlet channel) and depressing static ground water levels within the outflow area. Harrill (1973) further indicated approximate water levels in the outlet ranging from 4,940 to 5,020 feet within the outlet channel under what he identified as natural conditions by 1971, suggesting a drawdown of 60 or more feet within the cone of depression. Under natural conditions, aquifers are in a state of dynamic equilibrium with the volume of recharge equal to the volume of groundwater discharge. However, these rates will vary in response to climatic changes and may vary seasonally.

A maximum of 141.9 acre-feet was extracted by LVP3 from fractures in the granitic bedrock in 1973, with average annual production of 88.1 acre-feet/year in the 1970s, 77.2 acre-feet/year in the 1980s, 66.8 acre-feet/year in the 1990s, and 71.7 acre-feet/year from 2000 through 2002. Static water levels in LVP3 varied depending on annual production (**Table 5. Static Water Levels LVP3**). Static water level declined to a depth of 163 feet (elevation 4719 feet) in May of 1982, with the average static water level maintaining this depth during the interval from 1982 through 2002 despite variation in annual production (**Figure 83. Hydrograph and production in well LVP3 1963-2018**). Production was significantly decreased to 32 acre-feet/year in 2003, to 12.7 acre-feet/year in 2004, and then suspended in 2005 due to the increased use of imported water to Lemmon Valley. Maximum drawdown in LVP3 reach 205 feet (elevation 4677) in October 2002. Following cessation of pumping, static groundwater level in LVP3 recovered to an average depth of 138 feet (elevation 4744 feet) in 2003, an average depth of 91 feet (elevation 4791 feet) in 2004, and an average depth of 27 feet (elevation 4855 feet) in 2005 to 2006. Thus, the location and pumping rate of municipal well LVP3 significantly affected the dynamic response of the confined bedrock fracture system aquifer and the rate at which natural discharge could be captured.

Similarly, by 1971, municipal wells SKY, CMOR1 and CMOR2 caused a decline in water levels in the western portion of Golden Valley as these wells intercepted groundwater flowing eastward from Mount Peavine primarily within fractures in the andesites of Mount Peavine. Production from these municipal wells created a local cone of depression, which inhibited Peavine Inflow into the portion of Golden Valley west of Estates Fault. Since these wells were primarily screened in the andesitic volcanics of Mount Peavine, the impact on fracture flow within the underlying granitic fracture flow system was minimized.

During the 1970s, continued excess production of municipal well LVP3 tapped the granitic bedrock fracture system further steepening the gradient in the outflow channel and significantly lowering static water levels across the northern and eastern portions of Golden Valley. Continued interception of Peavine Inflow into

Golden Valley by the SKY and CMOR wells resulted in lowering water levels in the western portion of Golden Valley.

New domestic wells had static piezometric water levels that were up to several tens of feet lower than expected across the northern and eastern portions of Golden Valley and static phreatic groundwater levels of generally 10 to 20 feet lower than expected in Steadfield Estates **(Figure 84. Static water levels in new wells 1970s to 1990s**). Only one home was built in Steadfield Estates before 1965; most were built in 1973 through 1979. Therefore, most wells in Steadfield Estates were drilled after phreatic groundwater levels had been lowered below both natural levels and measured levels of 1971.

By 1991, induced drought caused by production of the municipal well LVP3, new domestic wells drilled within Golden Valley, and the ongoing lower-than-average precipitation necessitated the deepening of a number of domestic wells across the northern and eastern portions of Golden Valley. To intercept water-bearing fracture zones, these wells had to be deepened by as much as 110 feet. The piezometric water level across Golden Valley had generally been lowered by 30 to as much as 60 feet since the 1970s. Induced drought and the continued interception of Peavine Inflow by SKY and CMOR wells resulted in water levels declining by more than 30 feet in Steadfield Estates.

Comparison of the 1971 and 1991 static groundwater contours reflects the influence of Estates Fault that distinguishes groundwater conditions west of the fault from those north and east of the fault **(Figure 85. Comparison of static groundwater contours 1971 to 1991**).

The location of Estates Fault is reflected in depth to bedrock inferred from roughly 400 well logs in Golden Valley. The impact of this fault on hydrostatic groundwater levels is reflected in the 1984 groundwater contours and the shifting of hydrostatic groundwater levels from 1971 to 1991 (**Figure 86. Location & influence of Estates Fault on groundwater**).

In response to declining groundwater levels, the Washoe County Recharge Demonstration Study pilot program began injecting potable water in 1994 on the eastern margin of Golden Valley, continuing until federal funding ended in 1998. The winter of 1993-1994 was characterized by below-average precipitation. By late summer of 1994, surface flow "went dry" in the Truckee River in East Reno and Sparks which limited the availability of waters that could be diverted for recharge. Only 5 acre-feet of water was injected in Golden Valley in 1994. Since the injection wells were sequenced, the greatest amount of artificial recharge was injected into well GVI-1 (74.22 acre-feet) from 1993 through 1997 and well GVI-4 (102.61 acre-feet) from 1995 through 1998. Lesser amounts of recharge were injected into well GVI-2 (17.6 acre-feet) from 1993 through 1995 and into well GVI-3 (8.56 acre-feet) from 1993 through 1997. Increase in groundwater levels was noted during the interval 1993 to 1996 in the easternmost portion of Golden Valley while groundwater levels continued to decline in the area generally between Estates Road and the central portion of Spearhead Way.

Artificial recharge injection was resumed beginning in 2002 and the Golden Valley Artificial Recharge Program continued through 2016. Injected waters were not uniformly distributed among the various recharge wells nor were amounts of injected waters uniformly distributed through time due to design of the injection system and water delivery methods **(Figure 87. Distribution of injected waters).** The greatest amounts of artificial recharge were injected into GVI-1 as the first well served by the system (249.918 acre-feet) from 2002 through 2016 and then well GVI-4 (484.862 acre-feet) from 2003 through 2016. Lesser amounts of recharge were injected into well GVI-3 (58.062 acre-feet) from 2003 through 2016 and into well GVI-5 (80.516 acre-feet) from 2003 through 2016.

Hydrographs confirm the observation of Stone and Lopez (2006b) that the recharge program helped alleviate declining groundwater levels **(Figure 88. Recharge volumes and static groundwater levels**). The impact of the Golden Valley Artificial Recharge Program injection is illustrated on the hydrographs of the McNinch and Chavez wells. The McNinch well is near GVI-3 and the Chavez well is downgradient of GVI-1 and GVI-3. Both the McNinch and Chavez wells reflect seasonal groundwater level fluctuations of approximately 10 to 20 feet due to domestic use and both wells reflect rise of groundwater during the intervals of recharge injection with a lag time of two to three years. This same seasonal pattern of recharge and drawdown is reflected in the hydrographs for the installed monitoring wells, with seasonal water level fluctuations ranging from approximately 5 to 7 feet.

The production record for municipal well LVP3 reflects an expected inverse relationship between precipitation and annual production during the 1984 through 1994 and the 1999 through 2003 years of generally lower-than-average precipitation (**Figure 89. Groundwater levels – Precipitation - LVP3 production).** Hydrographs indicate seasonal groundwater level fluctuations, with a two- to three-year lag time for increasing water levels due to higher-than-average precipitation from 1995 through 1998. Pumping of LVP3 was terminated about 2002 when water was imported from the Truckee River by TMWA. A significant and prolonged rise in groundwater levels began after the cessation of pumping of LVP3 in 2002, following a roughly two-year lag time, and continued over the next two decades.

Pumping of the municipal wells (SKY, CMOR and LVP3) was terminated in 2002 to 2003, when water supply importation into Lemmon Valley was initiated. The SKY well was abandoned in April of 2002. Pumping of the CMOR well was likely terminated about 2002 or 2003 before the CMOR2 well was abandoned in May 2004. Cessation of pumping and abandonment of these municipal wells allowed Peavine Inflow to return to natural conditions (Terraphase 2023).

Beginning in the early 2000s, Medium Density Subdivisions have been constructed along the southern and western portions of Golden Valley. These subdivisions provide housing on 0.25 to 0.33 acre lots, have minimal areas for landscaping, and have added impermeable surfaces (e.g., paving and roofs) that can increase runoff by up to 50% with reduction in time lag between precipitation and peak runoff. This runoff follows the topography and generally flows toward the lower elevations in Golden Valley, including flowing to Golden Valley Wash via the Marlin Ditch.

By 2005, water levels began increasing in elevation in Steadfield Estates and along the lower reaches of Golden Valley Wash, phreatic water levels rose approximately 20 feet to an elevation exceeding 5,040 feet. In the eastern portion of Golden Valley, piezometric groundwater levels rose as reflected in the westward shifting of groundwater contours. The area of depressed groundwater contours identified by Terraphase (2023) in the summer of 2005 reflects seasonal use.

By 2015, these trends toward rising groundwater elevations are more readily observed and are likely a function of several factors, including the presence of Estates Fault, associated bedrock high, and relatively thin interval of basin fill in this area, which limits the amount of water that can flow through the area (Terraphase 2023). Piezometric groundwater elevation contour locations shifted from the eastern margin to the central portion of Golden Valley.

These trends continued and, by 2021, west of Estates Fault, shallow phreatic groundwater levels can be recognized in Steadfield Estates and the lower reaches of Golden Valley Wash on the western side of Cactus View Drive. From 2002 to 2022, phreatic groundwater level rose in well 24671 by roughly 29 feet on Colt Drive in the heart of Steadfield Estates. A lag time of two to three years after abandonment of the SKY and CMOR municipal wells occurred between recharge and water level response, likely reflecting porosity of the course-grained sediments, a rapid rate of groundwater flow, and a good degree of connectivity with the bedrock fracture system. Phreatic groundwater levels continued to rise during years of above-average precipitation and runoff.

East and north of Estates Fault, the cause-effect relationships can be recognized between piezometric groundwater levels and 1) precipitation as a source of natural recharge, 2) distribution and volume of injected waters via the Pilot Program and subsequent Golden Valley Aquifer Recharge Program, and 3) cessation of pumping in excess of natural yield of municipal well LVP3. These relationships are reflected in hydrographs of wells in the northern (**Figure 90. Static water level data for northern wells 2002-2022**) and eastern (**Figure 91. Static water level data for eastern wells 1991-2022**) portions of Golden Valley.

Piezometric pressure within the fractured bedrock aquifer decreased as municipal wells were pumped from the 1960s through 2002 and then recovered over the next two decades following abandonment of both the SKY and CMOR municipal wells and the cessation of pumping of municipal well LVP3 in 2005 (**Figure 92. Drawdown/recovery with municipal well pumping/cessation**). Average annual static water levels were used to preclude bias of seasonal pumping. Cessation of pumping of the municipal wells in the early 2000s allowed recovery of hydrostatic pressure in the granitic bedrock fracture system. Consequently, piezometric water levels began rising, reflecting a rapid response through the bedrock fracture system across the Valley. In retrospect, it is likely that the inferred 1971 natural condition water levels (Harrill 1973) were higher in elevation, with water levels having been drawn down by municipal well pumping since the early 1960s. Groundwater contours reflect elevations of both the phreatic and piezometric conditions, as well as the location and influence of Estates Fault on groundwater movement.

The hydrograph for the Mayo well 39609 illustrates the impact of the cessation of municipal well pumping on piezometric response and groundwater levels **(Figure 93. Hydrograph of Mayo wells 11735 and 39609)**. The Mayo well is 'upgradient' and approximately 0.8 miles from the nearest Artificial Recharge Injection well GVI-1. The Mayo well (log 11735) was originally drilled in July 1971 with static water level measured at an elevation of 5107 feet (i.e., depth of 64 feet below land surface elevation). Declining static groundwater levels led to the necessity of deepening this well in September 1992, when static water level was measured at an elevation of 5057 feet (well log 39609), roughly 50 feet lower than in 1971. By August 2004, static water level in this well was measured at an elevation of 5028 feet (depth of 144 feet), a roughly 30-foot decline over the 12-year interval since 1992, and 80 feet lower than the static water level measured in 1971.

Regular monitoring of the Mayo well indicated that, from 2002 to 2019, piezometric groundwater level rose by almost 100 feet. This rapid rise in static groundwater level in the Mayo well begins essentially with the cessation of pumping of municipal well LVP3 and parallels the rise of static groundwater level in LVP3 (**Figure 94. Hydrographs of LVP3 and Mayo well**). This rapid rise in water level in the Mayo well demonstrates how piezometric response can occur very quickly in a confined, fractured system with the area of influence encompassing Golden Valley. The location of municipal well LVP3 significantly affects the dynamic response of the confined bedrock fracture system aquifer and the rate at which natural discharge can be captured across Golden Valley. Piezometric response should not be construed as rate of flow of groundwater within the confined aquifer, which was calculated by Terraphase (2023) as ranging from 59 to 491 years for groundwater to travel across Golden Valley through the bedrock fracture system.

The rise of groundwater level in the Mayo well beginning about 2004 indicates a lag time of roughly 2 years after cessation of pumping of municipal well LVP3. Groundwater elevation in the Mayo well leveled off roughly 1 to 2 years after an interval of below-average precipitation that occurred in 2011 through 2014. A roughly 20-foot decline in water level in the Mayo well following 2019 may be due to several years of near- or below-average precipitation. No direct correlation is observed between water levels in the Mayo well and volumes of artificial recharge in Golden Valley, likely due to the amount of water injected annually and the distance between the Mayo well and the nearest recharge well.

A similar pattern is reflected by the Ariaz well (logs 12815 and 37614) located on Tamra Drive in the northern portion of Golden Valley (**Figure 95. Hydrographs of Ariaz, Mayo and LVP3 wells**). Static water level was at a depth of 112 feet when this well was initially drilled in 1972 and at 130 feet when the well was deepened in 1991. By 2002, static water level was measured at a depth of roughly 175 feet, with static water level rising to approximately 150 feet by 2014 and further rising to a depth of roughly 110 feet by 2020. Recharge to the Ariaz well from the granitic terrain along the northern margin of Golden Valley offset some of the impacts of pumping of LVP3.

Cause-effect relationships can also be recognized between phreatic groundwater levels and 1) precipitation as a source of natural recharge, 2) cessation of pumping in excess of natural yield by municipal wells SKY and CMOR, and, 3) to a lesser degree, construction of Medium Density Suburban developments which increased runoff (**Figure 96. Phreatic water level data for western wells 2002-2022).** Cessation of pumping of the SKY and CMOR municipal wells from the fractured andesites of Mount Peavine in 2002 allowed natural recharge from Peavine Inflow to flow eastward into Golden Valley. Consequently, phreatic water levels began rising by 2005, following a lag time of 2 to 3 years suggesting a rapid rate of response in an area that is semi-enclosed by the bedrock ridge associated with Estates Fault. This rapid rate implies good connection between bedrock fracture system and the overlying coarse-grained sediments. Runoff from the Medium Density Subdivision developments into Golden Valley Wash via the Marlin Ditch has increased since the early 2000s.

By 2021, phreatic groundwater levels had risen by 25 feet in Steadfield Estates wells. Phreatic groundwater levels, particularly in response to the second wettest water year on record in 2022/2023, have resulted in groundwater discharging to Golden Valley Wash (**Figure 97. Phreatic flow in Golden Valley Wash - 4 October 2023**).

SUMMARY AND CONCLUSIONS

By taking a synoptic view of all historical data within a chronological framework, the contributing factors and their relative importance to groundwater conditions in Golden Valley can be more clearly understood (**Figure 98. Timeline of groundwater use components**).

Groundwater conditions include both piezometric and phreatic water levels that are controlled by the bedrock fracture zones, the overlying valley fill, and the location of Estates Fault. The synoptic analysis of groundwater levels across the Golden Valley sub-basin indicates interactive impacts of:

- pumping of municipal wells in excess of perennial yield
- fluctuations in recharge from precipitation
- distribution and timing of artificial injection recharge
- location of Medium Density Suburban developments
- surface water runoff

While it is possible to compare groundwater conditions in Golden Valley with those described by Harrill (1973) as having existed under natural conditions, a return to such natural conditions is not feasible given the ongoing demands for water and the modifications that humans have wrought as development occurred over the past 50 years. Approved grading plans have altered the natural surface drainage by placement of engineered fill to raise surface grade of newer developments (e.g., Wild Stallion and Golden Mesa South), resulting in residents living above the floodplain and loss/reduction of the following floodplain functions:

- Abatement of kinetic energy of floodwaters to enhance infiltration and recharge
- Filtration of sediment, contaminants, and transported nutrients
- Reduction of flooding and limit flood-related damages through their floodwater conveyance and storage functions to keep erosion and siltation from occurring in the waterway
- Reduction of downstream and peak flooding

Piezometric groundwater conditions exist within Golden Valley generally east and north of Estates Fault:

- Thickest valley sediments with infiltration and percolation impeded by clay layers and lenses
- Static water level (SWL) varies with changes in hydrostatic pressure within the confined granitic bedrock fracture zones
- Most wells intercept water flow in bedrock fractures
- Inter-connected system of fractures with recharge primarily from precipitation
- "Rapid" response of hydrostatic water levels with lag times of a few years
- Municipal well LVP3 was pumped in excess of natural yield from fractured granite for more than 3 decades, causing not only steep drawdown through the Lemmon Valley Outflow channel, but also reducing hydrostatic pressure within the bedrock fracture system reflected in declining static groundwater levels across the northern and eastern portions of Golden Valley; cessation of pumping of LVP3 in the early 2000s resulted in rapid rise of static groundwater levels in the fracture flow system as hydrostatic pressure in the confined bedrock aquifer recovered

Phreatic groundwater conditions exist within limited areas of Golden Valley west of Estates Fault:

- Coarse-grained valley sediments 10 to 100 feet thick overlying fractured bedrock along topographically low areas adjacent to Golden Valley Wash
- Wells intercept saturated zone & bedrock fractures
- Inter-connected system of fractures in underlying bedrock & sediments with recharge primarily from Peavine Inflow and infiltration of surface runoff
- Some impacts of pumping of municipal wells (CMOR and SKY) that extracted water primarily from fractured andesitic bedrock prior to abandonment in the early 2000s
- "Rapid" response of water levels – lag times of less than 3 years

The Golden Valley Artificial Recharge Program proved viable as a pilot program and then provided beneficial functions with respect to groundwater resources particularly within the eastern portion of the valley:

- Offset below average precipitation of the 1990s and early 2000s
- Offset loss of loss of some hydrostatic pressure within the bedrock fracture system
- Fewer wells deepened across northern and eastern Golden Valley
- Facilitated recharge of static groundwater levels 2002 - 2016

Currently, groundwater levels and groundwater quality generally meet the needs of the more than 550 families who reside in Golden Valley. Under current climatic conditions, groundwater remains a viable resource to meet the needs of residents. Active injection of the Golden Valley Aquifer Recharge Program is currently suspended.

However, the future remains unknown. In this region of high seismic risk, several active faults in proximity to Golden Valley are capable of generating a major earthquake. In 1915, the M7.3 Pleasant Valley earthquake hit a largely rural area and caused minimal damage, but large increases and decreases were observed in the flow of springs and streams throughout northern Nevada. The impacts of that earthquake provide reason to be cautious of future seismic events and their potential impact on groundwater conditions within Golden Valley.

Policy and political decisions are unpredictable. Should the critical recharge zones for Golden Valley be adversely impacted by development, then the groundwater resource could be significantly diminished or lose viability. The steep slopes within the critical recharge zones are not readily amenable to development without substantial alteration of the natural grade that would further adversely impact recharge of the groundwater resource. The critical recharge zone in the ridges adjoining Golden Valley to the east and north could be subjected to the ravages of scarification of natural vegetation, regrading, and/or the imposition of impermeable surfaces.

Wildfires could denude the natural vegetation in the critical recharge zones. In the aftermath of wildfire, these areas of steeper slopes would be subject not only to debris flows or mudslides but also significantly decreased recharge.

While the Vidler Project offers substantial waters for the future growth of Lemmon Valley and the greater Truckee Meadows, there may come a time when demand once again exceeds the supply as residential and commercial/industrial growth are promoted. Municipal wells (including LVP3) and water rights are being maintained in Lemmon Valley by TMWA and could potentially be pumped. Future pumping of the existing well LVP3 or the drilling and pumping of new municipal wells in the southern portion of Lemmon Valley could once again impact Golden Valley groundwater resources by adversely reducing hydrostatic pressure within the bedrock fracture flow system. Reduced hydrostatic pressure would cause declining static groundwater levels within Golden Valley that would force residents to undertake the expensive task of deepening domestic wells, seeking to find another viable source of water, and/or resuming operation of the Golden Valley Artificial Recharge Program if potable waters supply can be obtained for groundwater injection.

The Golden Valley Artificial Recharge Program helped mitigate some of the adverse impacts of the excessive pumping of LVP3 on hydrostatic conditions across much of the northern and eastern portions of the Valley. The hydrograph of the Mayo well indicates that even in the southeastern portion of the Valley, excessive drawdown caused significant decline in static groundwater levels for more than 3 decades. The location of municipal well LVP3 significantly affects the dynamic response of the confined bedrock fracture system aquifer and the rate at which natural discharge can be captured across Golden Valley.

There is the potential for another below-average water year such as occurred in the winter of 1993-1994 that limited availability of potable water for diversion to the Golden Valley Recharge Program; only 5 acre-feet of water was injected in 1993. Should similar conditions recur in the future then the availability of water under existing agreements and permits will need to be considered. If history is any indication, then water years with less-less-average precipitation resulting in the Truckee River running dry are not frequent and are of limited duration.

A number of questions and future uncertainties remain. Would recharge injection into the bedrock fracture zones have resulted in greater benefit? Would an alternative system for recharge [e.g., additional well(s), singular rather than sequenced injection wells, or infiltration gallery] be more effective? Perhaps these questions might be answered with additional studies and groundwater modeling.

Several models have been developed for the Lemmon Valley/Golden Valley (Pohll 2017, 2019; Terraphase 2023). Models are intended to mimic real world conditions. No model can capture all the complexities and intricacies of the real-world conditions (e.g., lithologic variations in valley fill, bedrock fracture system, short-term weather, and long-term climate). Synoptic analysis of groundwater conditions over time within Golden Valley confirms the variations in groundwater conditions that are influenced by the location of Estates Fault, recharge within the granitic terrain on the eastern and northern margins of the valley and recharge from Mount Peavine. The location and pumping history of municipal wells in the southern portion of Lemmon Valley impacted both piezometric conditions within the bedrock fracture system across the entire valley and phreatic conditions in valley fill in the western portion of the valley. Municipal wells SKY and CMOR extracted groundwater from fractures primarily in the andesitic volcanic rocks of Mount Peavine; municipal well LVP3 extracted groundwater from fractures in the granitic rocks that extend eastward underlying Golden Valley.

But the models do indicate trends that can be compared with historically measured water levels. The added value of the Terraphase (2023) modeling is the recognition and incorporation of some impacts of the municipal wells in southern Lemmon Valley on static water levels in Golden Valley. These models incorporated hydro-stratigraphic layers, water budgets for the interval 1991 through 2001, and applied finite difference grids within graphical user interface software programs and MODFLOW-2005. These models predicted trends that are generally consistent with time-sequence analysis of hydrographic data based on historically measured water levels. But predicted water levels may differ by several tens of feet from measured values which can be significant depending on well depth.

On 14 November 2023, the Washoe County Board of County Commissioners adopted Resolution R23-149 to suspend the Golden Valley Artificial Recharge Program (Program) participant fee collection from January 1, 2024, through December 31, 2033. This Resolution continues Program activities in support of the maintenance of the State of Nevada Division of Water Resources injection permit performed pursuant to Washoe County Ordinance 1548 and requires all Program participants to bring any past due accounts current through the processes identified in Ordinance 1548. This Resolution allows for Washoe County to continue monitoring groundwater conditions and maintain necessary permits and water rights for the Golden Valley Artificial Recharge Program.

Historical data confirms that the Golden Valley Artificial Recharge Program cannot fully compensate for significant loss of hydrostatic pressure in the fractured bedrock aquifer system. And it is unlikely that the Recharge Program could fully compensate for significant loss of groundwater recharge from the local granitic terrain to the bedrock fracture system.

Periodic re-evaluation of groundwater resources will be required to assess groundwater levels and groundwater quality within Golden Valley. Groundwater modeling that incorporates this long-term conceptual understanding of both hydrostatic pressure and quantity of groundwater in the confined bedrock fracture system aquifer as well as the structural components within Golden Valley will play an important role in evaluating future conditions and the potential for reactivation of the Golden Valley Artificial Recharge Program to augment groundwater resources. Continued use of groundwater as a resource within Lemmon Valley (and the Golden Valley sub-basin) should prioritize sustainability in terms of groundwater quality and quantity, as well as hydrostatic pressure within the confined bedrock aquifer to ensure long-term availability of groundwater for domestic use by the more than 550 families living in Golden Valley.

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TABLES

Table 1. Modified Mercalli Intensity Scale & Richter Magnitude

Mercalli Intensity	Observations of Impacts	Approximate Richter Magnitude Equivalent
I	Instrumental - No effect observed	1 to 2 Micro EQ
II	Weak shaking - Noticed only by sensitive people; delicately suspended objects may sway	2 to 3 Minor EQ
III	Slight shaking - Felt noticeably indoors, but not always recognized as an earthquake; Resembles vibrations caused by heavy traffic	3 to 4 Minor EQ
IV	Moderate shaking - Felt indoors by many, outdoors by a few. May awaken some people. May be felt by people walking; rocking of free-standing objects; dishes, windows may rattle.	4
V	Rather strong shaking - Felt by most people; sleepers awakened. Some breakage of dishes, windows and plaster; tall objects disturbed; bells ring	4 to 5 Light EQ
VI	Strong shaking - Felt by all; many frightened and run outdoors; falling plaster and chimneys; trees sway; some damage from falling objects	5 to 6 Moderate EQ
VII	Very strong shaking - General alarm, almost everybody runs outdoors; damage to buildings varies depending on quality of construction; cracking of walls; noticed by drivers of vehicles.	6
VIII	Destructive shaking - Panel walls thrown out of frame; walls, monuments and chimneys fall and some damage to building. Drivers of autos disturbed; sand and mud ejected by liquefaction	6 to 7 Strong EQ
IX	Violent shaking - Buildings shift off foundations, cracked and thrown out of plumb. Ground crack, houses begin to collapse, pipes break	7
X	Intense shaking - Most masonry and frame structures destroyed. Ground badly cracked, rails bent. Some landslides	7 to 8 Major EQ
XI	Extreme shaking - Few buildings remain standing, bridges destroyed. Fissures in the ground, pipes broken, landslides, rails bent	8
XII	Catastrophic shaking - Total destruction, objects thrown in air, shaking and distortion of ground, waves seen on ground surface. Lines of sight and level distorted, objects thrown up into the air	>8 Great EQ

Table 2. Notable Historic Earthquakes Impacting Western Nevada

Event	Date	Magnitude	Description
Pyramid Lake fault zone	Circa 1851-1852	7.0 (estimated)	Ground cracks, water spouts up to 100 feet high, ground shaking and large landslide on Slide Mountain. Liquefaction & stream bank failures.
Reno	1860 – 15 March	6.5	Rock slides reported between Pyramid Lake & Carson City. General panic. Felt from Pyramid Lake to Genoa.
Virginia City	1868 – 30 May	6.0	Plaster knocked off almost every building in Virginia City. Brick buildings cracked. Flow at Steamboat Springs turned from hot water to hot mud. Felt at Austin, Humboldt & Reno.
Virginia City – NW	1869 – 26 & 27 December	6.4 & 6.2 occurred about 8 hours apart	Severe damage to masonry walls in Virginia City & Washoe City. Some damage in Carson City. Clocks stopped in Reno. Large rocks rolled onto railroad tracks between Reno & Wadsworth. Increased steam emitted at Steamboat Springs.
Reno – 3 km SSE	1914 – 18 February	6.0	Large cracks in structures. Some fires. Foreshock of April 1914 EQ. Strong shaking in Reno & Sparks lasting 10 to 11 seconds. In Reno, cracked walls, broken windows, building firewall crashed to street. Cracked plaster at Reno Courthouse.
Reno – 3 km SSE	1914 – 24 April	6.4	Largest EQ in US in 1914. Damage from Reno to Winnemucca. 5 overnight aftershocks. Major damage. Chimneys toppled at UNR. Broken windows & wall plaster. Shaking travelled through Reno in SW to NE direction. Numerous aftershocks.
Pleasant Valley – Tobin Range	1915 – 2 October	7.3	Range-front scarp 35-37 miles long, ground surface rupture and offset vertically by up to 19 feet, average vertical displacement of 6 feet. Partially & totally collapsed structures in epicentral area. Chimneys demolished above rooflines. Water tanks thrown down. Mine tunnels collapsed at Kennedy gold camp. Shaking lasted 40 to 55 seconds over most of northern Nevada. Largely uninhabited area, minimal property damages. Large increase (and decrease) in flow of springs and streams throughout northern Nevada.

Event	Date	Magnitude	Description
Cedar Mountain	1932 – 20 December	7.1	Near southern end of Central Nevada seismic belt. Strike-slip motion with more than 8-foot offset. Lightning bolts observed. 46 miles discontinuous surface ruptures (60 *en echelon* rifts). Few stone cabins collapsed in largely uninhabited area. Boulders shaken from cliffs and hillsides. Chimneys damaged in Fallon. Ore-treating plants and mines were damaged. People in Virgina City, Caron City, Reno and Sacramento California rushed into streets. Man suffered skull fracture. M6.1 to M6.4 aftershocks.
Verdi	1948 – 29 December	6.0	36 hours of foreshocks. Brick walls fell, chimneys twisted. Cracked plaster & windows, foundation damage to homes in Verdi. Chimneys fell and broke, concrete & plaster cracked in Reno. 75 buildings damaged.400 aftershocks over 3.5 months. Reportedly did not stop the whirling roulette wheels.
Stillwater (Rainbow Mountain) – 17 km ESE of Fallon Station	1954 – 6 July to 25 August	6.2 to 6.6	Earthquake sequence. Damaged nearby dams, irrigation facilities, roads & buildings. Liquefaction in Newlands Project canal system. Ground surface ruptures totaling 11 miles in length in July. 33 miles of surface rupture with maximum 3 ft right-lateral slip in August. 3 building structurally compromised in Fallon had to be torn down. Water mains were broken. Obliterated remedial work on canal system.
Fairview Peak – east side of Dixie Valley	1954 –16 December	7.3	Largest main shock. Surface ruptures extended 40 miles with both dip-slip and right-lateral strike-slip movement up to 4.5 meters. Numerous landslides, rockfalls & mudflows. Cracks & toppled chimneys in towns.
Dixie Valley – west side of Valley	1954 – 16 December	6.9	Large surface ruptures extending 29 miles with normal dip-slip offsets. This aftershock followed Fairview Peak 7.3 event by 4 minutes. Walls & chimneys cracked as far away as Carson City. Water lines broken in Lovelock, Mina & Gabbs.

Table 3. LOMA & LOMR for Golden Valley

Designation	Reference #	Effective Date
LOMA	19-09-2169A	10/7/2019
LOMA	23-09-0722A	5/19/2023
LOMA	20-09-1978A	9/25/2020
LOMA	16-09-1500A	4/29/2016
LOMA	08-09-0914A	5/20/2008
LOMR	17-09-1979A	7/6/2018

Table 4. Municipal Well Data

Table 24.--Selected well data--Continued

(Harrill 1973)

Location	Owner or name	Year drilled	Depth (feet)	Diameter (inches)	Use	Yield (gpm) /drawdown (feet)	Land surface altitude (feet)	Water-level measurement Date	Water-level measurement Depth (feet)	Remarks
20/19 - 4ddac aka LVP3	Lemmon Valley Land Co.	1963	296	8	PS	440/	4,882	1963	60 R	SLN 7830
20/19 - 15bcda aka CMOR-1	C-Mor Trailer Park	1961	217	8	PS	(60) / 113	5,139	7 - - 61 11 - 5 - 71	67 R 89.31	SLN 6126
20/19 - 15bcdc aka CMOR-2	C-Mor Trailer Park	1963	408	10	PS	300 / 67	5,150	8 - - 63 4 - 13 - 71 6 - 11 - 71 8 - 9 - 71 11 - 4 - 71	125 R 160.88 164.90 164.10 166.19	SLN 7534

Table 5. Static Water Levels LVP3

Date	Depth To Water (Feet)	SWL Elevation (Feet)
1/16/1963	60	4822
5/11/1982	163.06	4718.94
6/12/1988	133	4749
1/18/2001	95.91	4786.09
2/18/2001	115.38	4766.62
3/13/2001	125.62	4756.38
4/15/2001	135.19	4746.81
5/14/2001	145.6	4736.4
6/14/2001	151.49	4730.51
7/15/2001	159.22	4722.78
8/20/2001	168.38	4713.62
9/17/2001	172.68	4709.32
10/16/2001	172.36	4709.64
11/19/2001	171.8	4710.2
12/16/2001	160.89	4721.11
1/6/2002	159.9	4722.1
2/3/2002	158.75	4723.25
3/4/2002	161.35	4720.65
3/31/2002	167.42	4714.58
5/5/2002	177.36	4704.64
6/2/2002	162.58	4719.42
7/15/2002	194	4688
8/4/2002	195.88	4686.12
9/2/2002	181.7	4700.3
10/6/2002	205.15	4676.85
11/3/2002	201.38	4680.62
12/1/2002	197.5	4684.5
1/12/2003	150.11	4731.89
2/10/2003	123.2	4758.8
3/2/2003	124.5	4757.5
4/6/2003	143.5	4738.5
5/4/2003	128.8	4753.2
6/8/2003	203.5	4678.5
7/13/2003	135.5	4746.5
8/3/2003	140.8	4741.2
9/7/2003	138.57	4743.43
10/5/2003	137.3	4744.7
11/9/2003	119.6	4762.4
12/18/2003	105.87	4776.13
1/19/2004	96.5	4785.5
2/1/2004	92.8	4789.2

2/29/2004	88.5	4793.5
4/5/2004	87.5	4794.5
5/3/2004	95.15	4786.85
6/1/2004	95.3	4786.7
7/11/2004	100.43	4781.57
8/2/2004	92.2	4789.8
9/8/2004	90.7	4791.3
10/4/2004	100.7	4781.3
10/31/2004	92.46	4789.54
12/5/2004	64.9	4817.1
1/9/2005	63.2	4818.8
2/6/2005	49.3	4832.7
4/24/2005	16.46	4865.54
5/16/2005	16.51	4865.49
6/29/2005	23.51	4858.49
8/15/2005	36.65	4845.35
2/20/2006	13	4869
3/12/2006	11.6	4870.4
4/2/2006	10.2	4871.8
1/21/2015	19.63	4862.37
2/8/2015	19.84	4862.16
3/9/2015	16.13	4865.87
4/28/2015	24.53	4857.47
5/10/2015	29.62	4852.38
6/3/2015	26.33	4855.67
6/30/2015	28	4854
8/6/2015	21.56	4860.44
9/22/2015	28.52	4853.48
10/21/2015	28.55	4853.45
11/30/2015	17.31	4864.69
12/29/2015	15.9	4866.1
2/22/2016	12.25	4869.75
3/30/2016	14.77	4867.23
4/27/2016	15.46	4866.54
5/25/2016	17.5	4864.5
6/22/2016	62.68	4819.32

Table 6. Groundwater Chemistry 1980-1983, 1998, 2001, and 2021

	Concentration in ppm 1980-1983 (Cochran et al 1984)		Lemmon Valley #3 (DWR 1998 & 2001)		Monitoring Well GV3 (Washoe County 2021)
Constituent	**Mean**	**Standard Deviation**	**1998**	**2001**	**2021 (range*)**
Total Dissolved Solids	291.5	96.51	237	237	420-530
Calcium (Ca)	41.8	16.6	31	31	66 - 79
Magnesium (Mg)	17.7	7.33	17	17	25 - 35
Sodium (Na)	26.9	8.2	20	20	22 - 24
Potassium (K)	3.67	1.54	4	4	3.3 - 3.8
Iron (Fe)	0.292	0.469	0.01	0.01	<0.05 - <0.10
Manganese (Mn)	0.11	0.299	0.1	0	<0.002 - <0.010
Sulfate (SO4)	48.1	55.9	56	56	36 - 41
Chloride (Cl)	17.6	12.5	14	14	88 - 92
Nitrate (NO3)	10.7	9.25	2.7	6.2	10.0 - 14
Carbonate (HCO3)	193.5	46.6	147	147	130 - 160
Fluoride (F)	0.203	0.078	0.13	0.1	<0.1 - <0.30
Arsenic (As)	0.001	0.004	<0.003	<0.003	0.002 - <0.005
Alkalinity (pH)	7.61	0.287	7.7	7.7	7.32 - 7.68

* Range for 21 January, 27 May, 28 July and 8 November 2021

Table 7. Volumes of Injected Water

Year	GVI-1	GVI-2*	GVI-3	GVI-4	GVI-5	Total
1993	17.44	8.17	0.86	0	0	26.47
1994	3.2	1.95	0	0	0	5.15
1995	23.97	7.48	1.06	11.81	0	44.32
1996	17.75	0	4.26	40.88	0	62.89
1997	11.86	0	2.38	35.94	0	50.18
1998	0	0	0	13.98	0	13.98
1999	0	0	0	0	0	0
2000	0	0	0	0	0	0
2001	0	0	0	0	0	0
2002	2.3	0	0	9.96	0	12.26
2003	11.51	0	5	36.84	10.36	63.71
2004	18.06	0	5.51	43.07	7.99	74.63
2005	17.62	0	6.41	41.94	6.58	72.55
2006	17.29	0	5.96	38.84	6.14	68.23
2007	18.22	0	5.52	39.02	5.6	68.36
2008	18.2	0	4.95	35.8	4.68	63.63
2009	15.15	0	3.96	29.57	3.58	52.26
2010	15.84	0	4.09	31.86	3.51	55.3
2011	9.134	0	2.017	20.02	5.027	36.198
2012	17.977	0	3.815	35.471	8.449	65.712
2013	30.067	0	3.75	40.221	6.7	80.738
2014	25.59	0	2.91	34.84	5.36	68.7
2015	26.08	0	3.24	36.85	5.05	71.22
2016	6.88	0	0.93	10.56	1.49	19.86
Total	**324.138**	**17.6**	**66.622**	**587.472**	**80.516**	**1076.348**

***GVI-2 abandoned in 1995 due to leak in sanitary seal – replaced by GVI-4.**

FIGURES

Figure 1. Golden Valley, Nevada

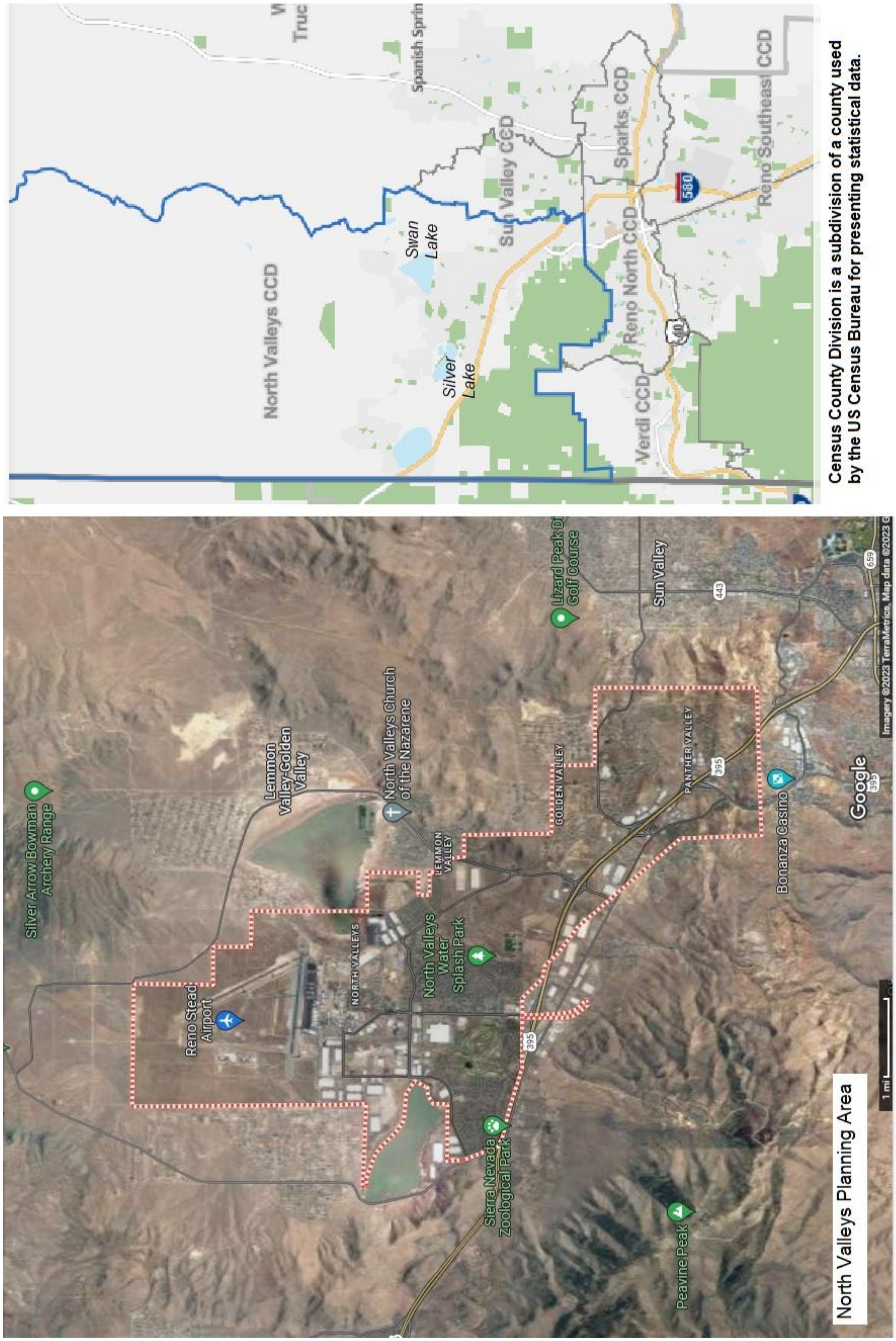


Figure 2. North Valleys in Washoe County, Nevada

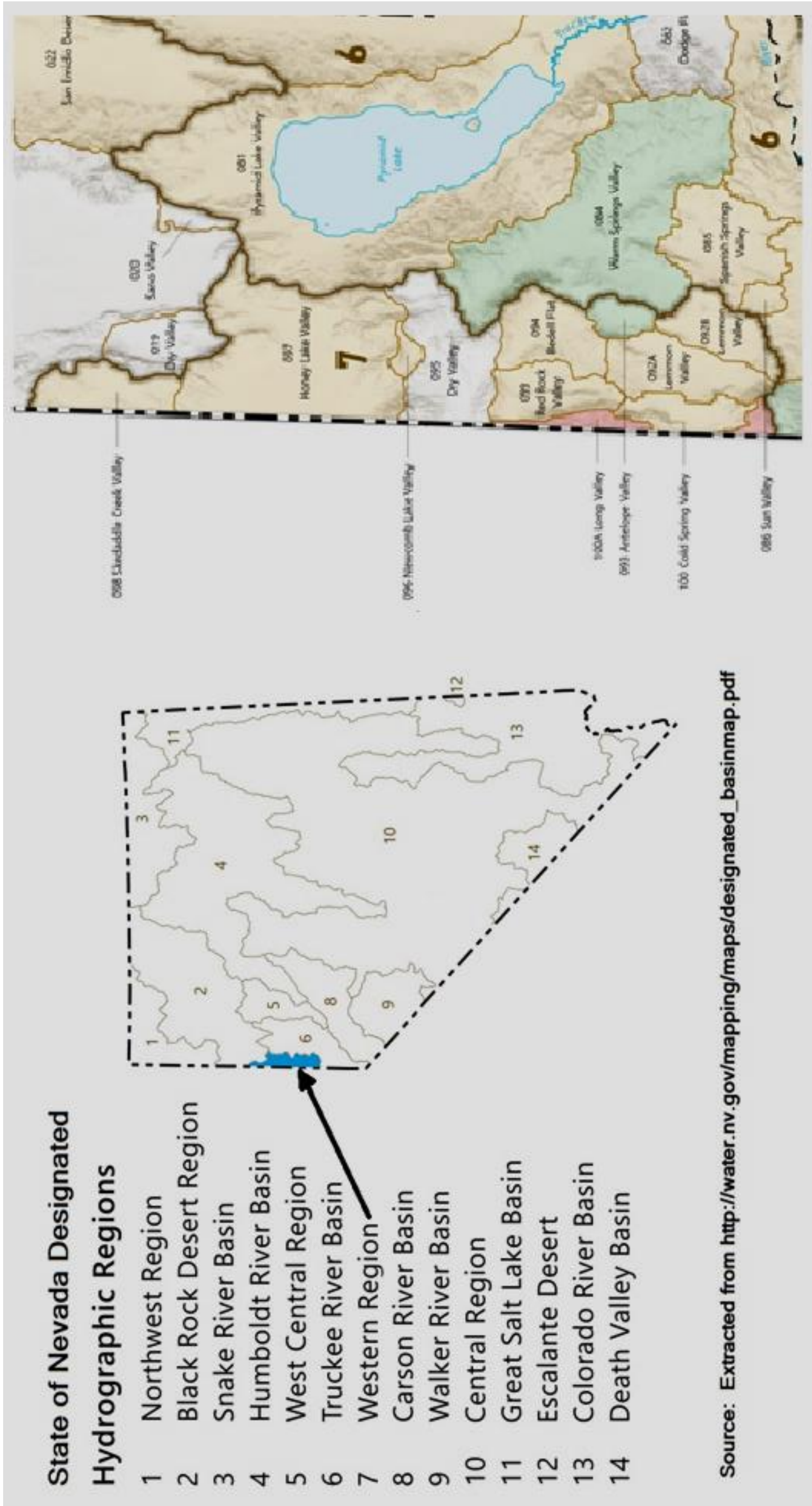


Figure 3. Designated hydrographic regions in Nevada

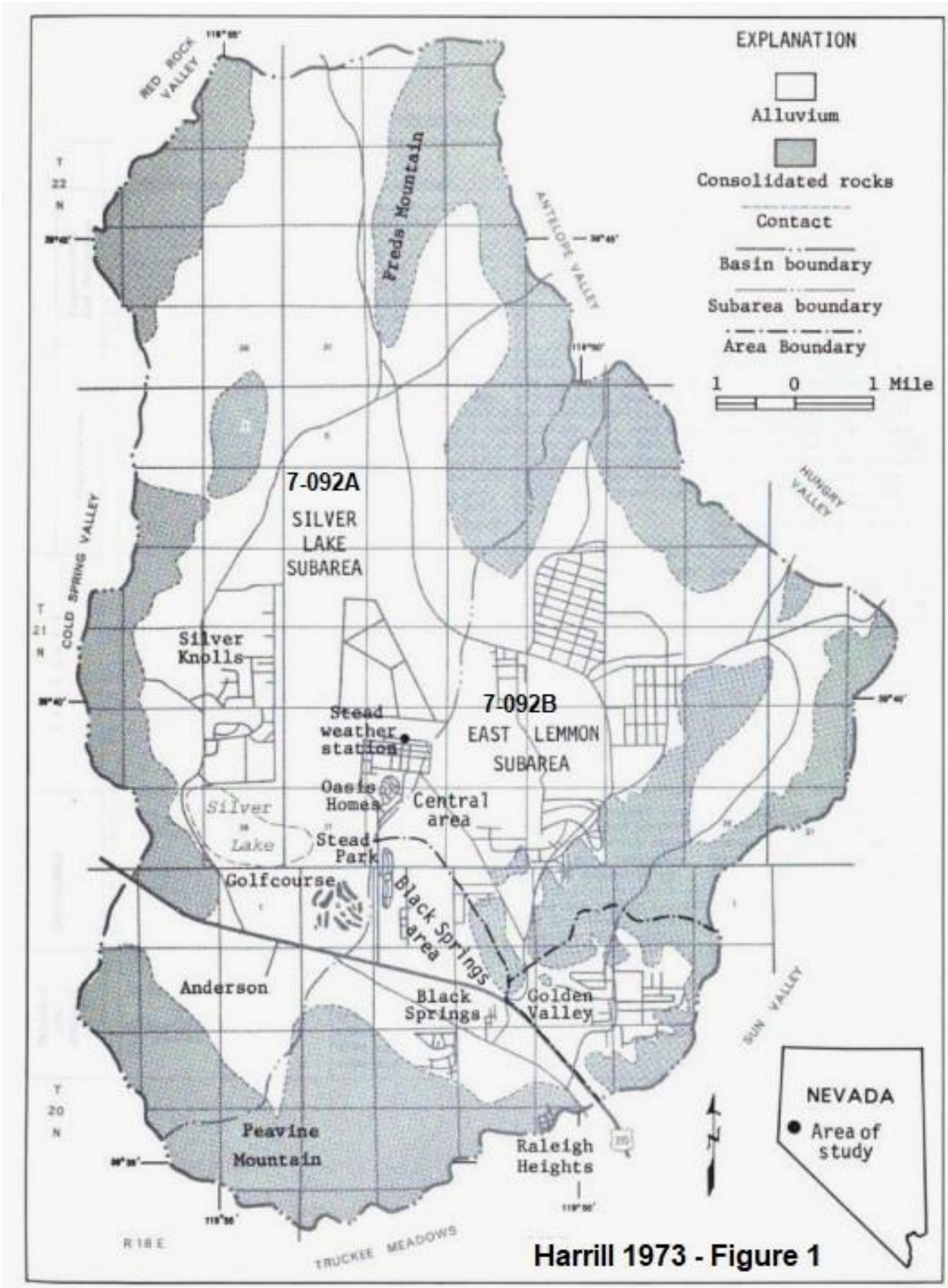


Figure 4. Designated hydrologic sub-basins within Lemmon Valley

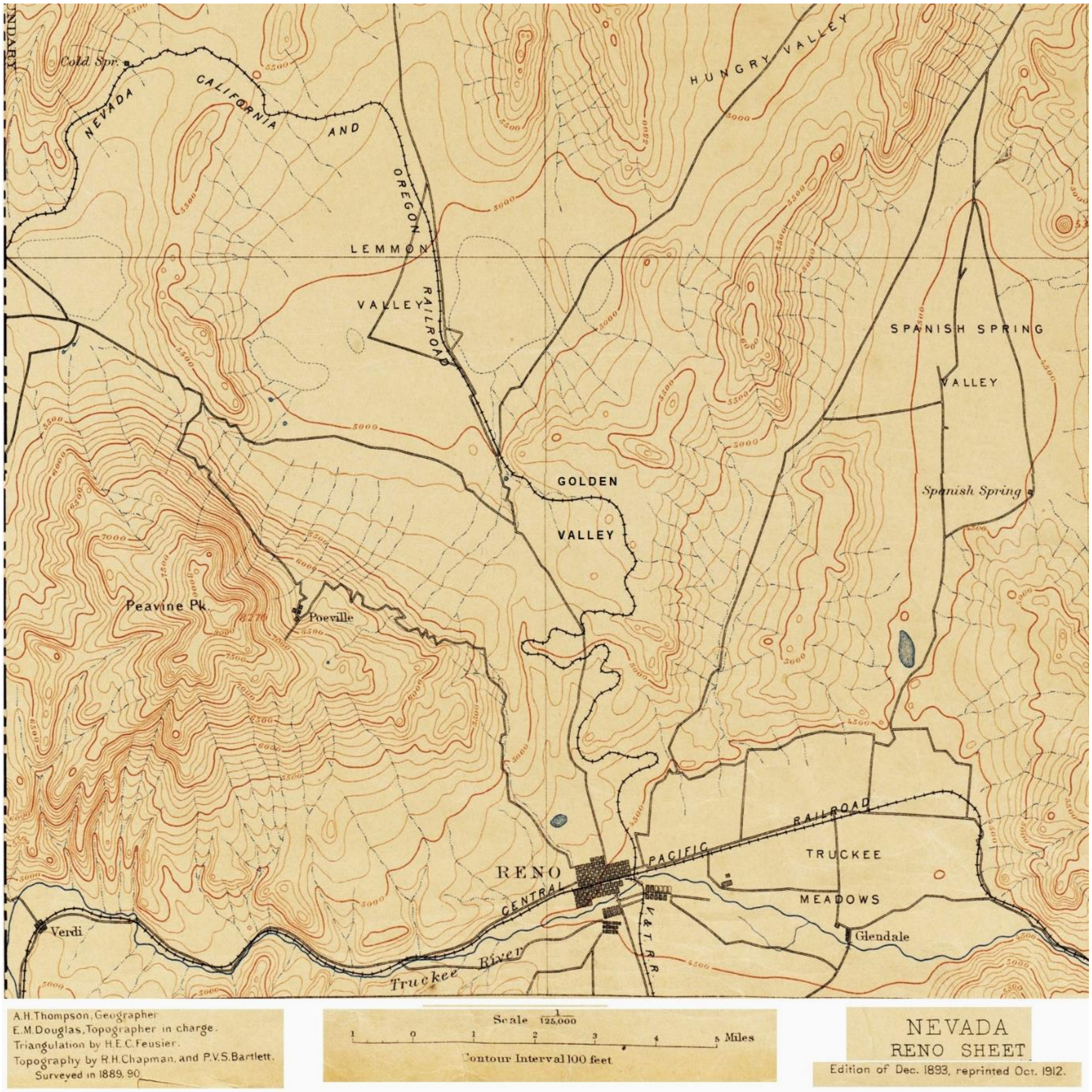
Study area of Harrill 1973 and Cochran et al 1986

Golden Valley Model Domain
Pohll 2017 - Figure 8

Aquifer Recharge Program Boundary
and Model Domain.
Terraphase 2023 - Figure 1

Figure 5. Study area and model domain boundaries

Figure 6. Basin and Range Physiographic Province



Extracted from: https://maps.lib.utexas.edu/maps/topo/nevada/txu-pclmaps-topo-nv-reno-1890.jpg

Figure 7. 2-degree topographic map for Lemmon and Golden Valleys - 1890

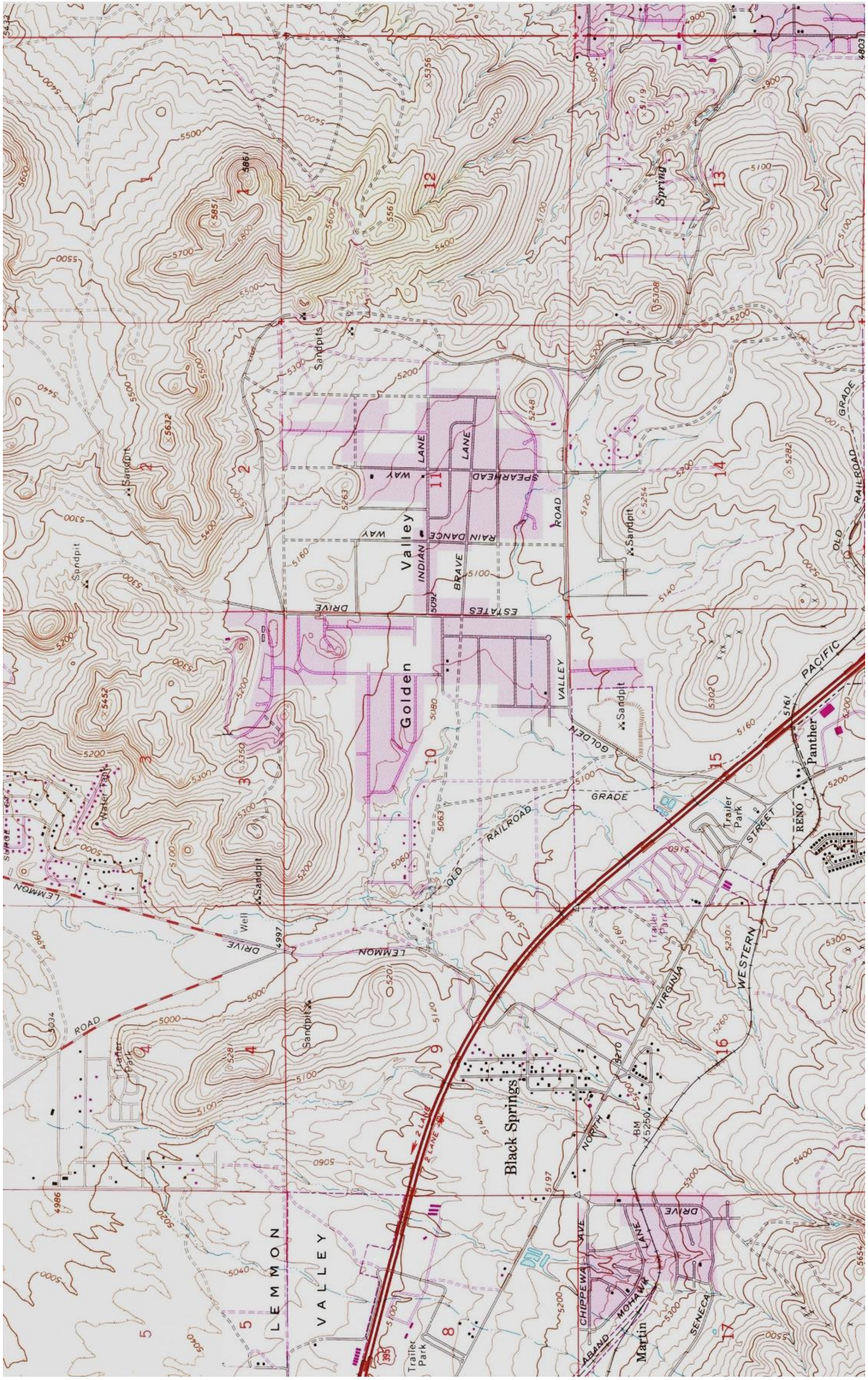


Figure 8. 15-minute topographic map for Golden Valley - 1967

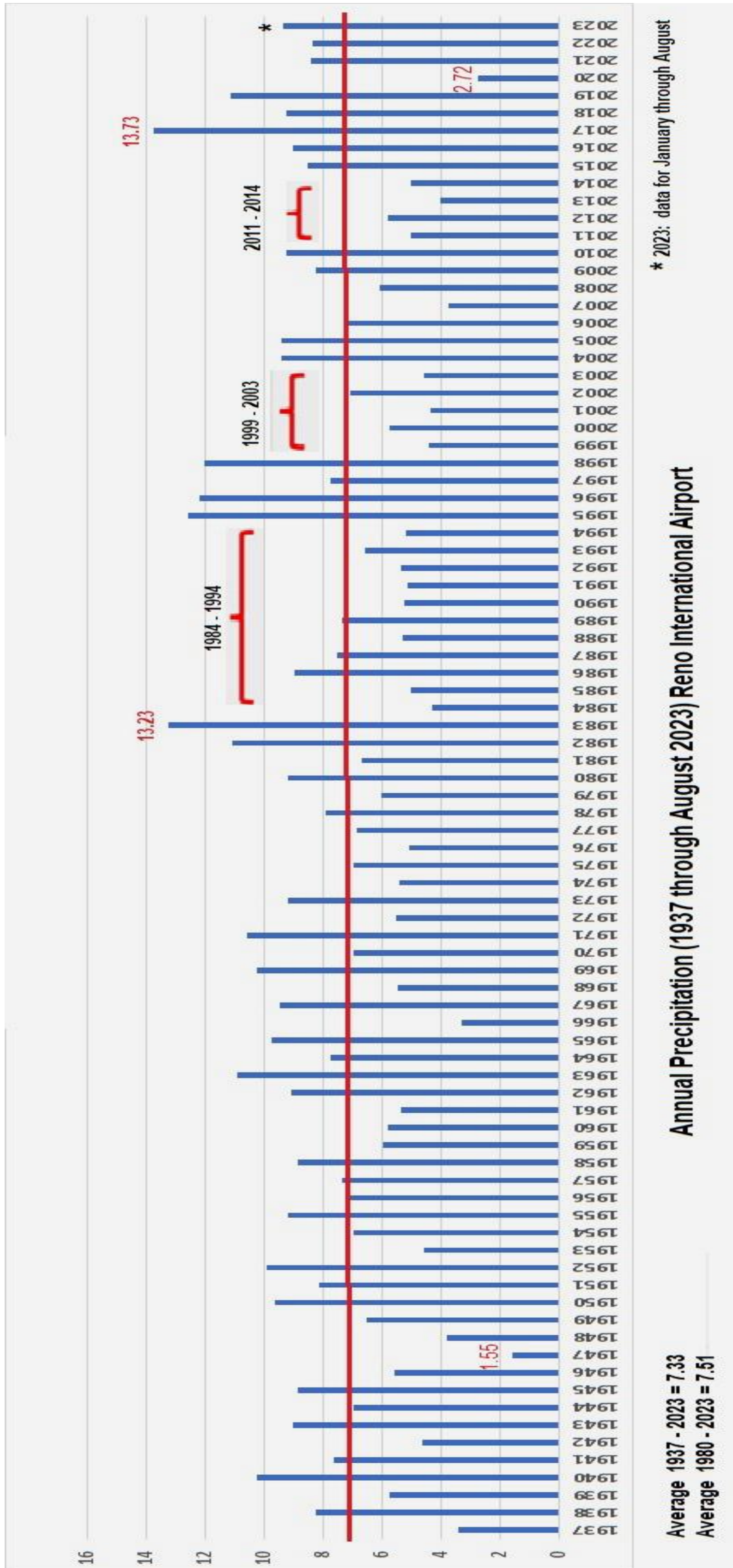
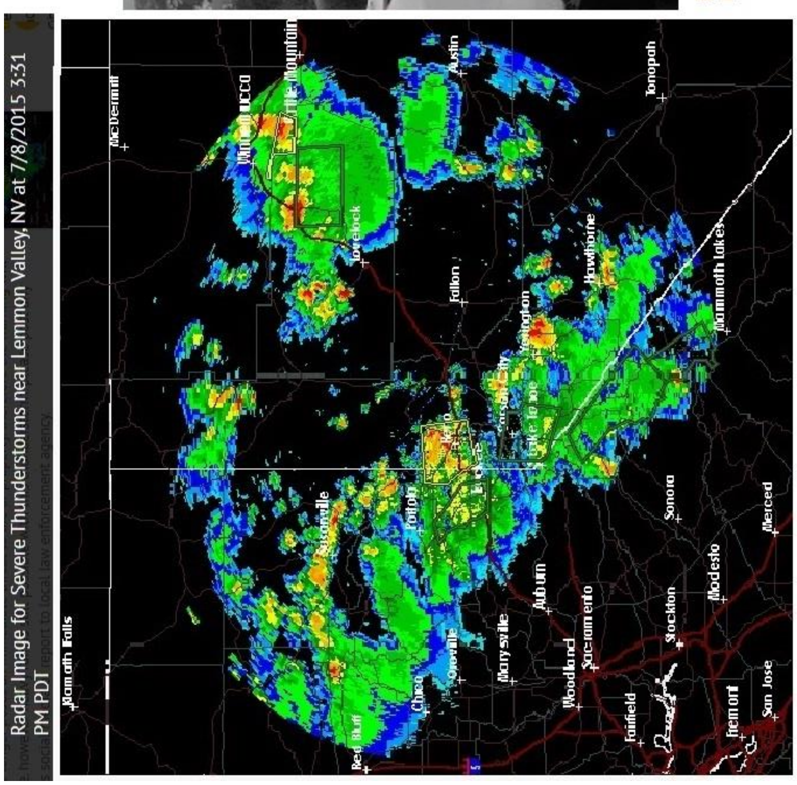


Figure 9. Precipitation Record for Reno International Airport 1937-Aug 2023

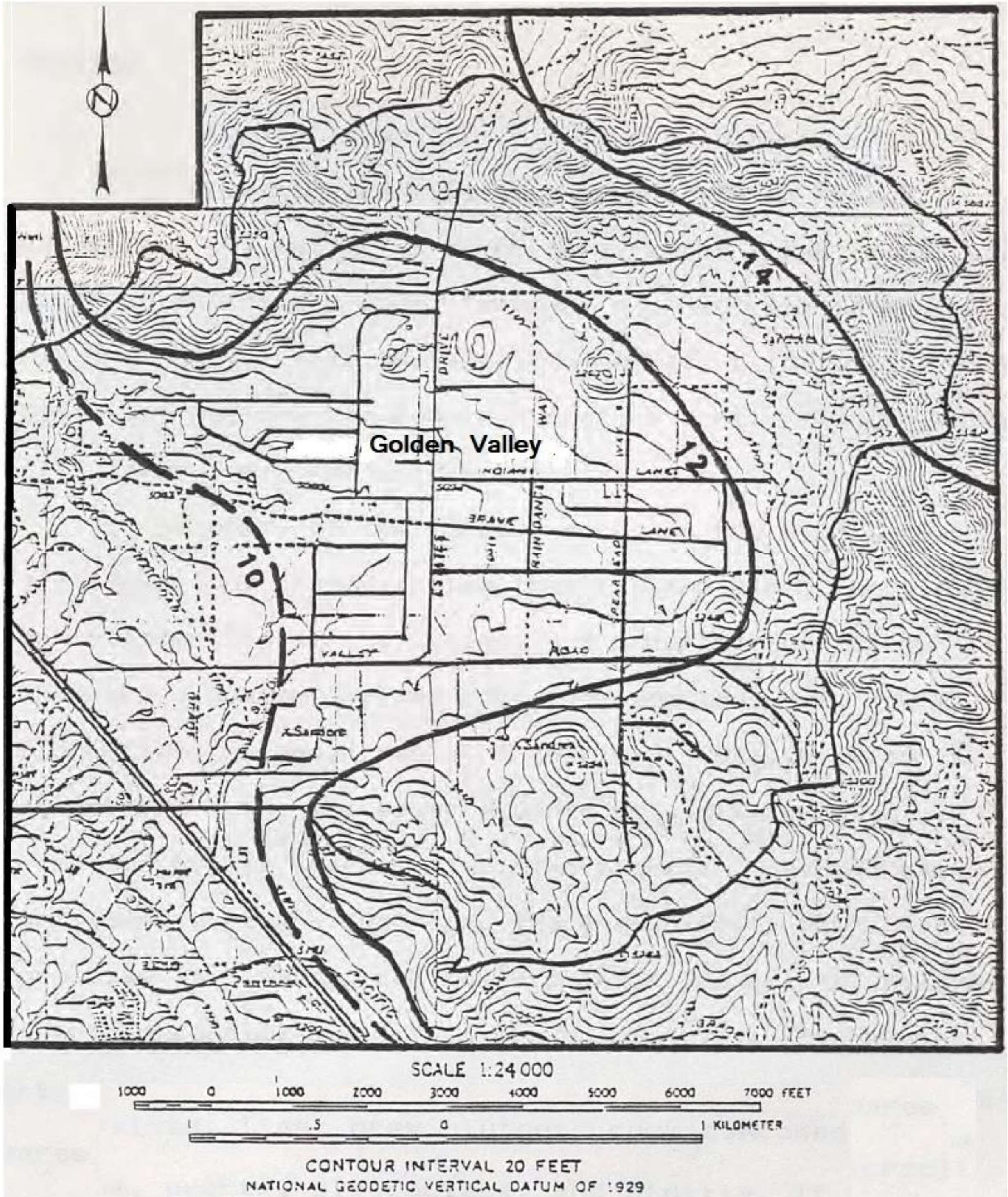


Thunderstorm hazards in Golden Valley included 60+ mph winds and quarter-sized hail that accumulated to several inches in depth.

https://www.interactivehailmaps.com/local-hail-map/lemmon-valley-nv/#prettyPhoto/2/

Plowable Hail Piles Up in Western Nevada - May 06, 2016
https://weather.com/science/weather-explainers/news/hail-piles-up-on-some-nevada-roads

Figure 10. Thunderstorms have produced quarter-sized hail



Source: Barry 1985 after Kleiforth 1982

Figure 11. Isohyets of average inches precipitation per year for Golden Valley

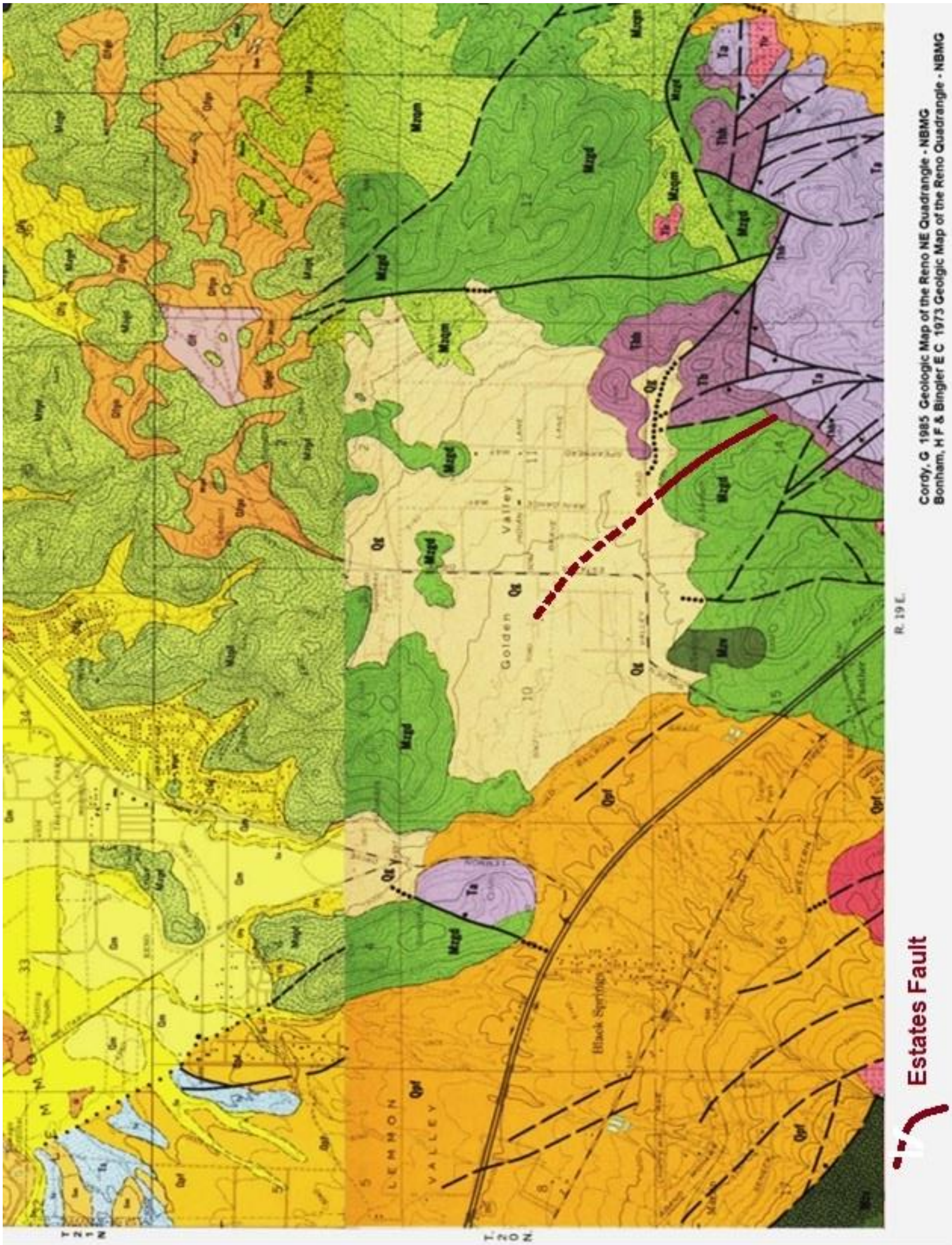


Figure 12. Geologic Map of Golden Valley and immediate vicinity

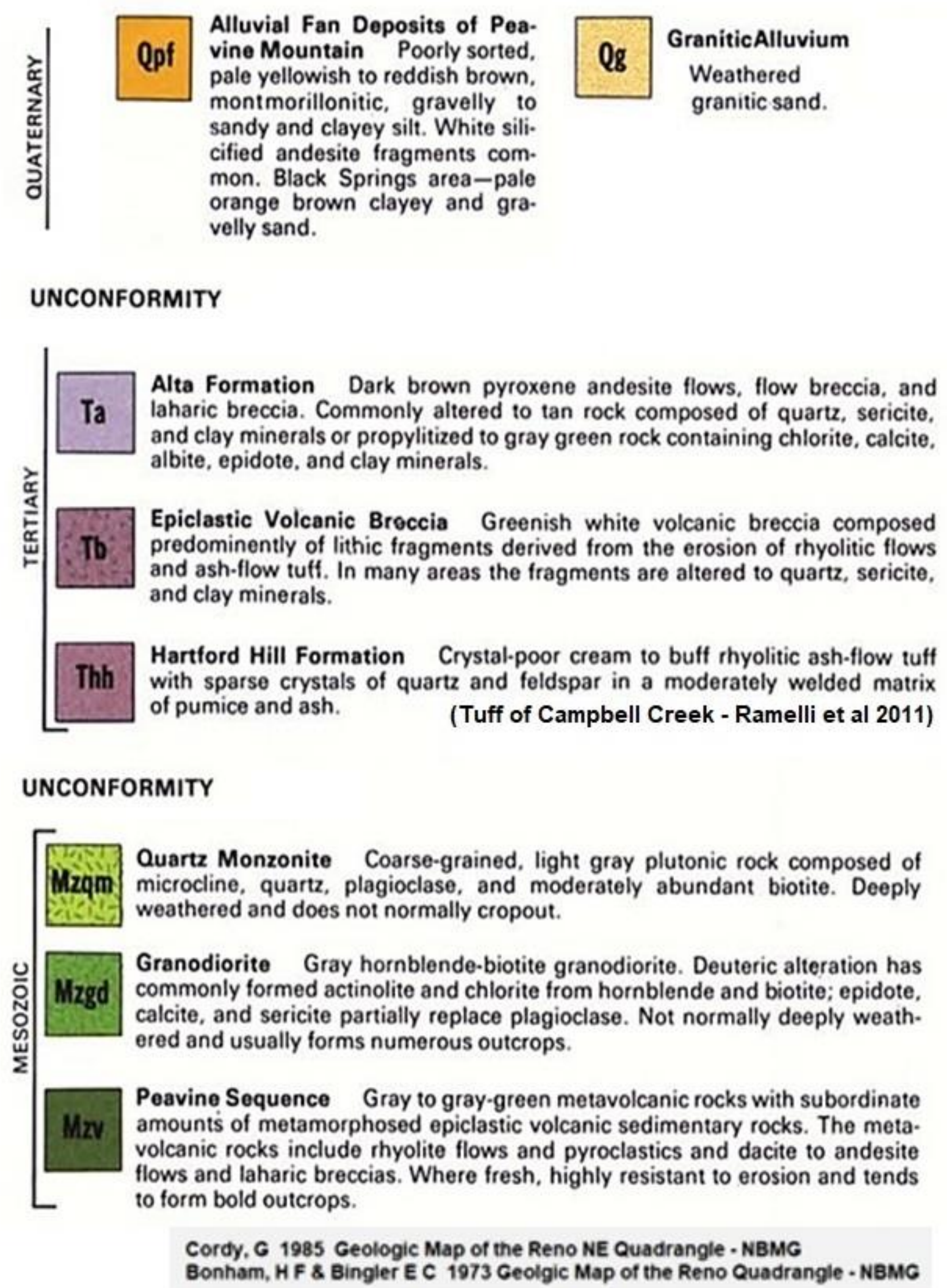
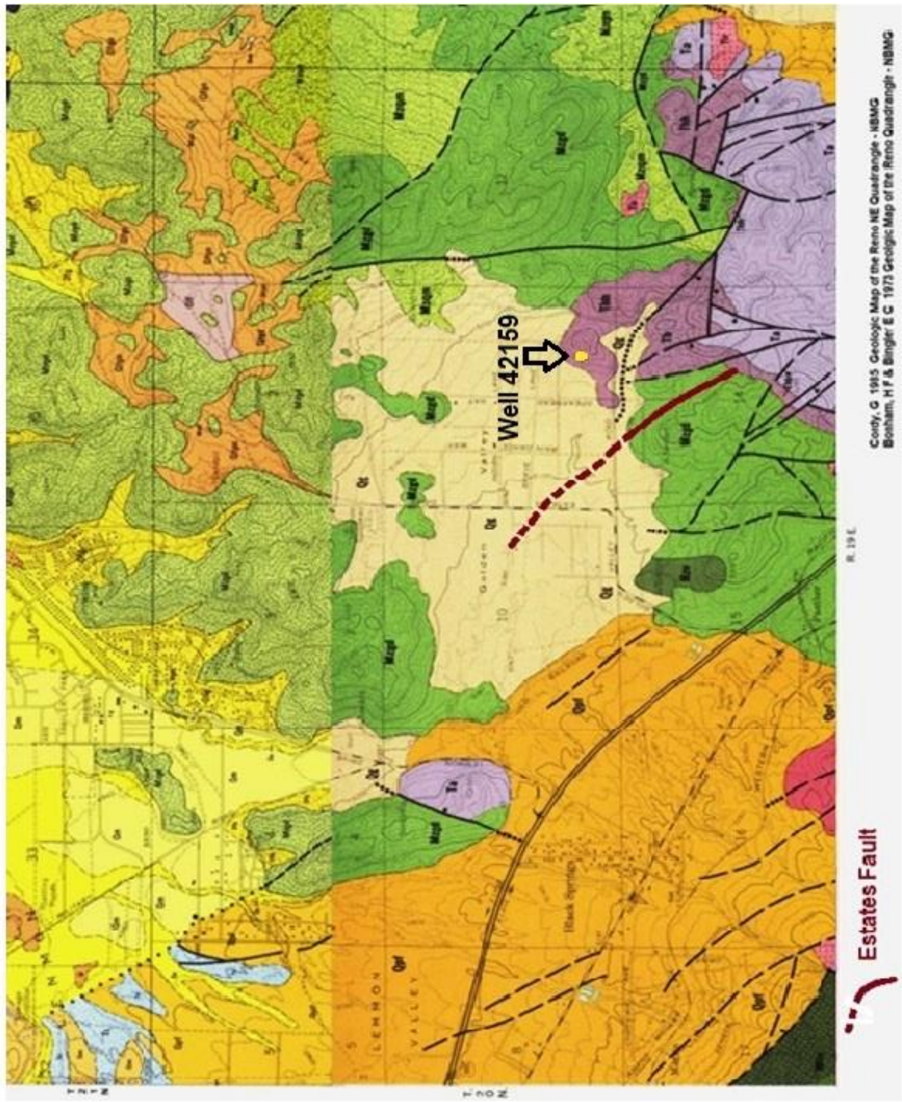
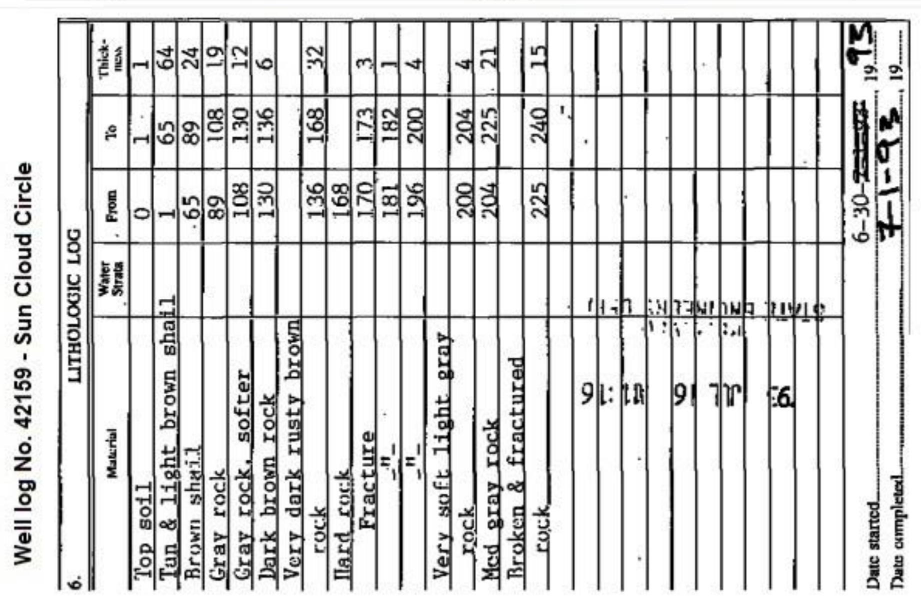


Figure 13. Geologic map legend





Well log No. 42159 - Sun Cloud Circle

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
Top soil		0	1	1
Tan & light brown shail		1	65	64
Brown shail		65	89	24
Gray rock		89	108	19
Gray rock, softer		108	130	12
Dark brown rock		130	136	6
Very dark rusty brown rock		136	168	32
Hard rock		168		
Fracture		170	173	3
"		181	182	1
"		196	200	4
Very soft light gray rock		200	204	4
Med gray rock		204	225	21
Broken & fractured rock		225	240	15

Date started 6-30-93

Date completed 7-1-93

Figure 14. Comparison of drill log and geologic map

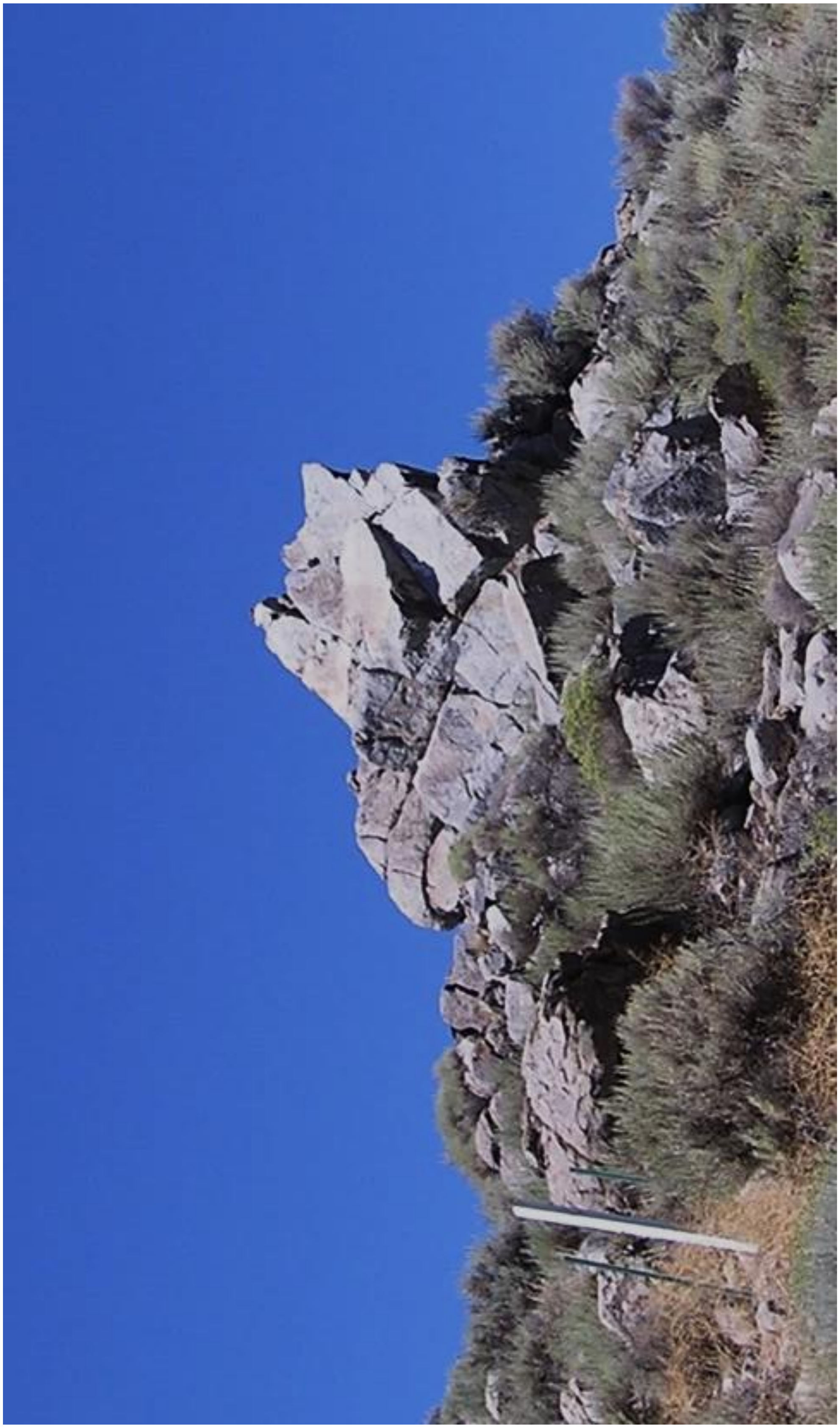


Figure 15. Outcrop of granodiorite in northern Golden Valley

Figure 16. Golden Valley Aggregate Pit

Figure 17. Outcrop of Hartford Hill/Tuff of Cambell Creek volcanics

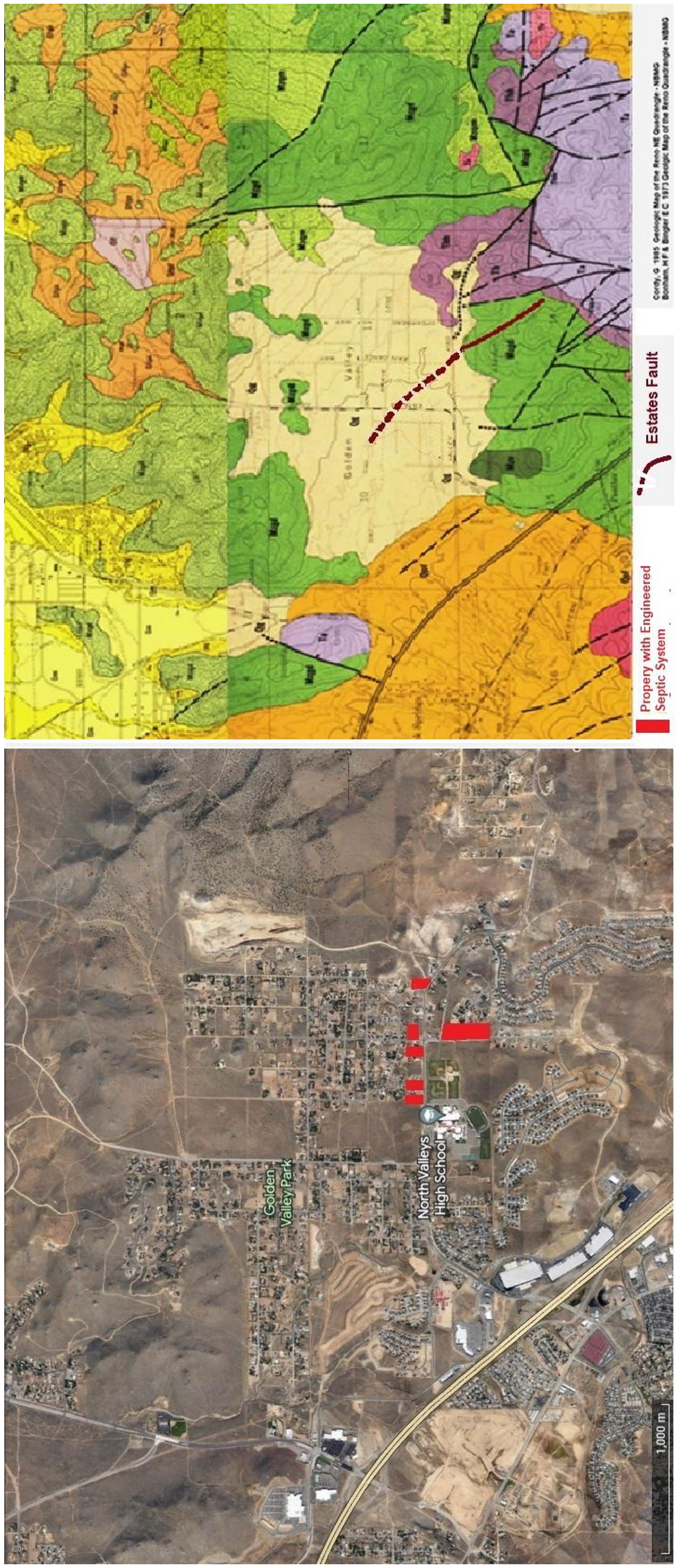


Figure 18. Engineered septic systems in volcanic terrain

Figure 19. Outcrop of Peavine volcanics

Figure 20. Pluvial Lake Lahontan as delineated by Russell 1885

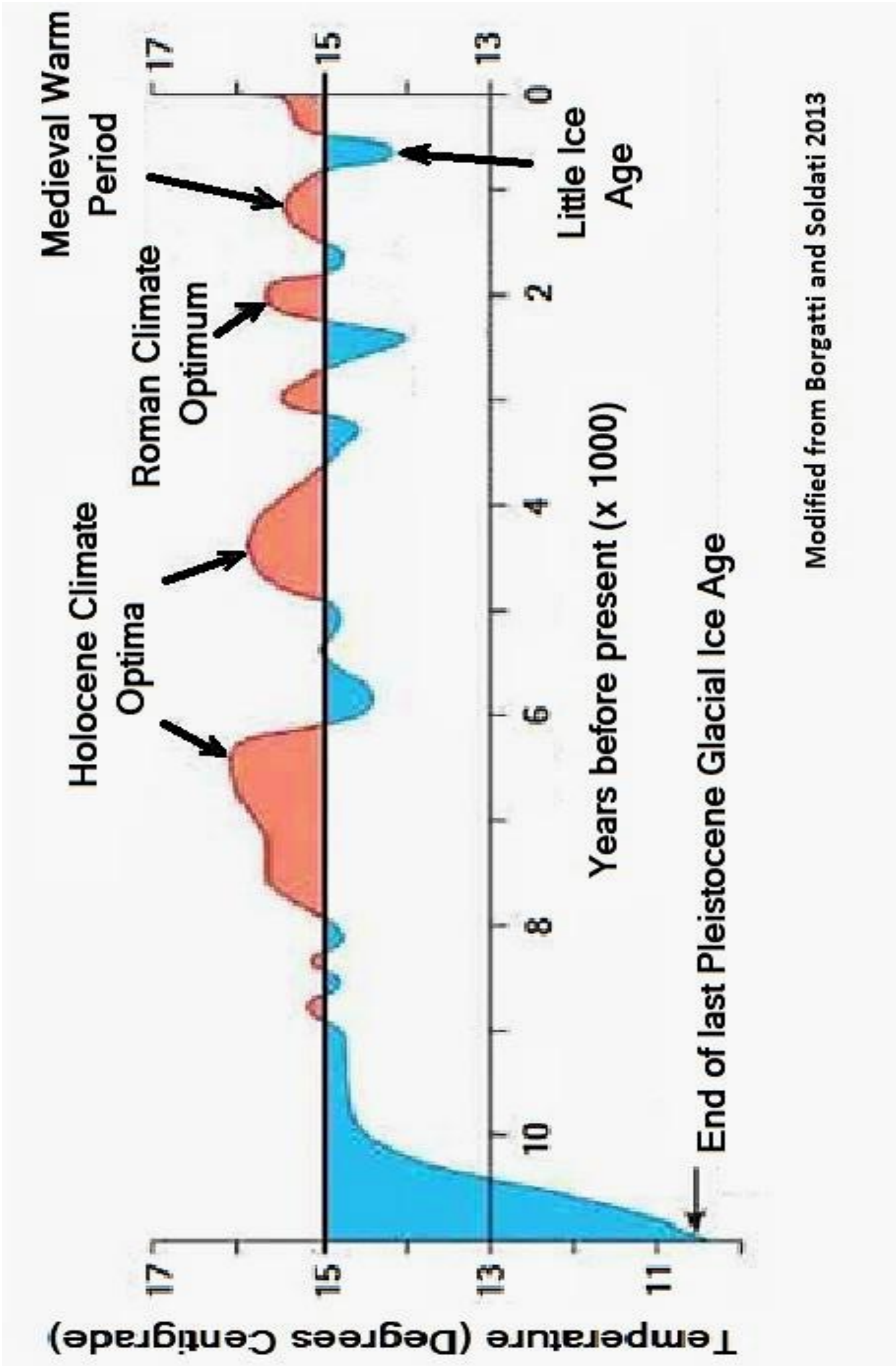
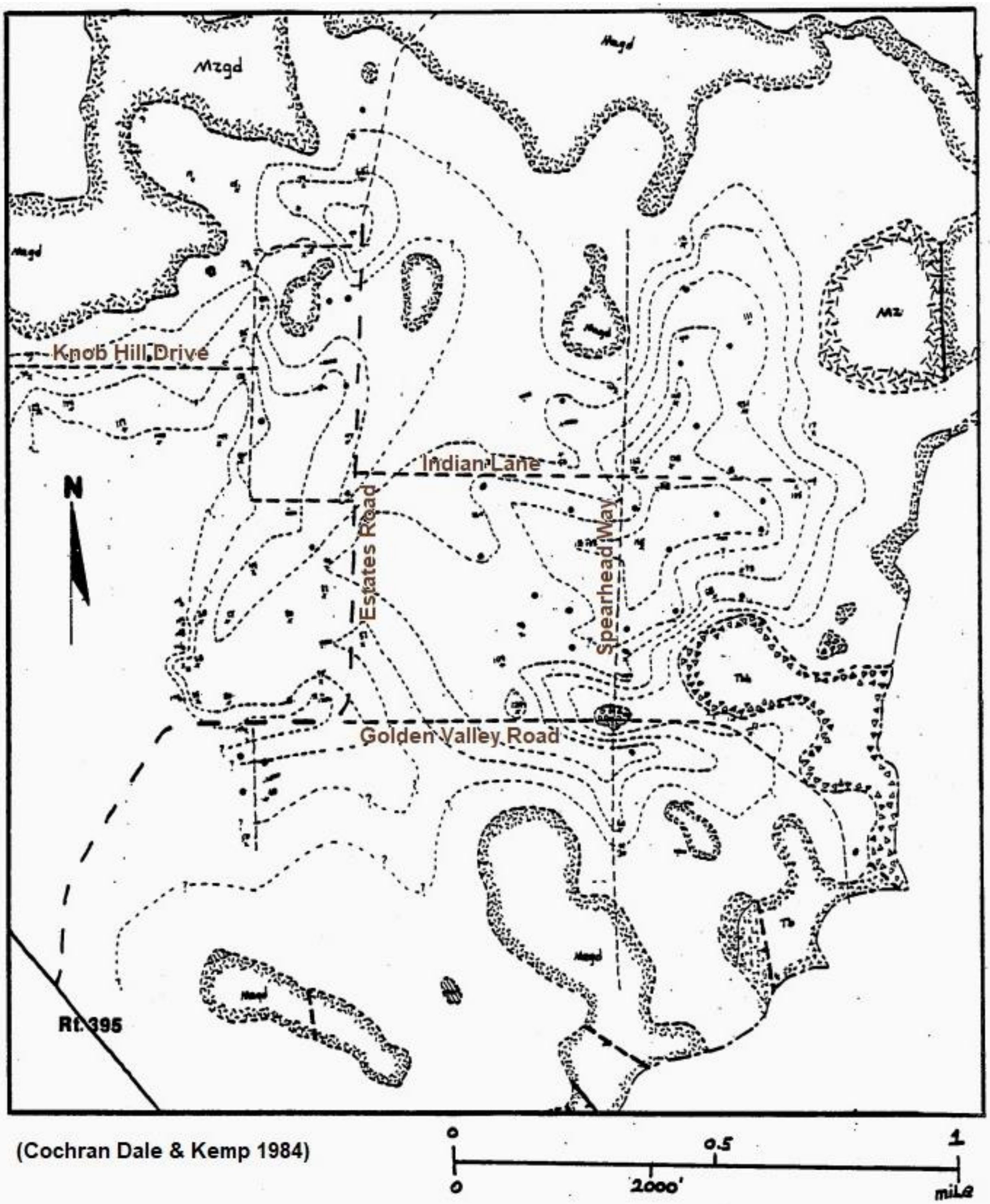


Figure 21. Average Holocene near-surface temperatures in Northern Hemisphere

Reno-Stead aerial photography - July 1946   Source: https://data.nbmg.unr.edu/Public/AirPhotos/Reno/reno_stead_1946.jpg

Figure 22. Aerial photograph of Lake Lemmon and vicinity 1946

Figure 23. Aerial photography of Lake Lemmon and vicinity 2020-newer



(Cochran Dale & Kemp 1984)

FIGURE 8. Isopach map of depth to fractured bedrock 30 ft. contour interval.

Figure 24. Isopach map of valley fill in Golden Valley (i.e., depth to bedrock)

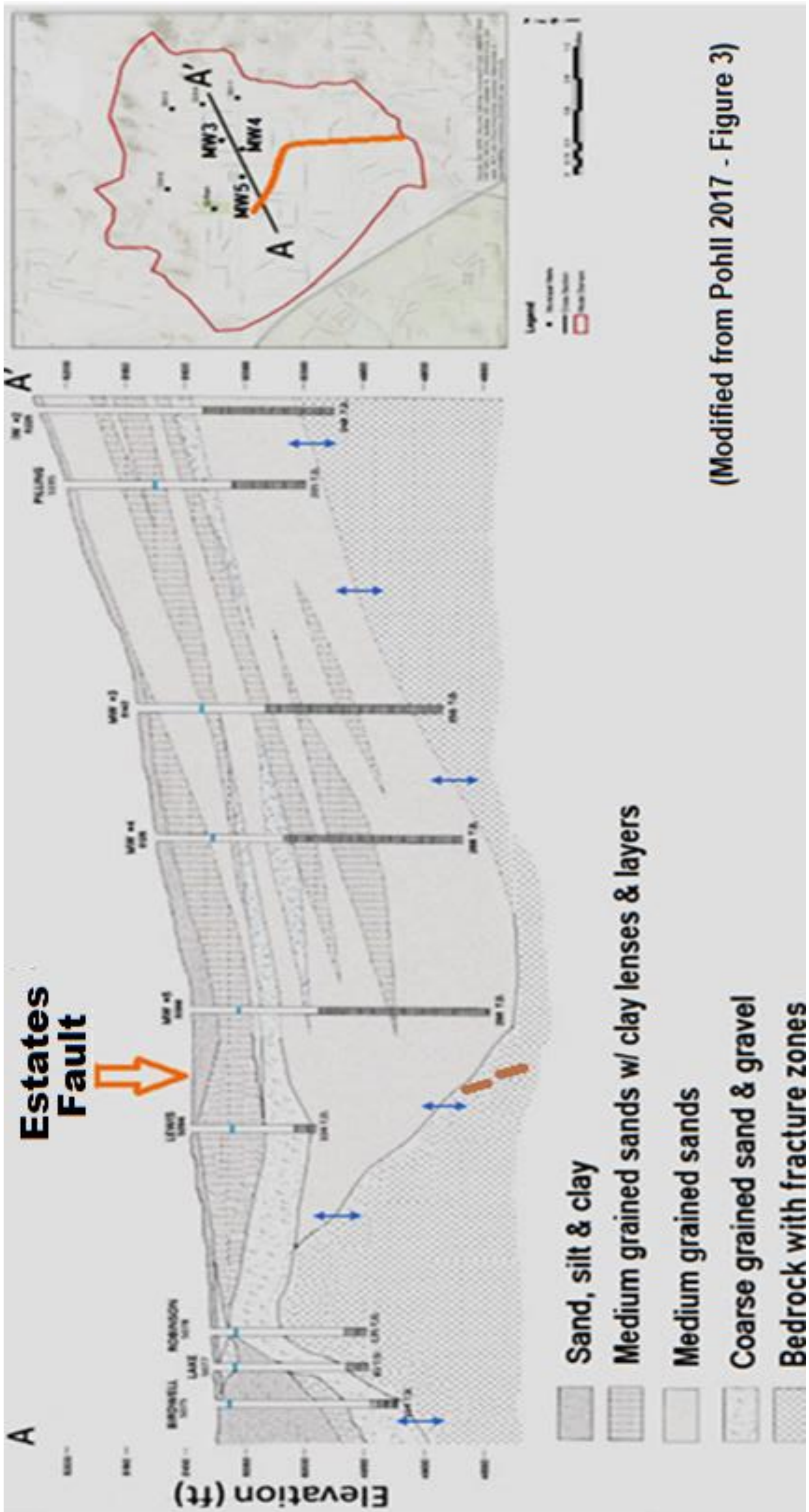


Figure 25. Generalized east-west geologic cross-section of Golden Valley

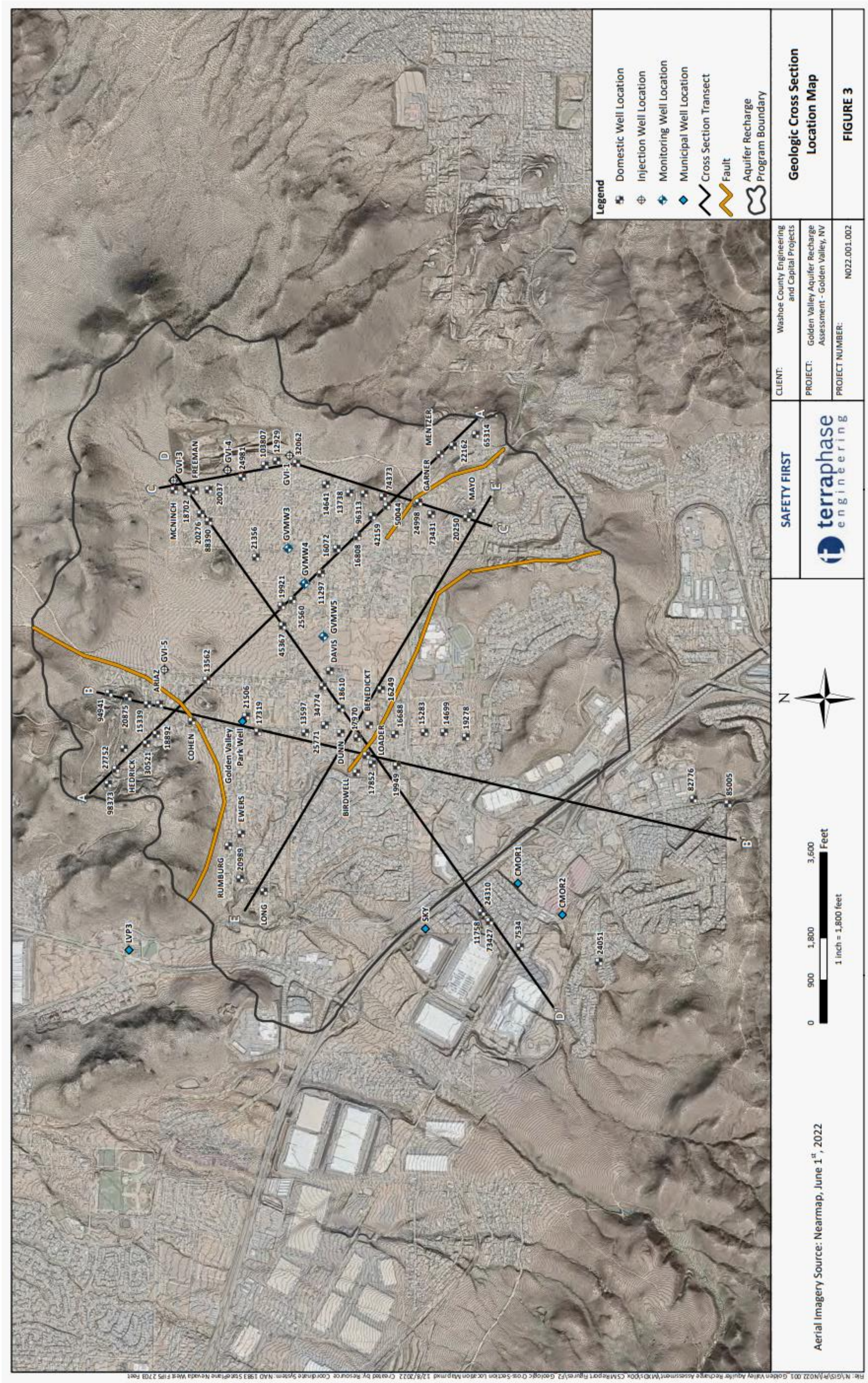


Figure 26. Terraphase profile locations

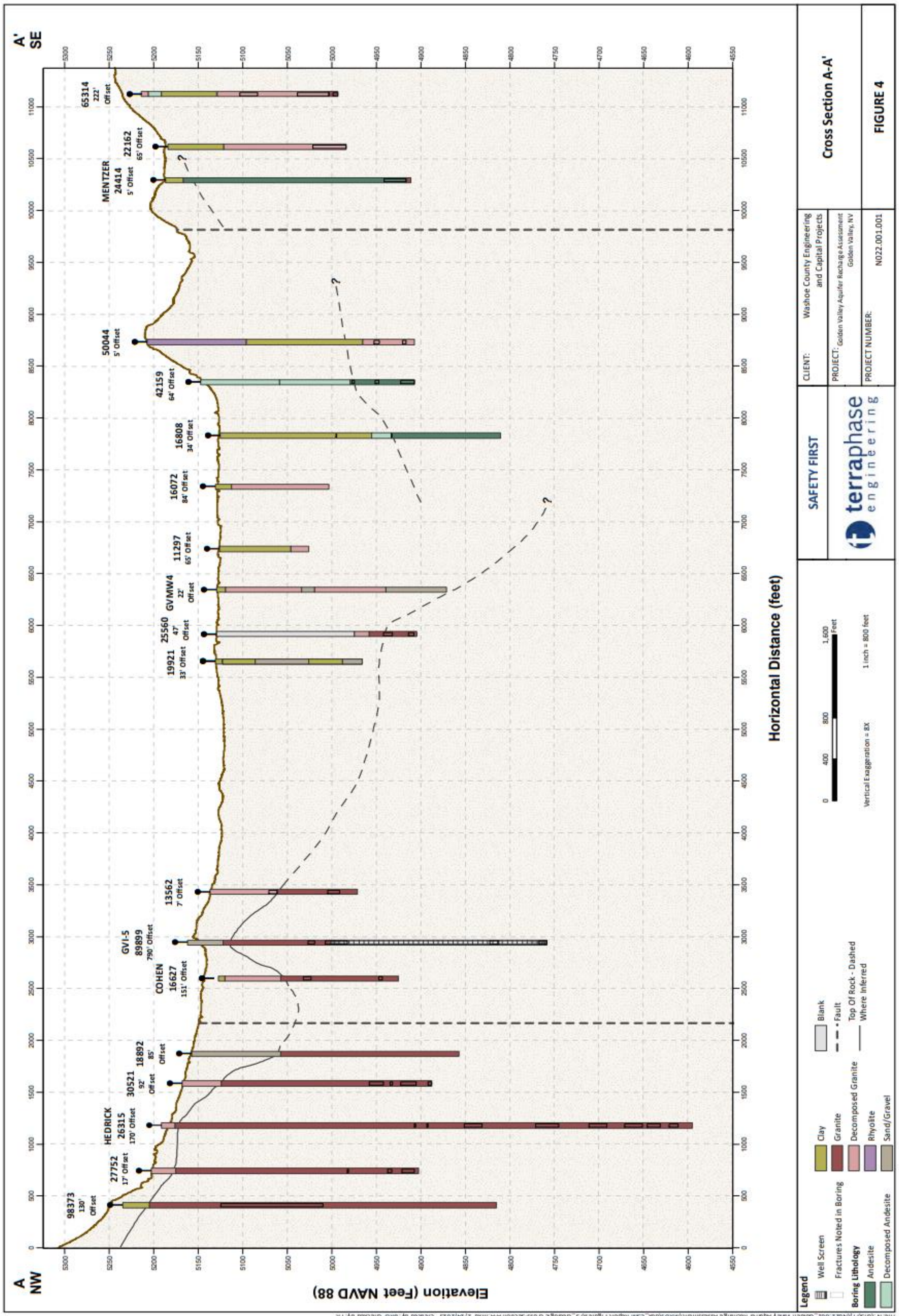


Figure 27. Terraphase profile A-A'

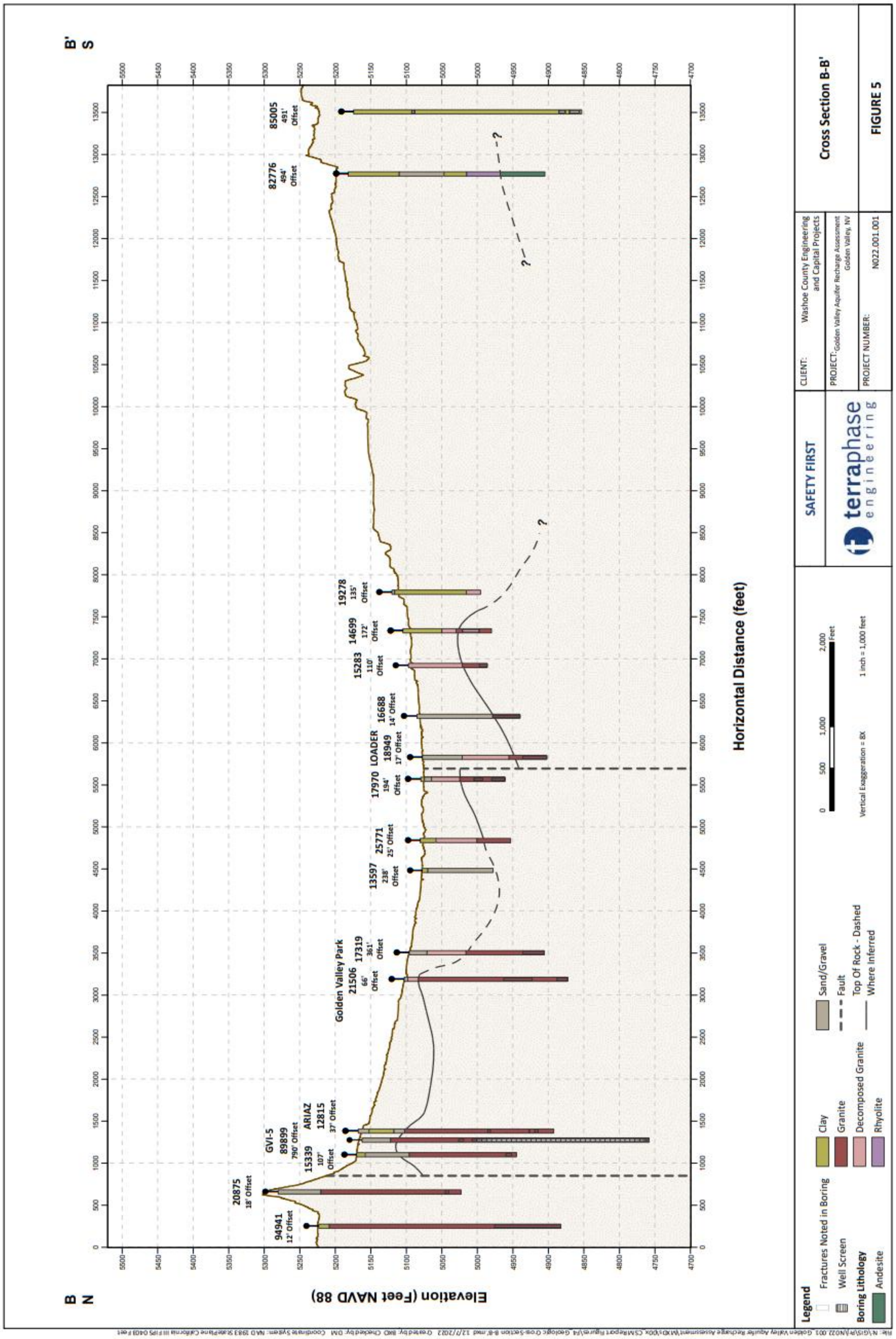


Figure 28. Terraphase profile B-B'

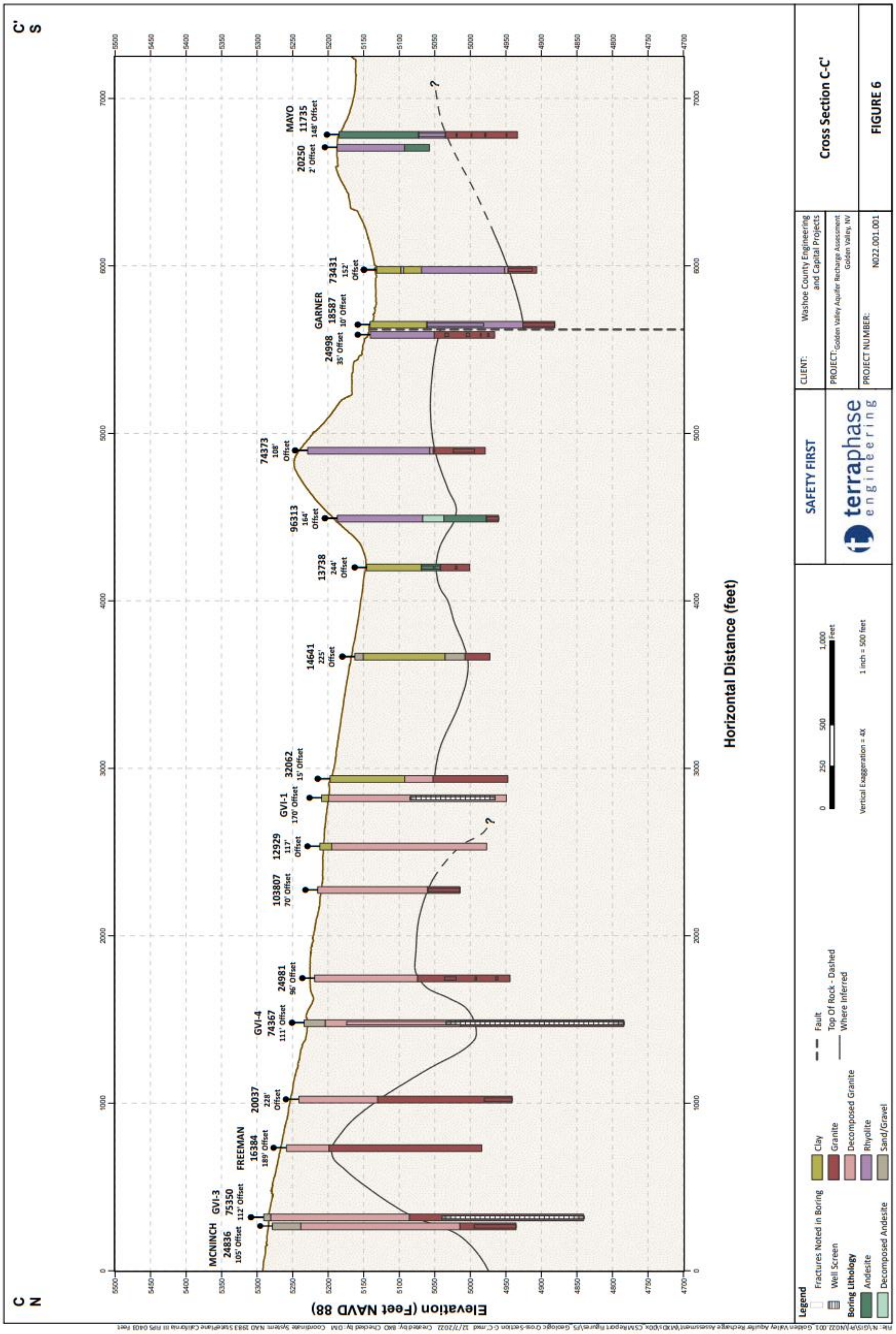


Figure 29. Terraphase profile C-C'

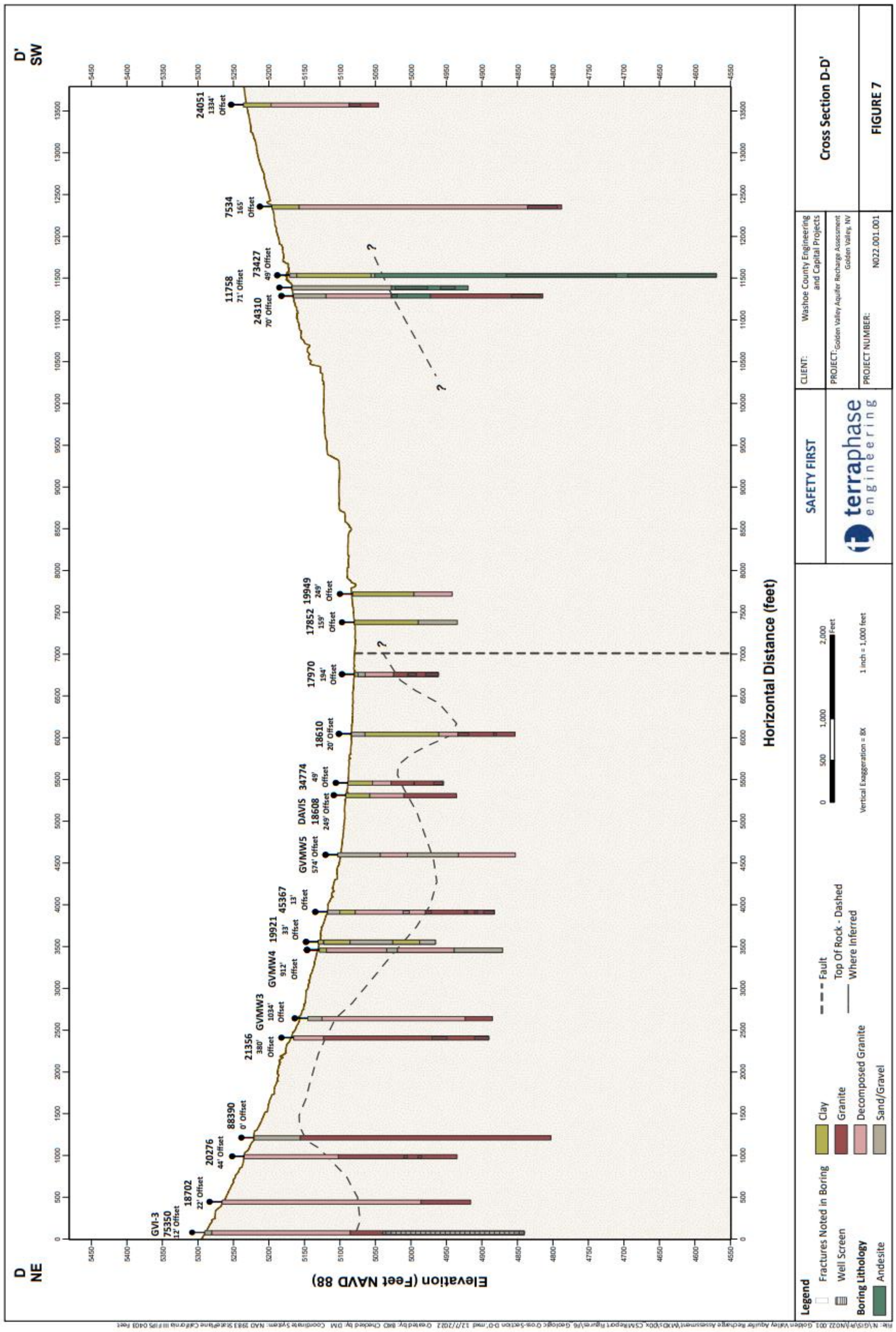


Figure 30. Terraphase profile D-D'

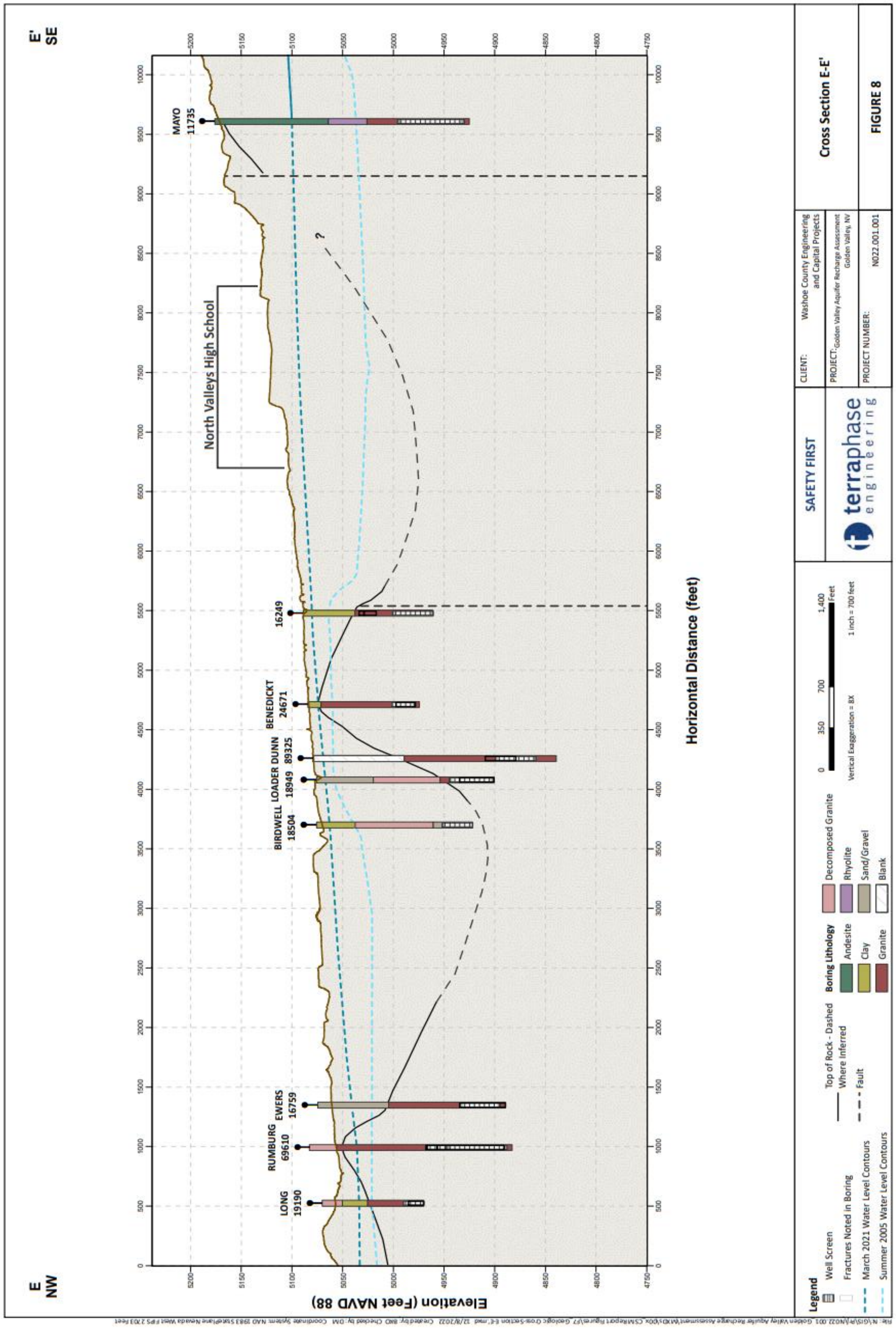


Figure 31. Terraphase profile E-E'

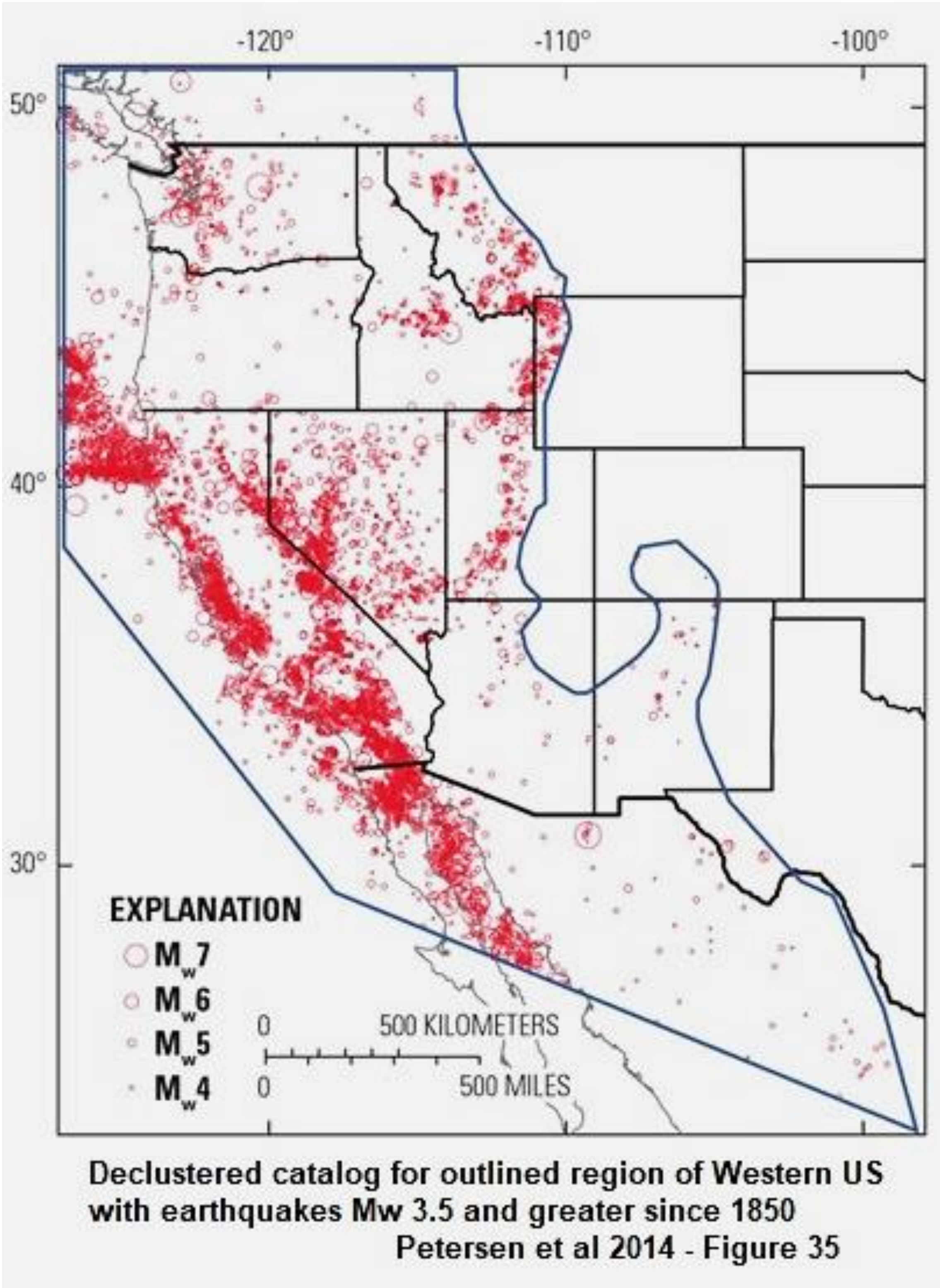


Figure 32. Seismicity of the Western US since 1850

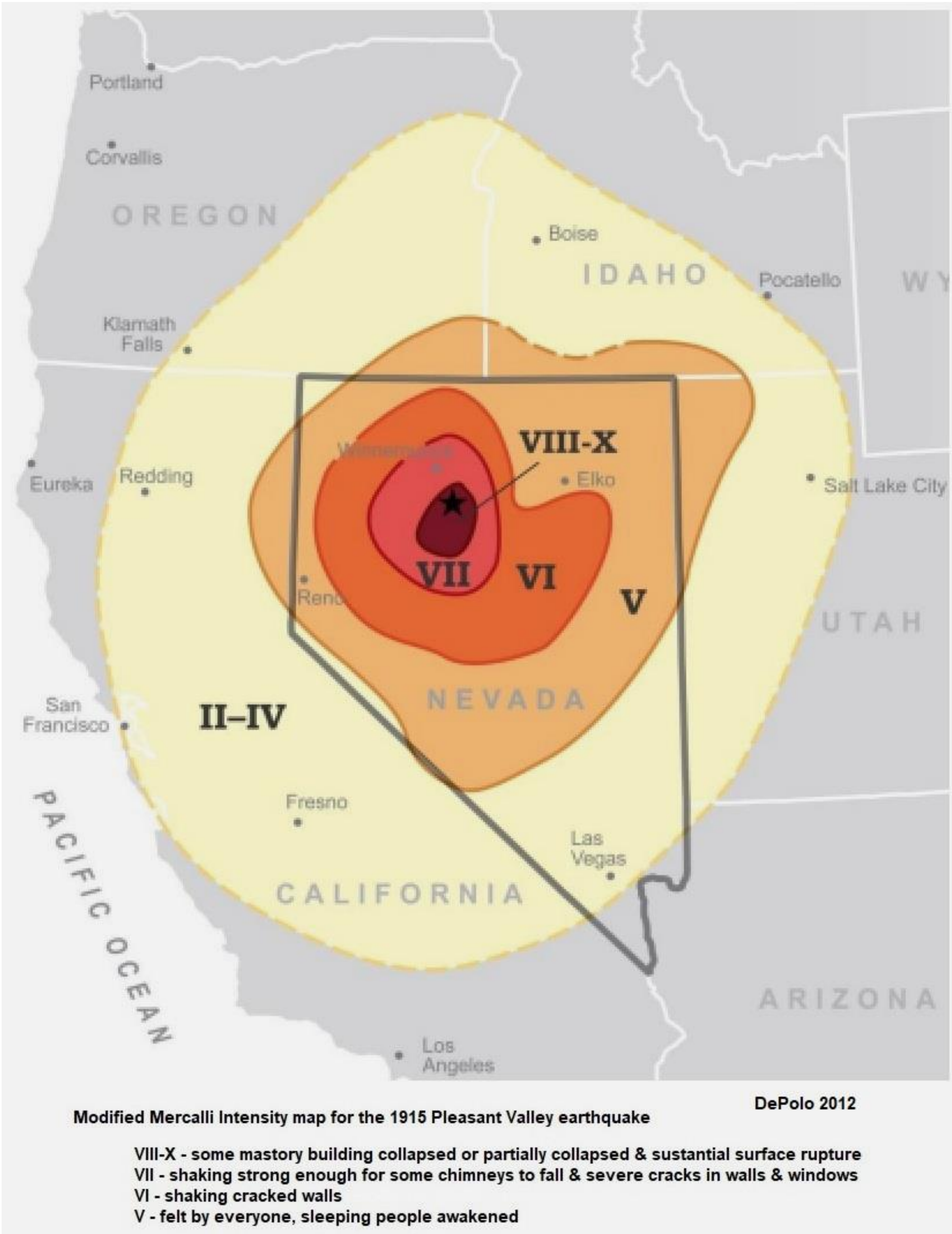


Figure 33. Modified Mercalli Intensity map for 1915 Pleasant Valley Earthquake

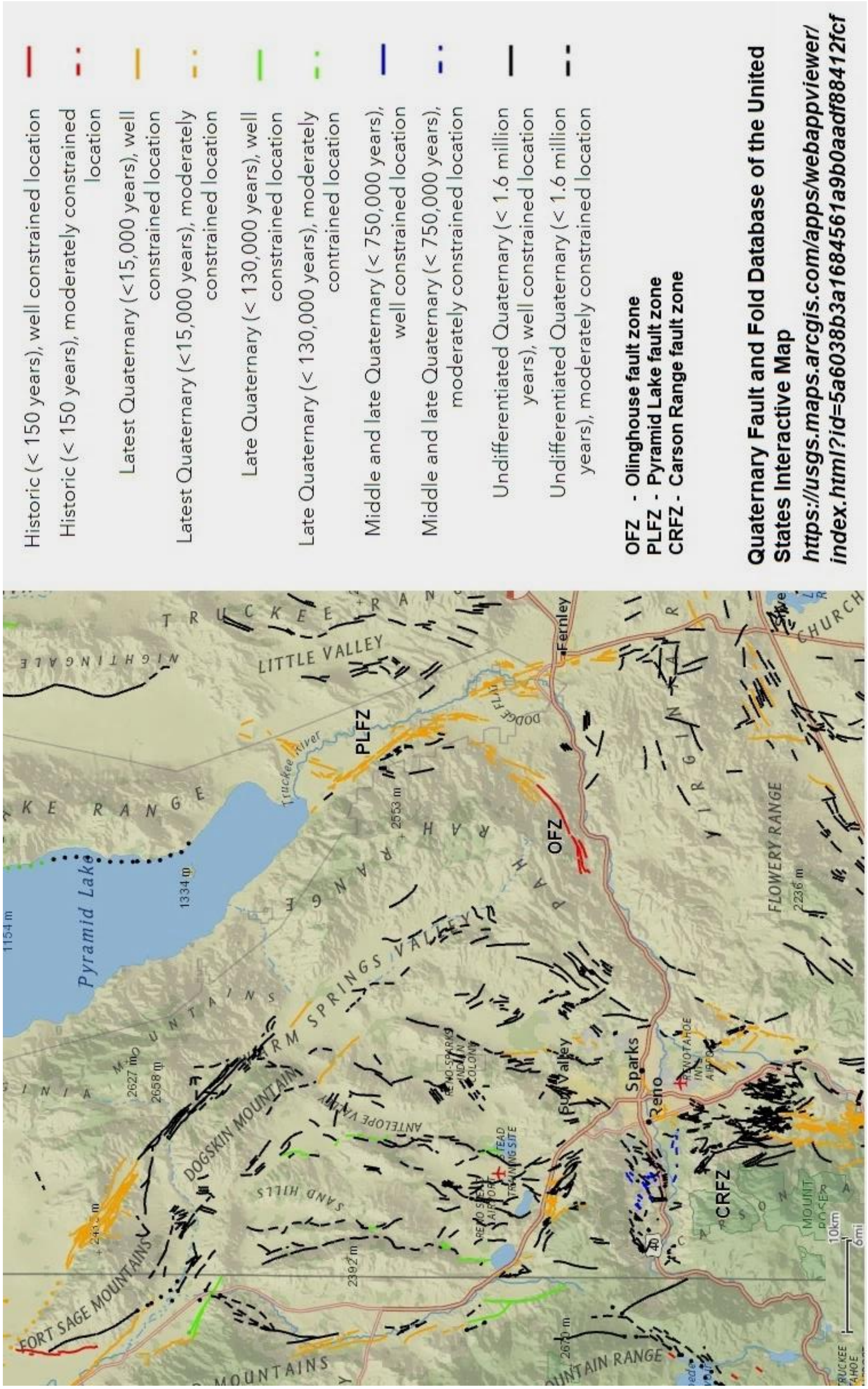


Figure 34. Quaternary fault map of Western Nevada

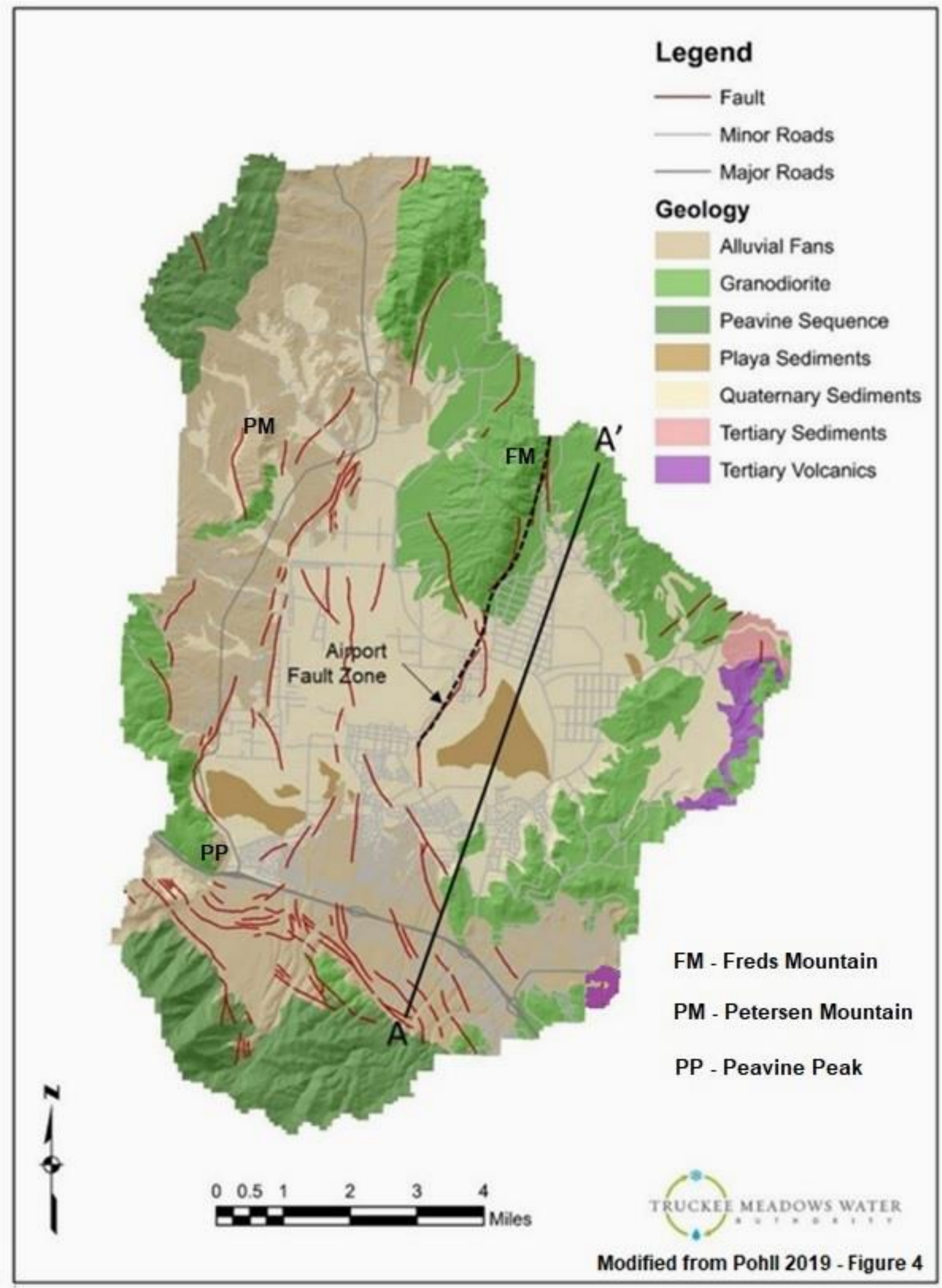


Figure 35. Geologic map & faults in Lemmon Valley

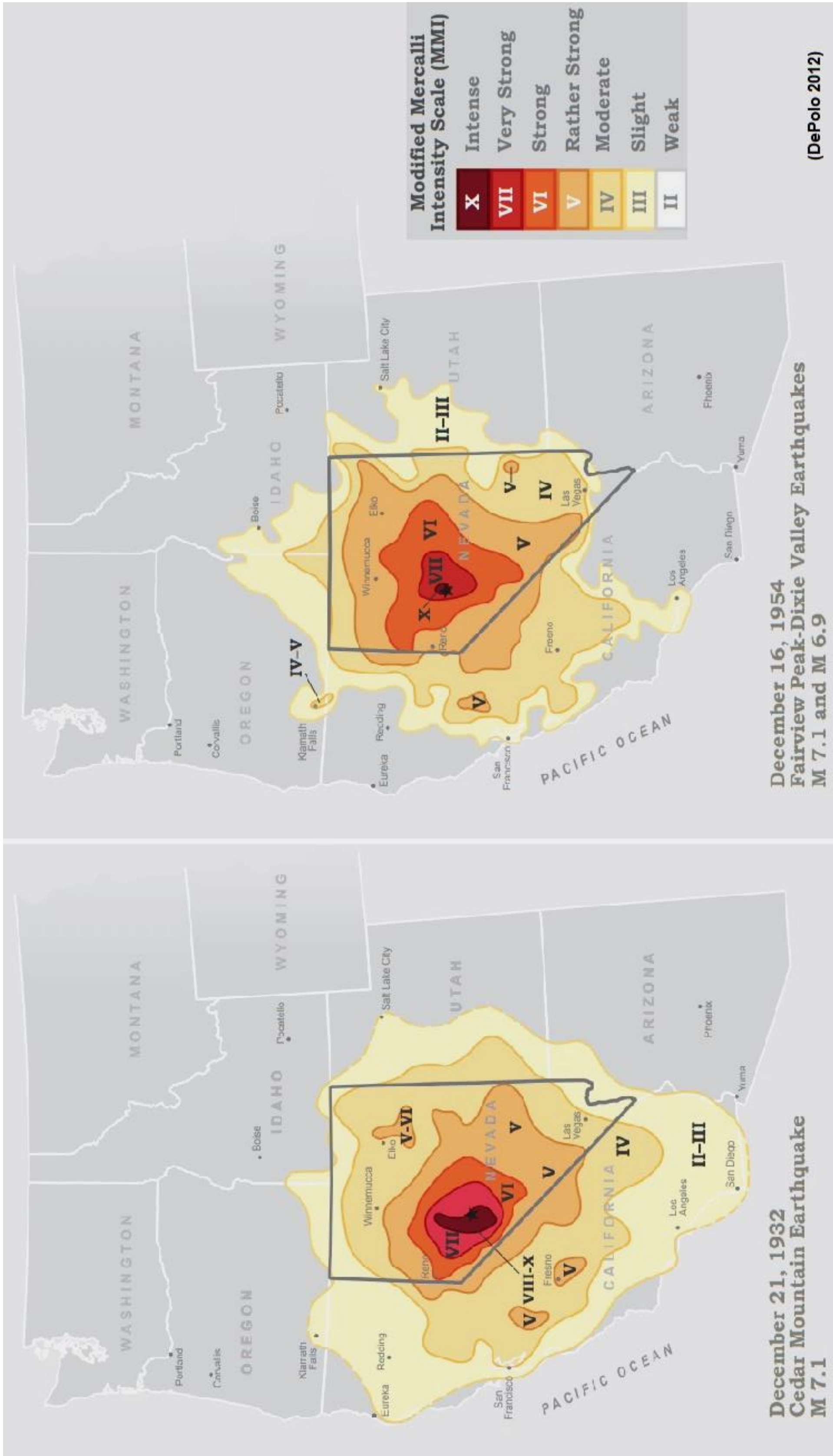


Figure 36. Modified Mercalli Intensity maps for selected historic earthquakes

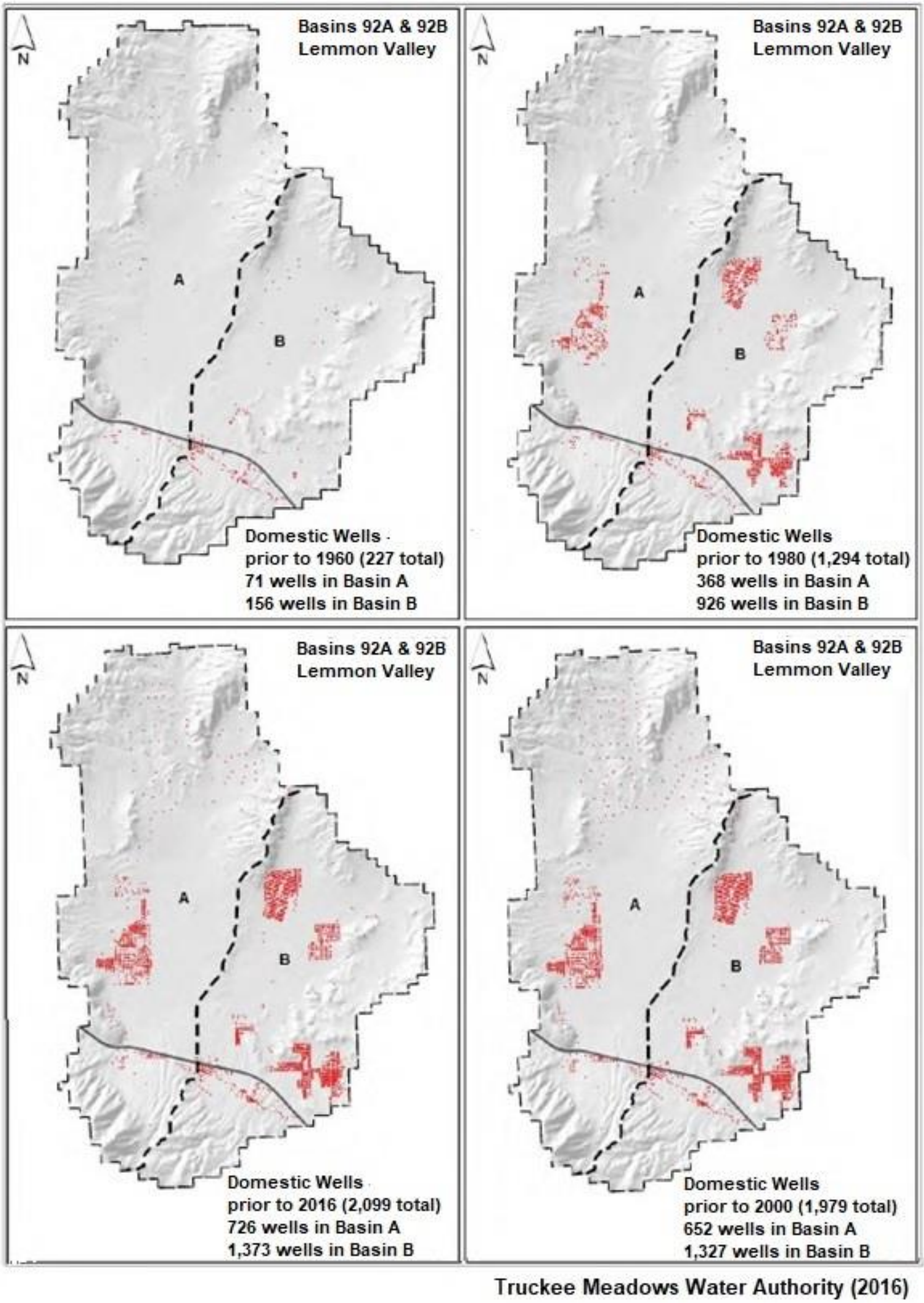


Figure 37. Domestic wells in Lemmon Valley Sub-basins

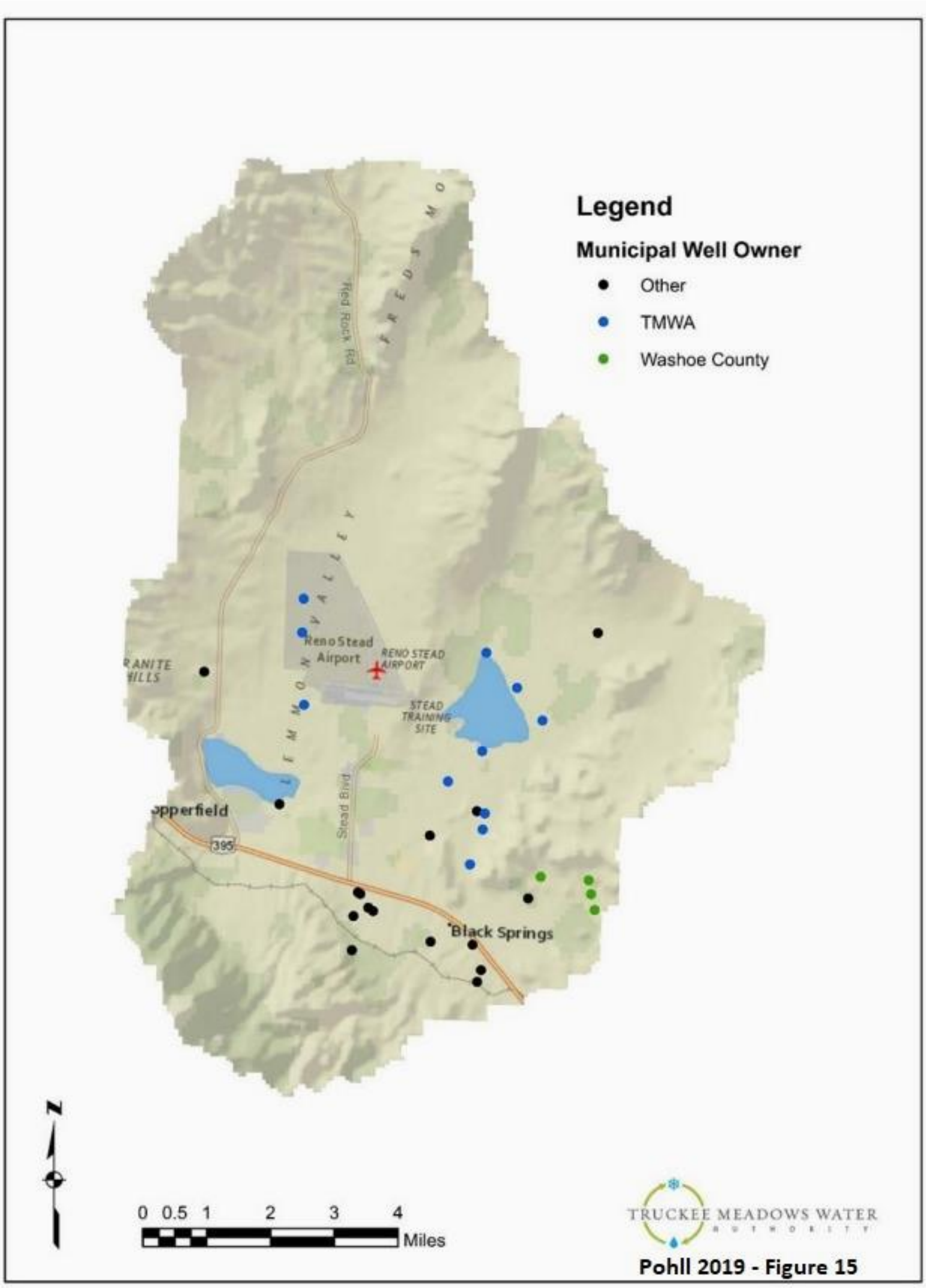


Figure 38. Municipal wells in Lemmon Valley

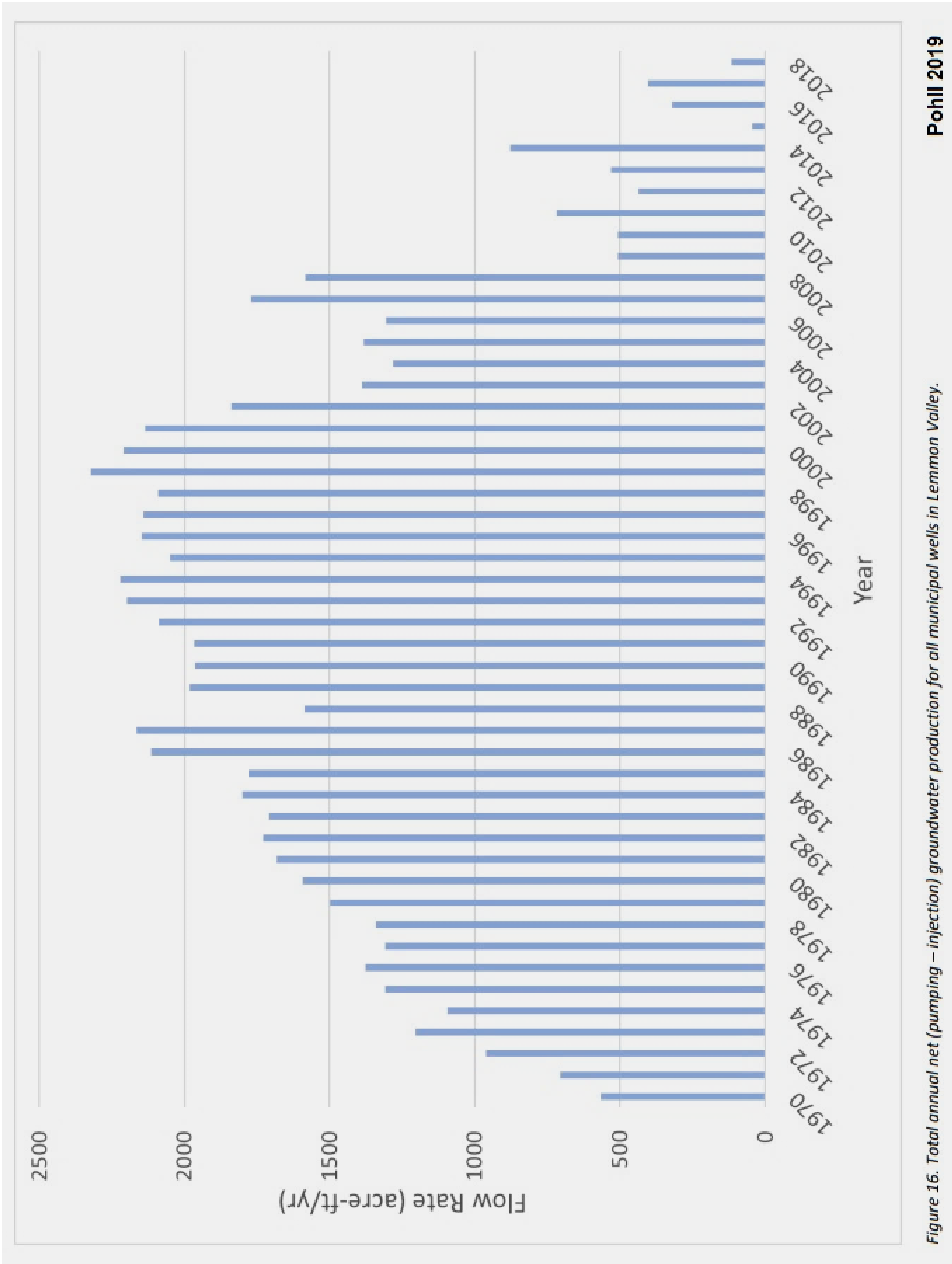


Figure 39. Net annual groundwater pumping in Lemmon Valley 1970-2018

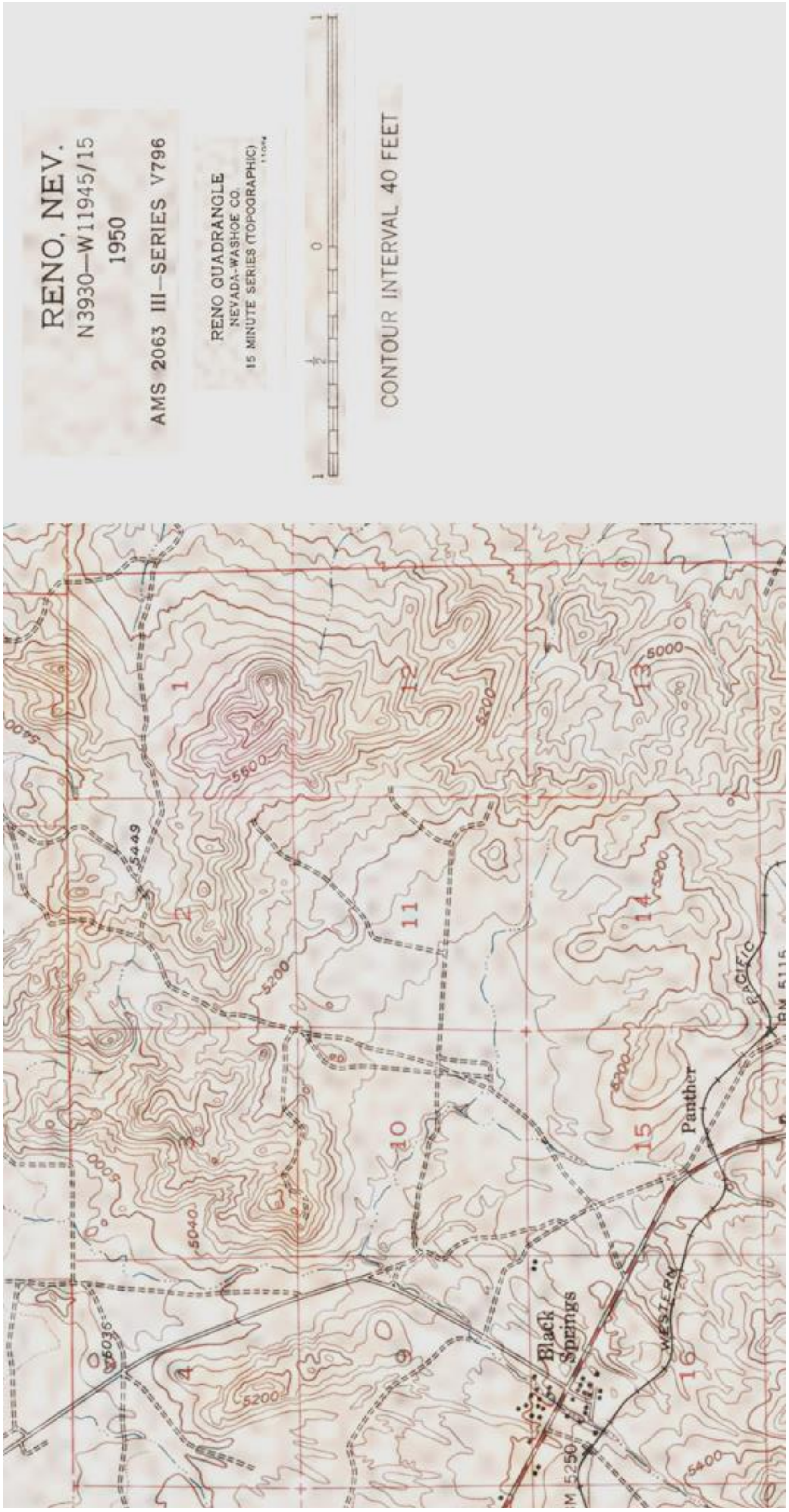


Figure 40. Topographic map of Golden Valley 1950

Figure 41. Platted subdivisions and home sites

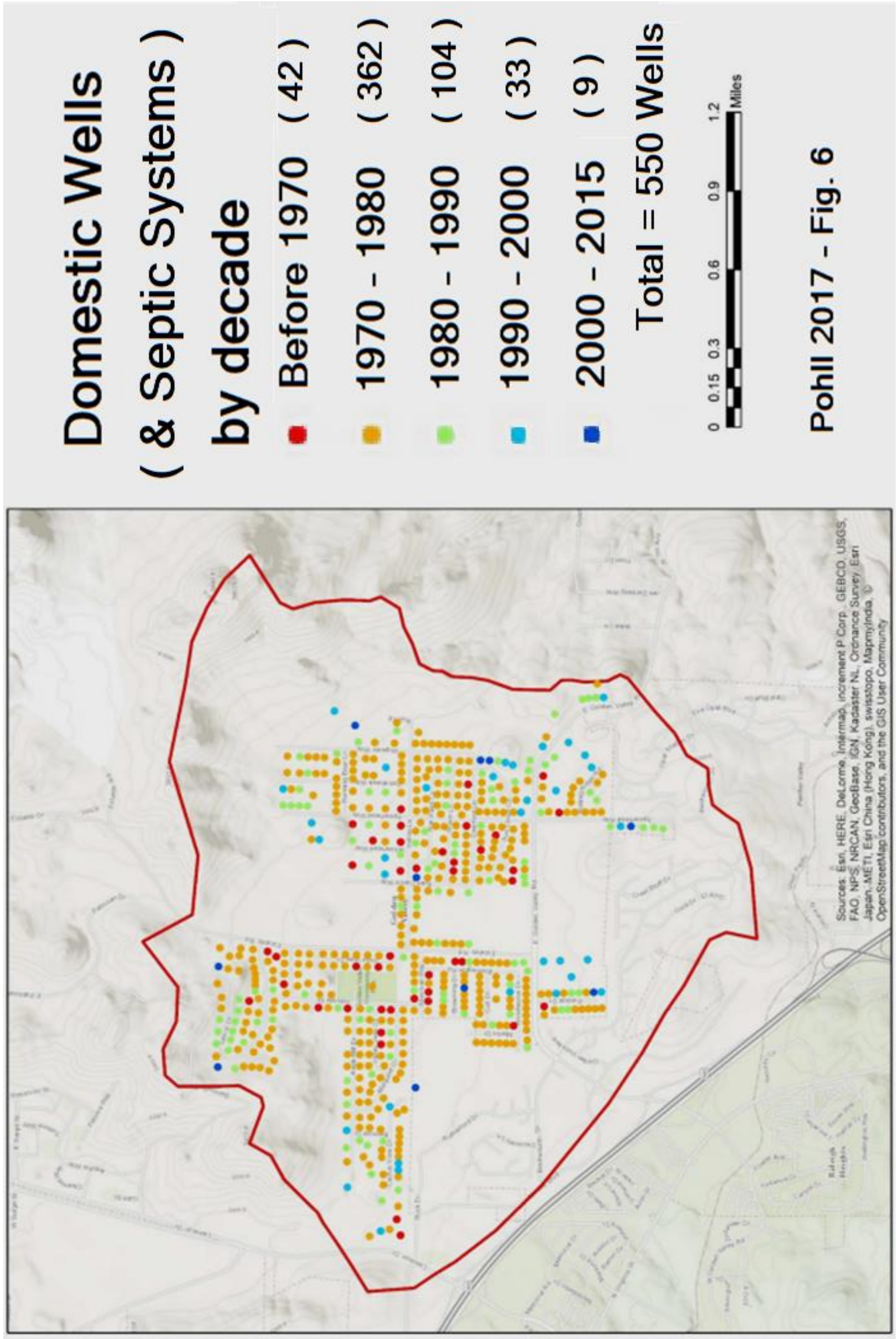


Figure 42. Residential well and septic system installations by decade

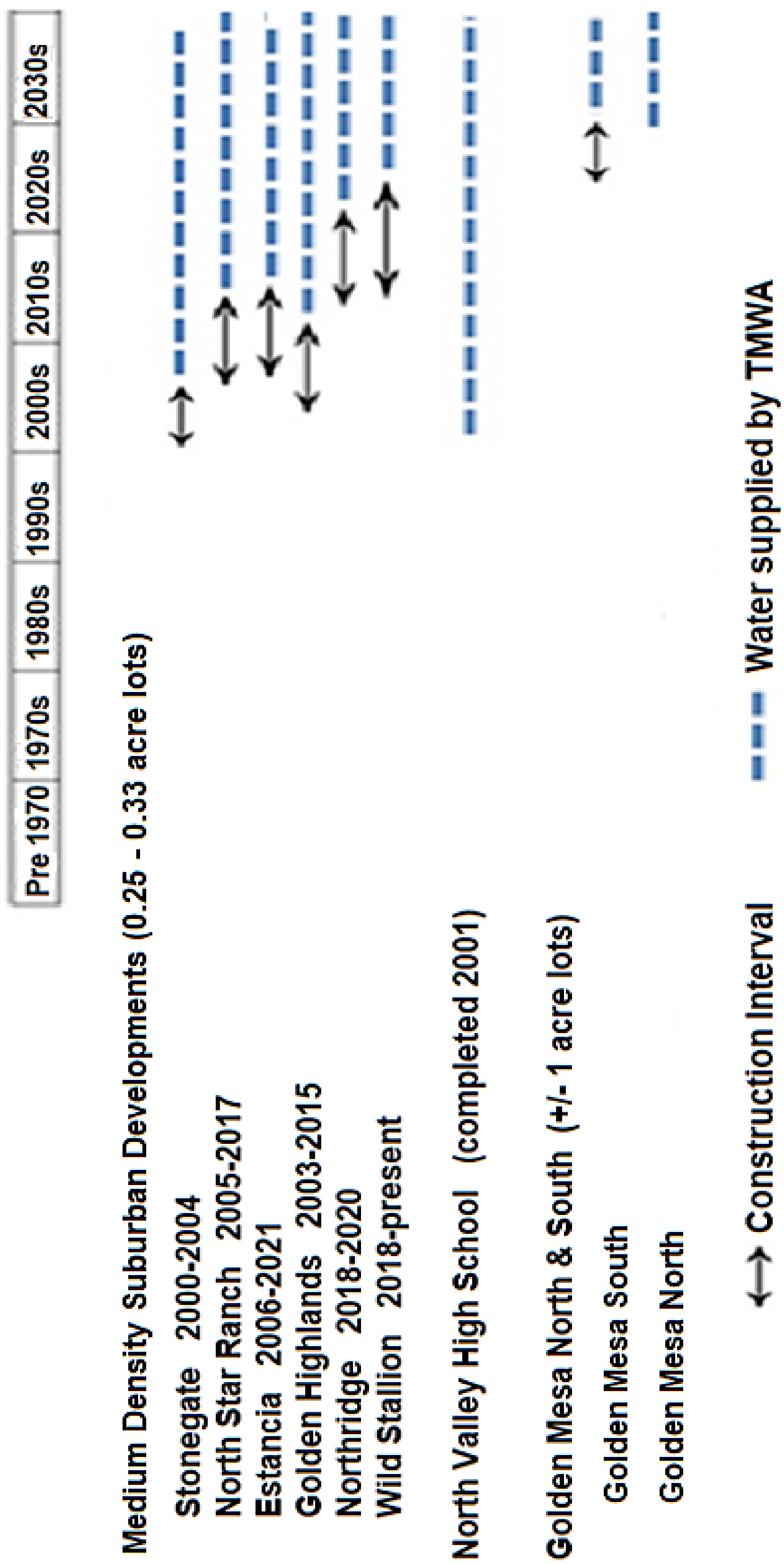


Figure 43. Medium Density Suburban (MDS) developments

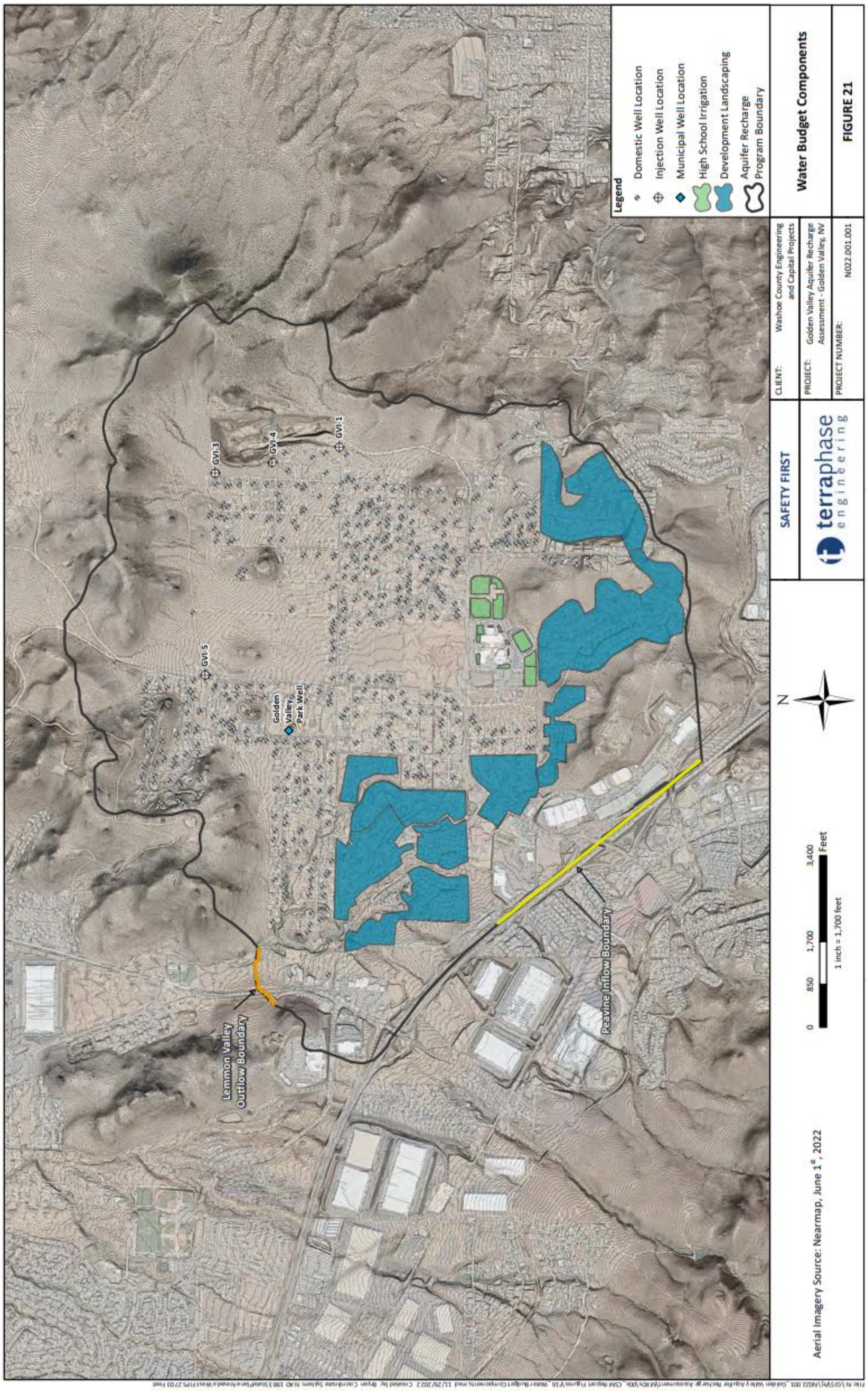


Figure 44. Distribution of Medium Density Subdivision (MDS) developments

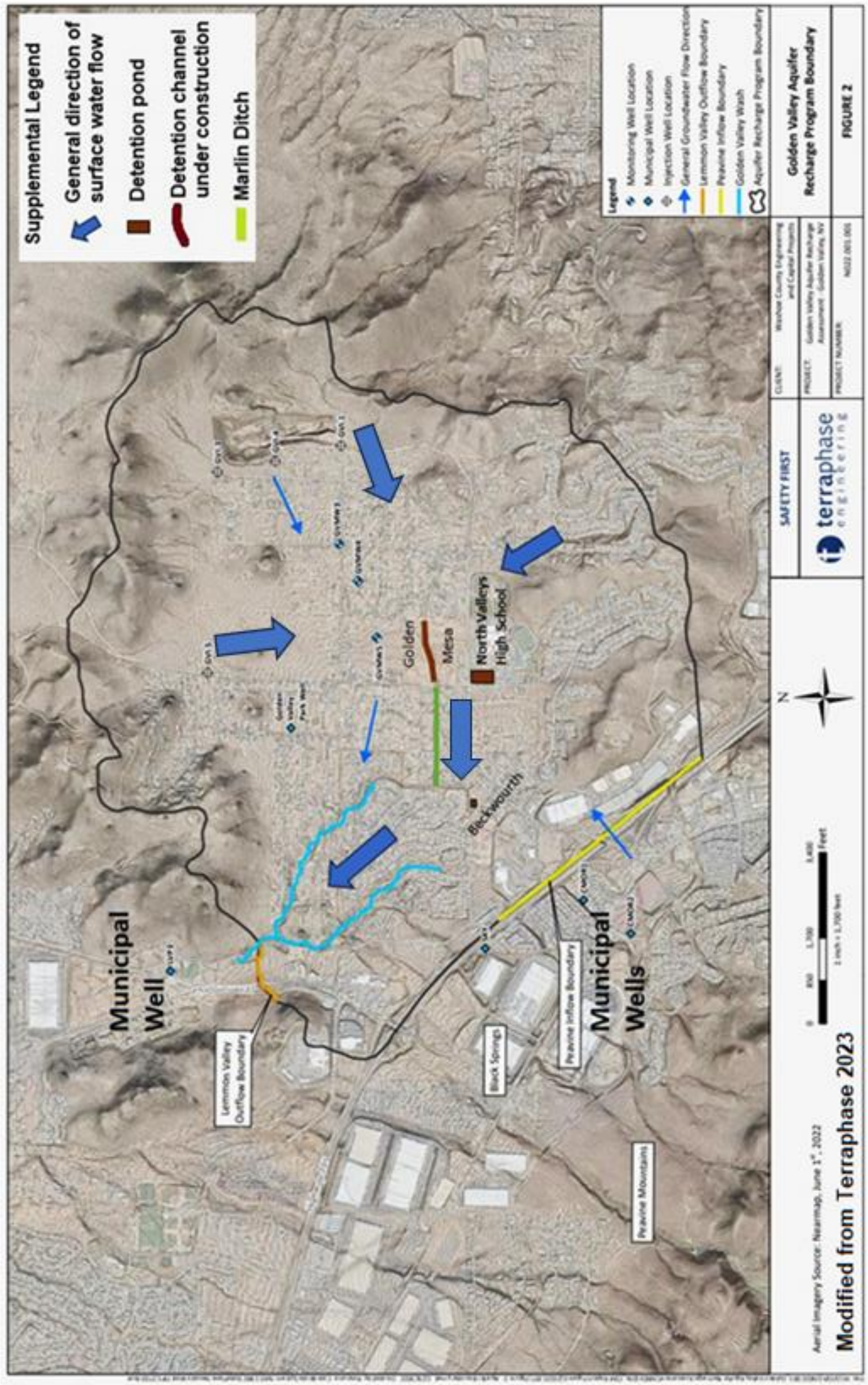
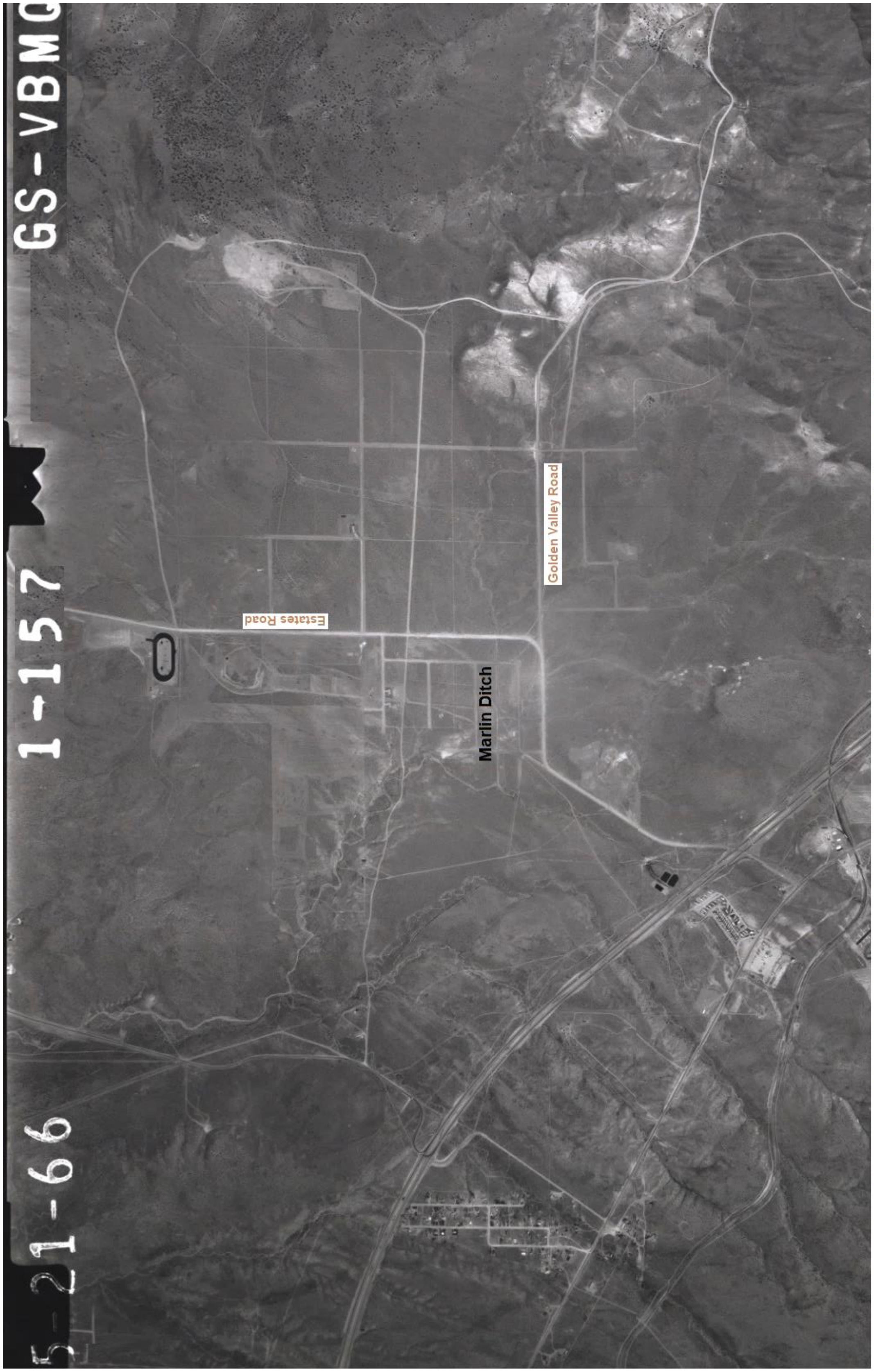


Figure 45. Surface water components and groundwater flow directions



North Virginia St., Reno and Sun Valley, 21 May 1966, scale approximately 1-to-30,000

Source: https://data.nbmg.unr.edu/Public/AirPhotos/Reno/north_reno_sun_valley_1966.jpg

Figure 46. Trace of Marlin Ditch - May 1966

Marlin Ditch - View looking West from Marlin Drive - 25 September 2023

Marlin Ditch - View looking West from Remington Road - 25 September 2023

Figure 47. Views of Marlin Ditch – September 2023

Undercut drive and ditch erosion on Hillview Drive - 4 October 2023

Turbulent flow in roadside ditch along Estates Road resulting from rain & snow melt - 12 March 2023

Landscape block to prevent undercutting & rip rap in ditch to minimize erosion - Margaret Drive - 4 Oct 2023

Culvert beneath Knob Hill & rip rap in ditch to minimize erosion - 4 October 2023

Figure 48. Roadside ditches & culverts

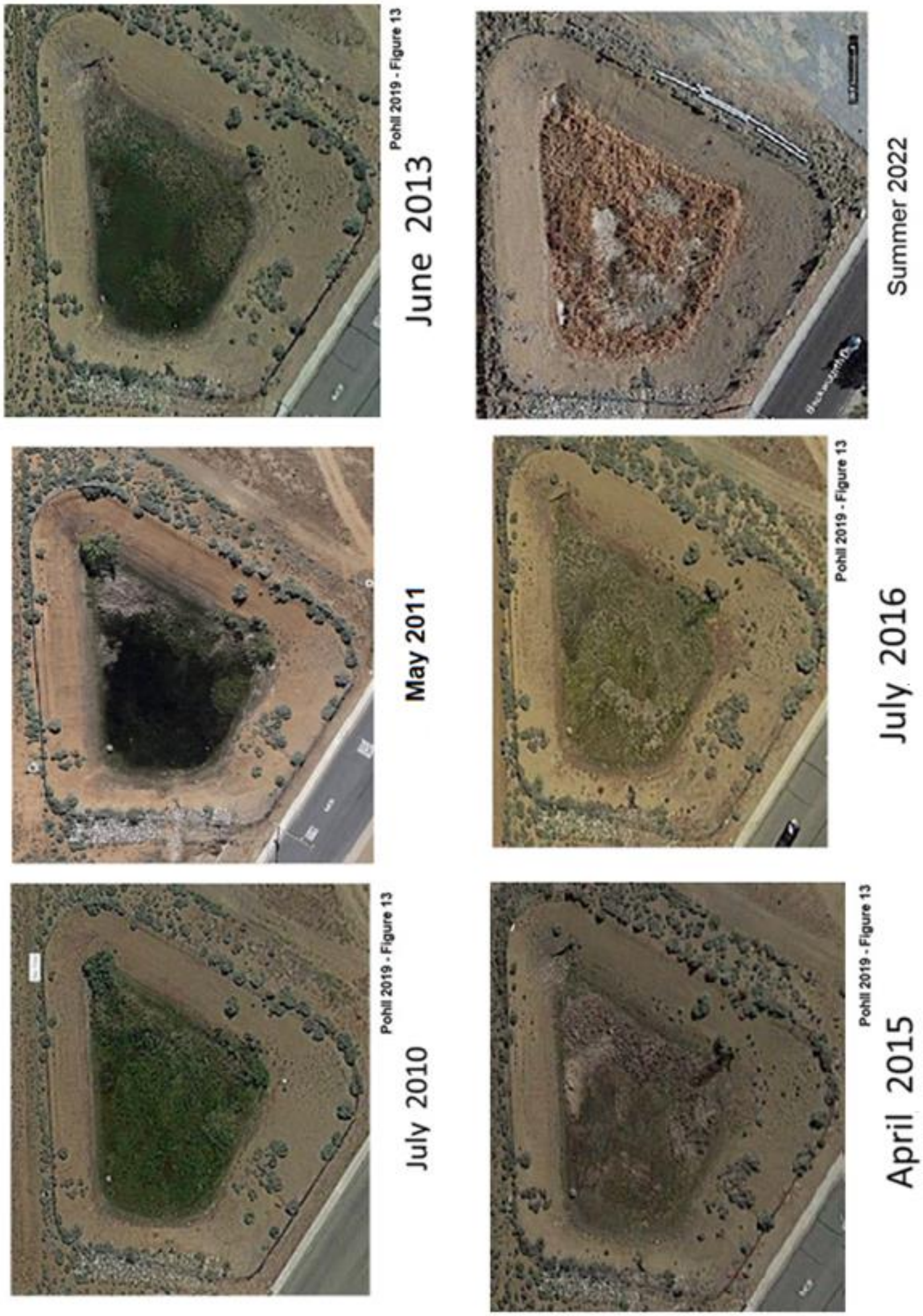


Figure 49. Detention basin adjacent to Beckwourth Drive

Figure 50. North Valleys High School detention basin

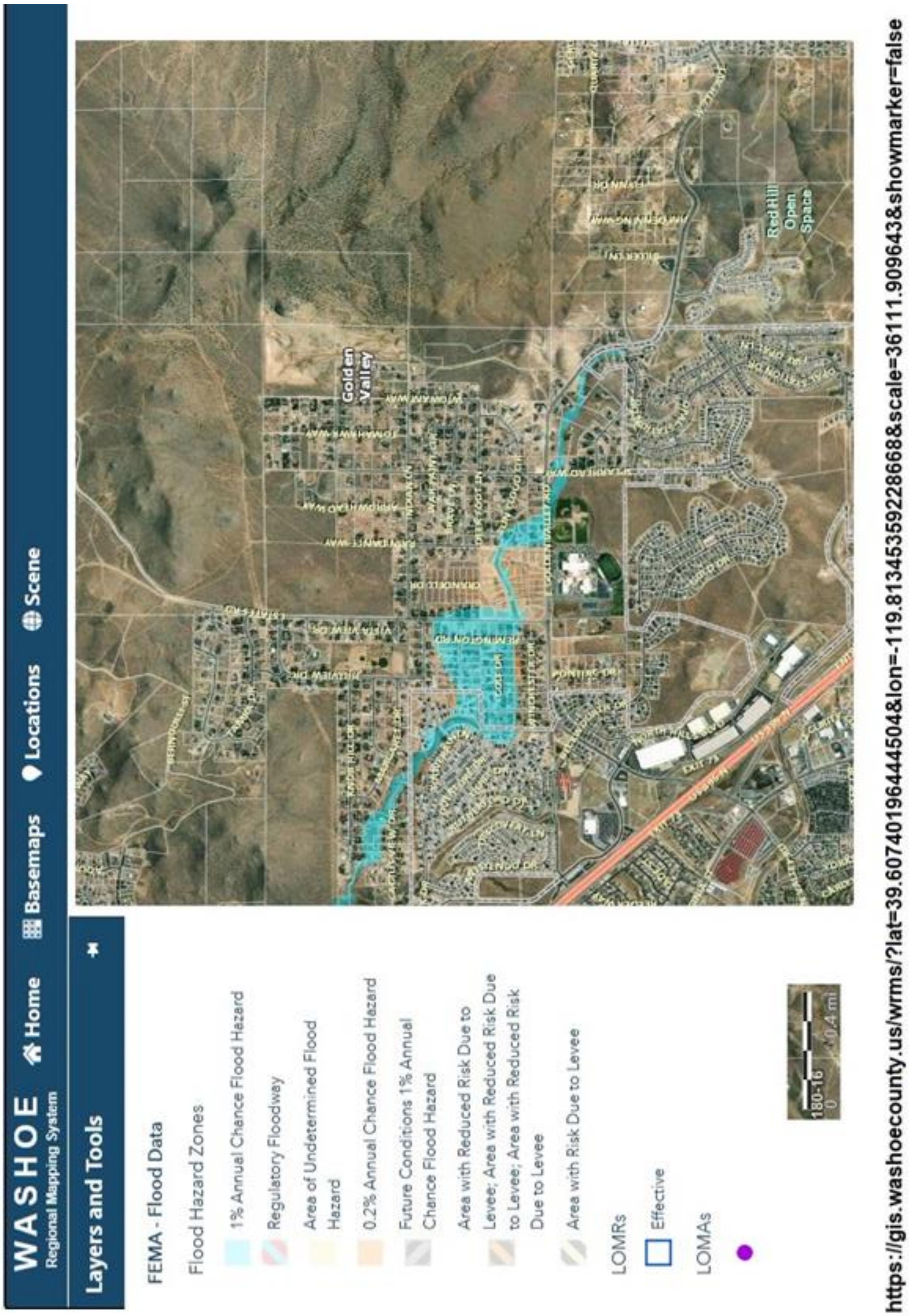


Figure 51. FEMA designated flood zone

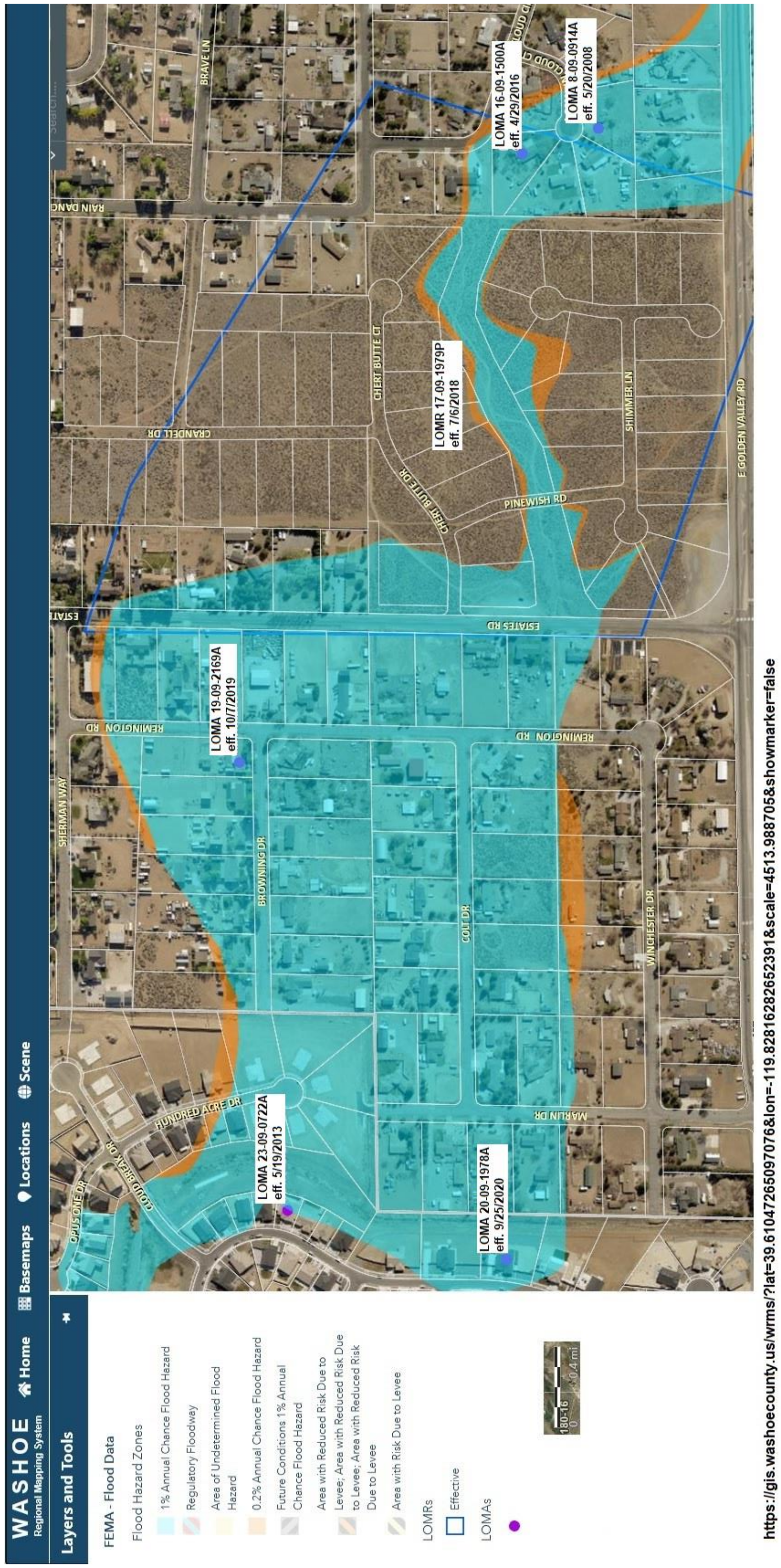


Figure 52. LOMA & LOMR approved in Flood Hazard Zone

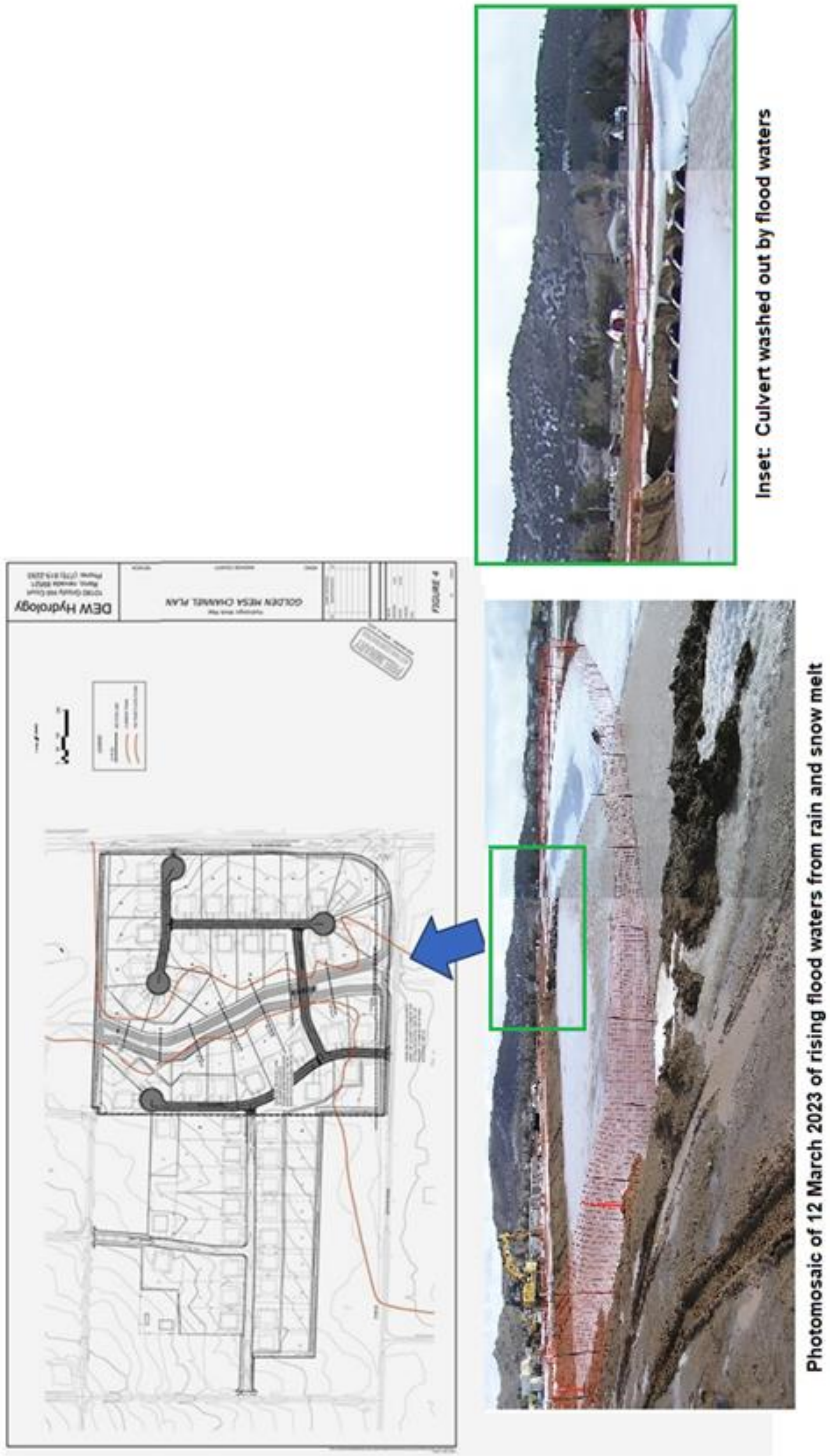


Figure 53. Golden Mesa South detention channel flooded by rain/snow melt

Figure 54. Golden Mesa South detention channel – reconstructed

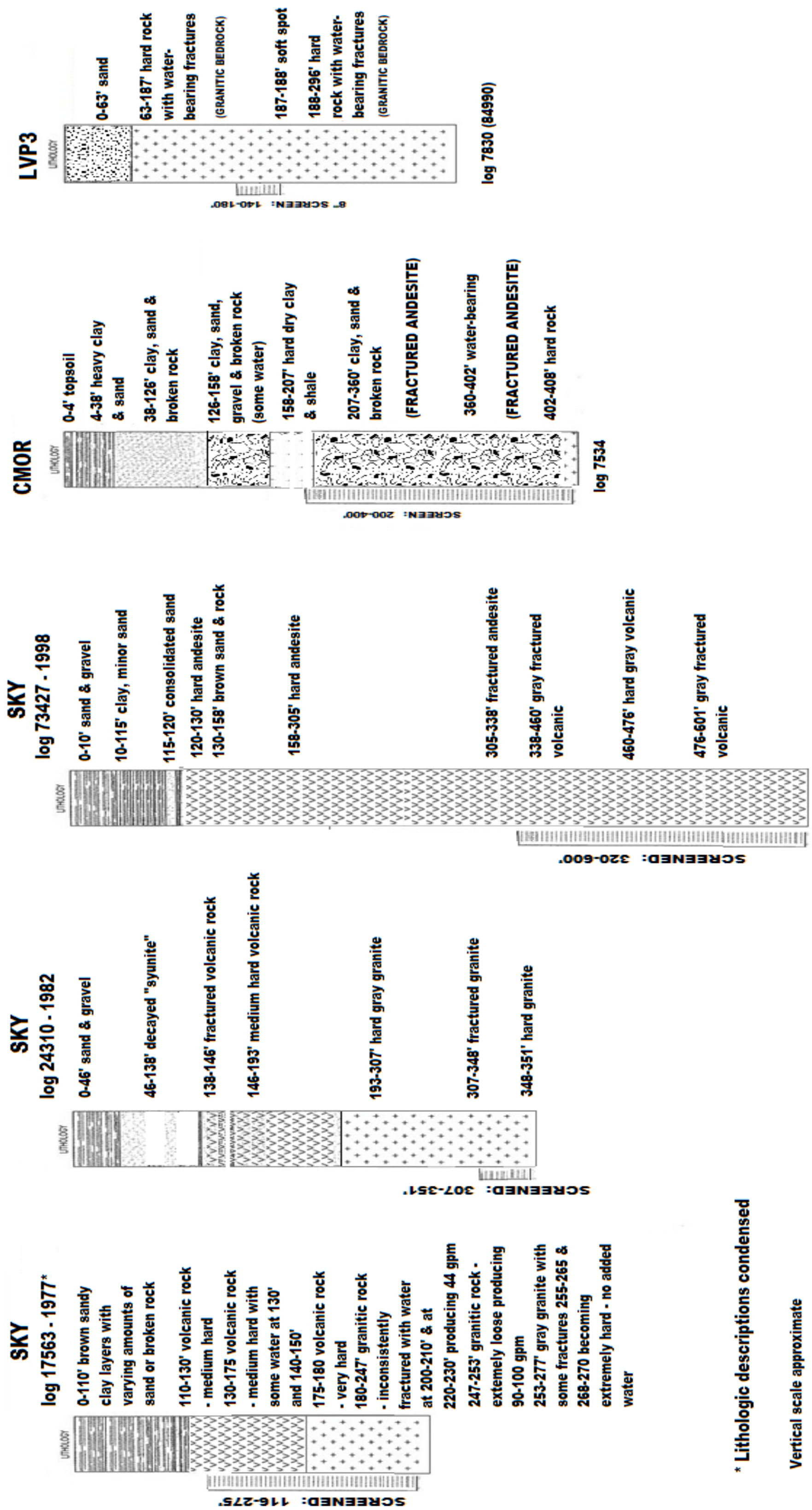


Figure 55. Municipal well logs - SKY, CMOR and LVP3

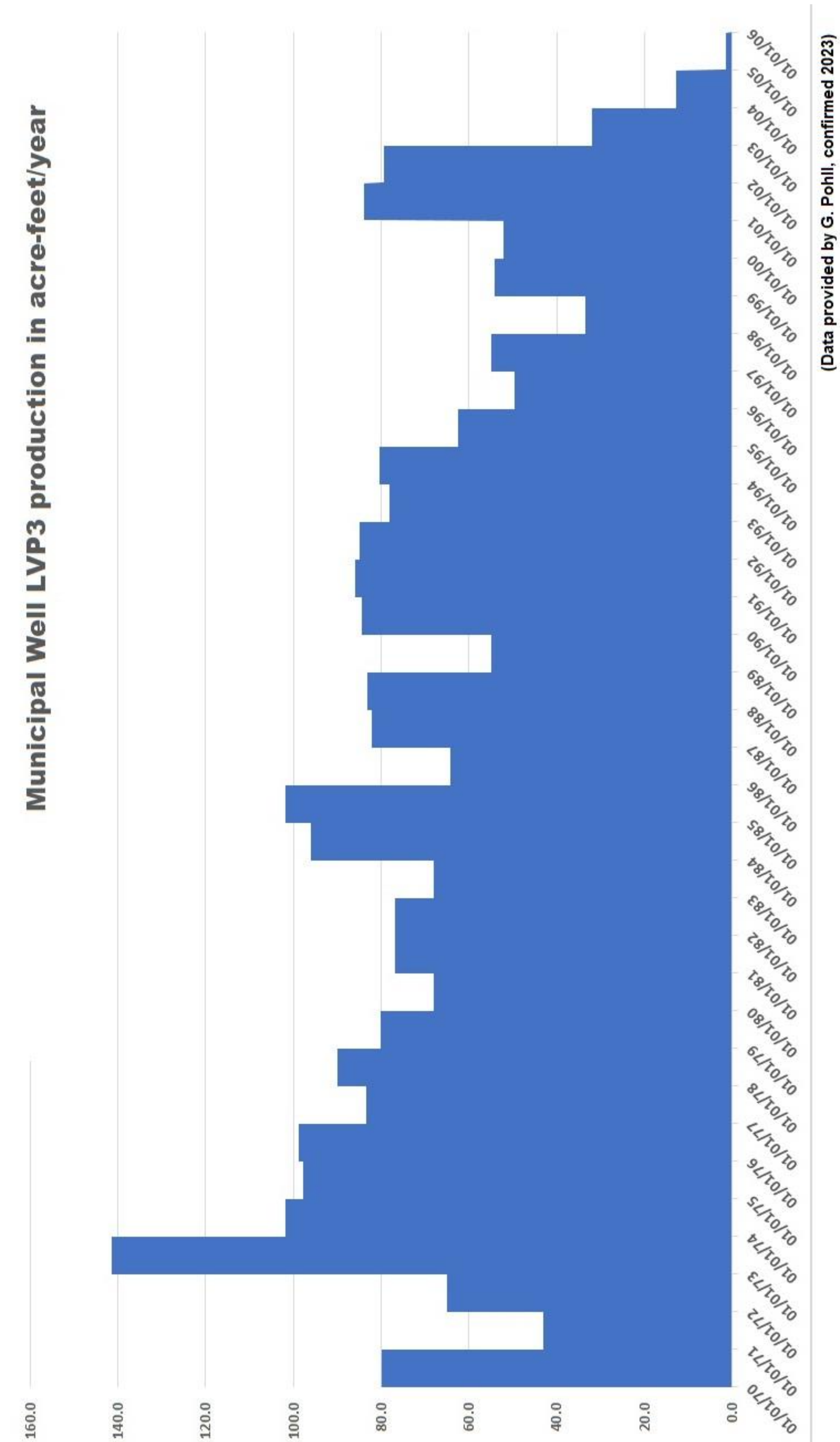


Figure 56. Annual production of municipal well LVP3 1970 – 2006

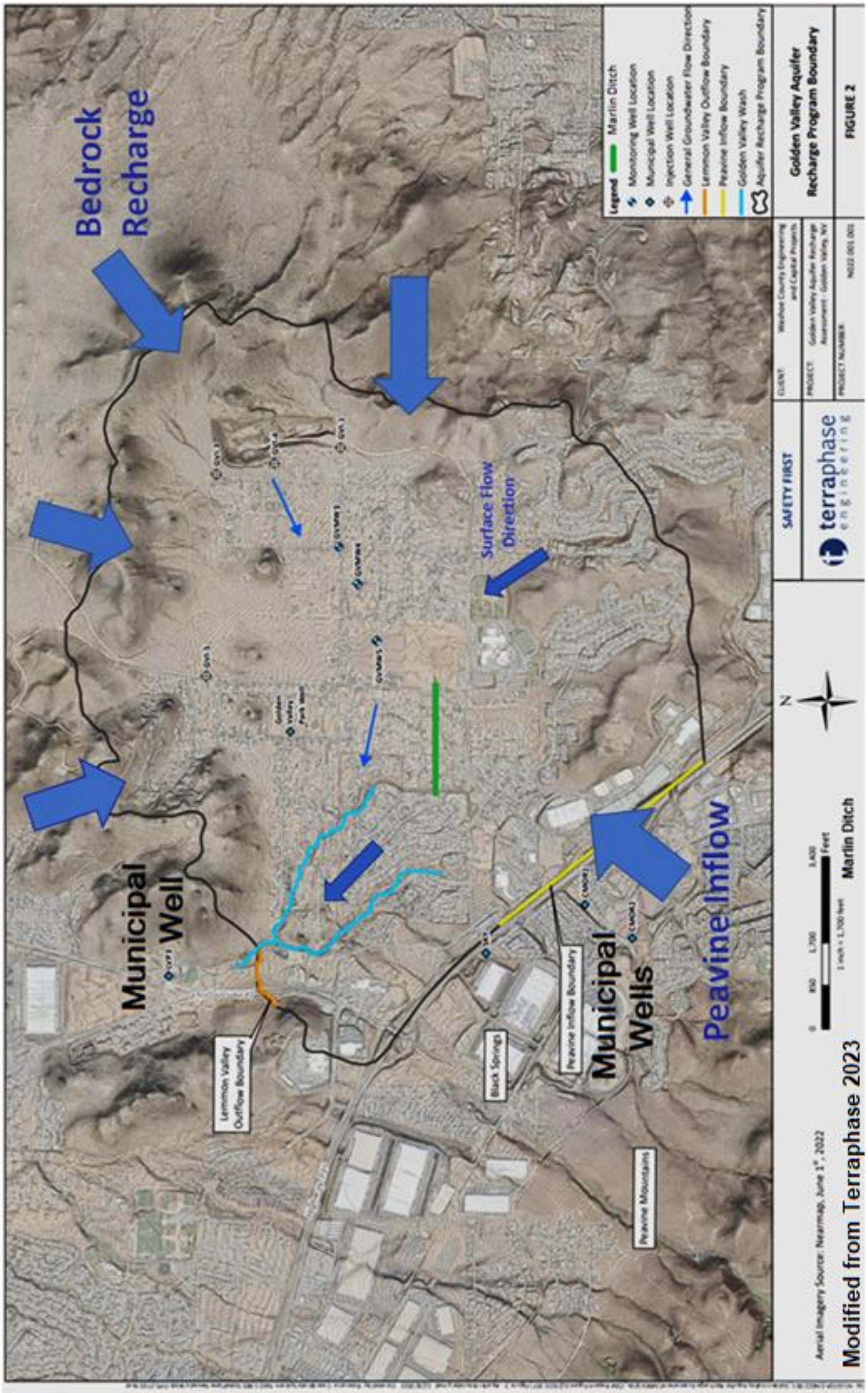


Figure 57. Groundwater Recharge zones

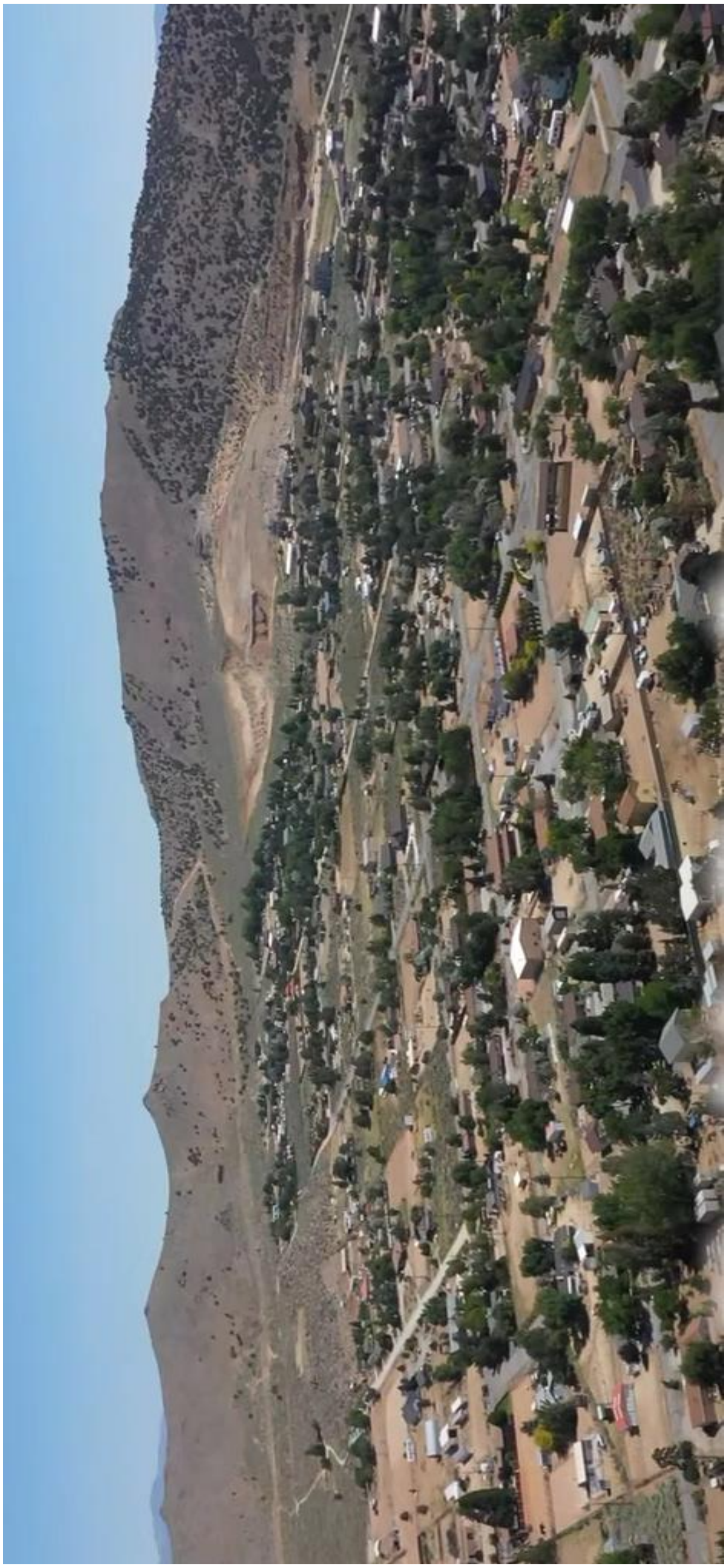


Figure 58. Critical recharge zone on northern & eastern Golden Valley margins

Figure 59. Zones of reduced recharge on western & southern Golden Valley margins

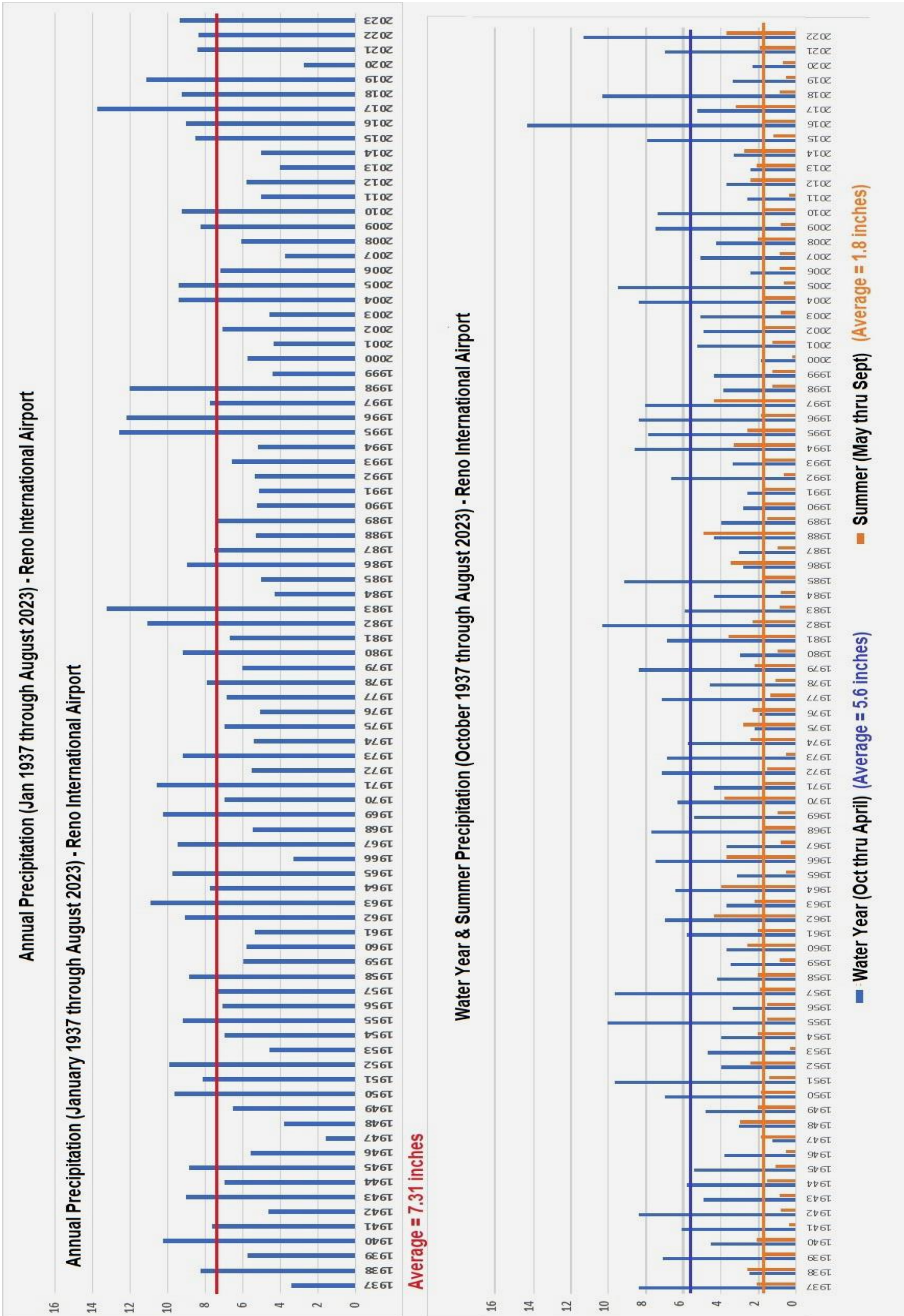


Figure 60. Annual versus Water-Year precipitation

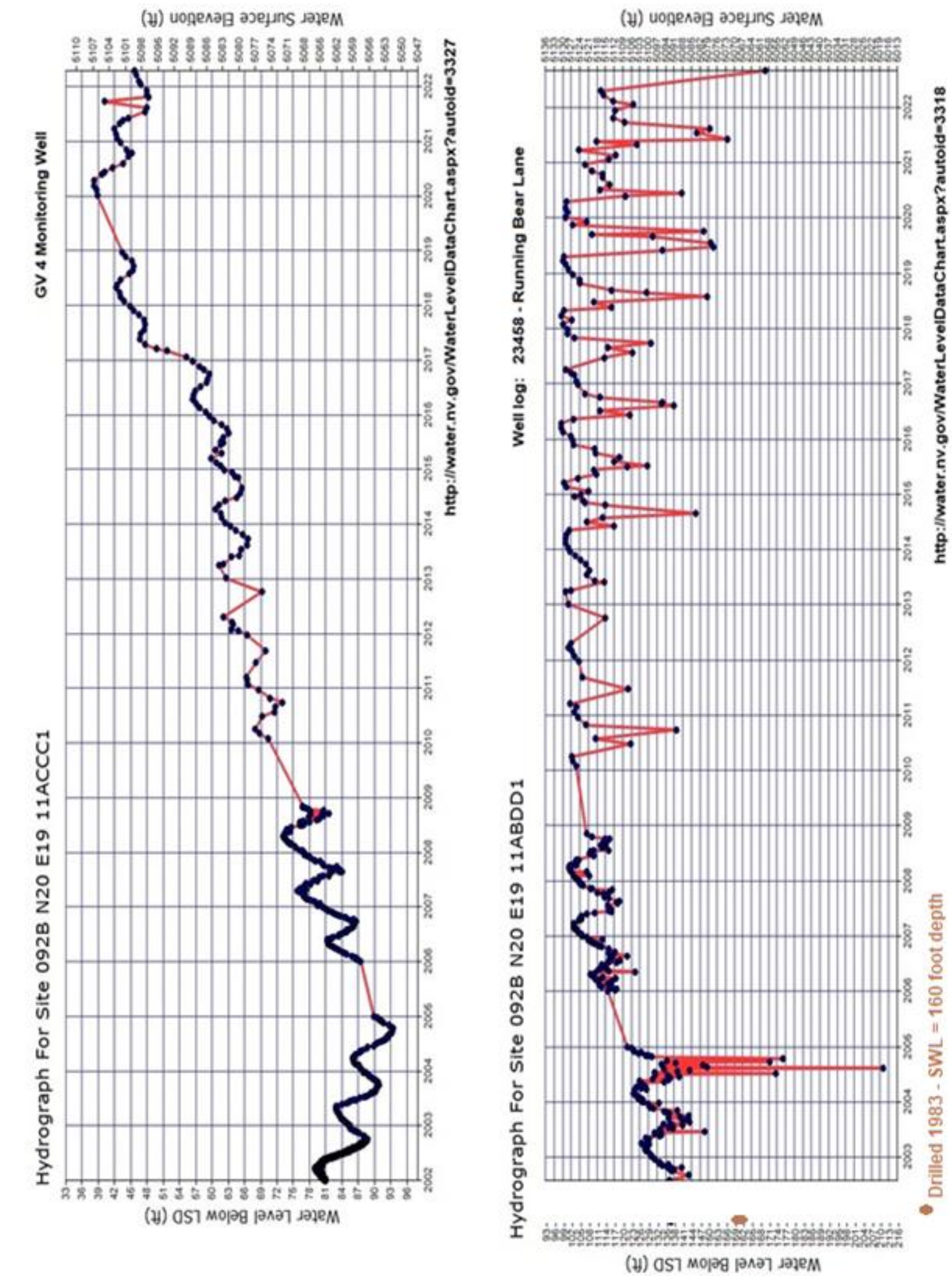


Figure 61. Hydrograph of seasonal groundwater levels

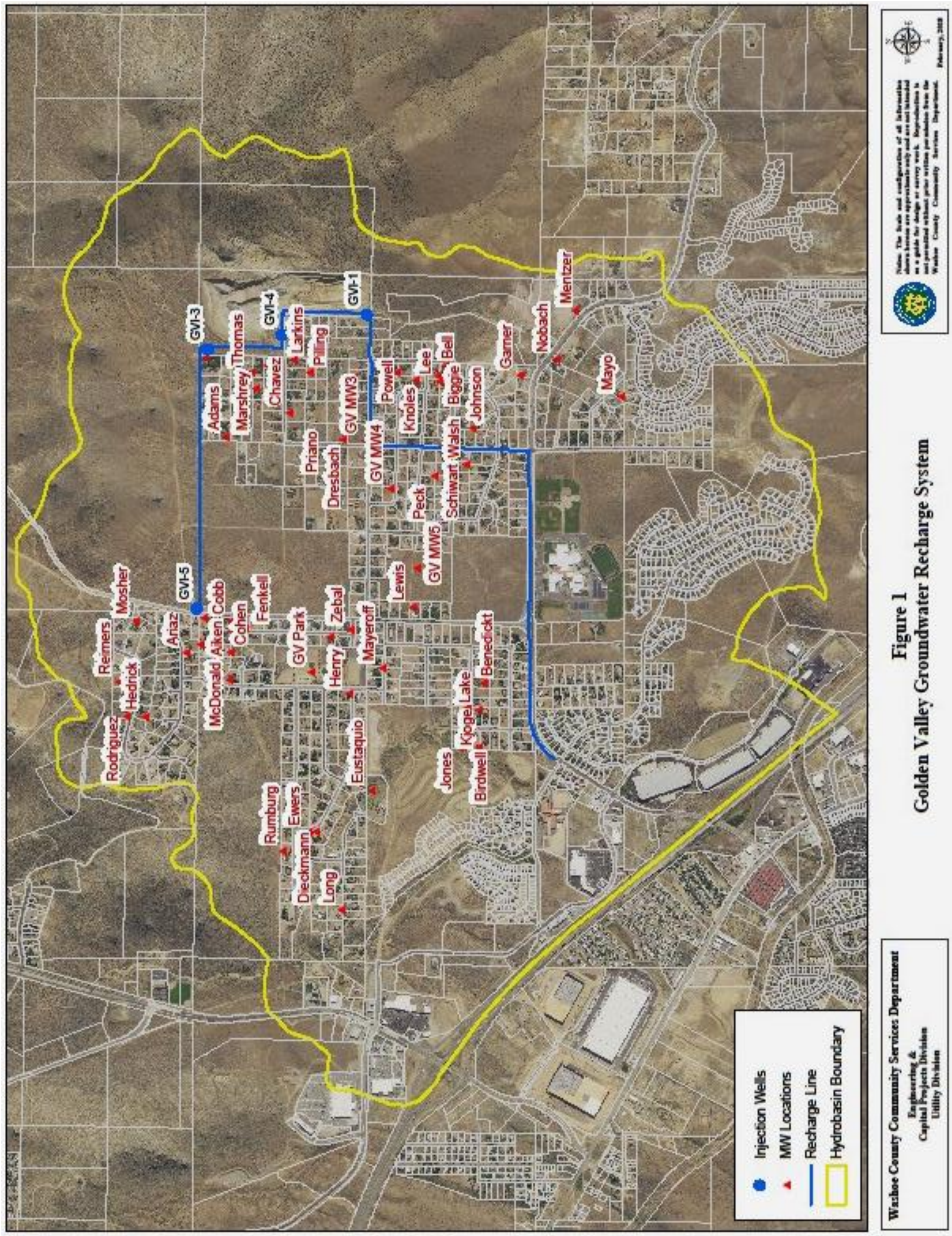


Figure 62. Golden Valley Groundwater Recharge System

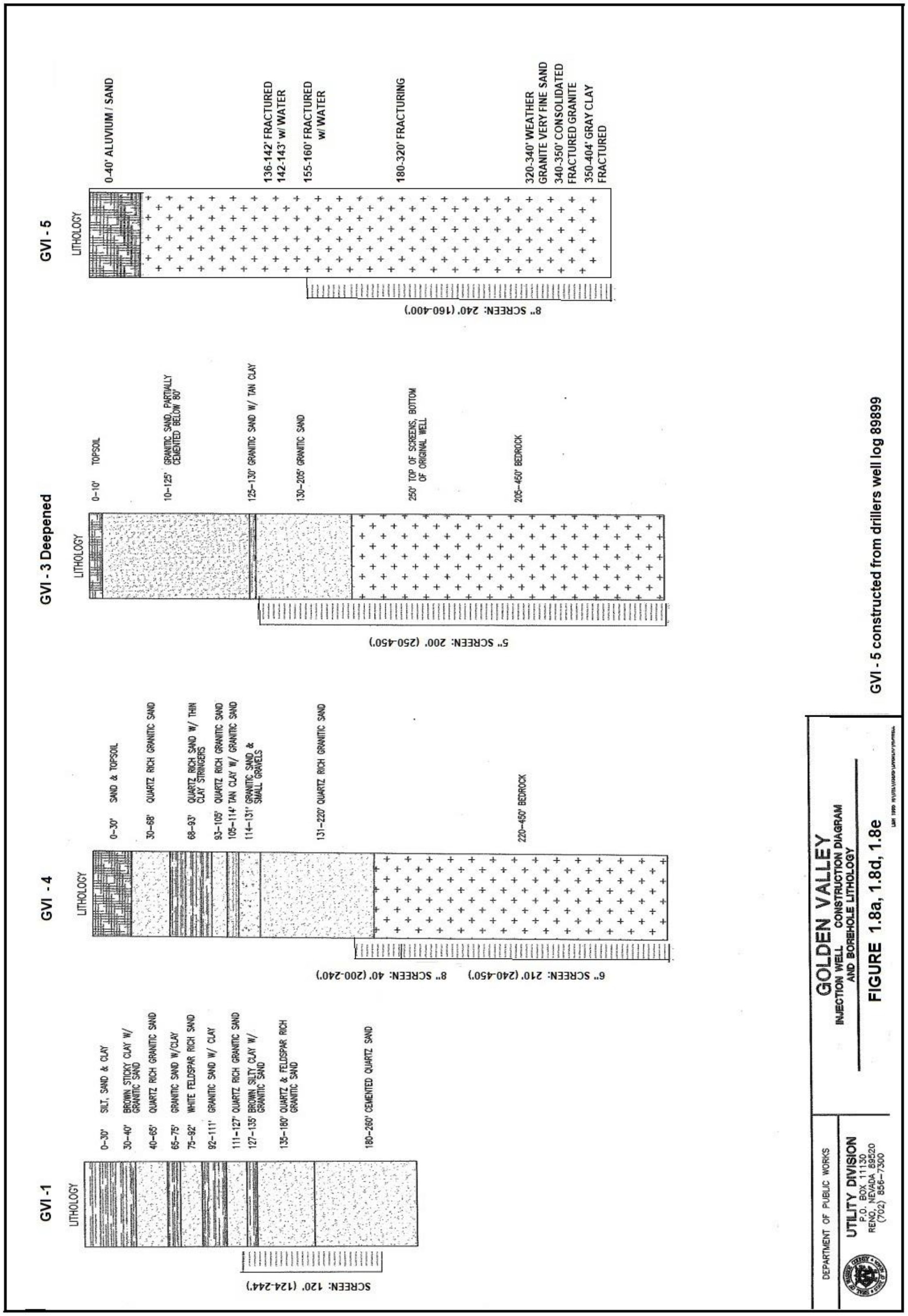
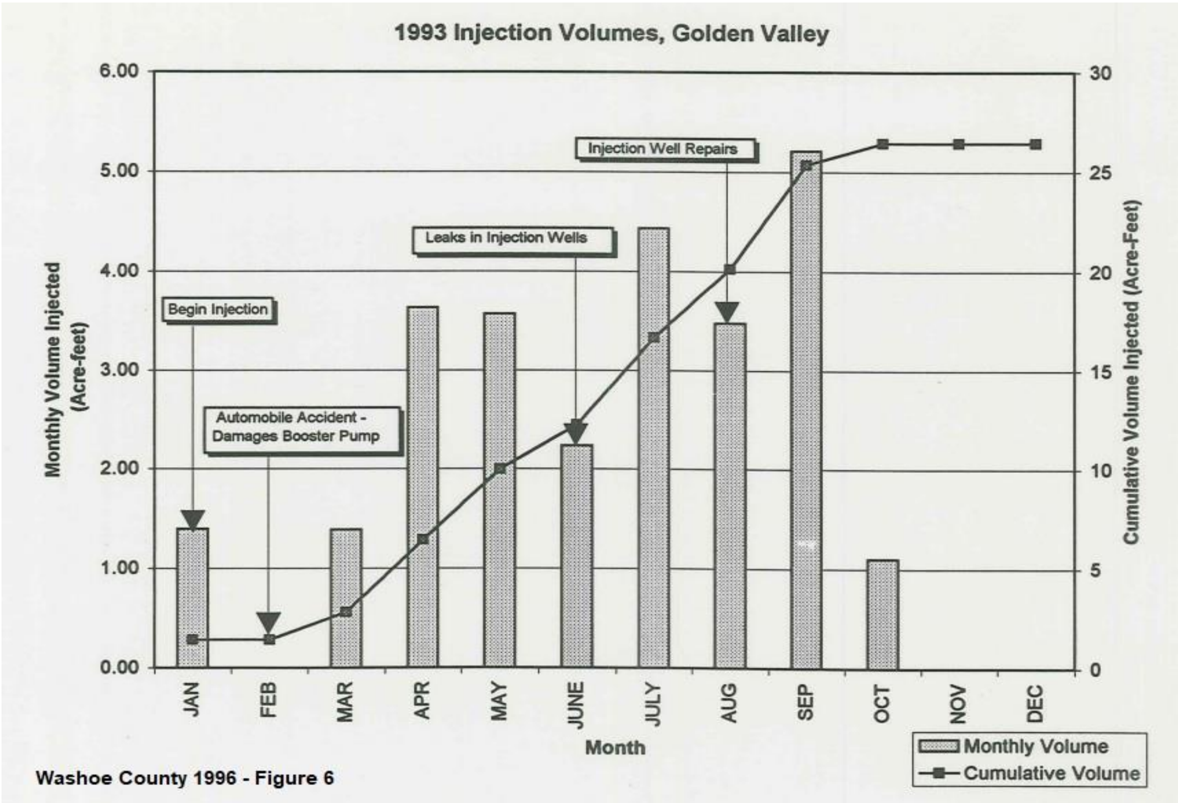


Figure 63. Golden Valley injection well logs & screened intervals



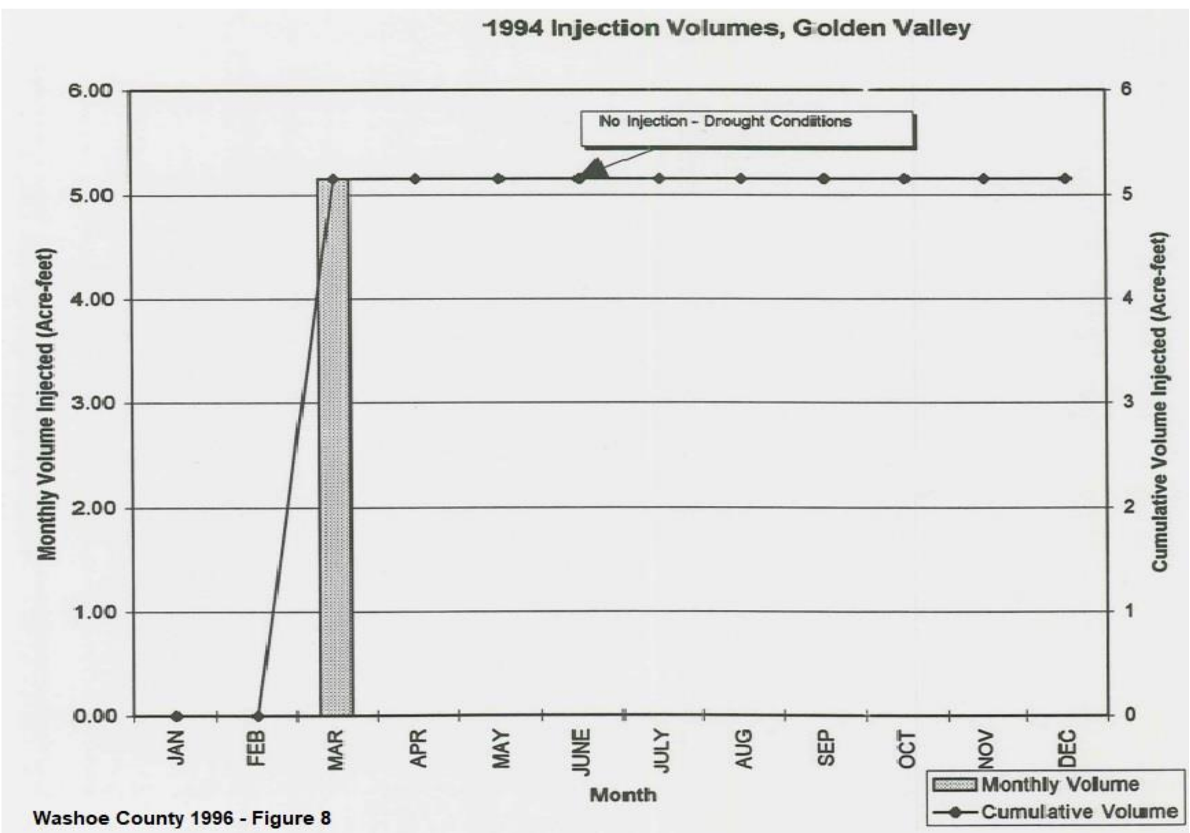
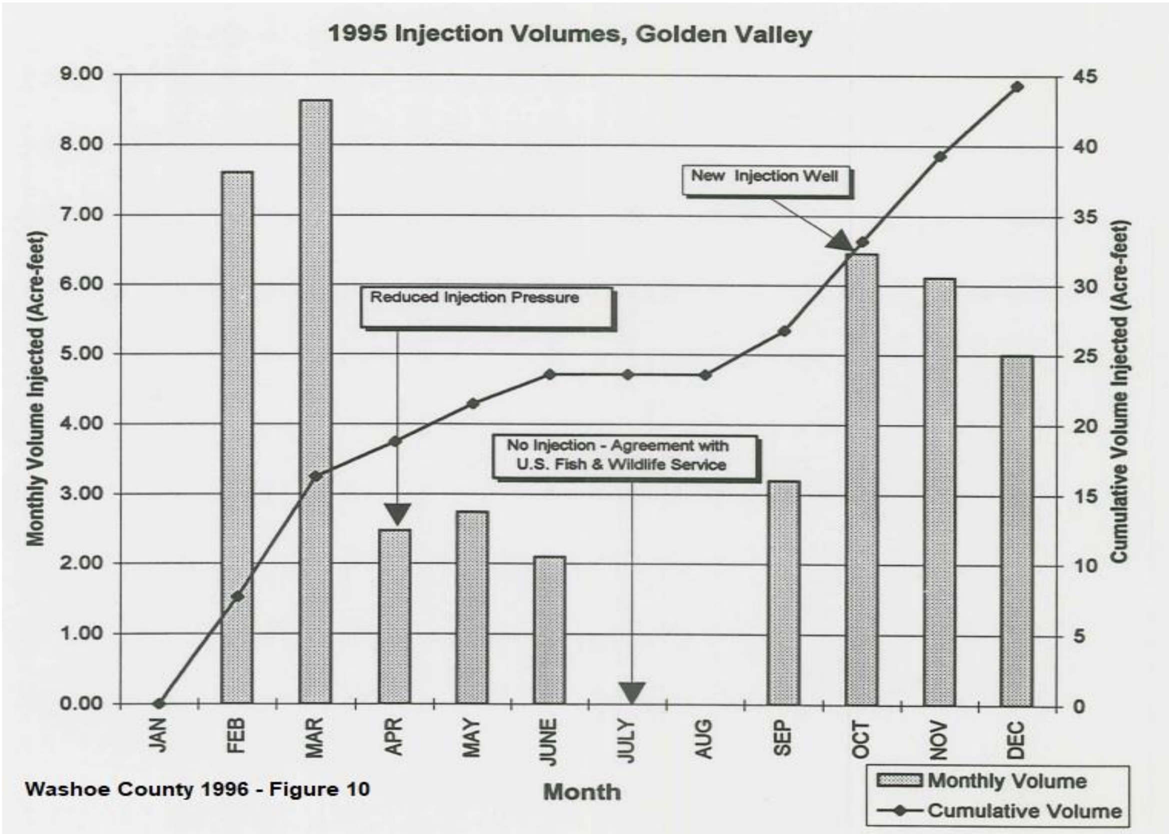


Figure 64. Injection volumes 1993-1994



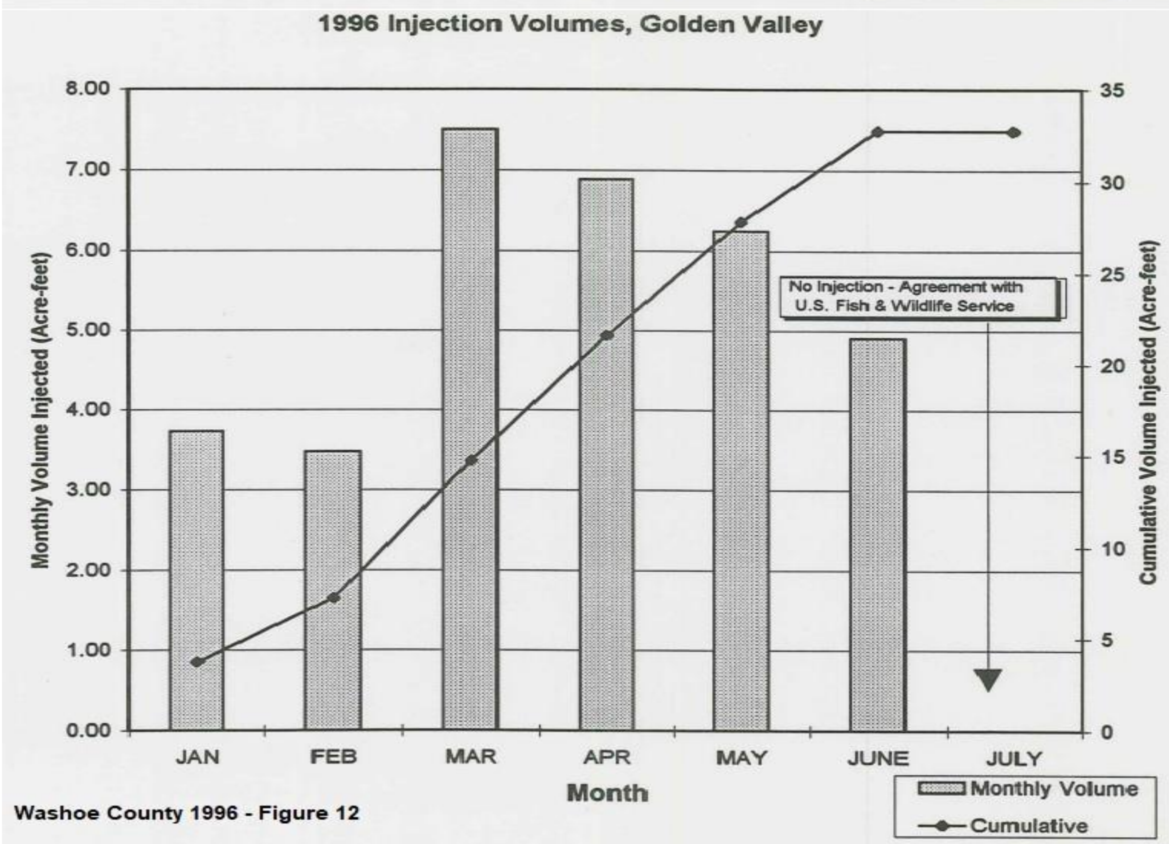


Figure 65. Injection volumes and replacement well 1995 & 1996

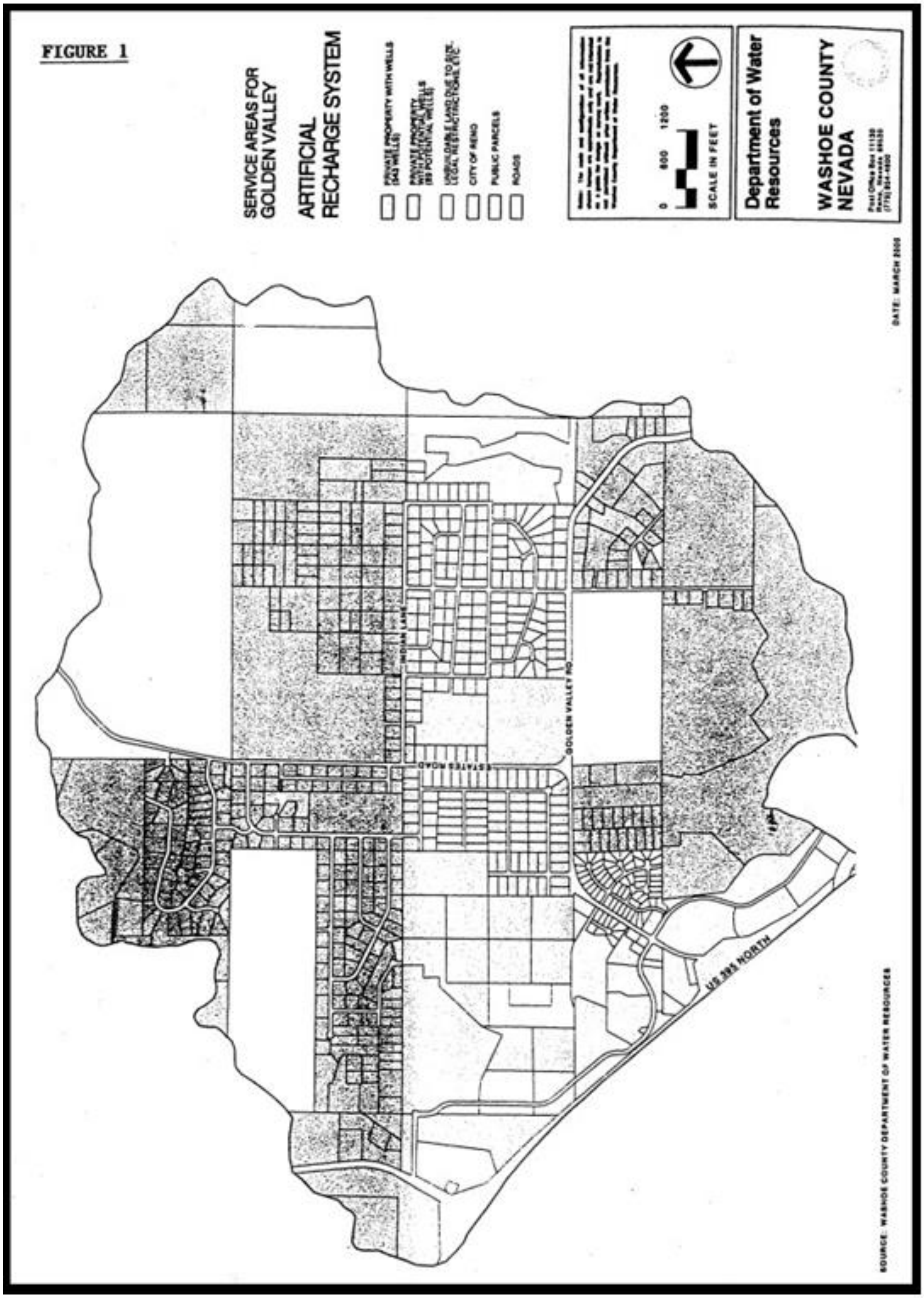


Figure 66. Golden Valley Artificial Recharge Program Service Area – 2002

Figure 3-1

Golden Valley Artificial Recharge Program Service Area

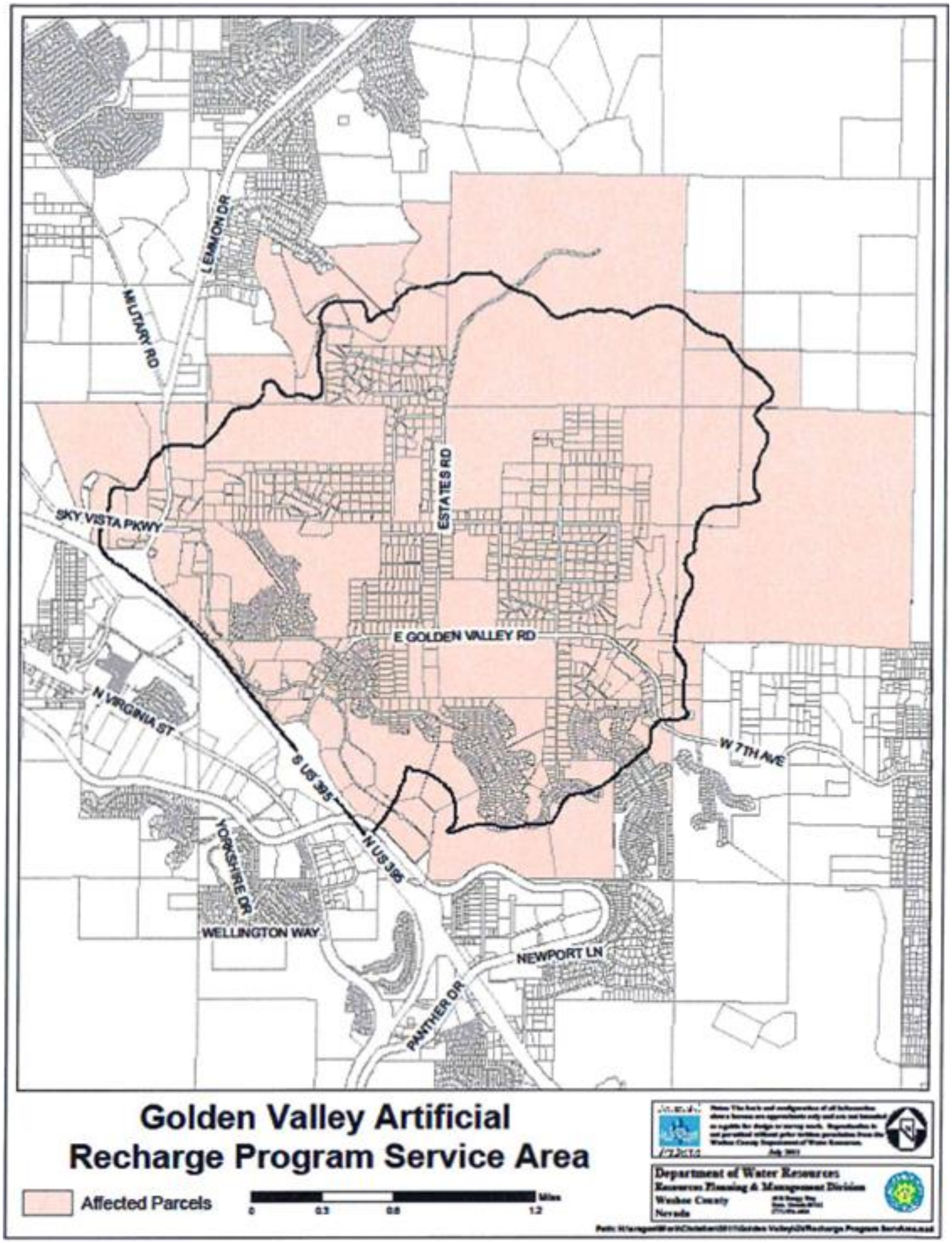


Figure 67. Golden Valley Artificial Recharge Program Service Area – 2014

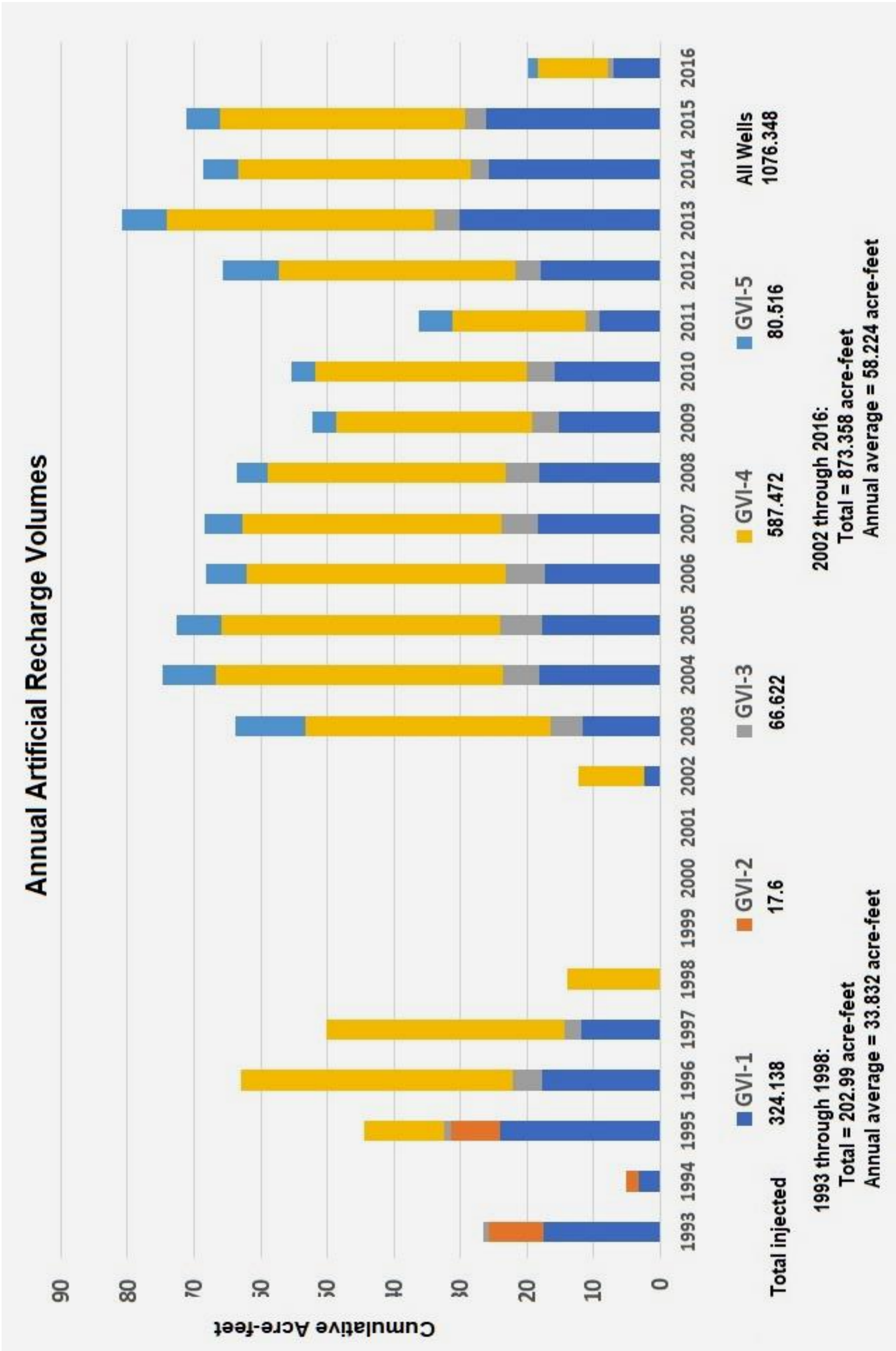


Figure 68. Artificial recharge volumes 1993-2016

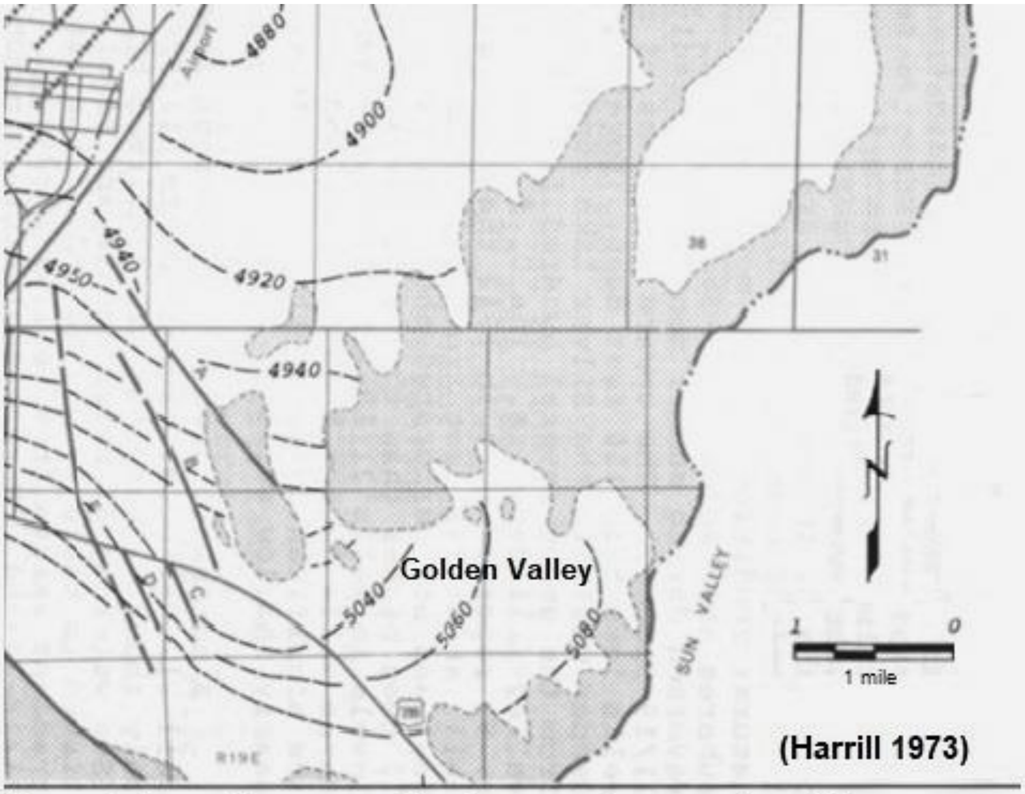


Figure 7. Approximate water-level contours for natural conditions

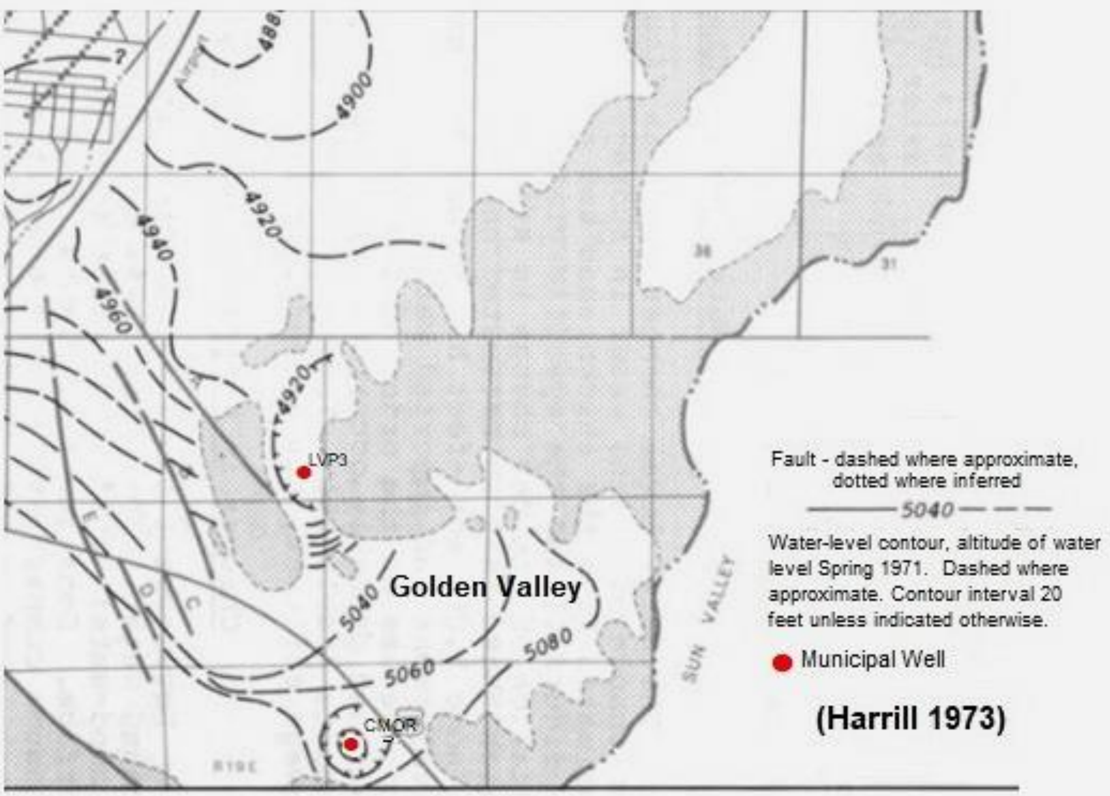
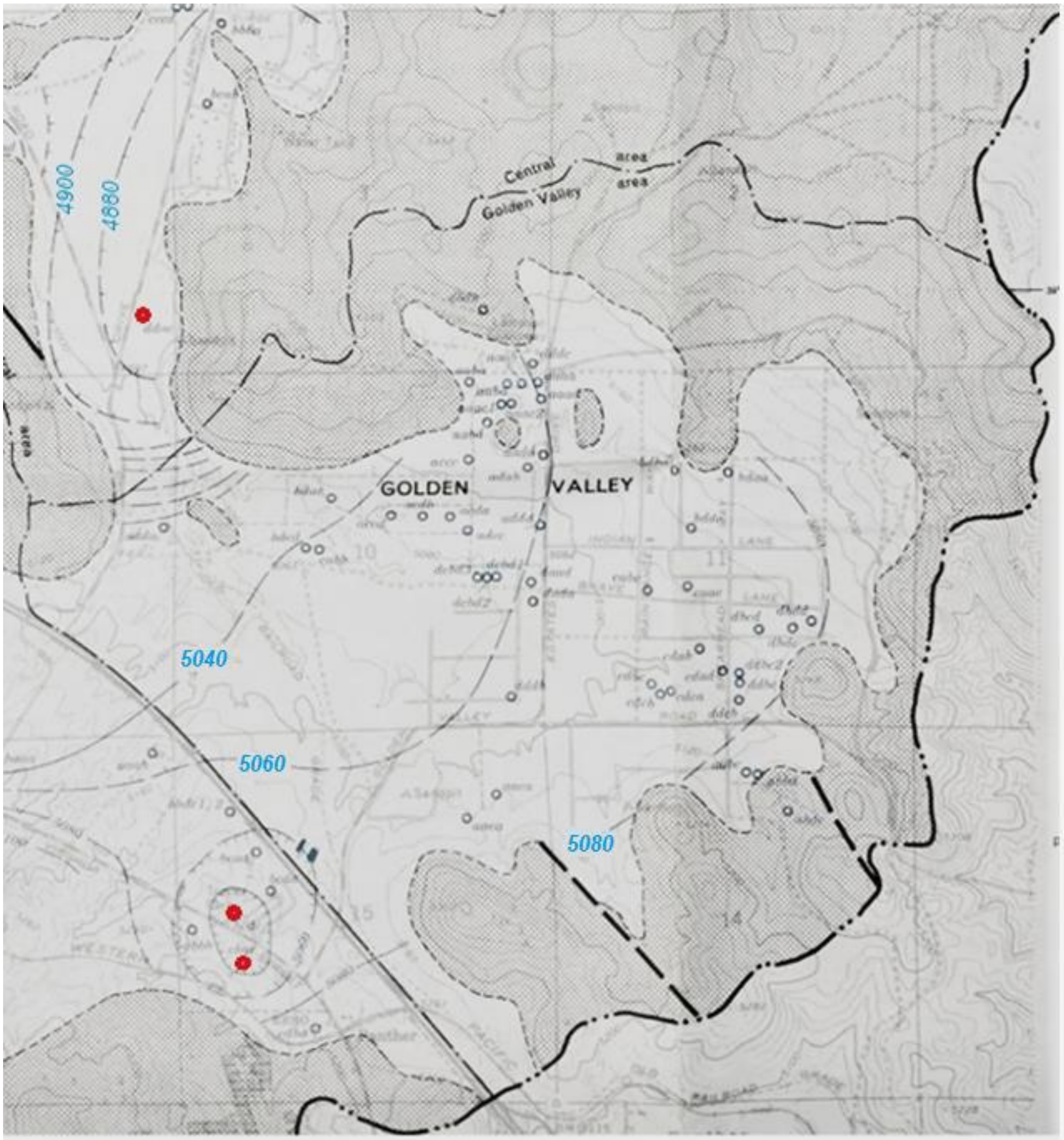


Figure 12. Approximate water-level contours Spring 1971

Figure 69. Groundwater levels – Natural conditions and Spring 1971



Extracted from Harrill 1973 - Plate. Municipal wells highlighted in red.

Figure 70. Groundwater levels November 1971

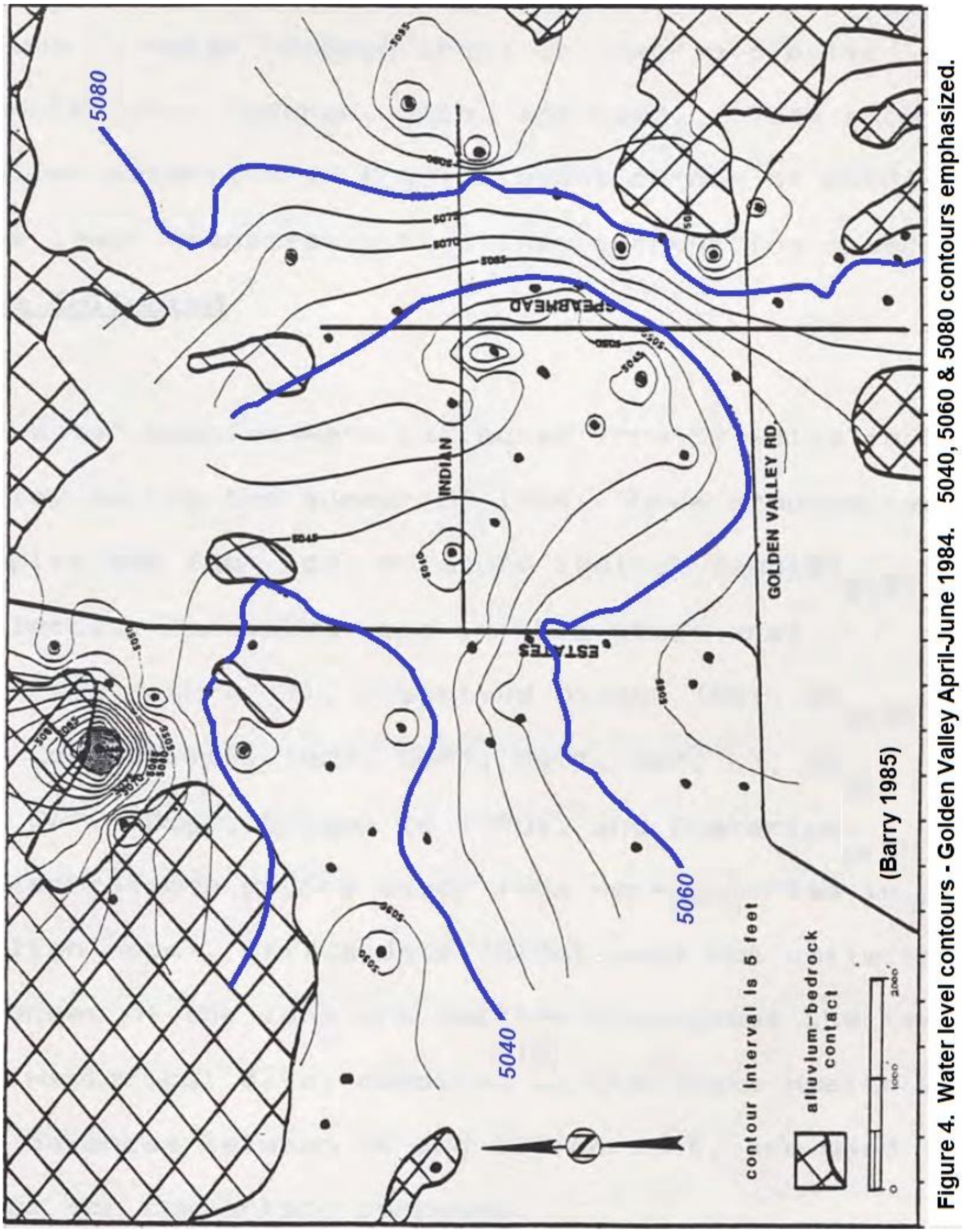
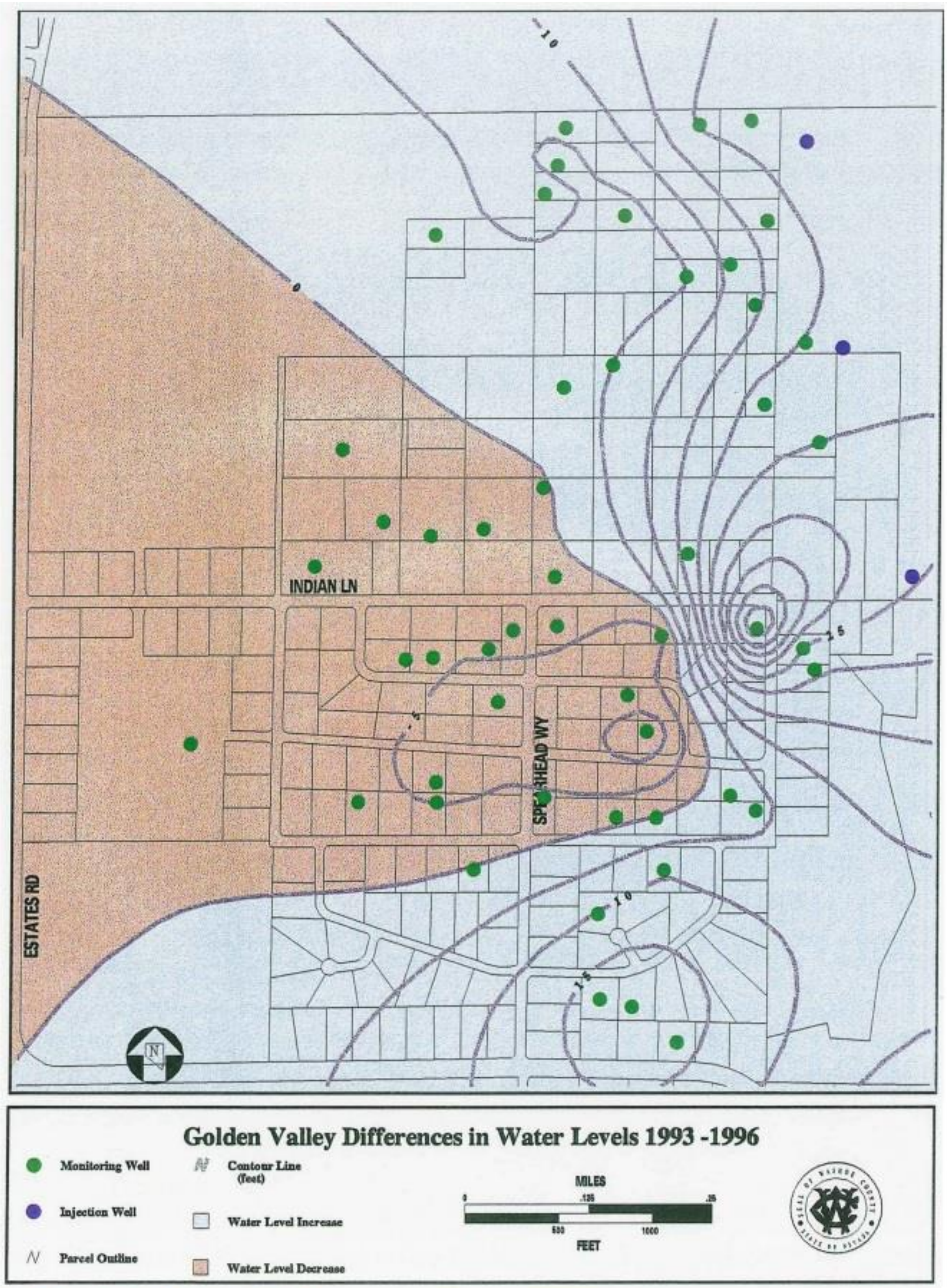
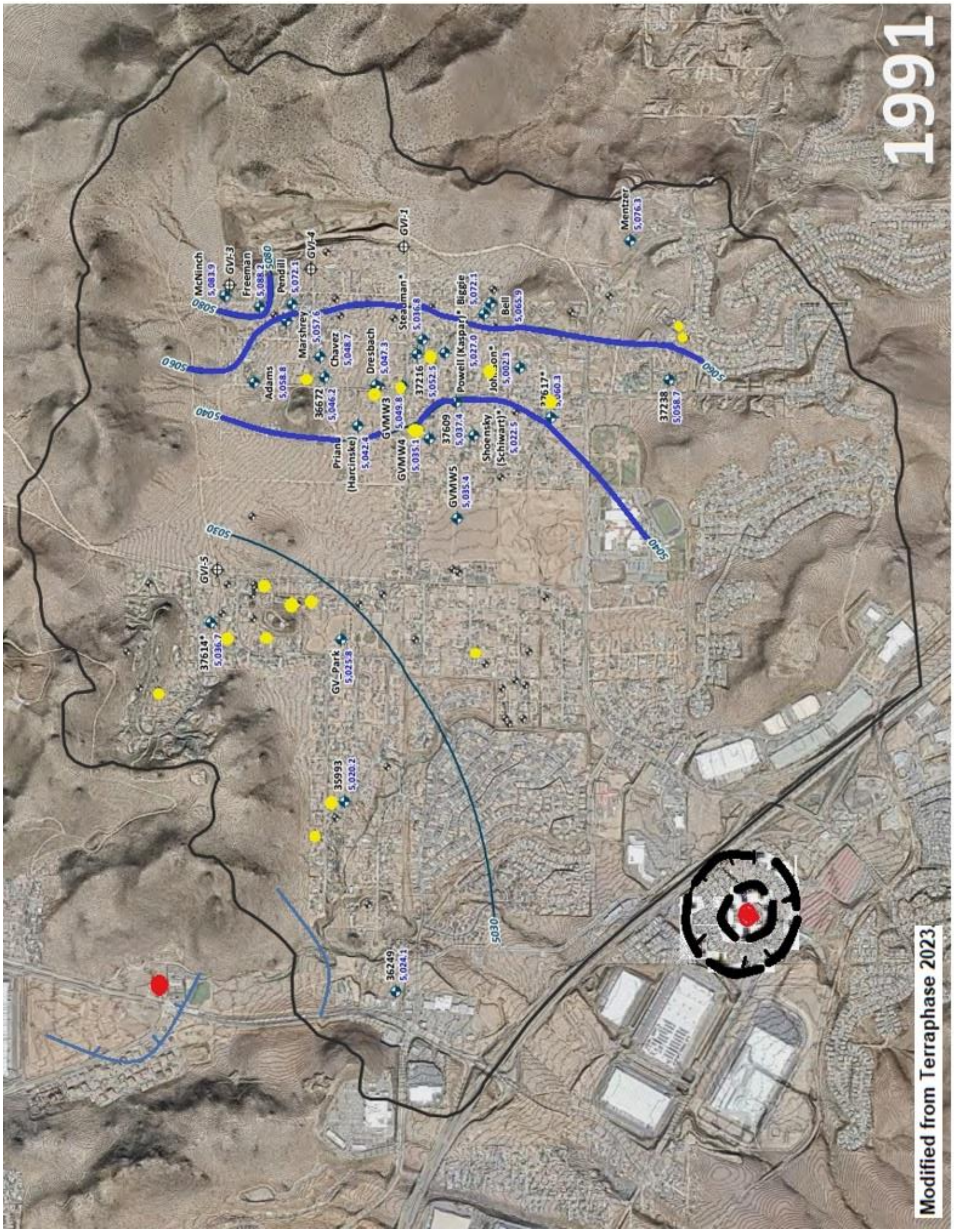


Figure 71. Groundwater levels April-June 1984



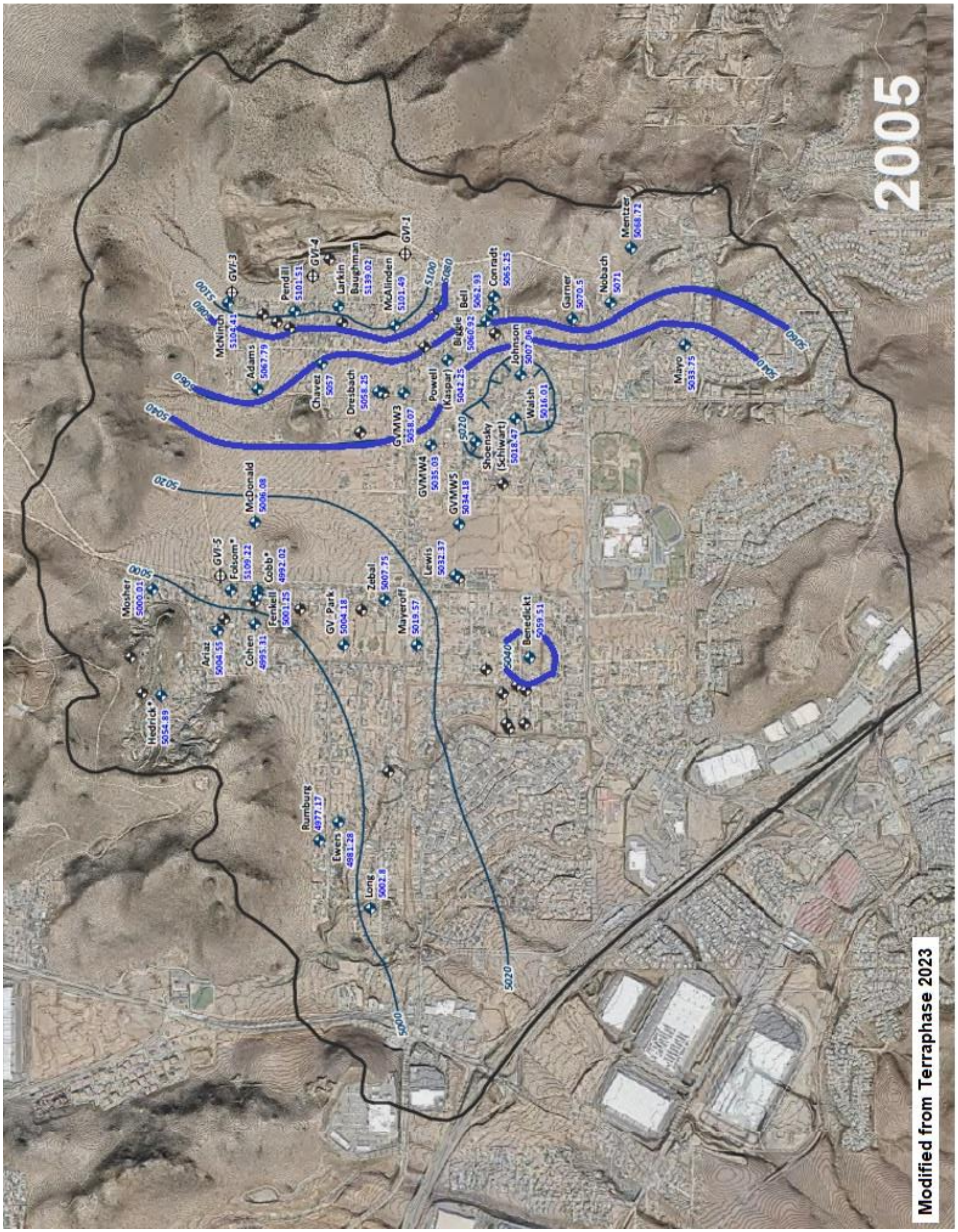
Washoe County 1996 - Figure 1

Figure 72. Differences in groundwater levels 1993-1996



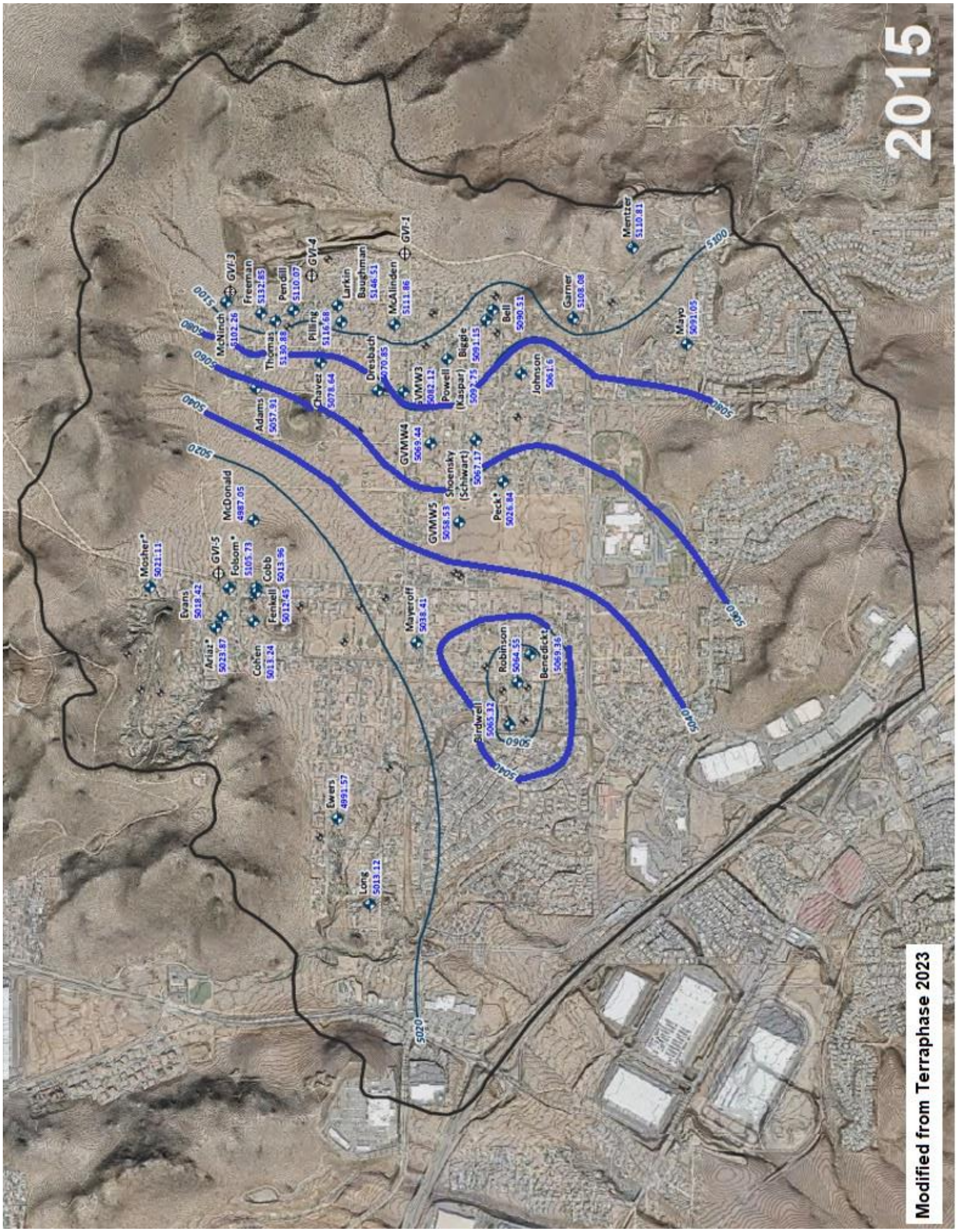
5040, 5060 & 5080 contours emphasized. Deeped wells highlighted in yellow.

Figure 73. Groundwater levels 1991



5040, 5060 & 5080 contours empasized.

Figure 74. Groundwater levels 2005



5040, 5060 & 5080 contours empasized.

Figure 75. Groundwater levels 2015

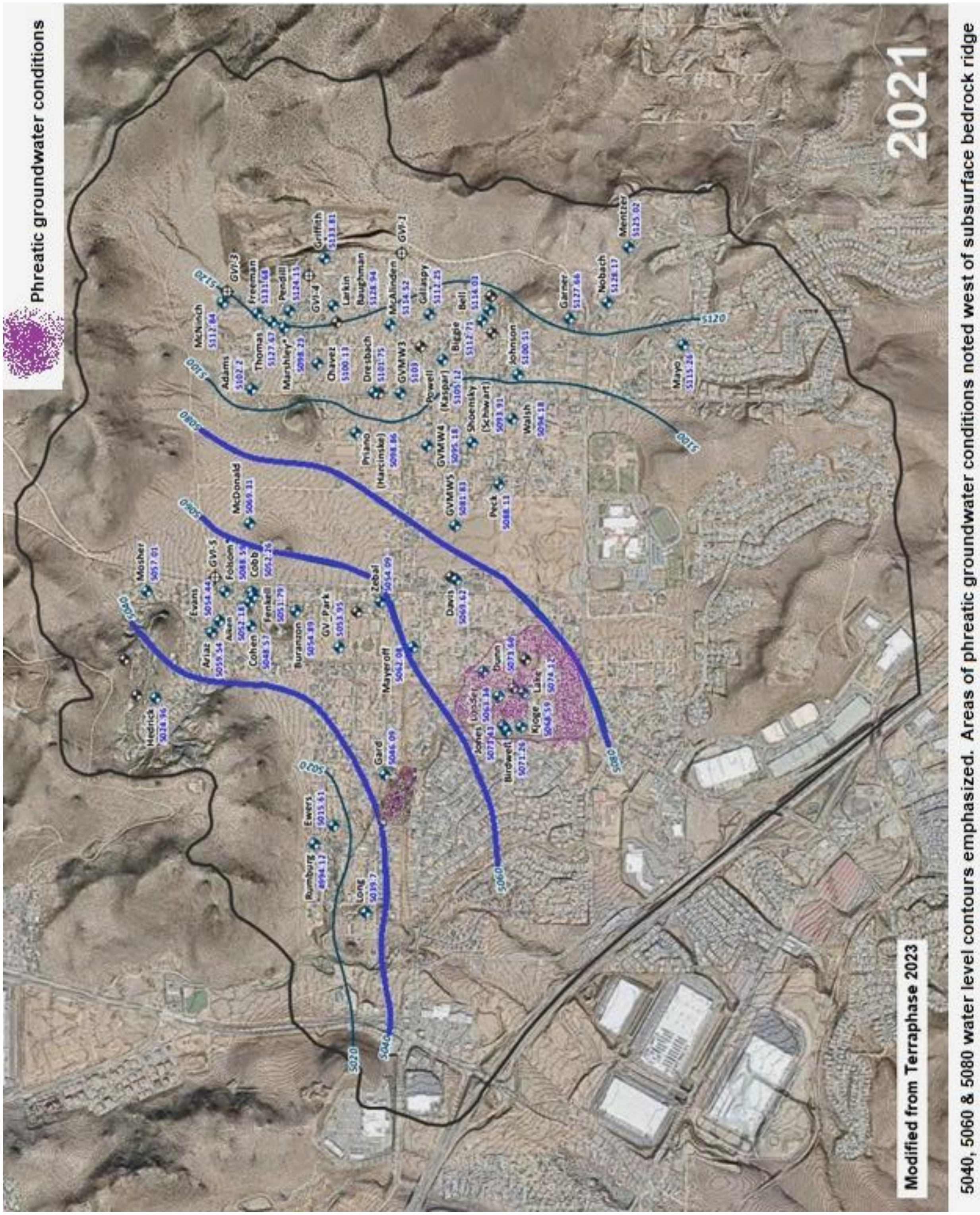


Figure 76. Groundwater levels 2021

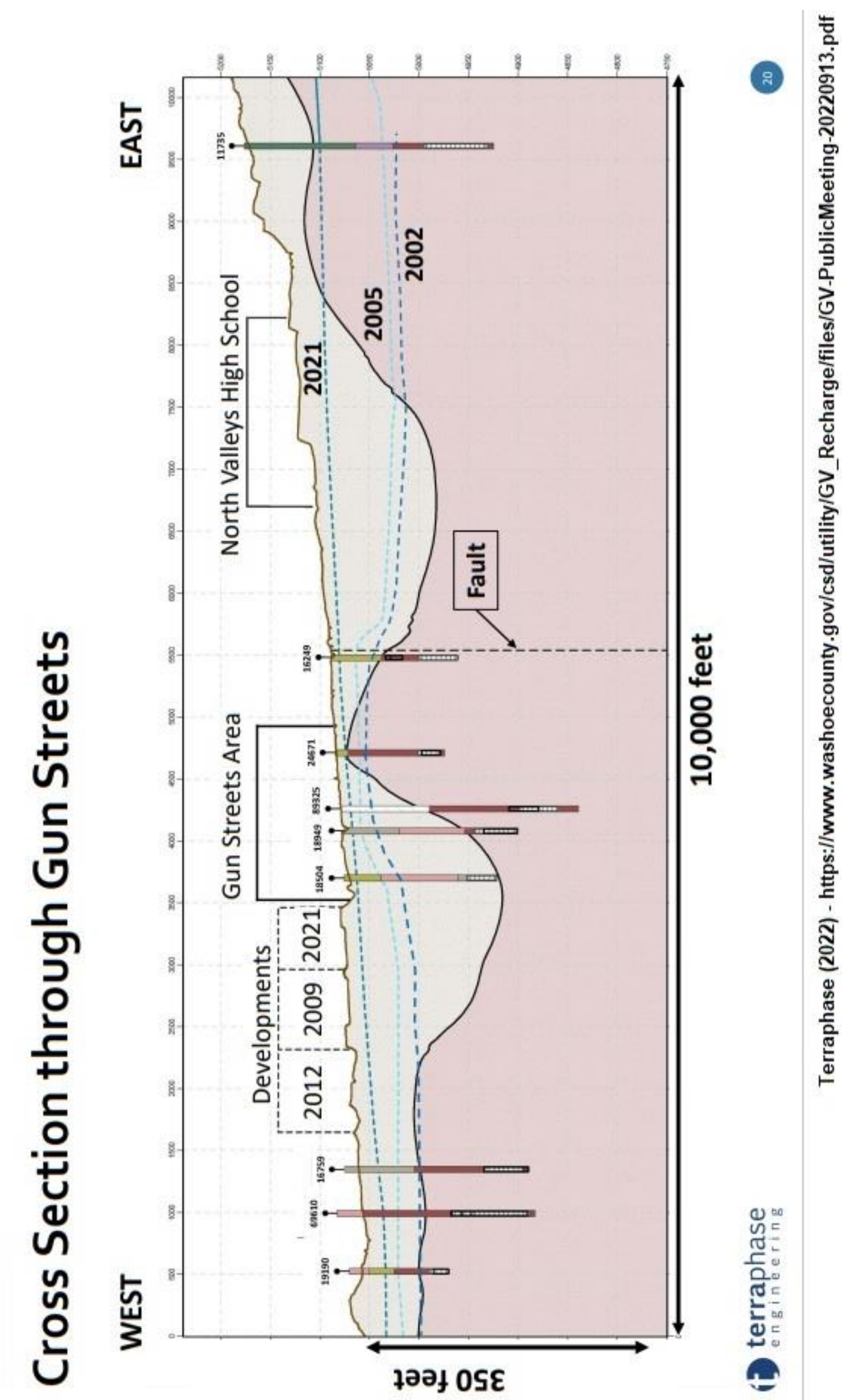


Figure 77. Groundwater levels North Valleys HS to Steadfield Estates 2002-2021

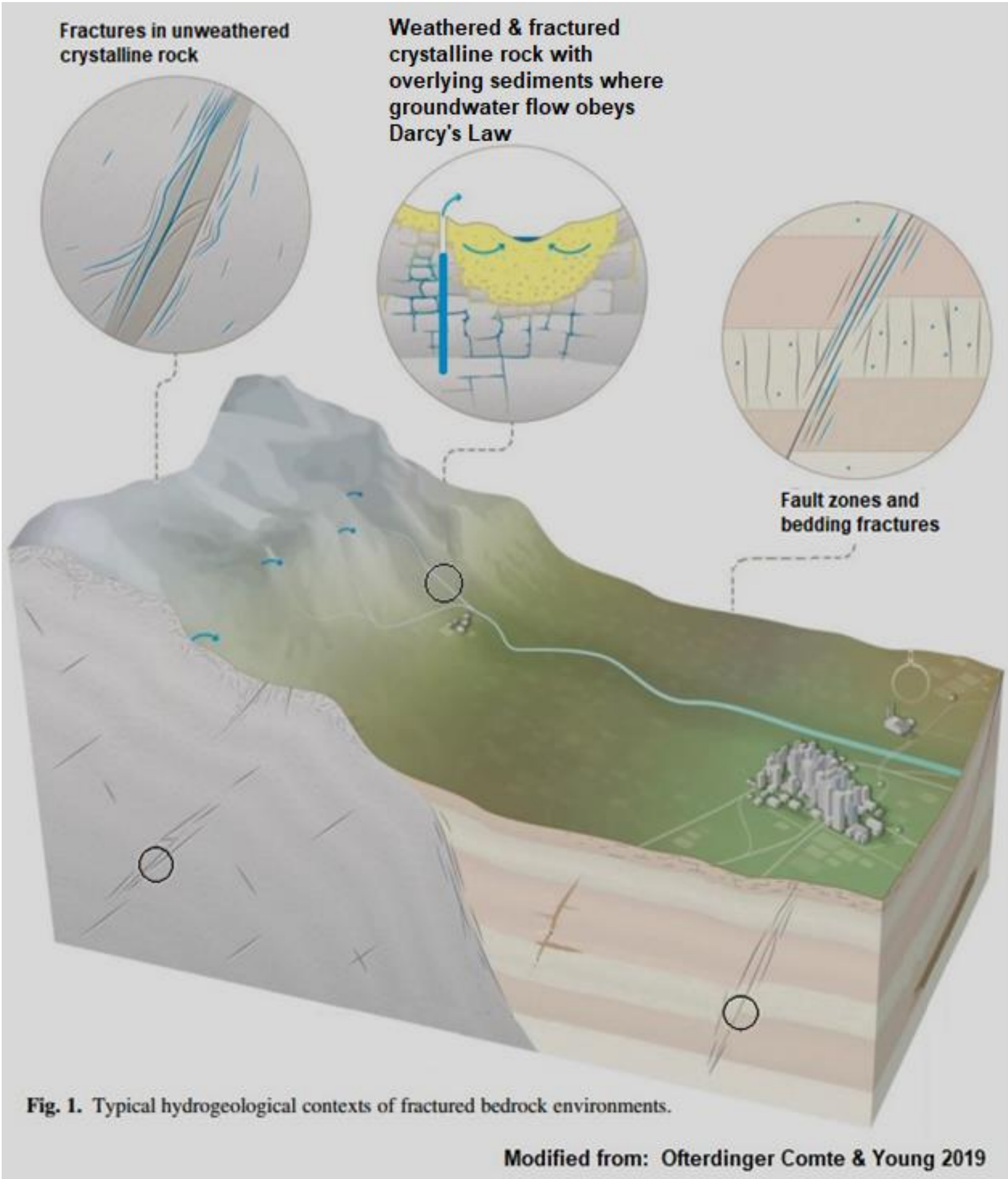


Figure 78. Confined conditions in fractured bedrock

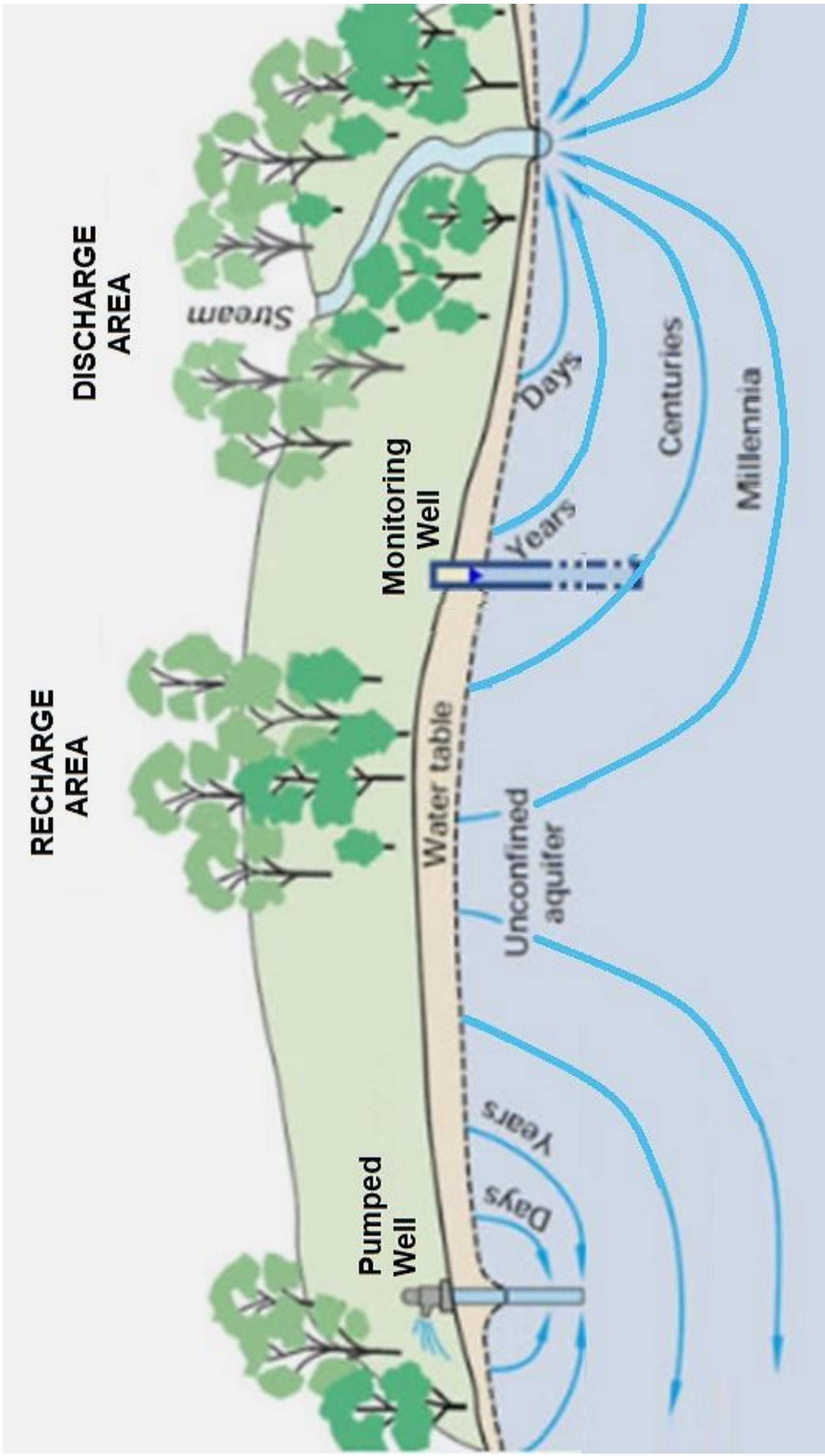


Figure 79. Groundwater movement and travel times in unconfined aquifers

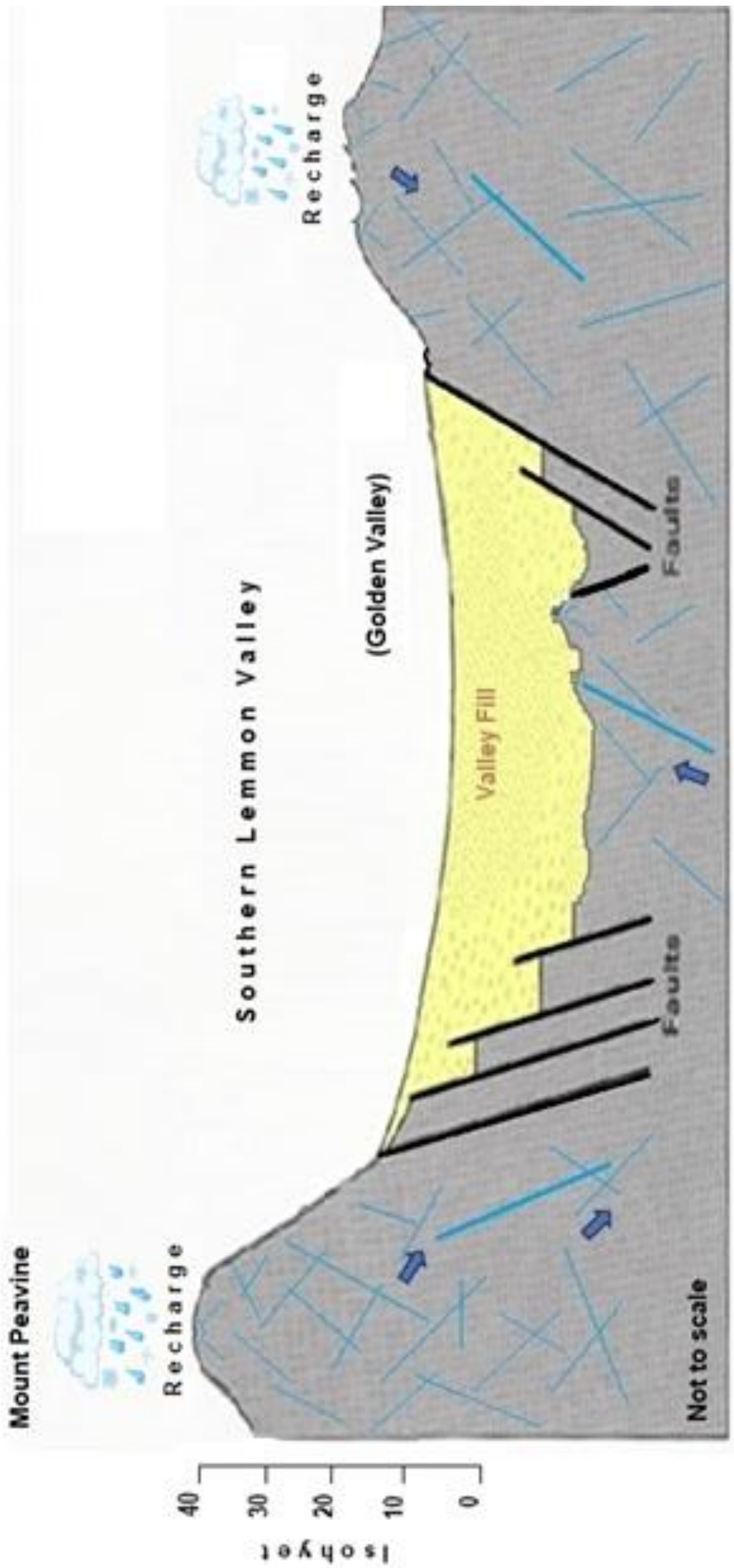
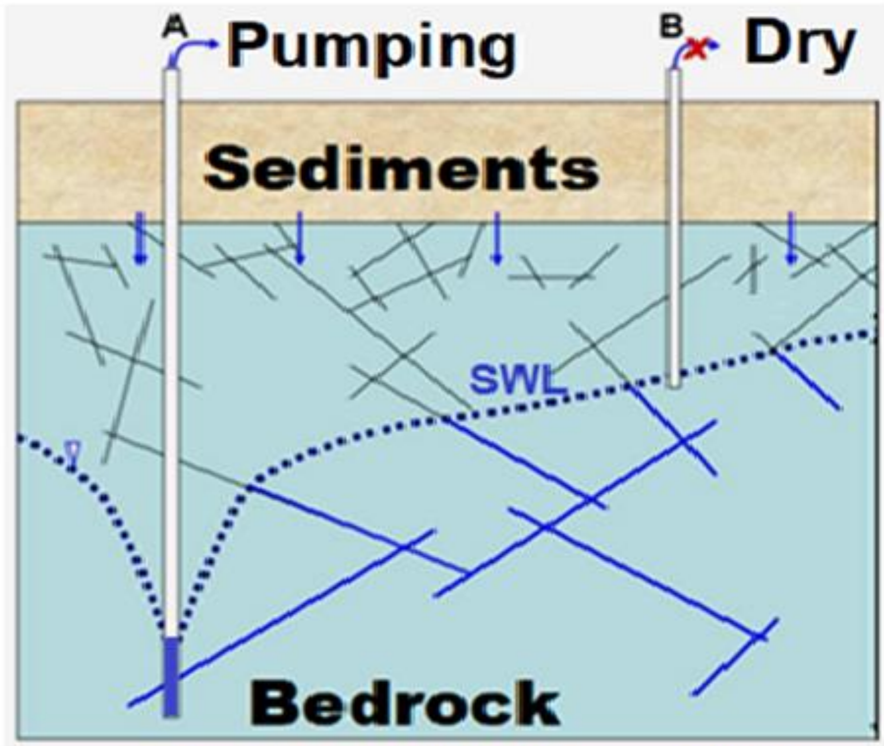
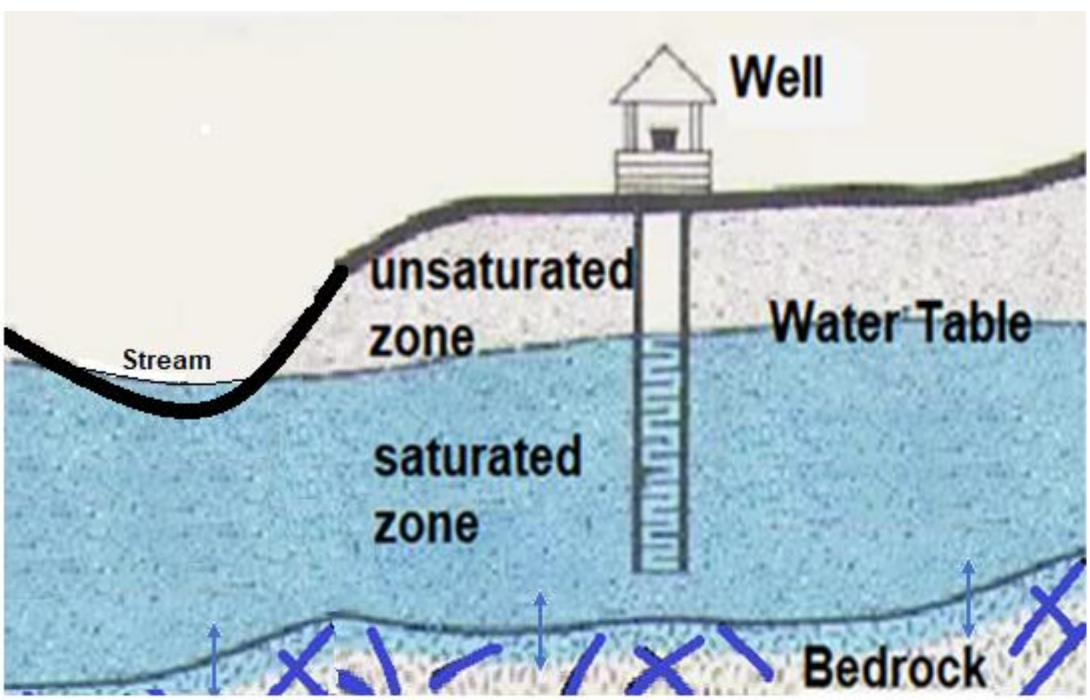


Figure 80. Schematic cross-section of southern Lemmon Valley



SWL = Piezometric suface resulting from hydrostatic pressue within fracture system

Figure 81. Piezometric water level in bedrock fracture system



Water Table = Phreatic water surface of saturated zone

Figure 82. Phreatic groundwater conditions in valley fill

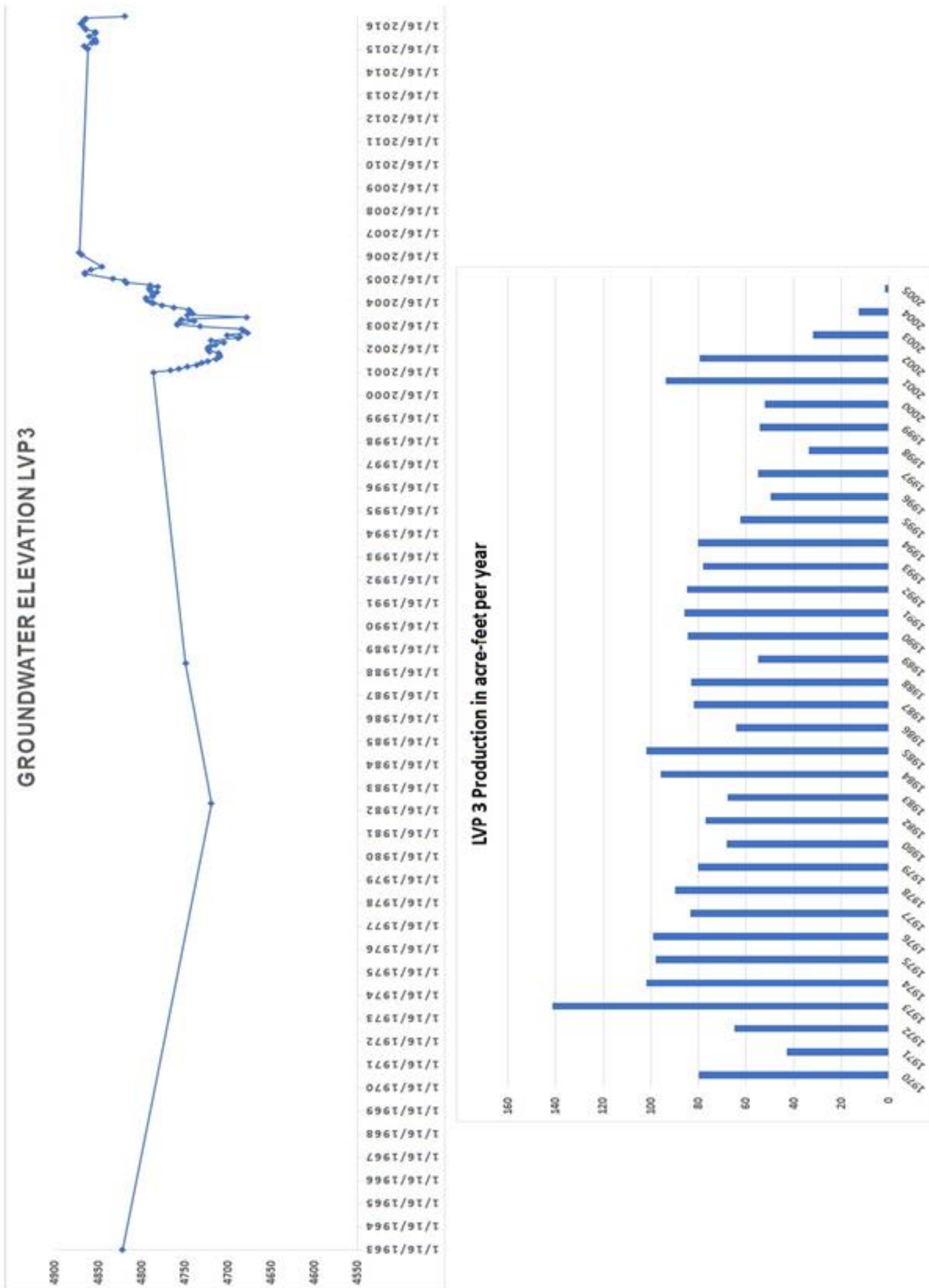


Figure 83. Hydrograph and production in well LVP3 1963-2018

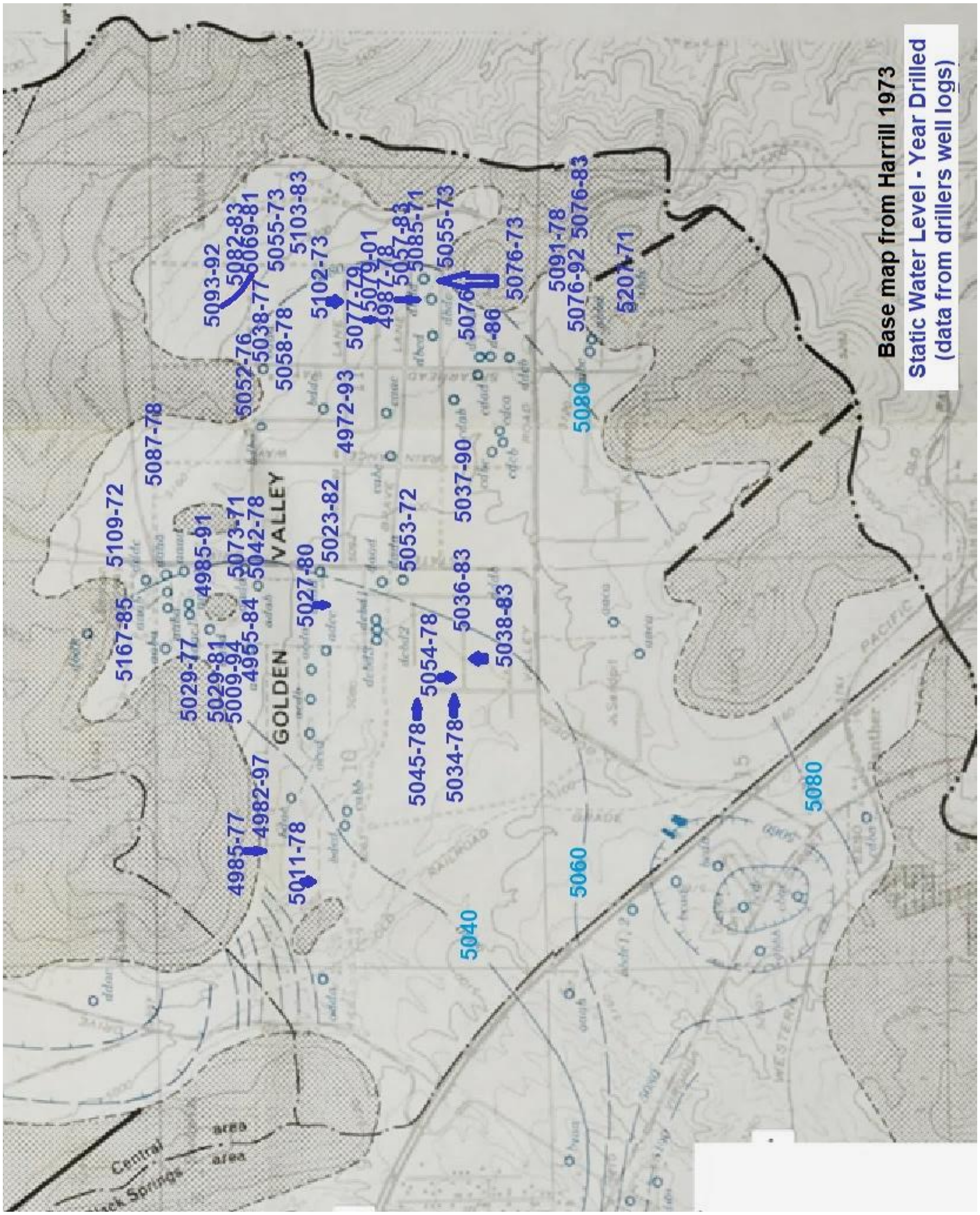


Figure 84. Static water levels in new wells 1970s to 1990s

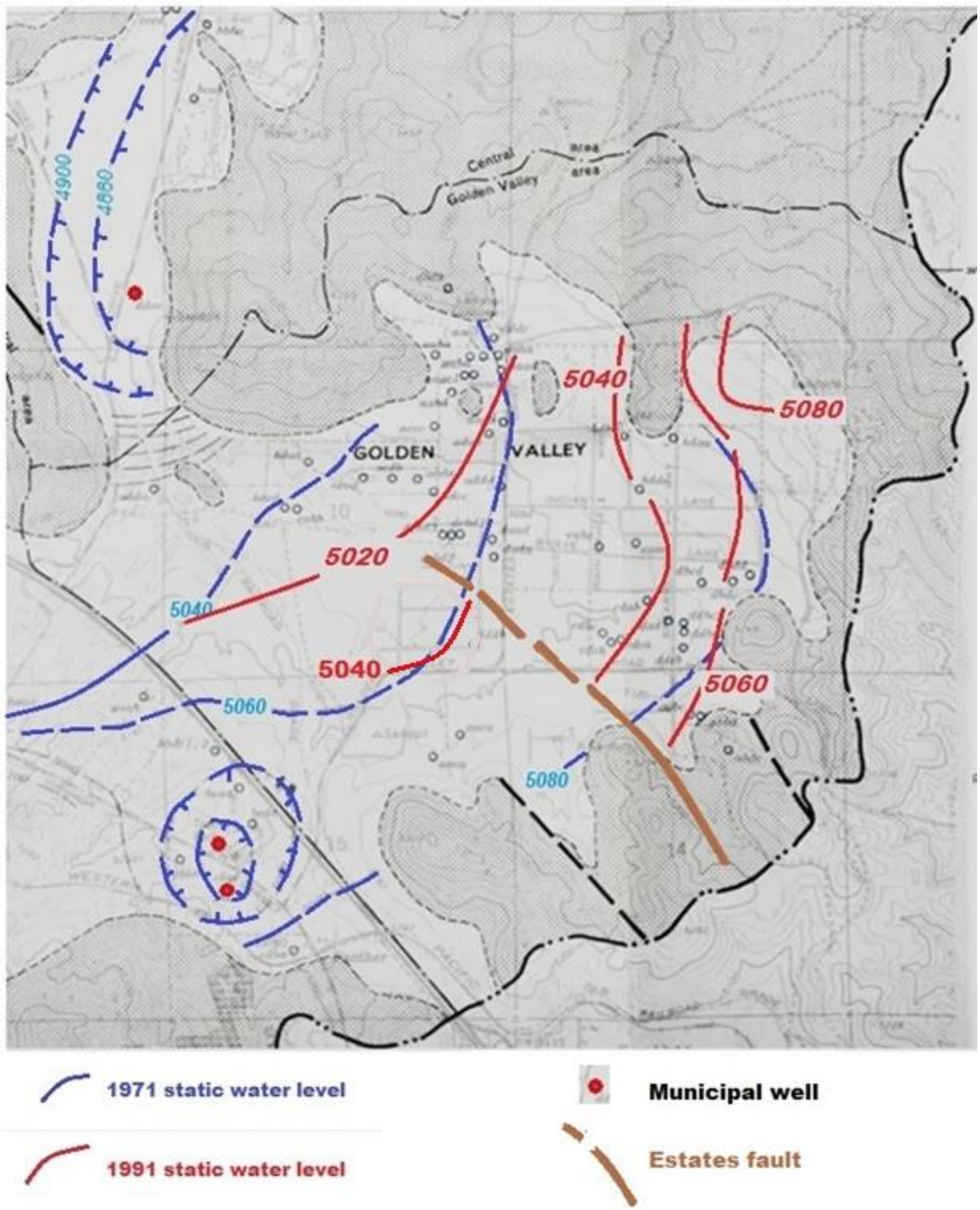


Figure 85. Comparison of static groundwater contours 1971 to 1991

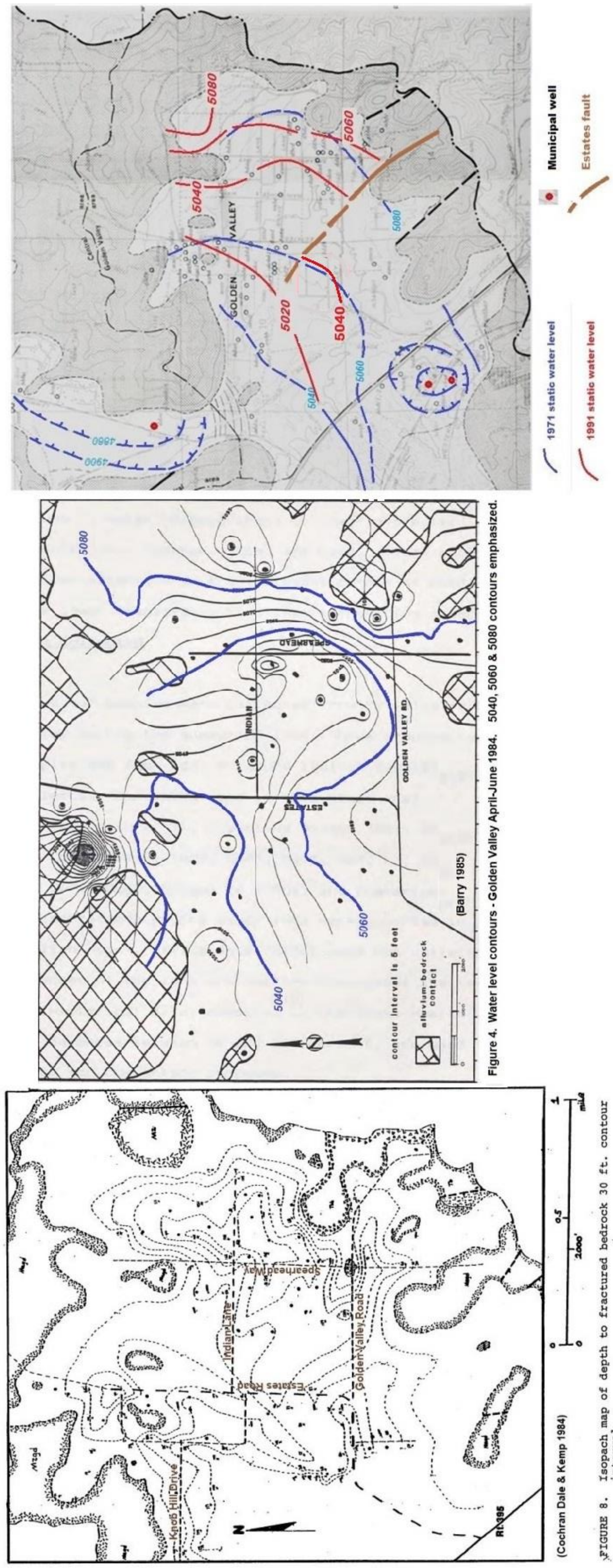


Figure 86. Location & influence of Estates Fault on groundwater

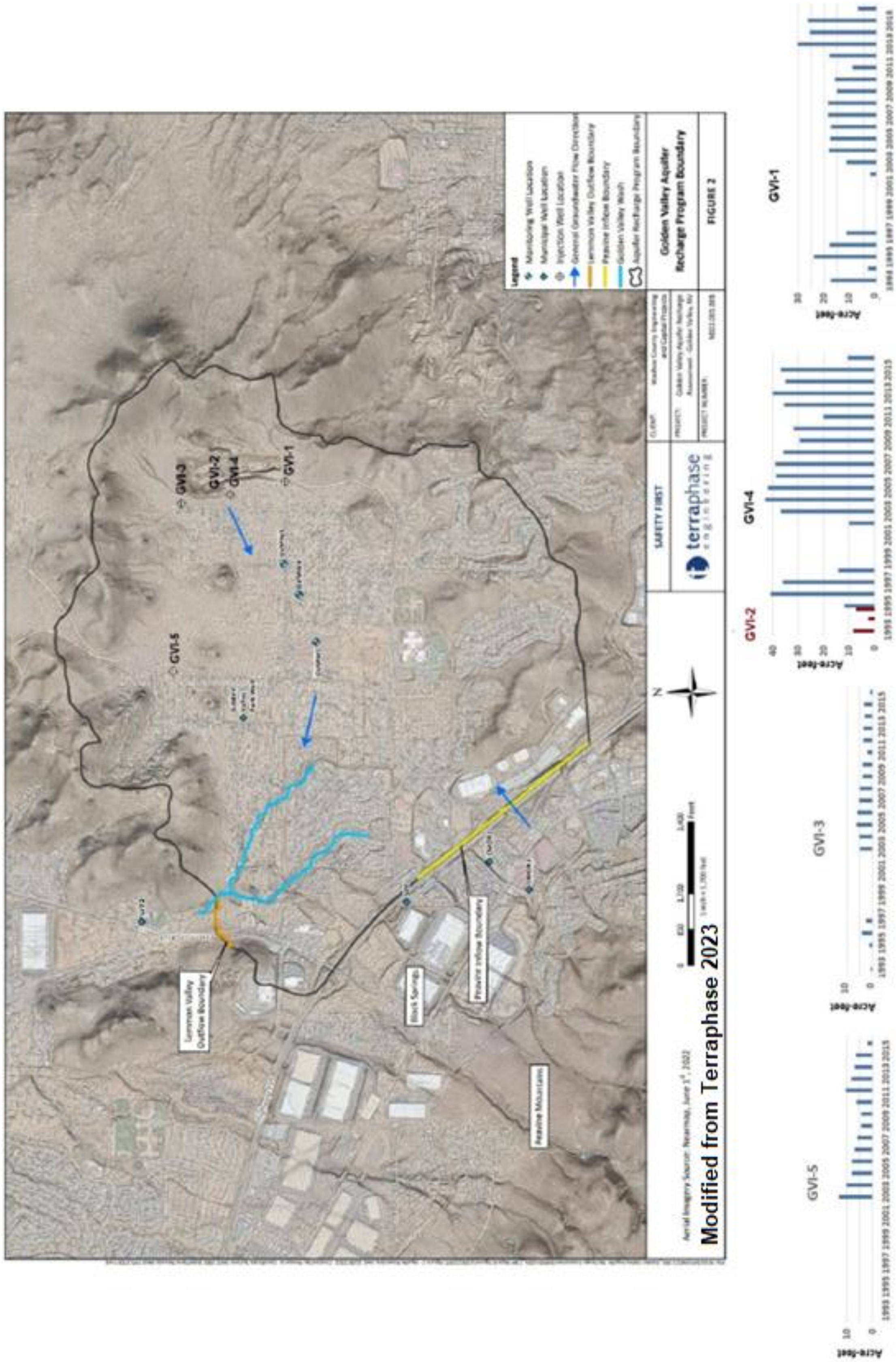
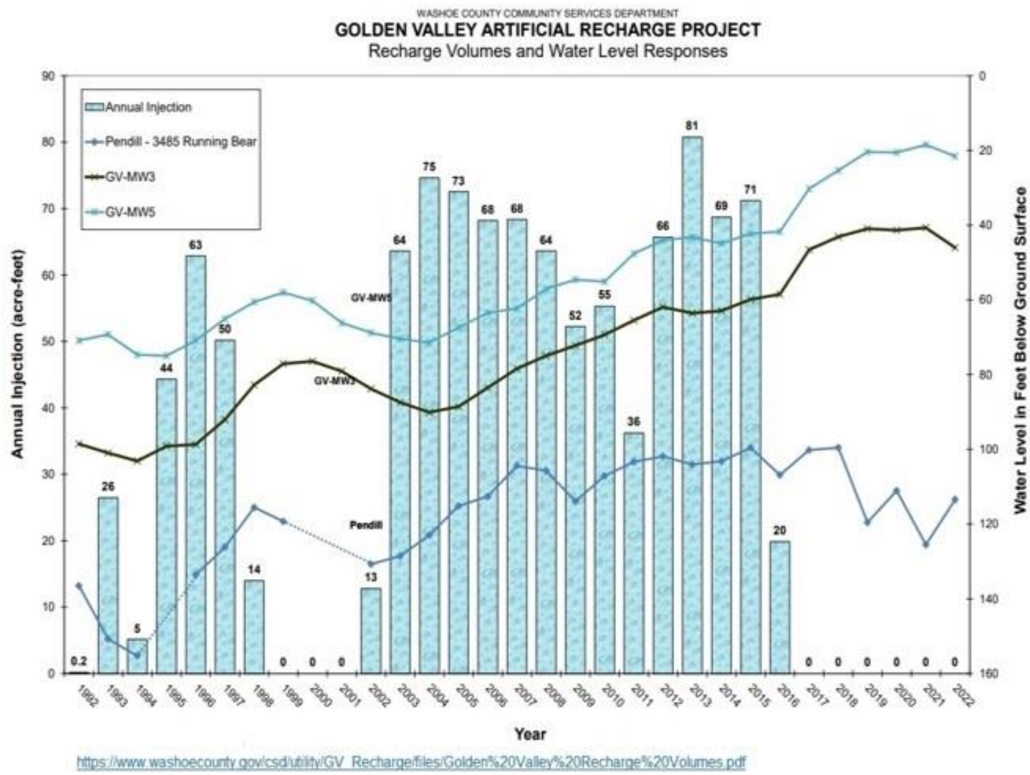


Figure 87. Distribution of injected waters



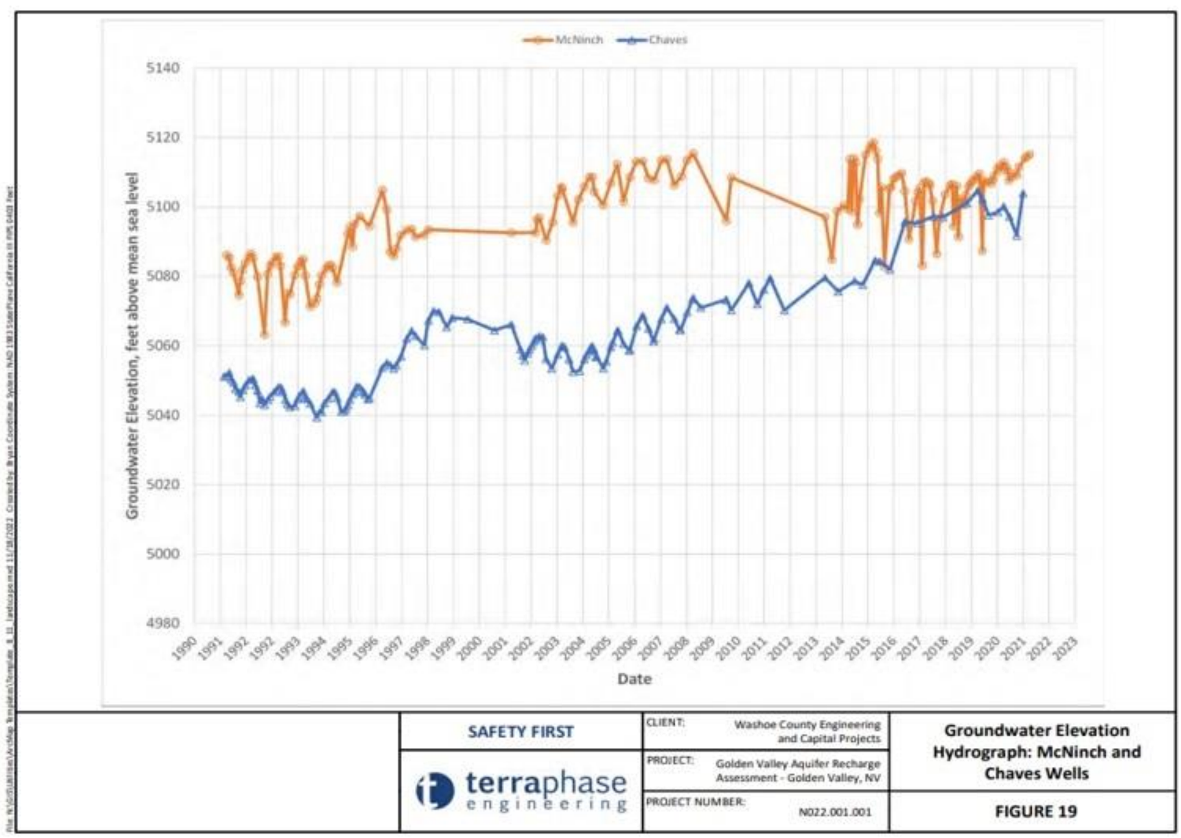
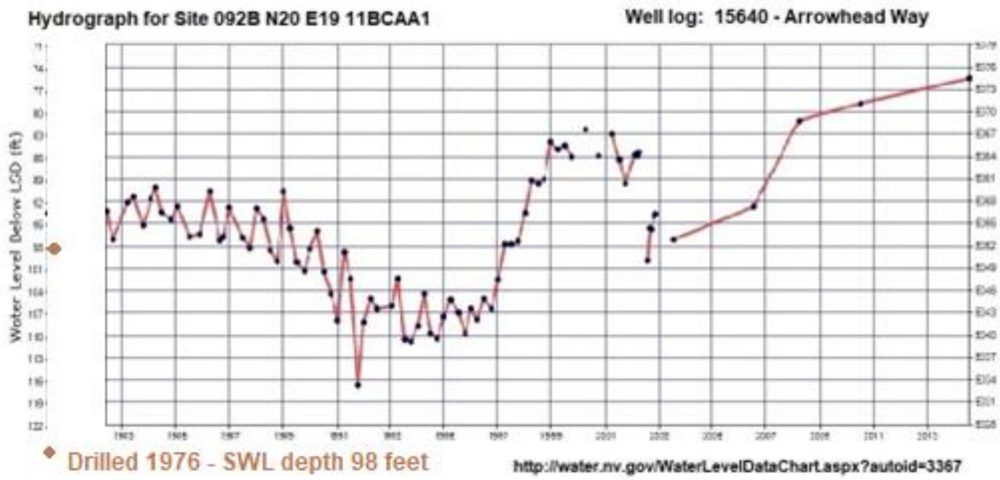
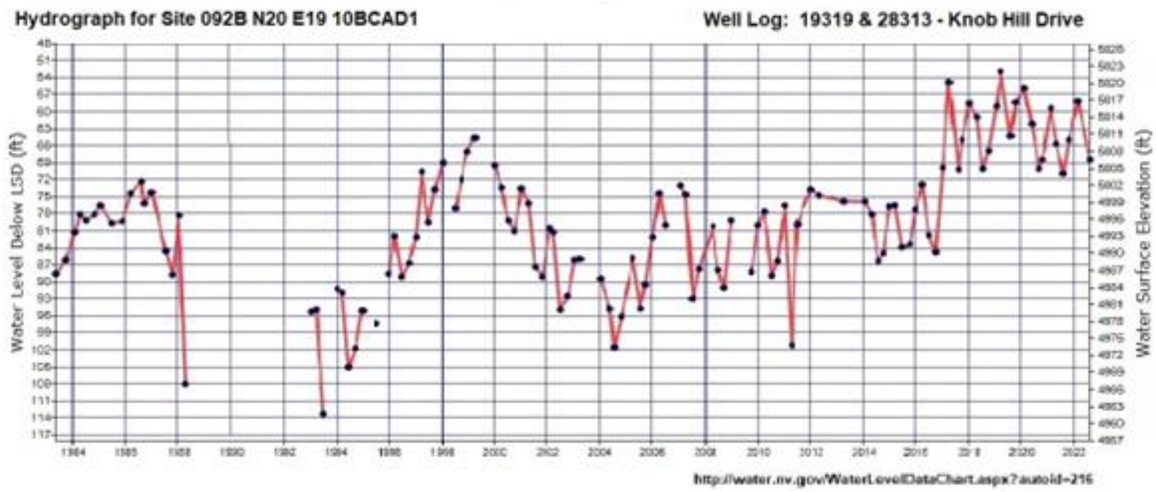
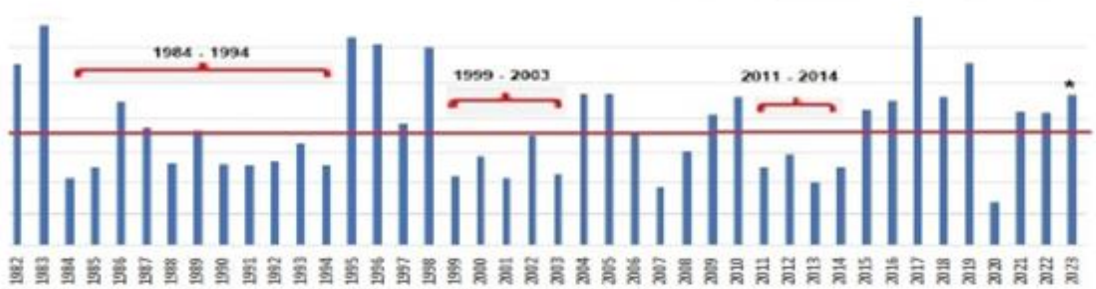


Figure 88. Recharge volumes and static groundwater levels







Precipitation pattern 1982 - 2023 noting intervals of less than average precipitation

Production of LVP 3 in acre-feet per year for 1982 - 2005

Figure 89. Groundwater levels – Precipitation - LVP3 production

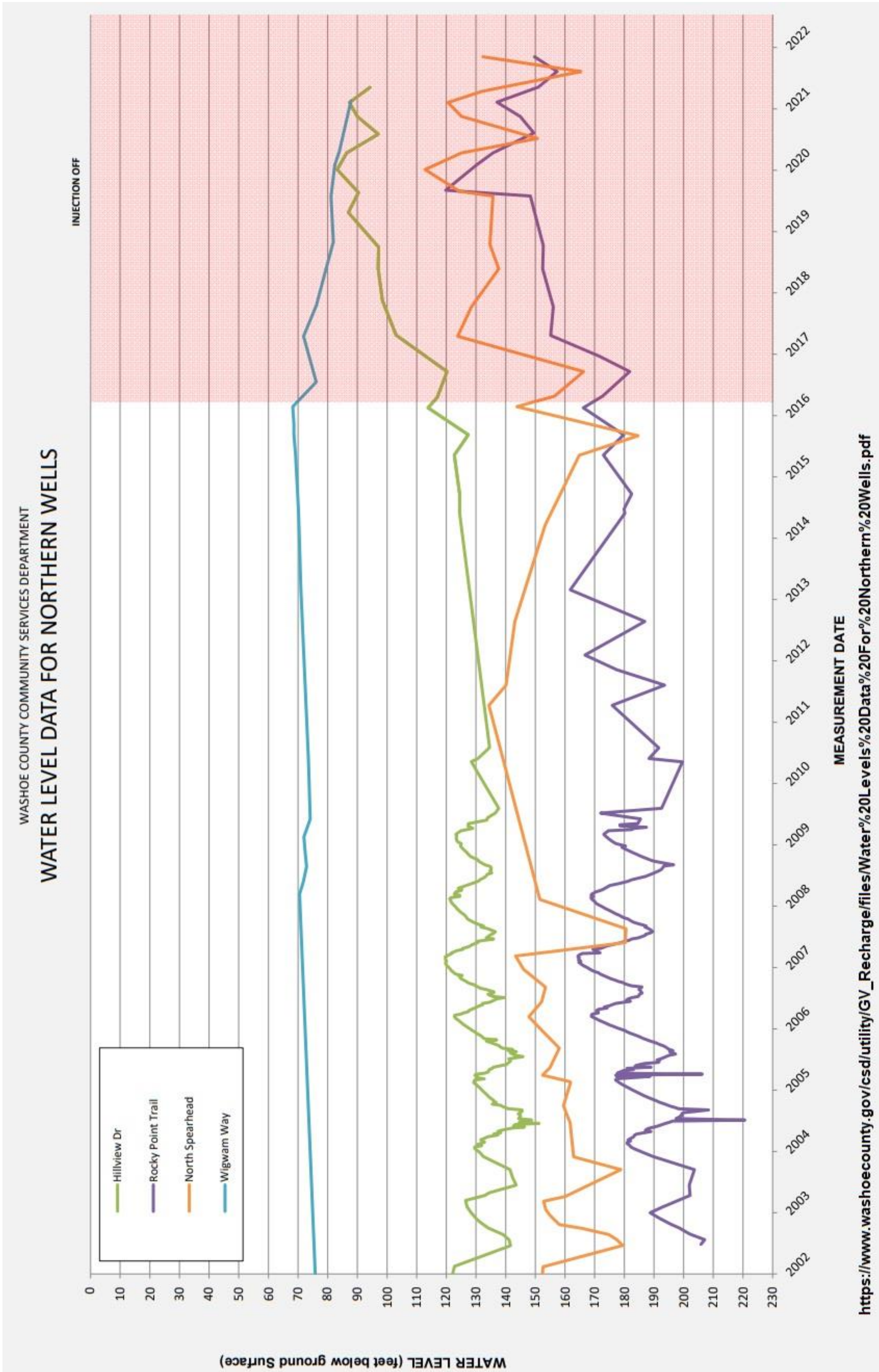


Figure 90. Static water level data for northern wells 2002-2022

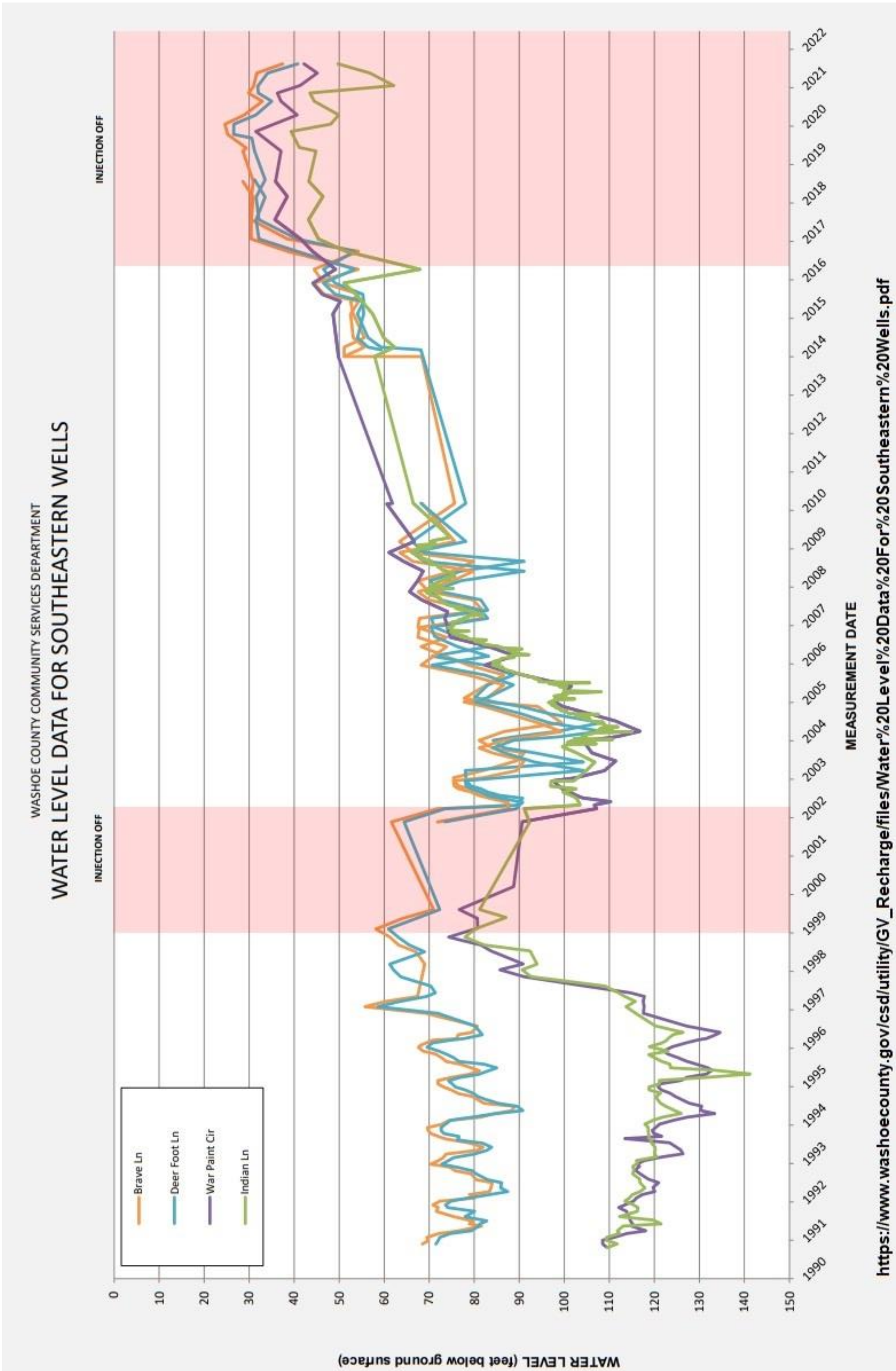


Figure 91. Static water level data for eastern wells 1991-2022

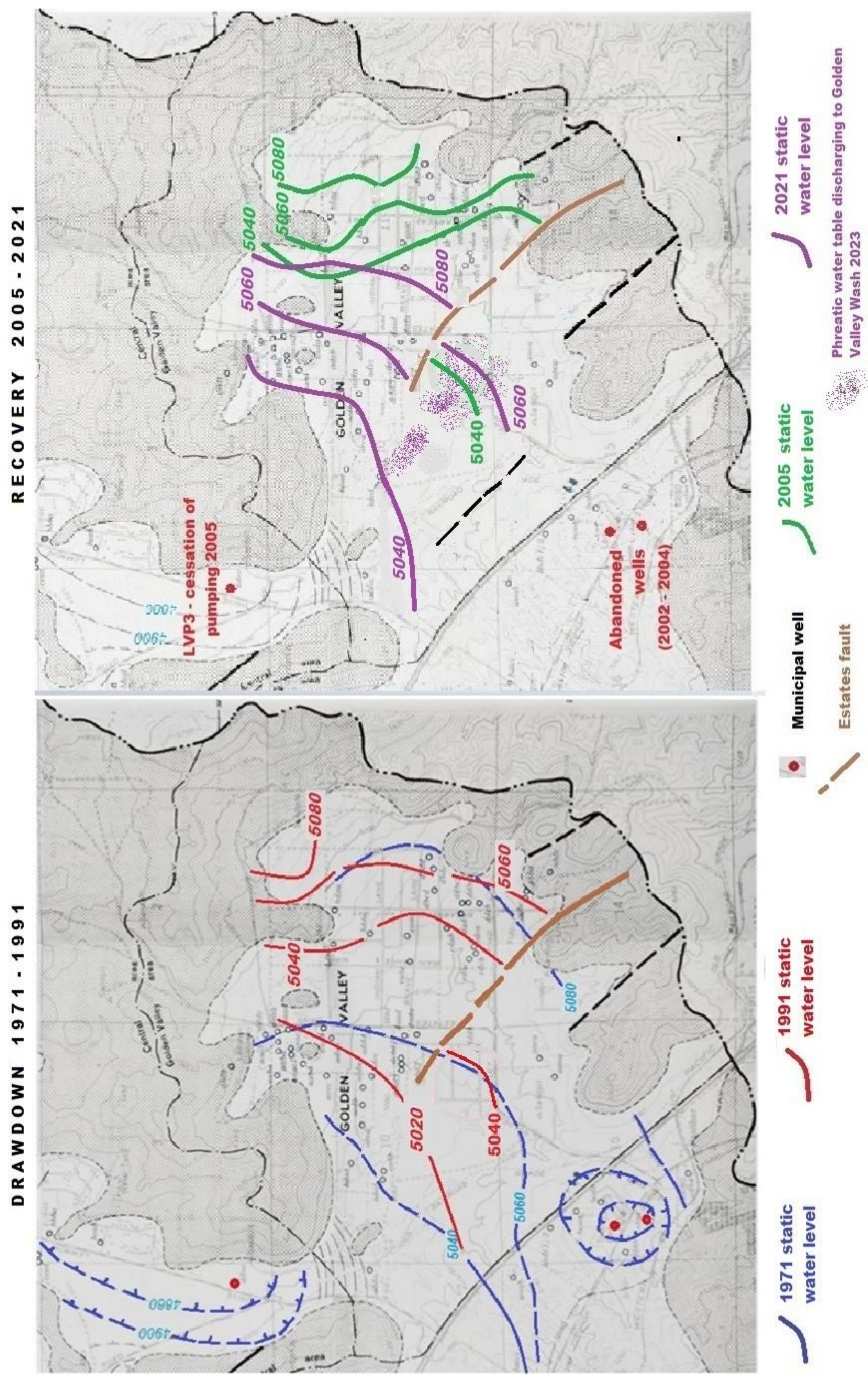


Figure 92. Drawdown/recovery with municipal well pumping/cessation

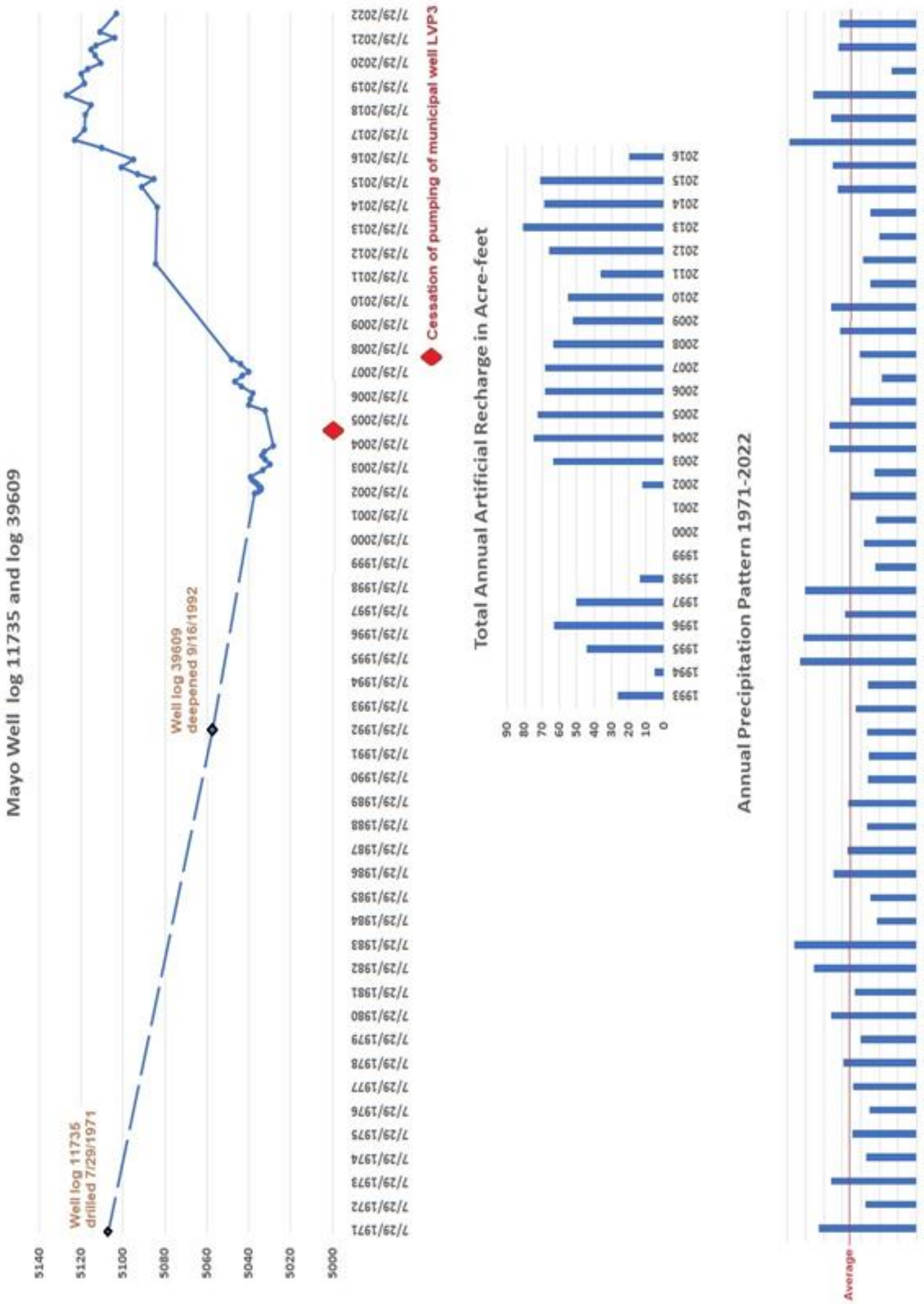


Figure 93. Hydrograph of Mayo wells 11735 and 39609

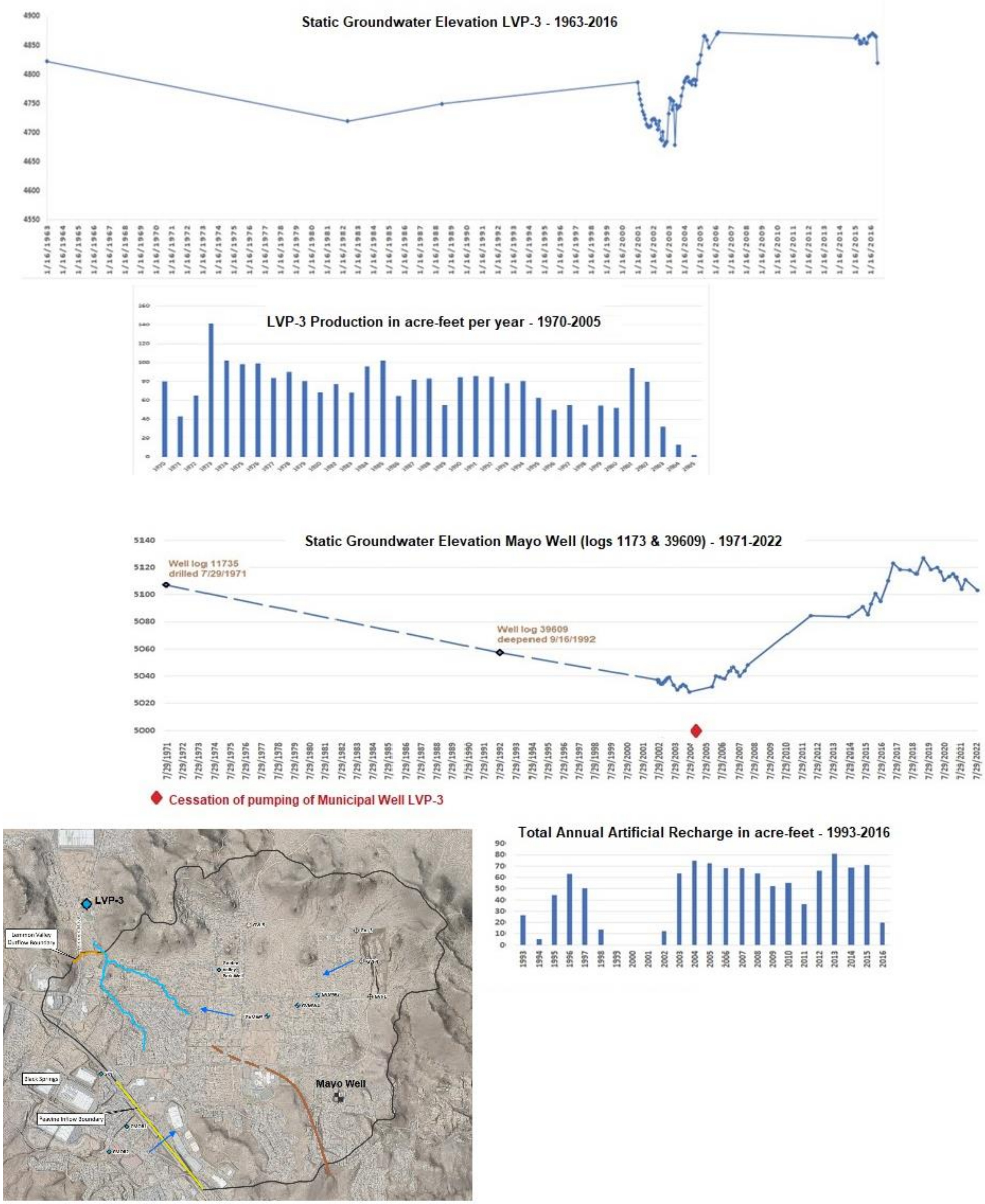


Figure 94. Hydrographs of LVP3 and Mayo well

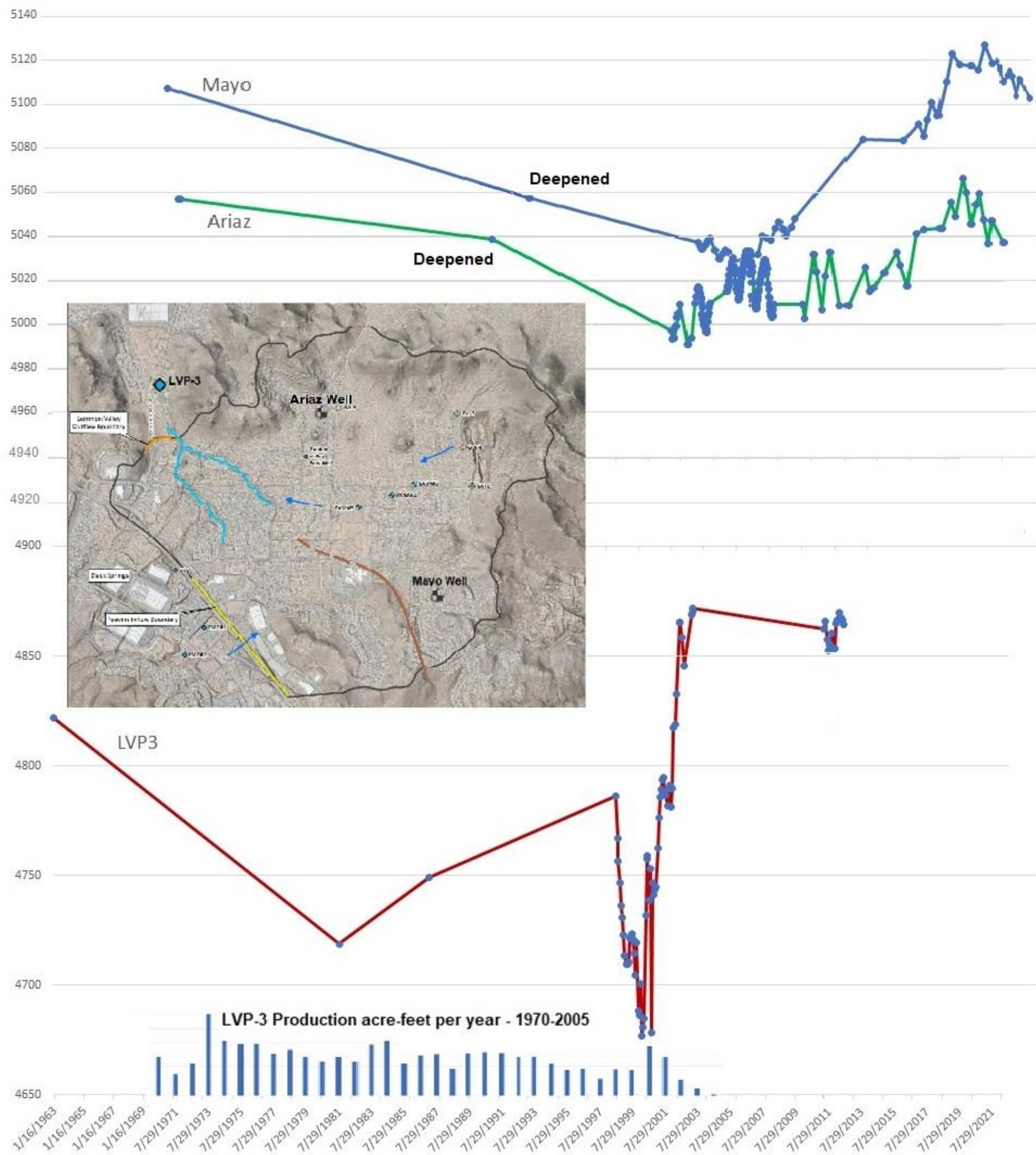


Figure 95. Hydrographs of Ariaz, Mayo and LVP3 wells

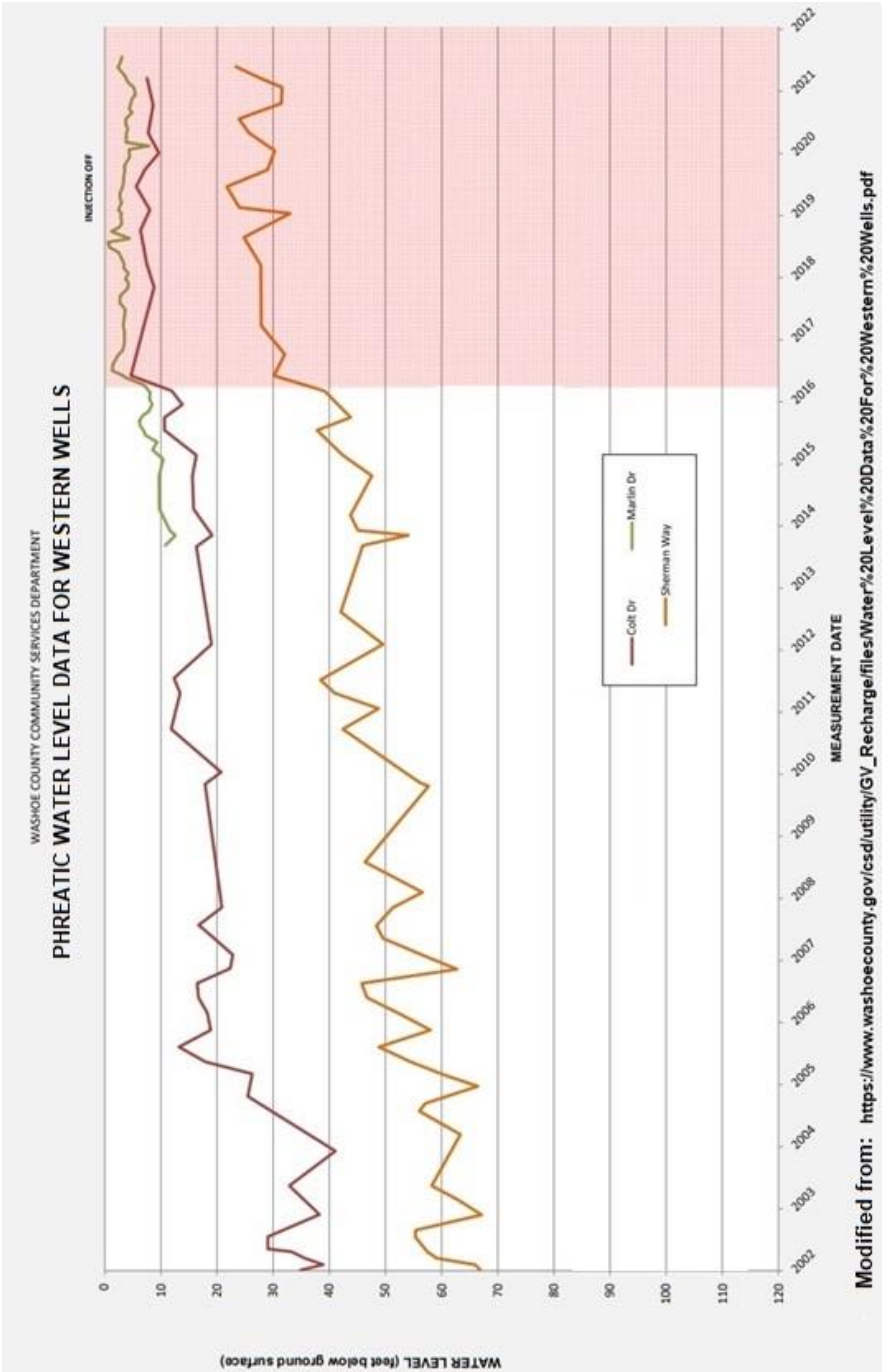


Figure 96. Phreatic water level data for western wells 2002-2022

Phreatic water table discharging into Golden Valley Wash - water flowing into culvert on Belmont Drive

Water exiting west side of Belmont Drive culvert - flowing along rip-rapped channel of Golden Valley Wash

Figure 97. Phreatic flow in Golden Valley Wash - 4 October 2023

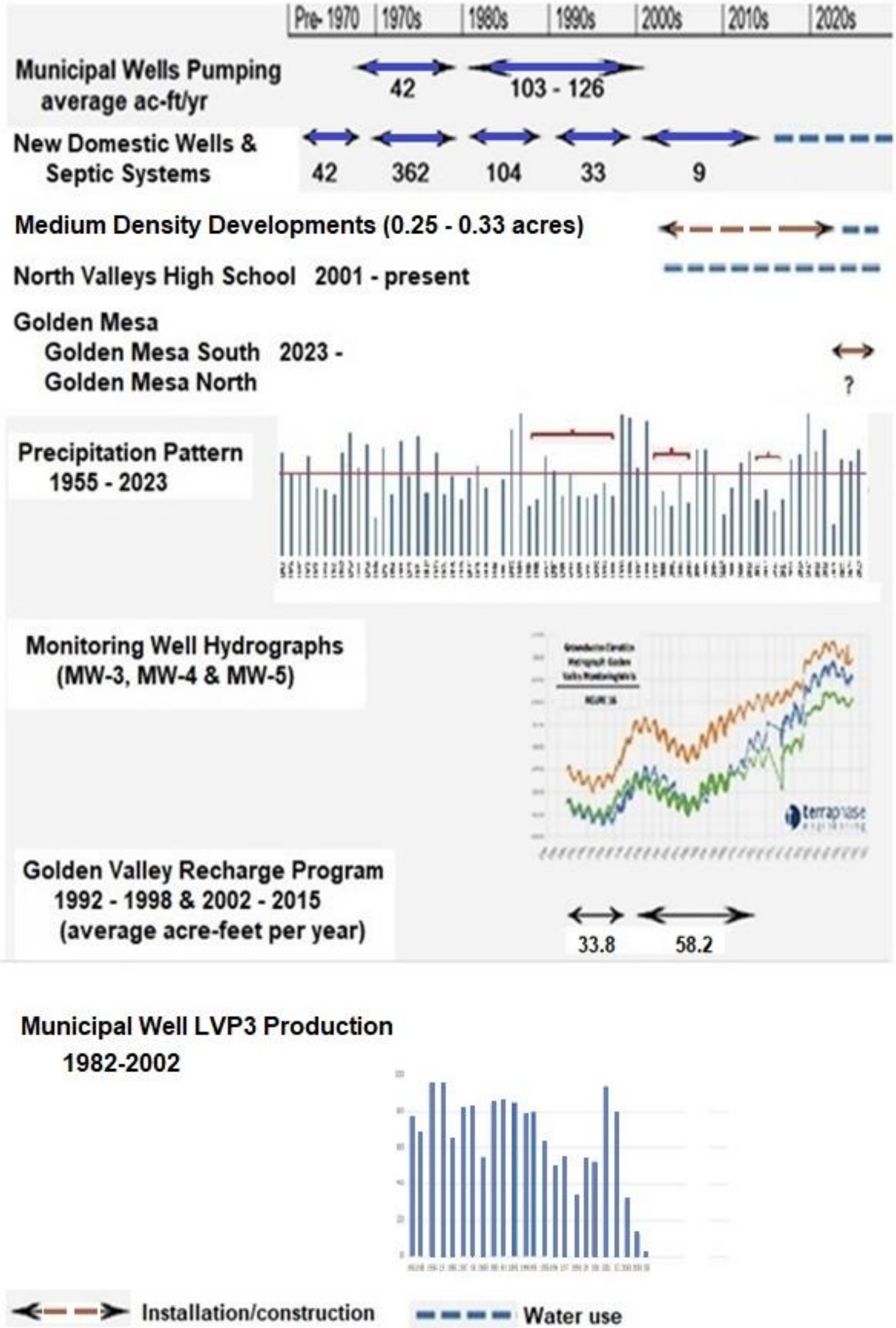


Figure 98. Timeline of groundwater use components

APPENDIX A: WELL LOG TABULATION

Numbering system for hydrologic sites is based on public lands survey, referenced to the Mount Diablo base line and meridian using the Township (N), the Range (E), and Section number. The section number is followed by a letter designation for quarter section and quarter-quarter-quarter section with the letters a, b, c, and d designating the NE, NW, SW, and SE quarters respectively. For example, well 21/19-15bbbb is in the NW/4, NW/4, NW/4, NW/4 of Section 15, T21N, R19E.

Tabulated well logs

> Well logs are in sequential order by log number, with location, year drilled, well log description, static water level (SWL) and land surface elevation (LSE), and screened interval. Well owners are listed, but may change over time.
>
> Decomposed granite is presented by “DG.” Materials listed in the well log have not been geologically interpreted, unless specifically noted. Deepened wells are noted and cross-referenced as appropriate.

Logs for respective cross section/profiles:

- Pohll (2017) Geologic Cross Section A-A’
- Terraphase (2023) Profiles A-A’, B-B’, C-C’, D-D’ and E-E’

Well ID	House #	Street	Year drilled	Well log	SWL	Screened Interval(s)
7534 **See 24310** **See 73427**	8600	N Virginia Street C&R Trailer Park	1963-8-20	Heavy clay & sand to 38 ft Clay, sand & broken rock 38-126 Clay, sand, gravel & broken rock with some water 126-158 Hard dry clay & shale 158-207 Clay, sand & broken rock 207-360 Water bearing 306-402 Hard rock 402-408	SWL 125	Screened 200-400
10402 - Schoensky (Schiwart)	3275	Brave Lane	1974-5-20	DG with clay to 148 ft Decomposed granite 148-152 Granite 152-205	SWL not listed on well log	Screened 140-160
11297	3275	Brave Lane	1970-11-15	Clay to 80 ft Decomposed granite 80-100	SWL 60	Screened 80-100
11354 Deepened – prior well not constructed properly	7571	Bluff View Way	2010-6-15	Gray hard granite 150-196 with fracture zone 186-188 Weathered granite 196-240 with fracture zones 205-206 & 230-231	SWL 130	Screened 200-240
11370 - Biggie 20-19-11dbdd2	9075	Wigwam Way	1971-2-1	Soil/clay to 6 ft Decomposed granite 6-65 Red clay 65-73 Hard granite 73-82 Sand 82-84 Decomposed granite 84-90 Sand 90-93 Hard granite 93-100 Decomposed granite 100-135	SWL 58 below LSE 5143.7	Screened 56-96
11383 - Hahn 20-29-Sec 10	7630	Hillview Drive	1971-2-13	Soil to 3 ft DG and clay 3-82 DG 82-88 Dry sand 88-89 Hard DG 89-118 DG & sand 118-120	SWL 72	Screened 102-120
11439 **Deepened**	7665	Hillview Drive	1971-9-5	Hard fractured gray granite 122-182 with some water & weathering 162-167	SWL 48	Screened interval not noted on log
11467 - Cobb 20-19-10aaad1	7660	Hillview Drive	1971-3-21	Boulders & yellow clay to 52 ft Decomposed granite 52-90 Hard blue granite 90-124	SWL not listed on well log – LSE 5148	Screened 84-104

11683 – Hedrick3 **Deepened** **See 26314** – Hedrick1 **See 88386** – Hedrick2	7800	Tamra Drive	2013-5-24	Fractured gray granite 235-290 Multi-colored rock 290-340 Fractured black/white granite 340-360 Alternating zones of grey-white granite to tan granite 360-596 – decomposed granite & tan clay zones may represent fractures	SWL 210 below LSE 5190.51	Screened 516-596
11726-N – Rhodes **See 24041** 20-19-10adda1	7515	Estates Road NE/2 Sec 14 T20NR19E	1971-8-2	Broken brown rock to 15 ft Gray hard rock 15-95 Bown broken rock 95-105 Hard yellow rock 105-110 Red rhyolite very hard, broken & creviced 110-135	SWL 68	No screened interval
11735 – Mayo1 20-19-14abdc1 **See 39609**	3460	Rolling Ridge Drive	1971-7-29	Hard & soft gray rock sometimes fractured 3-112 Red rhyolite fractures 112-150 Hard gray rock 150-155	SWL 64 below LSE 5171.32	No screened interval
11758	7900	N Virginia Street Skyline Mobile Home Park	1971-8-31	DG to 30 ft Sandy gravel with clay 30-90 Boulders 90-93 Very hard rock 93-140 Sandy clays with hard & soft streaks 140-320 Hard white clay 230-248	SWL 63	Screened 60-227
11834 20-19-10 E/2	291	Hillcrest	1971-9-18	Soil to 1 ft Clay 1-40 Sand 40-47 DG 47-86	SWL 45	Screened 54-74
11883-N - Priano (Harcinske)	9350	Spearhead Drive	1971-8-25	DG to 65 ft Fractured granite 65-105 Med hard granite 105-135 Med hard & very hard granite 135-150 Very hard granite 150-187	SWL 80	Screened 137-187
11908 - Hahn 20-19-10NE	7505	Hill View Drive	1969-1-16	Topsoil to 3 ft Hardpan Coarse sand & clay 3-15 DG 15-57 Water sand & pea gravel 57-68 Broken rock & DG 68-78 DG & sand light grey water 78-85 Sand & pea gravel 85-94 Broken rock 94-96	LSE 5088	Screened 76-96

12043 - Bader 29-19-11 SW/SE	9040	Spearhead Drive	1971-8-18	Topsoil to 6 ft DG /reddish silt mixed 6-87 Fine to coarse yellow sand with some water (4 gpm) 87-90 Brown rock 90-145 Broken grey rock with water (8 gpm) 145-150	SWL 60	Screened 77-97
12555 - Lewis 20-19-11cbcb1	7350	Estates Road	1972-8-17	Sandy clay & gravel to 70 ft Gravel 70-104 First water at 55 ft	SWL 40 below LSE 5093	Screened 80-100
12737 - Mosher 20-19-3ddad1	7530	Rocky Point Trail	1972-9-28	DG sand with some clay to 15 ft Reddish brown sandy clay 15-31 Weathered granite 31-90 Hard gray granite 90-200 with fracture zones 95-97 & 101-103 & 136-139 & 143-144; heavily fractured & water bearing 165-190	SWL 85 below LSE 5194.06	Screened 170-200
12815 – Ariaz1 20-19-3dddc1 **See 37614**	7575	Tamra Drive	1972-12-25-	Occasionally fractured hard grey granite 65-200 ft	SWL 112	Screened 160-200
12916-N - Marshley	3445	Running Bear Lane	1973-1-25	Reddish clay w/ DG to 11 ft Decomposed granite with silt & some clay streaks 11-90 Silty sand w/ occ clay 90-131 Weathered gray granite 131-250 very soft but gradually becoming harder	SWL 96	Screened 166-205
12929	9244	Bull Road	1973-2-27	Soil to 2 ft Dry clay 2-17 Decomposed granite 17-235	SWL not recorded on log	Screened 146-211
13061-N – GV41	3275	War Paint Circle	1972-6-19	Brown to reddish brown sandy clay & silt layers to 49 ft Green to grey clay with some small gravel 49-90 Brown sandy clay 90-110 Weathered black or grey granite 110-140	SWL 62	Screened 100-140
13513 or 13514 - Pilling 20-19-11acad1	9325	Wigwam Way	1973-4-18	Clay with gravel lenses to 66 ft Extra hard gray granite 66-193 with fracture zones 165-167 & 187-189	SWL 140 below LSE 5195	Open hole – no pump test

13562	7565	Estates Drive	1973-7-27	DG to 8 ft DG hardpan 8-12 Weathered gray granite with some clay 12-66 Soft broken granite 66-75 Med hard granite 75-106 with fracture zone 95-97 Very hard green granite 106-132 Med hard green granite 132-145 Very hard green granite 145-165	SWL 104	Screened 110-16
13582 – MacAlinden – Couch 20-19-11acdd1	3425	Indian Lane	1973-10-3	DG with clay, hardpan, occasional clay lenses to 65 ft Weathered granite broken with some clay in fractures 65-70 DG brown 70-80 Weathered gray granite med hard 80-91 Weathered granite brown 91-98 Weathered gray granite med hard 98-141 very hard below 112	SWL 68 below LSE 5170	Screened 91-141
13597	630	Sherman Way	1973-4-30	Red clay with hard pan to 8 ft DG to 75 with alternating layers of some clay, some gravels Coarse sand 75-100	SWL 33	Screened 50-100
13738 – Bell – Conradt - Holzworth 20-19-11dbdd3	3495	Deerfoot Lane	1973-12-17	Topsoil to 2 ft Hardpan 2-20 Clay layers with small gravel 20-77 with hardpan 43-47 Med hard to hard volcanics 77-104 Med hard to hard fractured dark green granite 104-127 Dark green granite 127-145	SWL 70 below LSE 5145.95	Screened 124-164
14548	3185	Indian Lane	1972-11-3	DG with yellow clay to 74 ft DG – brown sand 74-101	SWL 60	Screened 75-101

14641	9110	Wigwam Way	1975-3-13	Decomposed granite sand topsoil to 3 ft Layers of brown to yellow to reddish brown clay with varying amounts of coarse sand or small gravel 3-127 Yellow sandy clays with coarse sand (water) 127-158 Hard gray granite 158-166 Hard to med hard brown rock (some water) 166-180 Hard black rock (water) 180-190	SWL 78	Screened 113-155
14699	6915	Pontiac Drive	1975-4-24	Hard brown to yellow clay with some sand to 55 ft Sandy brown clay with DG 55-65 Loose brown DG 65-75 Hard blue-green granite 75-84 Hard & soft sandy brown clay with DG 84-108 Hard to med hard gray-green granite 108-125	SWL 48	Screened 68-110
15283	6975	Pontiac Drive	1975-12-17	DG sand with mix of brown clay to 76 ft Blue sand coarse with blue grey granite 76-100 Hard blue-grey granite with fractures & water bearing 100-111	SWL 35	Screened 93-111
15339	7570	Tamra Drive	1975-12-30	Overburden to 12 ft Blue rock w/ brown streaks 12-55 Brown clay & boulders 55-74 Gray granite 74-210 Broken gray granite 210-218 Granite 218-225	SWL 65	Screened 205-225

15640 - Harcinske-Word 20-19-11bcaa1	9720	Arrowhead Way	1976-6-1	DG topsoil to 5 ft Coarse DG wand with brown cay 5-20 Greenish DG sand with brown clay mixed 20-30 Green granite – hard to very hard 30-90 Blue/green granite – medium hard 90-98 Blue/green granite hard to medium hard 98-149 Slightly weathered or decomposed granite – almost loose – water bearing 149-170 Hard brownish granite 170-175	SWL 98 below LSE 5149.93	Screened 145-171
16072	9070	Spearhead Way	1976-12-9	Brown clay to 18 ft Clay & DG sand mixed 18-85 Loose brown decomposed granite 85-128	SWL 75	Screened 88-128
16249	7130	Estates Road	1977-1-12	Clay to sandy clay – brown to 51 ft Gray hard granite 51-55 Fractured blue-green granite 55-60 Hard blue-green granite 60-72 with fracture zone 65-71 Blue granite with brown decomposed granite sand lens 72-128	SWL 32	Screened 88-128
16384 - Freeman 20-19-11abad1	9469	Wigwam Way	1977-4-22	Decomposed granite to 60 ft Gray granite 60-76 Decomposed granite with high quartz content 76-275	SWL 154 below LSE 5256.4	Screened 225-275
16627 - Cohen 20-19-10aaac1	7600	Hillview Drive	1977-6-25	Red clay & granitic sand to 12 ft Decomposed granitic sand 12-75 ft Hard granite 75-100 Tight granite with small fractures 100-169 Fractured 169-185 Green granite with small fractures 185-194 Fine to rocky comes out as coarse sand 194-211	SWL 107 below LSE 5135.93	Screened 163-207
16668-M – Johnson SW/4 SE/4 Sec 11 T20NR19E		Sun Cloud Circle – NE corner Teepee Lane	1977-7-15	Rhyolite 1-260 with Fractured Rhyolite 200-260	SWL 90	Screened 215-255
16759 - Ewers 20-19-10bdbd1	2610	Margaret Drive	1977-8-15	Valley fill to 70 ft Granite solid 70-140 Fractured granite 140-185	SWL 85 below LSE 5070	Screened 140-180

16763 - Gard	2660	Margaret Drive	1977-7-13	DG & sand to 57 ft Sand & gravel 57 to 59 Diorite – broken 59-1985	SWL 56	Screened 140-180
16808	3430	Deerfoot Lane	1977-7-19	Brown to red clay to 42 ft Sticky clay – brown to white to brown 42-170 Gray soft rock 170-188 Brown decomposed soft rock 188-192 Hard broken brown rock 192-215	SWL 75	Screened 173-209
16834	9469	Wigwam Way	1977-3-22	DG to 60 ft Grey granite 60-76 Decomposed gray granite high quartz content 76-275	SWL 154	Screened 25-275
17016 - Allen-Shriver 20-19-11dcca1		Sun Cloud Circle	1977-10-4	Brocken rock & clay to 40 ft Clay 40-95 Rock 96-140 Clay 140-150 Rock 150-200 Clay 200-212 Gravel 212-240	SWL 100 below LSE 5135.31	Screened 200-240
17049 - Gillaspy **pre-drilled**	9155	Wigwam Way	1977-10-6	Pre-drilled to 130 ft Decomposed granite - Brown & white 130-158 Gray granite med hard 158-200	SWL 105	Screened 91-200
17273 - Dresbach 20-19-11accb1	9720	Spearhead Way	1977-7-29	Clay to 110 ft Sand 100-121 DG 121-135 Sand – water bearing 135-138 Clay 138-142 Sand – water bearing 142-150	SWL 115 below LSE 5153.05	Screened 90-150
17293	3225	Sun Cloud Circle	1977-11-11	Overburden to 4 ft Granite 4-34 Decomposed granite 34-68 Gravel/sand cemented 68-96 with water-bearing fracture at 90 Granite with soft zones 96-200 – water bearing fractures at 125, 154 & 187	SWL 87	Screened 140-200
17319	2965	Valley View Drive	1977-10-19	Valley fill to 25 ft DG 25-80 Granite 80-190 with fractures 160-190 & some water at 80 ft	SWL 45	Screened 70-90 & 170-190
17380 - Gonzales		Steadfield Estates lot 26	1977-11-20	Clay to 10 ft DG 10-55 Clay and sand 55-70 Sand and gravel 70-85	SWL 50	Screened 73-8375

17459 – Dyer	2720	Margaret Drive 088-93-12	1977-12-7	Overburden to 2 ft Medium hard clay with DG 2-35 Loose broken rock with sand 35-70 Medium hard rock 70-120 water bearing fractures at 70 ft & 120 ft Hard Gray tock 120-150 with water bearing fractures at 135	SWL 73	Screened 90-140
17813 - Fenkell - Mazone 20-19-10aada1 **Deepened See 47017**	7565	Bluff View Way	1978-3-20	Clay to 2 ft Fractured granite 9-160	SWL 106 below LSE 5148	Screened 140-160
17852	7145	Marlin Drive	1978-3-13	Brown tight clay to 30 ft Brown clay with soft streaks 30-90 Sand 90-125 Sand with clay 125-145	SWL 32	Screened 110-135
17853 - Kjoge	7185	Marlin Drive	1978-3-14	Brown clay to 101 Sand 101-105 Clay 105-115 Brown sand w/ some gravel 115-130 Brown clay 130-150	SWL 32	Screened 100-140
17970	645	Colt Drive	1978-4-11	Clay to 5 ft Fine sand 5-15 Soft DG 15-55 Granite hard 55-118 with f 104-209racture zones with some water 75-87 & 100-118	SWL not recorded on log	Screened 50-118
18209 - Barali	7560	Hillview	1977-8-10	Soil with clay to 7 ft DG with clay 7-19 DG 19-81 Dark granite 81-85	No Water – to be Deepened	Screened 62-82
18237 - Chavez 20-19-11acba1	3410	Running Bear Lane	1978-5-29	Brown sand to 70 ft Brown decomposed granite 70-205 Brown yellow decomposed granite 205-235	SWL 135 below LSE 5192.97	Screened 215-230
18503 – Jones	7225	Marlin Drive	1978-6-30	Top soil & brown clay to 38 ft Brown DG with some clay 38-72 Decomposed granite brown & loose 72-120 Decomposed granite brown & coarse 120-145	SWL 40	Screened 125-145
18504 - Birdwell 20-19-10dcab1	7215	Marlin Drive	1978-6-21	Brown clay layers to 115 ft Coarse sand 115-154	SWL 26 below LSE 5060	Screened 124-154

18505 - Robinson 20-19-10dcaa1 **See 32205**	7210	Marlin Drive	1978-6-21	Top soil to 4 ft Yellow clay 4-10 Brown DG 10-68 Green granite 68-95 with fractures 78-95 Blue granite 95-135 with fractures and with water below 106	SWL 28 below LSE 5082	Screened 115-135
18587 - Garner 20-19-11dcdd1	3495	Golden Valley Road	1978-7-20	Light brown clay to 80 ft Blue gray clay fractured 80-160 Purple clay 160-190 Blue gray clay 190-215 Purple rock fractured 215-260 Note: the “clay” below 160 ft is likely Hartford Hill volcanics	SWL 75 below LSE 5166	Screened 221-260
18607 - Zabal	945	Margaret Drive NE/4 SE/4 Sec 10 T20NR19E	1978-7-18	Overburden to 9 ft Sand 9-17 Sand & red clay 17-24 DG oxidized color 24-31 Red clay 31-47 DG with some clay layers 47-53 Fairy tight DG with some oxidation 53-78 Layers of tight & loose DG high oxidation 78-155	SWL not listed on well log	Screened 95-155
18608 - Davis	7320	Estates Road	1978-7-24	Sand to 3 ft Decomposed granite & clay 3-20 Clay 20-34 Decomposed granite – highly oxidized 34-82 Decomposed granite 82-156	SWL 44	Screened 95-156
18610	840	Browning Drive	1978-7-31	Clay & sand with some DG to 93 ft Blue clay 93-123 DG 123-150 Faults 150-165 Fairly hard rock 165-180 DG & granite 180-200 Fractured granite w/ water 200-204 Sand & gravel with some water 104-230	SWL 50	Screened 120-180 & 170-230
18702 – Thomas - Borge 20-19-11abda1	9479	Wigwam Way	1978-6-30	DG to 120 ft DG 121-280 Granite 281-340 DG 341-350	LSE 5243	Dry Hole
18889-N - Reimers 20-19-3ddbb1	7815	Tamra Drive	1978-8-21	Rock & dirt to 50 ft Rock 50-275 Sand & gravel 275-300 Rock 300-450	SWL 250 below LSE 5337	Screened 205-275 & 430-450
18892	7625	Tamra Drive	1978-9-4	Dirt & rock to 25 ft Sand 25-100 Granite 100-300	SWL 150	Screened 280-300

18949 – Loader 20-199-10dcaa2	7220	Marlin Drive	1978-9-25	Brown sand & clay to 56 ft Decomposed granite brown & loose 56-122 Decomposed granite brown med hard 122-141 Coarse granite sand 141-175	SWL 30 below LSE 5075	Screened 131-175
19278	8655	Pontiac Drive	1979-1-4	Clay with DG to 105 ft DG with large gravel 105-125 and water at 120	SWL 80	Screened 105-125
19190 - Long 20-19-10bcdb1	2775	Cactus View Drive	1978-11-16	Decomposed granite to 20 ft Brown clay 20-45 Solid granite 45-85 Granite fractured 85-100	SWL 55 below LSE 5066	Screened 80-100
19291 – Mauterstock - Gallian 20-19-3dcdc1			1978-12-21	Top soil to 2 ft White granite 2-10 Light green granite 10-90 Green granite medium hard with soft areas 90-150 Light blue granite hard 150-225 Blue granite hard with fractures & broken area with water 225-270	SWL 175 below LSE 5206.25	Screened 236-270
19319 **See 28313**	2605 (2580)	Knob Hill 88-040-36	1979-1-26	Topsoil to 6 ft Firm DG 6-200 DG & gravel 200-210	SWL 130	Screened 170-210
19327 - Lee 20-19-11dbdd1	3470	Brave Lane	1978-10-1	Decomposed granite 2-105 Boulder 105-107 Black rock 107-135 Clay 135-158 with some gravel 138-149 Cemented sand & gravel 158-220	SWL 158 below LSE 5145	Screened 105-115 & 135-155 & 185-205
19523 - Powell (Kaspar)	3430	War Paint Circle	1979-3-15	Sand to 30 ft Sandstone 30-170 Gravel 170-180 Granite 180-190	SWL 90	Screened 170-190
19715 - Powell 20-19-11dbbd1	3430	Warpaint Circle	1979-3-14	Sand & gravel to 40 ft Volcanic rock 40-180 Red sand & gravel 180-190	SWL 70 below LSE 5141.37	Screened 170-190
19921	3205	Indian Lane	1979-5-24	Sand with clay to 45 ft Sand, gravel w/ clay 45-86 Large gravel, sand & clay 86-105 Brown clay & sand 105-143 Course gravel & sand with clay 143-165	SWL 30	Screened 62-155
19949	550	Winchester Drive	1979-5-30	Brown clay med hard to 61 ft Brown clay with fine sand 61-86 ft Brown DG coarse 86-132 ft Brown clay 132-140 ft	SWL 35	Screened 88-130

20015 – Stipech 20-19-10SW, SE	7190	Marlin	1979-2-25	Top soil to 6 ft DG 6-19 Clay 19-40 Coarse sand 40-61 Rock 61-85		Screened 50-85
20037 - Thomas	9441	Wigwam Way	1979-6-13	Top soil to 4 ft Brown med hard DG 4-48 Brown med loose DG 48-111 Brown DG hard 111-185 Light brown granite med hard 185-261 Light blue granite med hard & fractured 261-300	SWL 150	Screened 258-294
20250	3450	Rolling Ridge Road	1979-8-13	Rhyolite to 95 ft Volcanic & quartz 95-130	SWL 100	Screened 90-130
20276	9440	Tomahawk Way	1979-8-14	Brown DG with clay streaks to 117 ft DG 117-133 Brown rock medium hard 133-278 with soft streaks at 155-160, 177-179, 202-204, 245-250, and broken & fractured 225-230 Rock – medium hard brown 278-300 Granite at 300	SWL 55	Screened 228-250 & 262-290
20293	2780	Cactus View Drive	1979-9-4	Topsoil to 3 ft Red clay & gravel 3-50 Conglomerated fractured rock 50-76	SWL 15	Screened 56-76
20875	7840	Tamra Drive	1980-3-17	Clay & rocks to 60 ft Granite 61-257 with fracture zone 235-240	SWL not recorded on log	Screened 237-257
20989 **See 19319 & 29313**	2580	Knob Hill Drive	1980-4-22	Top soil to 1.5 ft Brown clay 1.5-65 Green rock with clay layers 65-129 Gray granite with fractures 129-198	SWL 93	Screened 156-198
21356	9305	Spearhead Way	1980-7-11	DG to 42 ft Green gray granite 42-172 White granite 172-216 WB (?) 195-275 with fractures 216-275	SWL 102	Screened 186-275
21506 – Golden Valley Park 20-19-10adbd1		SE/4 NE/4 Sec 10 T20NR19	1980-6-23	Overburden to 5 ft Decomposed granite soft 5-20 Fractured granite 20-120 Hard granite 120-140 Fractured granite 140-1880 Granite & sand 180-200 Hard granite 200-250 with fracture zone from 215-230	SWL 75 below LSE 5102.02	Screened 140-230

21700 – Mulligan-Haskell 20-19-3ddcd1		Tamra & Alameda	1980-8-30	Overburden to 5 ft DG 5-10 Fractures gray granite 10-50 Fractured granite, basalt 50-180 Fractured granite, basalt with some water 180-230 Fractured granite, sand with water 230-280	SWL at 120 below LSE 5149	Screened 259-420
22162	3575	Golden Valley Drive	1980-10-28	Clay & rock to 63 ft Hard DG 63-71 Gray clay & little DG 71-163 Fracture DG 163-200	SWL 122	Screened 170-200
22808 - McDonald 20-19-10aabc1	7580	Hillview Drive	1981-5-11	DG with mix of clay to 40 ft Gray granite 40-185 Green granite 185-225 Broken gray granite fractures 225-250	SWL 105 below LSE 5134	Screened 230-250
23458 - Pendill 20-19-11abdd1	3485	Running Bear Lane	1981-10-23	Brown clay w/ DG to 78 ft Weathered granite with some clay 78-249 White granite with fractures 249-285 Gray granite 285-338 with fracture zones 305-307 & 330-335	SWL 160 below LSE 5228.78	Screened 225-275 & 285-305 & 318-338
24041 – Rhodes - Jauron 20-19-10adda1 **Deepened** **See 11726-N**	7515	Estates Road	1982-8-19	Gray granite 90-200 ft with water-bearing fracture at 110-112 and water-bearing fracture at 153-156	SWL 75 below LSE 5098	Screened 150-200
24051	680	Golden Valley Road	1982-8-30	Brown clay with DG mixed to 39 ft Gray weathered granite 39-95 Yellow weathered rock 95-107 Gray weathered granite 107-149 – water bearing Fractured rock 149-165 Gray granite 165-190	SWL 55	Screened 160-190
24310 **See 73427** **See 7534** 20-19-15 NW/4	7900	N Virginia Street	1982-12-12	Sand & gravel to 46 f Decayed gravel 46-138 Fractured volcanic rock 138-146 Volcanic rock – med hard 146-193 Granite hard gray 193-307 Fractured granite 307-348 Hard granite 348-351	SWL 215	Screened 307-351

24414 - Mentzer 20-19-14aaac1	3565	Golden Valley Road	1983-2-17	Brown clay to 20 ft White med hard rock 20-65 Gray rock 65-140 Green & brown rock 140-210 Med hard rock 210-245 Fractured rock 245-270 with water 250-270 Green hard granite 270-275	SWL 110 below LSE 5186.21	Screened 249-269
24574 - Mayeroff 20-19-daba1	775	Sherman Way	1983-4-20	Brown clay w/ some DG to 35 ft Decomposed granite 35-63 Green granite 65-116 weathered below 106 Green granite 116-166 with water-bearing fracture zones 116-120 & 165-166 Hard granite 166-175	SWL 50 below LSE 5086	Screened 122-144 & 164-175
24605 - Knoles 20-19-11dbda1	3505	War Paint Circle	1983-5-4	Brown clay with DG to 63 ft Brown clay 63-115 Yellow clay 115-172 White clay 172-270 Black rock 270-290 Weathered granite 290-370 with soft zones 316-318 & 335-338 & 359-370 Green granite 370-375	SWL 95 below LSE 5152	Screened 301-367
24671 - Benedict 20-19-10ddbd1	650	Colt Drive	1983-6-20	Brown clay to 13 ft Hard gray granite 13-87 Fractured granite 87-106 Gray granite 106-110	SWL 45 below LSE 5083	Screened 83-105
24836 - Duncan-Kennedy 20-19-11abaa1	9499	Wigwam Way	1983-8-29	Overburden to 4 ft DG 4-184 Hard fractured DG and quartz 284-343	SWL 200 below LSE 5282.46	Screened 324-343
24836 - McNinch	9499	Wigwam Way	1983-2-26	Overburden to 4 ft DG 4-264 Hard fractured DG & quartz 284-343	SWL 200	Screened 324-343
24981 - Donshick 20-19-11adbc1	9355	Wigwam Way	1983-10-6	Loose DG to 9 ft DG with brown clay 9-35 Weathered granite 35-145 Gray granite 145-183 Fractured granite 183-199 Gray granite 199-275 with fractured zones 116-228 & 255-258	SWL 115 below LSE 5218	Screened 209-228 & 248-268

24998	3495	Golden Valley Road	1983-10-11	Light brown rock to 9 feet Red volcanic rock 9-20 Purple rock 20-90 Green granite 90-140 with fracture zone (water) 105-110 Gray granite 140-175 with fracture zones (water) 135-140 & 155-156 & 165-167	SWL 89	Screened 115-135 & 15-175
25282	7410	Estates Road	1984-4-8	Brown sandy clay to 43 ft DG loose 43-63 Brown weathered granite 63-95 Fractured granite – water bearing 95-112 Med hard granite 112-125	SWL 45	Screened 91-118
25534 - Adams 20-19-11abbc1	9484	Spearhead Way	1984-7-11	Weathered green granite 24-94 Gray granite 94-188 with occasional fracture zones Hard gray granite 188-200	SWL 148 below LSE 5222.71	Screened 165-195
25545	1785	Cactus View Drive	1984-7-13	DG to 10 ft Green granite with some weathered 10-65 Gray granite 65-156 Fractured granite 156-178 Green granite 178-190	SWL 55	Screened 160-190
25560	3230	Indian Lane	1984-7-18	Weathered DG & quartz 155-172 Weathered quartz & granite 180-184 Med hard white granite 184-188 Qtz & granite coarse large grained 188-206 Soft quartz 206-212 White granite 212-216 Soft quartz weathered 216-222 Med hard white granite 222-225	SWL 94	Screened 185-225
25771(1)	735	Browning Drive	1984-10-3	Hard pan to 22 ft DG 22-80 Hard granite with small amt of water 80-126 Clay 126-127	SWL 37	Screened 107-127
26165	665	Winchester Drive	1985-5-7	Brown clay w/ DG to 10 ft Weathered granite 10-17 Gray granite 17-155 with fractures zones 90-92 with water & 118-120 & 135-144	SWL 30	Screened 103-147

26167 - Johnson 20-19-11dcbb1		Tee Pee Lane	1986-4-4	Sandy clay to 28 ft DG and clay 28-103 Medium hard granite 103-184 Fractured granite 184-221 Hard rock 221-247	SWL 45 below LSE 5121	Screened 154-247
26313 - Rodriguez **See 94441**	7805	Tamra Drive	1985-6-24	DG to 6 ft Weathered green granite 6-35 Gray granite 35-101 Fracture zone 101-106 Weathered green granite 106-136 Gray granite 136-150 with fracture zone 143-144	SWL 89 Below LSE 5256	Screened 111-150
26314– Hedrick1 20-19-3dcad1 **See 88386** – Hedrick2 **See 11683** – Hedrick3	7745	Tamra Drive	1984-10-24	Decomposed granite to 3 ft Soft weathered granite 3-15 Green med hard granite 15-96 Green granite 98-181 with soft zones 135-137 & 147-151 Gray granite 181-308 with soft zone 215-231 and fracture zones 284-285 & 298-299	SWL 235 below LSE 5190.51	Screened 272-308
27752	7740	Tamra Drive	1986-9-8	Weathered granite to 27 ft Gray granite 27-300 with fractures 87-88 & 165-166 & 214-215 & 220-221 & 265-270 & 281-295	SWL 199	Screened 154-194
28313 **Deepened** **See 19319**	2605 (2580)	Knob Hill 88-040-36	1986-11-18	Topsoil to 6 ft Firm DG 6-200 DG & gravel 200-210 Granite 210-220 Fractured granite 220-240	SWL 85	Screened 170-210 Extended well below casing 30 ft & backfilled with coarse rock to bottom of casing making 30 gpm
29068	2760	Cactus View Drive	1987-9-3	DG to 4 ft Hard DG with boulders 4-38 Granite 38-61 Cemented gravel 61-89 Red clay 89-95 Fractured granite 95-138	SWL 55	Screened 100-138
30153-N – GV42 **Deepened**	3275	Warpaint Circle APN 83-176-03	1988-7-21	Weathered granite 143-155 with soft zone 145-147 Brown soft sandy clay 155-165 Weathered granite 165-200 with soft zone 174-179	SWL 102	Screened 140-160 & 180-200

30521	7670	Tamra Drive	1988-9-27	Decomposed granite to 44 ft Granite 44-53 Weathered granite 53-210 with alt softer layers Broken & fractured granite 210-280 with fractured zones 233-236 & 245-263 & 276-280	SWL 180	Screened 207-267
30797	6510	Meyers Avenue	1988-12-21	Brown sandy clay with some gravel to 89 ft Soft zone – no water 89-93 Brown sandy clay with some gravels 93-149 Soft sandy clay 149-183 Brown sandy clay with gravels 183-245 Weathered green granite 245-295 Fractured granite 295-338 Green granite 338-350	SWL 255	Screened 279-339
32062	4325	Indian Lane	1989-7-28	Brown lay with DG to 105 ft Weathered granite 105-145 White granite 145-188 with soft zone 165-166 & 180-188 Weathered granite 188-250 with soft zones 194-197 & 204-250	SWL 108	Screened 203-243
32205 – Robinson **See 18505**	640	Browning Drive	1989-9-11	Brown clay w/ DG to 35 ft Green weathered granite 35-86 Green granite 86-131 with fracture zone 115-120 Gray granite 131-150 with fracture zones 136-138 & 145-147	SWL 40	Screened 100-140

33120	9215	N Virginia Street	1990-3-1	Multi-colored gravels with fine sand and clays to 76 ft Brown sticky clay 76-84 Multi-colored gravel with some brown clay 84-223 Blue-green rock with some fine sand 223-257 Brown sticky clay with gravels & sand 257-282 Green clay with some fine sand 282-362 Blue green white & red rock with some glue clay and fine sand 362-367 Blue clay 367-441 Blue black red & tan coarse gravels with some fine sand 441-477	SWL 310	Screened 337-357 & 457-477
34773 - Burke **Deepened** SW/4, NE/4 Sec 10 T20N R19E	2735	Knob Hill Drive 88-111-01	1990-10-18	Hard green rock 140-165 Freen fractured semi-decomposed granite 165-180 Green brown yellow white decomposed granite 180-235	SWL 105	Screened 195-215
34774	7360	Remington Road	1990-12-12	Brown clay with DG to 35 ft Weathered granite 35-61 Gray granite 61-135 with fractures 93-94 & 121-133	SWL 58	Screened 95-135
34775-N – Peck **Deepened** 20-19-11caccc1	3200	Sun Cloud Circle	1990-10-15	Gray granite 79-115 with fracture zone 103-104 Gay granite 104-115 Weathered granite with clay streaks 115-127 Gray granite 127-152 with fracture zone 130-138	SWL 71 below LSE 5108	Screened 107-147
34911 - Mason	2555	Cactus View Drive	1990-11-10	Tan yellow white DG sand to 6 ft Brown clay tan green white DG 6-54 Green brown white DG 54-137	SWL 50	Screened 117-137
36249	332	Lemmon Drive	1991-4-1	Clay & gravel to 28 ft Fractured granite 28-125	SWL 35	No screened interval noted on log
36671 - Aiken 20-19-10aaad2	7650	Hillview Drive	1991-5-17	Green gray granite 169-338	SWL 150 below LSE 5135	Screened 298-338

37614 – Ariaz2 **Deepened** **See 12815** 20-19-3dddc1	7575	Tamra Drive	1991-10-31	Hard gray granite 197-244 with occ fracture zones Hard black granite 244-265 with one fracture zone Gray granite 265-275	SWL 130 below LSE 5169.22	Screened 182-202 & 222-262
37616 **Deepened** 20N R19E sec 11 NW, NW	3405	Running Bear	1991-10-30	Green granit3 192-219 ft DG 219-307 Granite softer med hard 307-351 Hard fractured granite 351-392 Hard gray granite 392-414	SWL 120	Screened 374-394
38352 – Buranzon **Deepened**	7555	Vista View Drive	1992-7-27	Weathered granite with a few fracture zones & few hard granite layers 118-260	SWL 103	Screened 180-200 & 220-260
38667 **Deepened**	740	Browning Drive	1992-2-16	Hard green & black granite 118-170 Green & white granite with pyrite 170-180 Light green-dark green- white and reddish tan granite 180-239	SWL 36	Screened 209-229
39609 – Mayo2 **Deepened** **See 11735**	3460	Rolling Ridge Drive	1992-9-16	Brown to red volcanic rock 106-150 Granite gray & hard 150-251 with fracture zones 165-166 & 186-187 & 205-207 & 235-235	SWL 115	Screened 186-246
39851 - Larkins Baughman 20-19-11acaa1	9421	Wigwam Way	1992-10-21	Brown clay w/ DG to 59 ft Weathered granite rusty colored 59-145 Harder granite weathered 145-375 with fracture zone 189-193 & soft zones 231-239 and 312-323 and 354-369	SWL 117 below LSE 5210.16	Screened 170-190 & 290-310 & 350-370
39852 **Deepened**	3450	Rolling Ridge Road	1992-10-13	Purple volcanic rock 130-165 Multi-colored rock 165-197	SWL 100	Screened 147-167

39853	9050	N Virginia Street	1992-10-24	Brown clay, cobbles, silt & broken rock to 42 ft Sands & gravel 42-64 Brown clay w/ broken rock 65-92 Sands & gravel 95-121 Brown clay sands with broken rock 121-200 Light blue clays sand w/ broken rock 200-239 Blue broken rock, brown clay, green clay layers 239-325 Blue clay, blue rock chips 325-630 Light blue rock, fractures w/brown silt clay 630-770	SWL 63	Screened 210-350 & 390-430 & 470-510 & 320-570 & 590-730 & 750-770
41784-M – Walsh **Deepened** 20-19-11cdaa1	9205	Spearhead Way	1993-5-3	Fine sand & small gravel 118-121 Hard broken gay rock 121-143 Broken fractured rock 143-146 Hard gray rock 146-155 Broken & fractured rock 155-165	SWL 142 below LSE 5113.96	Screened 121-161
42159	3606	Sun Cloud Circle	1993-6-30	Tan & brown “shail” to 89 ft Gray rock 89-130 softer 108-130 Dark brown rock 130-136 Very dark rusty brown rock 136-168 Hard rock 168-200 with fracture zones 170-173 & 181-182 & 196-200 with some water Light gray rock 200-225 with soft zone 200-204 Broken & fractured rock 225-240	SWL 78.3	Screened 200-240
43768	3405	Deerfoot Lane	1993-10-11	Granite sands 127-130 Soft brown clay with granite sands 130-140 with soft zone 138-140 Weathered granite with clay streaks 140-227 with soft zones 163-165 & 210-212	SWL 110	Screened 120-130 & 150-160 & 200-220

45367	3185	Indian Lane	1994-8-17	Brown clay with DG to 8 ft Brown sandy clay & brown clay 8-39 Weathered granite 47-146 with soft fracture zones 95-97 (no water), 106-115 (water bearing), 138-146 Hard weathered granite 146-250 with fracture zones 195-197, 207-211, 2200-235	SWO 93	Screened 140-150, 190-200 & 220-240
44317-M - Nobach 20-19-14aabb1	3550	Golden Valley Road	1992-7-6	Clay & sand clay to 15 ft Soft purple clay 15-22 Soft dark brown clay 22-29 Hard gray roc 29-35 Rock broken & fractured 35-51 Medium hard tan rock 51-96 with soft zone 51-53 & 71-88 Med rock tan 88-96 Med rock gray 96-114 Med rock purple 114-116 Fractured gray rock 116-131	SWL 66.8 below LSE 5143	Screened 91-131
46290 Deepened	7680	Jays Place	1994-9-19	Decomposed granite 252-256 Granite 256-301 with soft zones 283-290 & 296-301 Broken fractured granite 301-334 Granite with weathered streaks 334-360	SWL 233.5	Screened 300-360
46487-N – Evans **Deepened** **20-19-10aaab1**	7635	Hillview Drive	1994-8-15	Grante with some fractures 165-187 Hard granite fractured 187-300	SWL 146 below LSE 5155	Screened 160-300
47017 – Fenkell **Deepened** **See 17813** Fenkell (Mazone)	7565	Bluff View Way	1995-3-6	Gray granite 182-184 Weathered granite 184-203 Gray granite 203-270 with fracture zones 203-217 & 225-228 & 255-257	SWL 142	Screened 161-181 & 201-221 & 241-262
49206-N – Dresbach **Deepened**	9255	Spearhead Way	1995-8-21	Gray granite 145-180 with fracture zone 167-172 Brown volcanic rock 180-192 over 1 ft white clay layer Gray granite 193-277 with fracture zone 209-211 & 261-272	SWL 112	Screened 177-197 & 217-237 & 257-277

50044	3600	Sun Cloud Circle	1995-11-6	Yellow volcanic rock to 111 ft with rusty yellow color 49-64 Gray sandy clay 111-141 Brown to dark brown sandy clay 141-205 Gray clay 205-218 Brown sandy clay 218-242 Gray weathered granite 242-300 with fracture zones 255-261 & 287-291	SWL 134	Screened 255-295
65314	3605	Golen Valley Road	1997-2-20	Red & brown DG to 8 ft Red & gray clay 8-15 Multi-colored volcanic rock med hard 15-110 Weathered granite with fractures 110-130 Green & gray clay stone 130-145 Multi-colored volcanic rock 145-155 Weathered granite 155-175 Multi-colored volcanic rock 175-210 Weathered granite hard 210-215 Green & black gravel 215-220	SWL 110	Screened 200-220
69610 - Rumburg 20-19-10bdba1	2625	Knob Hill Drive	1997-10-14	Clay with DG to 11 ft Weathered granite 11-27 Hard green granite 27-61 Weathered granite with clay streaks 61-95 Gray granite 95-160 with fracture zones 115-116 & 122-126 Weathered granite 160-192 with fracture zone 180-192 Gray hard granite 192-200	SWL 101 below LSE 5082.84	Screened 115-135 & 175-195

69668	9495	Tomahawk Way	1996-2-7	Brown DG to 30 ft Black & white granite with brown sand 30-42 Black & white granite – medium hard 42-80 Multi-colored volcanic rock – fractured 80-95 Multi-colored volcanic rock 95-115 Gray sandstone 115-135 Black & white granite – hard 135-205 Black granite – hard 135-205 Black granite – hard 205-220 Black & white granite – medium hard 220-295	SWL 200	Screened 275-295
73427 **New deeper well** **See 24310** **See 7534**	7900	N Virginia Street	1998-10-9	Sand & gravel to 10 ft Clay with minor sand 10-115 Consolidated sand 115-120 Andesite hard 120-130 Brown sand, rock 130-158 Andesite hard 158-305 Fractured andesite 305-338 Gray fractured volcanic 338-460 Hard gray volcanic 460-476 Gray fractured volcanic 476-601	SWL 320	Screened 320-600
73431	8550	Spearhead Way	1998-9-1	Brown sandy clay to 34 ft Decomposed sands 34-38 Brown sandy clay 38-61 Gray clay 61-145 Purple clay 145-180 Weathered granite 180-185 Black fractured granite 185-219 Black hard granite 219-225	SWL 75	Screened 180-220
74367 – **Recharge Well**		NE/4 NE/4 Sec 11 T20NR19E	1995-9-25	Soft DG to 12 ft Firm DG 12-60 Mostly hard granodiorite with some softer zones – all this if fractured and broken 60-450	No SWL recorded	Screened 200-240 Screened 240-450

74373	3650	Sun Cloud Circle	1998-12-16	Brown to reddish brown volcanic rock to 91 ft Purple volcanic rock 91-146 Brown volcanic rock 146-172 Weathered granite 172-177 Gray granite 177-250 with fracture zones 177-179 & 205-235	SWL 50	Screened 204-244
75350 – GV5 **Recharge Well**		NE/4 NE/4 Sec 11 T20NR19E	1995 – 10-1	Semi-solid granodiorite with softer areas of small sand. 250-450		Screened 240-450
82613-N – Steadman (Pratt) 20-19-11dbab1	3435	Warpaint Circle	2001-1-22	DG to 130 ft White rock & quartz 130-173	SWL 70 below LSE 5149.06	Screened 163-173
82776	7200	N Virginia Street	2001-3-21	Clay & gravel to 72 ft DG & boulders 72-135 Sand clay 135-167 Orange porphyry 167-214 White clay 214-218 Gray rock 218-277	SWL 111	Screened 217-277
84990 20-19-4dd **Municipal Well LVP3**			1963-1-17	Sand to 63 ft Hard rock with fractures 63-187 – first water at 63 Soft spot 187-188 Hard rock with fractures 188-296	SWL 60 below LSE 4882	Screened 140-180
85005	6980	N Virginia Street	1981-10-1	Red to brown clay 3-82 with hardpan 21-36 Gravel (water) 82-86 Red to brown clay with small rocks) 86-289 Gravel (water) 289-298 Brown clay with small rocks 198-304 Gravel (water) 304-318 Brown clay 318-321	SWL 82	Screened 297-321
85341- Folsom 20-19-10aaaa1	7665	Hillview Drive	1971-3-11	Soil & clay to 75 ft Decomposed granite 75-115 Boulders 115-120 Hard granite 120-125	SWL 75 below LSE 5148.45	Screened 85-125
88360 - Griffith	9430	Arrowhead Way	2002-8-18	DG to 188 ft Fractured granite 186-223 Hard granite 223-248 with fracture zone 228-236	SWL 140	Screened 188-248
88386 – Hedrick2 **Deepened** **See 26315 –** Hedrick1 **See 11683 –** Hedrick3	7800	Tamra Drive	2002-10-22	Green granite 150-240	SWL 118	Screened 220-240

88390	9445	Tomahawk Way	2002-7-26	DG coarse to 25 ft Coarse sand & brown clay 25-65 Reddish-brown clay, hard granite 65-95 Bright green granite 95-160 Tan & white granite, rust-colored chips 160-200 Hard granite maroon & rust-colored 200-418	SWL 164	Screened 378-398
89325 – Dunn **Deepened**	680	Browning Drive	2003-4-25	Hard green granite 80-170 Yellow DG 170-200 Black basalt 200-230 Green granite black rock 230-240	SWL 26	Screened 180-200 & 200-220
97253 **Deepened**	7575	Bluff View Way	2005-5-9	Gray granite 163-300 with soft zone 194-196 & 218-220 & 239-241 & 289-290	SWL 140	Screened 240-300
94441 - Rodriguez **Deepened** 20-19-3dcaa1 **See 26313**	7805	Tamra Drive	2004-7-22	Hard granite 150-250 with fractured rock 170-171, 186-188, 245-246	SWL 150 below LSE 5256	Screened 169-209 & 229-250
94941	7860	Tamra Drive	2004-10-11	DG with yellow clay to 15 ft Hard dark green granite 15-25 Dark blue green granite 25-248 Fractured granite 248-341	SWL 1555	Screened 281-321
96313	3750	Sun Cloud Circle	2005-5-5	Yellow clay with rock to 15 ft Gray, blue, yellow, red rock 15-120 Hard purple sticky clay 120-150 Dark green, blue volcanic rock 150-210 Blue green fractured rock 210-127	SWL 145	Screened 207-227
98373	7765	Tamra Drive	2005-7-5	DG green clay to 10 ft Green granite 10-30 Blue/green/yellow granite 30-90 Red-brown clay blue-green granite 90-110 Fractured granite 110-195 Mostly black fractured granite 195-225 Blue-green granite with specs yellow clay 225-420	SWL 239	Screened 389-409
Lake 20-19-10dcad1	620	Colt Drive	1990	Bedrock at total depth 85	LSE 5086	Screened

GVI-1 **Recharge Well**			1992	Silt, sand & clay to 30 ft Brown sticky clay with granitic sand 30-40 Quartz-rich granitic sand 40-65 Granitic sand with clay 65-75 White feldspar-rich sand 75-92 Granitic sand with clay 92-111 Quartz-rich granitic sand with clay 111-127 Brown silty clay with granitic sand 127-135 Quartz- & feldspar-rich granitic sand 135-180 Cemented quartz sand 180-260		Screened 124-244
GVI - 2 **Recharge well – Abandoned 1995 due to sanitary seal leak - Replaced with GVI - 4**			1992	Total depth 248 ft	LSE 5225	Screened 135-248
GVI – 3 **Deepened – original well drilled to 250, deepened to 450** **Recharge Well**			1992	Topsoil to 10 ft Granitic sand, 10-125 - partially cemented below 80' Granitic sand with tan clay 125-130 Granitic sand 130-205 Bedrock 205-450		Screened 250-450
GVI – 4 **Recharge Well – Replaced GVI – 2 abandoned in 1995 due to sanitary seal leak** **See 74367**		NE/4 NE/4 Sec 11 T20NR19E	1995-9-25	Sand & top soil to 30 ft Quarta-rich granitic sand 30-68 Quartz-rich sand with thin clay stringers 68-93 Quartz-rich granitic sand 93-105 Tan clay with granitic sand 1-5-114 Granitic sand & small gravels 114-131 Quartz-rich granitic sand 131-220 Bedrock 220-450		8" diameter screen 200-240 & 6" diameter screen 240-450

GV1-5 89899 **Recharge Well See 75350 – GV5**				Alluvium to 40 ft Granite no weathering 40-136 Fractured granite 136-143 Granite very hard 143-150 Weathered granite 150-155 Fractured granite 155-160 Granite major fracturing 160-180 Granite multiple fractures 180-320 Weathered granite 320-340 Consolidated fractured granite 340-350	SWL 70	Screened 160-400
MW1 20-19-11addd1 **Monitoring Well**				Silt & sand to 10 ft Quartz-rich granitic sand 10-136 Sandy clay 136-138 Cemented granitic sand 138-165 Bedrock 166-250	LSE 5227.5	Screened 95-244
MW3 20-19-11accc1 **Monitoring Well**				Sand, silt & clay to 10 ft Sand with clay lenses 10-20 Coarse granitic sand 20-60 Coarse granitic sand with tan clay stringers 60-70 Clean quartz sand 70-222 with tan clay 136-140 & 175-193 Bedrock 222-260	LSE 5145.26	Screened 105-255
MW4 20-19-11caac1 **Monitoring Well**				Sand, silt & clay to 10 ft Granitic sand with clay 10-50 Granitic sand with clay or small gavel in some intervals 50-190 Cemented sand 190-260	LSE 5128.93	Screened 111-258
MW5 20-19-11cbdb1 **Monitoring Well**				Silt & sand to 22 ft Sand with clay 22-52 Sand 52-60 Angular quartzite(?) fragments with sand & gravel 60-78 Sand 78-102 with small gravels below 98 Cemented sand 102-170 Quartz sand w/ brown silty clay 170-173 Cemented quartz sand 173-250	LSE 5102.9	Screened 105-255

Pohll (2017) Geologic Cross Section A-A'

Well ID	House #	Street	Year drilled	Well log	SWL	Screened Interval(s)
18504 20-19-10dcab1	7215	Marlin Drive	1978-6-21	Brown clay layers to 115 ft Coarse sand 115-154	SWL 26 below LSE 5060	Screened 124-154
Lake 20-19-10dcad1	620	Colt Drive 552-114-04	1990	Bedrock Total depth 85	LSE 5086	Screened
18505 - Robinson 20-19-10dcaa1 **See 32205**	7210	Marlin	1978-6-21	Top soil to 4 ft Yellow clay 4-10 Brown DG 10-68 Green granite 68-78 Green granite with fractures 78-95 Blue granite with fractures 95-106 Blue granite hard fractures with water 106-135	SWL 28 below LSE 5082	Screened 115-135
32205 – Robinson **See 18505**	640	Browning Drive	1989-9-11	Brown clay w/ DG to 35 ft Green weathered granite 35-86 Green granite 86-131 with fracture zone 115-120 Gray granite 131-150 with fracture zones 136-138 & 145-147	SWL 40	Screened 100-140
Lewis - 12555 20-19-11cbcb1	7350	Estates Road	1972-8-17	Sandy clay & gravel to 70 ft Gravel 70-104 First water at 55 ft	SWL 40 below LSE 5093	Screened 80-100
MW5 20-19-11cbdb1 Hydrograph 2002-2019			1992	Silt & sand to 22 ft Sand with clay 22-52 Sand 52-60 Angular quartzite(?) fragments with sand & gravel 60-78 Sand 78-102 with small gravels below 98 Cemented sand 102-170 Quartz sand w/ brown silty clay 170-173 Cemented quartz sand 173-250	LSE 5102.9	Screened 105-255
MW4 20-19-11caac1				Sand, silt & clay to 10 Granitic sand with clay 10-50 Granitic sand with clay or small gavel in some intervals 50-190 Cemented sand 190-260	LSE 5128.93	Screened 111-258

MW3 20-19-11accc1				Sand, silt & clay to 10 ft Sand with clay lenses 10-20 Coarse granitic sand 20-60 Coarse granitic sand with tan clay stringers 60-70 Clean quartz sand 70-222 with tan clay 136-140 & 175-193 Bedrock 222-260	LSE 5145.26	Screened 105-255
13514 - Pilling 20-19-11acad1	9325	Wigwam Way	1973-4-18	Clay with gravel lenses to 66 ft Extra hard gray granite 66-193 with fracture zones 165-167 & 187-189	SWL 140 below LSE 5195	Open hole – no pump test
GVI – 2 **injection well #2 Replaced with GVI #4**			1992	Total depth 248 ft	LSE 5225	Screened 135-248
74367-GV14		NE/4 NE/4 Section 11 T20NR19E	1995-8-24	DG soft to 12 ft Firm DG 12-60 Mostly hard granodiorite with some softer zones – fractured & broken 60-450		Screened 200-240 & 140-450

Terraphase (2023) Profile A-A'

Well ID	House #	Street	Year drilled	Well log	SWL	Screened Interval(s)
11297	3275	Brave Lane	1970-11-15	Clay to 80 ft Decomposed granite 80-100	SWL 60 ft	Screened 80-100
13061	3275	Warpaint Circle	1972-6-19	DG to 2 ft Clay, sandy clay layers to 20 ft Reddish sandy clay 20-49 Green-gray clay with some small gravel 49-90 Brown sandy clay 90-110 Weathered black or gray granite 110-140	SWL 62	Screened 100-140
13562	7565	Estates Drive	1973-7-27	DG to 8 ft DG hardpan 8-12 Weathered gray granite with some clay 12-66 Soft broken granite 66-75 Med hard granite 75-106 with fracture zone 95-97 Very hard green granite 106-132 Med hard green granite 132-145 Very hard green granite 145-165	SWL 104	Screened 110-165
16072	9070	Spearhead Way	1976-12-9	Brown clay to 18 ft Clay & DG sand mixed 18-85 Loose brown decomposed granite 85-128	SWL 75	Screened 88-128
16627	7600	Hillview Drive	1977-6-25	Red clay & DG to 12 ft Decomposed granite 12-50 DG sand, clay some fractured areas 50-75 Hard granite 75-109 Granite tight with some small fractures 109-185 Green granite with fractures & some clay 185-194 Fine to rocky 194-207 Cemented sand & gravel 207-236	SWL 107	Screened 163-207
16808	3430	Deerfoot Lane	1977-7-19	Brown to red clay to 42 ft Sticky clay – brown to white to brown 42-170 Gray soft rock 170-188 Brown decomposed soft rock 188-192 Hard broken brown rock 192-215	SWL 75	Screened 173-209
18892	7625	Tamra Drive	1978-9-4	Dirt & rock to 25 ft Sand 25-100 Granite 100-300	SWL 150	Screened 280-300
19921	3205	Indian Lane	1979-5-24	Sand with clay to 45 ft Sand, gravel w/ clay 45-86 Large gravel, sand & clay 86-105 Brown clay & sand 105-143 Course gravel & sand with clay 143-165	SWL 30	Screened 62-165

22162	3575	Golden Valley Drive	1980-10-28	Clay & rock to 63 ft Hard DG 63-71 Gray clay & little DG 71-163 Fracture DG 163-200	SWL 122	Serene 170-200
24414	3565	Golden Valley Road	1983-2-17	Brown clay to 20 ft White med hard rock 20-65 Gray rock 65-140 Green & brown rock 140-210 Med hard rock 210-245 Fractured rock 245-270 Green hard granite 270-275	SWL 110	Screened 249-269
25560 - **Deepened**	3230	Indian Lane	1984-7-18	Weathered DG & quartz 155-172 Weathered quartz & granite 180-184 Med hard white granite 184-188 Qtz & granite coarse large grained 188-206 Soft quartz 206-212 White granite 212-216 Soft quartz weathered 216-222 Med hard white granite 222-225	SWL 94	Screened 185-225
27752	7740	Tamra Drive	1986-9-8	Weathered granite to 27 ft Gray granite 27-300 with fractures 87-88 & 165-166 & 214-215 & 220-221 & 265-270 & 281-295	SWL 199	Screened 154-194
30153 - **Deepened**	3275	Warpaint Circle	1988-7-21	Weathered granite 143-200 with soft zone 145-147 & 155-165 & 174-179	SWL 102	Screened 140-160 & 180-200
30521	7670	Tamra Drive	1988-9-27	Decomposed granite to 44 ft Granite 44-53 Weathered granite 53-210 with alt softer layers Broken & fractured granite 210-280 with fractured zones 233-236 & 245-263 & 276-280	SWL 180	Screened 207-267
42159	3605	Sun Cloud Circle	1993-6-30	Tan & brown “shail” to 89 ft Gray rock 89-130 softer 108-130 Dark brown rock 130-136 Very dark rusty brown rock 136-168 Hard rock 168-200 with fracture zones 170-173 & 181-182 & 196-200 with some water Light gray rock 200-225 with soft zone 200-204 Broken & fractured rock 225-240	SWL 78.3	Screened 200-240
43768 – **Deepened**	3405	Deerfoot Lane	1993-10-11	Granite sands 127-130 Soft brown clay with granite sands 130-140 with soft zone 138-140 Weathered granite with clay streaks 140-227 with soft zones 163-165 & 210-212	SWL 110	Screened 120-130 & 150-160 & 200-220

46290 – **Deepened**	7680	Jays Place	1994-9-19	Decomposed granite 252-256 Granite 256-301 with soft zones 283-290 & 296-301 Broken fractured granite 301-334 Granite with weathered streaks 334-360	SWL 233.5	Screened 300-360
46487 – **Deepened**	7635	Hillview Drive	1994-8-15	Granite soft 165-187 Hard granite with fractures 187-300	SWL 146	Screened 160-300
50044	3600	Sun Cloud Circle	1995-11-6	Yellow volcanic rock to 111 ft with rusty yellow color 49-64 Gray sandy clay 111-141 Brown to dark brown sandy clay 141-205 Gray clay 205-218 Brown sandy clay 218-242 Gray weathered granite 242-300 with fracture zones 255-261 & 287-291	SWL 134	Screened 255-295
65314	3605	Golden Valley Road	1997 – 2-20	Red & brown DG to 8 ft Red & gray clay 8-15 Multi-colored volcanic rock med hard 15-110 Weathered granite with fractures 110-130 Green & gray clay stone 130-145 Multi-colored volcanic rock 145-155 Weathered granite 155-175 Multi-colored volcanic rock 175-210 Weathered granite hard 210-215 Green & black gravel 215-220	SWL 110	Screened 200-220
97253 – **Deepened**	7575	Bluff View Way	2005-5-9	Gray granite 163-300 with soft zone 194-196 & 218-220 & 239-241 & 289-290	SWL 140	Screened 240-300
98373	7765	Tamra Drive	2005-7-5	DG green clay to 10 ft Green granite 10-30 Blue/green/yellow granite 30-90 Red-brown clay blue-green granite 90-110 Fractured granite 110-195 Mostly black fractured granite 195-225 Blue-green granite with specs yellow clay 225-420	SWL 239	Screened 389-409

Terraphase (2023) Profile B-B'

Well ID	House #	Street	Year drilled	Well log	SWL	Screened Interval(s)
11354 – **Deepened – prior well not constructed properly**	7571	Bluff View Way	2010-6-15	Gray hard granite 150-196 with fracture zone 186-188 Weathered granite 196-240 with fracture zones 205-206 & 230-231	SWL 130	Screened 200-240
11439 – **Deepened**	7665	Hillview Drive	1971-9-5	Hard fractured gray granite 122-182 with some water & weathering 162-167	SWL 48	Screened interval not noted on log
12815	7575	Tamra Drive	1972-12-5	Alternating layers of sandy clay, silty sand & clay to 25 ft Dry yellow silt 25-30 Dry green-like silty 30-48 Yellow sandy clay 48-50 Green to brown silty sand 50-65 Hard grey granite occasionally fractured 65-200 with water bearing fractures 182-186 & 192-194	SWL 112	Screened 160-200
13597	630	Sherman Way	1973-4-30	Red clay with hard pan to 8 ft DG to 75 with alternating layers of some clay, some gravels Coarse sand 75-100	SWL 33	Screened 50-100
14699	6915	Pontiac Drive	1975-4-24	Hard brown to yellow clay with some sand to 55 ft Sandy brown clay with DG 55-65 Loose brown DG 65-75 Hard blue-green granite 75-84 Hard & soft sandy brown clay with DG 84-108 Hard to med hard gray-green granite 108-125	SWL 48	Screened 68-110
15283	6975	Pontiac Drive	1975-12-17	DG sand with mix of brown clay to 76 ft Blue sand coarse with blue grey granite 76-100 Hard blue-grey granite with fractures & water bearing 100-111	SWL 35	Screened 93-111
15339	7570	Tamra Drive	1975-12-30	Overburden to 12 ft Blue rock w/ brown streaks 12-55 Brown clay & boulders 55-74 Gray granite 74-210 Broken gray granite 210-218 Granite 218-225	SWL 65	Screened 205-225

16688	700	Winchester Road	1977-7-13	Overburden to 6 ft Sandy clay with gravel 6-80 Brown sandstone 80-107 Fractured granite & volcanic rock 107-145	SWL 56	Screened 122-149
17319	2965	Valley View Drive	1977-10-19	Valley fill to 25 ft DG 25-80 Granite 80-190 with fractures 160-190 & some water at 80 ft	SWL 45	Screened 70-90 & 170-190
17970	345	Colt Drive	1978-4-11	Clay to 5 ft Fine sand 5-15 Soft DG 15-55 Granite hard 55-118 with fracture zones with some water 75-87 & 100-118	SWL not recorded on log	Screened 50-118
18949	7220	Marlin Drive	1978-9-25	Sandy clay to 56 ft Brown DG loose 56-122 Brown DG medium hard 122-141 Course granite sand 141-175	SWL 30	Screened 131-175
19278	6855	Pontiac Drive	1979-1-4	Clay with DG to 105 ft DG with large gravel 105-125 and water at 120	SWL 80	Screened 105-125
20875	7840	Tamra Drive	1980-3-17	Clay & rocks to 60 ft Granite 61-257 with fracture zone 235-240	SWL not recorded on log	Screened 237-257
21506 – Golden Valley Park 20-19-10adbd1		SE/4 NE/4 Sec 10 T20NR19	1980-6-23	Overburden to 5 ft Decomposed granite soft 5-20 Fractured granite 20-120 Hard granite 120-140 Fractured granite 140-1880 Granite & sand 180-200 Hard granite 200-250 with fracture zone from 215-230	SWL 75	Screened 140-230
24671	650	Colt Drive	1983-6-16	Brown clay to 13 ft Hard gray granite 13-110 with fracture zone 87-106	SWL 45	Screened 83-105
25771(1)	735	Browning Drive	1984-10-3	Hard pan to 22 ft DG 22-80 Hard granite with small amt of water 80-126 Clay 126-127	SWL 37	Screened 107-127
26165	665	Winchester Drive	1985-5-7	Brown clay w/ DG to 10 ft Weathered granite 10-17 Gray granite 17-155 with fractures zones 90-92 with water & 118-120 & 135-144	SWL 30	Screened 103-147
37614 – **Deepened**	7575	Tamra Drive	1991-10-28	Gray granite hard 197-244 Black granite hard 244-265 with fracture zone 248-253 Gray granite 265-275	SWL 130	Screened 182-202 & 222-262

38667 – **Deepened**	740	Browning Drive	1992-2-26	Hard green & black granite 118-170 Green & white granite with pyrite 170-180 Light green-dark green-white and reddish tan granite 180-239	SWL 36	Screened 209-229
82776	7200	N Virginia Street WEST OF US 395	2001-3-21	Clay & gravel to 72 ft DG & boulders 72-135 Sand clay 135-167 Orange porphyry 167-214 White clay 214-218 Gray rock 218-277	SWL 111	Screened 217-277
85005	6980	N Virginia Street WEST OF US 395	1981-10-1	Red to brown clay 3-82 with hardpan 21-36 Gravel (water) 82-86 Red to brown clay with small rocks) 86-289 Gravel (water) 289-298 Brown clay with small rocks 198-304 Gravel (water) 304-318 Brown clay 318-321	SWL 82	Screened 297-321
94941	7860	Tamra Drive	2004-10-11	DG with yellow clay to 15 ft Hard dark green granite 15-25 Dark blue green granite 25-248 Fractured granite 248-341	SWL 155	Screened 281-321
89899 - GV15		Estates & Hillview SW/4 SW/4 Sec 2 T10NR19E	2003-2-19	Alluvium to 40 ft Granite not weathered 40-136 Fractured granite 136-143 Granite very hard 143-150 Weathered granite 150-155 Fractured granite 155-160 Granite major fracturing 160-180 Granite multiple fractures 180-320 Weathered granite 320-340 Consolidated fractured granite 340-350	Recharge Permit SWL 70	Screened 160-400

Terraphase (2023) Profile C-C'

Well ID	House #	Street	Year drilled	Well log	SWL	Screened Interval(s)
103807	9310	Bull Road SE/4 NE/4 Sec 11 T20NR19E	2006-10-12	Decomposed granite to 155 Fractured rock 155-200	SWL 73	Screened 160-200
11735	3460	Rolling Ridge Road	1971-7-29	Topsoil to 3 ft Hard & soft gray rock sometimes fractured 3-112 Red rhyolite – fractures & water bearing 112-150 Hard gray rock 150-155	SWL 64	Screen interval not recorded on log
12929	9255	Bull Road	1973-2-27	Soil to 2 ft Dry clay 2-17 Decomposed granite 17-235	SWL not recorded on log	Screened 146-211
13738 - **Conradt duplicate of Bell – duplicate of Holzworth**	3495	Deerfoot Lane	1973-12-17	Clay layers with small gravel 20-77 Med hard to hard volcanics 77-104 Med hard to hard fractured dark green granite 104-127 Dark green granite 127-145	SWL 70 below LSE 5145.95	Screened 124-164
14641	9110	Wigwam Way	1975-3-13	Decomposed granite sand topsoil to 3 ft Layers of brown to yellow to reddish brown clay with varying amounts of coarse sand or small gravel 3-127 Yellow sandy clays with coarse sand (water) 127-158 Hard gray granite 158-166 Hard to med hard brown rock (some water) 166-180 Hard black rock (water) 180-190	SWL 78	Screened 113-155
16384	9469	Wigwam Way	1977-3-22	DG to 60 ft Grey granite 60-76 Decomposed gray granite high quartz content 76-275	SWL 154	Screened 225-275
18587 – Garner 20-19-11dcdd1	3495	Golden Valley Road	1978-7-20	Light brown clay to 80 ft Blue gray clay fractured 80-160 Purple clay 160-190 Blue gray clay 190-215 Purple rock fractured 215-260	SWL 75 below LSE 5166	Screened 221-260

20037 - Thomas	9441	Wigwam Way	1979-6-13	Top soil to 4 ft Brown med hard DG 4-48 Brown med loose DG 48-111 Brown DG hard 111-185 Light brown granite med hard 185-261 Light blue granite med hard & fractured 261-300	SWL 150	Screened 258-294
20250	3450	Rolling Ridge Road	1979-8-13	Rhyolite to 95 ft Volcanic & quartz 95-130	SWL 100	Screened 90-130
24836 – McNinch – Duncan 20-19-11abaa1	9499	Wigwam Way	1983-2-26	Overburden to 4 ft DG 4-264 Hard fractured DG & quartz 284-343	SWL 200 below LSE 5282.46	Screened 324-343
24981 – Donshick 20-19-11adbc1	9355	Wigwam Way	1983-10-6	Loose DG to 9 ft DG with brown clay 9-35 Weathered granite 35-145 Gray granite 145-183 Fractured granite 183-199 Gray granite 199-275 with fractured zones 116-228 & 255-258	SWL 115 below LSE 5218	Screened 209-228 & 248-268
24998	3495	Golden Valley Road	1983-10-11	Light brown rock to 9 feet Red volcanic rock 9-20 Purple rock 20-90 Green granite 90-140 with fracture zone (water) 105-110 Gray granite 140-175 with fracture zones (water) 135-140 & 155-156 & 165-167	SWL 89	Screened 115-135 & 155-175
32062	4325	Indian Lane	1989-7-28	Brown lay with DG to 105 ft Weathered granite 105-145 White granite 145-188 with soft zone 165-166 & 180-188 Weathered granite 188-250 with soft zones 194-197 & 204-250	SWL 108	Screened 203-243
39609 – Mayo2 **Deepened**	3460	Rolling Ridge Drive	1992-9-16	Brown to red volcanic rock 106-150 Granite gray & hard 150-251 with fracture zones 165-166 & 186-187 & 205-207 & 235-235	SWL 115 below LSE 5172.3	Screened 186-246
39852 **Deepened**	3450	Rolling Ridge Road	1992-10-13	Purple volcanic rock 130-165 Multi-colored rock 165-197	SWL 100	Screened 147-167

73431	8550	Spearhead Way	1998-9-1	Brown sandy clay to 34 ft Decomposed sands 34-38 Brown sandy clay 38-61 Gray clay 61-145 Purple clay 145-180 Weathered granite 180-185 Black fractured granite 185-219 Black hard granite 219-225	SWL 75	Screened 180-220
74367 - GV14		NE/4 NE/4 Section 11 T20NR19E	1995-8-24	Soft DG to 12 ft Firm DG 12-60 Mostly hard granodiorite with some softer zones – fractured & broken 60-450	SWL not recorded on well log	Screened 200-240 & 140-450
74373	3650	Sun Cloud Circle	1998-12-16	Brown to reddish brown volcanic rock to 91 ft Purple volcanic rock 91-146 Brown volcanic rock 146-172 Weathered granite 172-177 Gray granite 177-250 with fracture zones 177-179 & 205-235	SWL 50	Screened 204-244
96313	3750	Sun Cloud Circle	2005-5-5	Yellow clay with rock to 15 ft Gray, blue, yellow, red rock 15-120 Hard purple sticky clay 120-150 Dark green, blue volcanic rock 150-210 Blue green fractured rock 210-127	SWL 145	Screened 207-227

Terraphase (2023) Profile D-D'

Well ID	House #	Street	Year drilled	Well log	SWL	Screened Interval(s)
11758	7900	N Virginia – Skyline Mobile Home Park WEST OF US 395	1971-8-31	DG to 30 ft Sandy gravel with clay 30-90 Boulders 90-93 Very hard rock 93-140 Sandy clays with hard & soft streaks 140-320 Hard white clay 230-248	SWL 63	Screened 60-227
12555 – Lewis 20-19-11cbcb1	7350	Estates Road	1972-8-17	Sandy clay & gravel to 70 ft Gravel 70-104	SWL 40 below LSE 5093	Screened 80-100
14548	3185	Indian Lane	1972-11-3	DG with yellow clay to 74 ft DG – brown sand 74-101	SWL 60	Screened 75-101
17852	7145	Marlin Drive	1978-3-13	Brown tight clay to 30 ft Brown clay with soft streaks 30-90 Sand 90-125 Sand with clay 125-145	SWL 32	Screened 110-135
17970	645	Colt Drive	1978-4-11	Clay to 5 ft Fine sand 5-15 Soft DG 15-55 Granite hard 55-118 with f 104-209racture zones with some water 75-87 & 100-118	SWL not recorded on log	Screened 50-118
18608 - Davis	7320	Estates Road	1978-7-24	Sand to 3 ft Decomposed granite & clay 3-20 Clay 20-34 Decomposed granite – highly oxidized 34-82 Decomposed granite 82-156	SWL 44	Screened 95-156
18610	840	Browning Drive	1978-7-31	Clay & sand with some DG to 93 ft Blue clay 93-123 DG 123-150 Faults 150-165 Fairly hard rock 165-180 DG & granite 180-200 Fractured granite w/ water 200-204 Sand & gravel with some water 104-230	SWL 50	Screened 120-180 & 170-230
18702 20-19-11abca1	9479	Wigwam Way	1978-6-30	DG to 280 ft Granite 281-340 DG 341-350	Dry Hole LSE 5243	

19921	3205	Indian Lane	1979-5-24	Sand with clay to 45 ft Sand, gravel w/ clay 45-86 Large gravel, sand & clay 86-105 Brown clay & sand 105-143 Course gravel & sand with clay 143-165	SWL 30	Screened 62-165
19949	550	Winchester Drive	1979-5-30	Brown clay med hard to 61 ft Brown clay with fine sand 61-86 ft Brown DG coarse 86-132 ft Brown clay 132-140 ft	SWL 35	Screened 88-130
20276	9440	Tomahawk Way	1979-8-14	Brown DG with clay streaks to 117 ft DG 117-133 Brown rock medium hard 133-278 with soft streaks at 155-160, 177-179, 202-204, 245-250, and broken & fractured 225-230 Rock – medium hard brown 278-300 Granite at 300	SWL 55	Screened 228-250 & 262-290
21356	9305	Spearhead Way	1980-7-11	DG to 42 ft Green gray granite 42-172 White granite 172-216 WB (?) 195-275 with fractures 216-275	SWL 102	Screened 186-275
24051	680	Golden Valley Road	1982-8-30	Brown clay with DG mixed to 39 ft Gray weathered granite 39-95 Yellow weathered rock 95-107 Gray weathered granite 107-149 – water bearing Fractured rock 149-165 Gray granite 165-190	SWL 55	Screened 160-190
24310 **See 73427** **See 7534**	7900	Skyline Mobile Home Park NW/4 Sec 15 T20N R19D – North Virginia Street	1982-12-12	Sand & gravel to 46 f Decayed gravel 46-138 Fractured volcanic rock 138-146 Volcanic rock – med hard 146-193 Granite hard gray 193-307 Fractured granite 307-348 Hard granite 348-351	SWL 215	Screened 307-351
25282	7410	Estates Road	1984-4-18	Brown sandy clay to 43 ft DG loose 43-63 Brown weathered granite 63-95 Fractured granite – water bearing 95-112 Med hard granite 112-125	SWL 45	Screened 91-118

34774	7360	Remington Road	1990-12-12	Brown clay with DG to 35 ft Weathered granite 35-61 Gray granite 61-135 with fractures 93-94 & 121-133	SWL 58	Screened 95-135
37616 **Deepened**	3405	Running Bear Lane 20N R19E sec 11 NW, NW	1991-10-30	Green granit3 192-219 ft DG 219-307 Granite softer med hard 307-351 Hard fractured granite 351-392 Hard gray granite 392-414	SWL 120	Screened 374-394
45367	3185	Indian Lane	1994-8-17	Brown clay with DG to 8 ft Brown sandy clay & brown clay 8-39 Weathered granite 47-146 with soft fracture zones 95-97 (no water), 106-115 (water bearing), 138-146 Hard weathered granite 146-250 with fracture zones 195-197, 207-211, 2200-235	SWL 93	Screened 140-150, 190-200 & 220-240
69668	9495	Tomahawk Way	1996-2-7	Brown DG to 30 ft Black & white granite with brown sand 30-42 Black & white granite – medium hard 42-80 Multi-colored volcanic rock – fractured 80-95 Multi-colored volcanic rock 95-115 Gray sandstone 115-135 Black & white granite – hard 135-205 Black granite – hard 135-205 Black granite – hard 205-220 Black & white granite – medium hard 220-295	SWL 200	Screened 275-295
73427 **New deeper well** **See 24310** **See 7534**	7900	N Virginia Street	1998-10-9	Sand & gravel to 10 ft Clay with minor sand 10-115 Consolidated sand 115-120 Andesite hard 120-130 Brown sand, rock 130-158 Andesite hard 158-305 Fractured andesite 305-338 Gray fractured volcanic 338-460 Hard gray volcanic 460-476 Gray fractured volcanic 476-601	SWL 320	Screened 320-600

7534 **See 24310** **See 73427**	8600	N Virginia Street C&R Trailer Park	1963-8-20	Heavy clay & sand to 38 ft Clay, sand & broken rock 38-126 Clay, sand, gravel & broken rock with some water 126-158 Hard dry clay & shale 158-207 Clay, sand & broken rock 207-360 Water bearing 306-402 Hard rock 402-408	SWL 125	Screened 200-400
75530 - **Deepened**		NE/4 NE/4 Sec 11 T20N R19E		250-540 Semi-solid granodiorite with softer areas of small land slump	SWL not recorded on log	Screened 240-450
88390	9445	Tomahawk Way	2002-7-26	DG coarse to 25 ft Coarse sand & brown clay 25-65 Reddish-brown clay, hard granite 65-95 Bright green granite 95-160 Tan & white granite, 160-200 Hard granite maroon & rust-colored 200-418	SWL 164	Screened 378-398

Terraphase (2023) Profile E-E'

Well ID	House #	Street	Year drilled	Well log	SWL	Screened Interval(s)
101415	6540	Meyers Avenue	2006-6-30	Clay with small gravel to 325 ft Blue "lime stone" 325-385	SWL 270	Screened 325-385
16249	7130	Estates Road	1977-1-12	Clay to sandy clay – brown to 51 ft Gray hard granite 51-55 Fractured blue-green granite 55-60 Hard blue-green granite 60-72 with fracture zone 65-71 Blue granite with brown decomposed granite sand lens 72-128	SWL 32	Screened 88-128
17293	3225	Sun Cloud Circle	1977-11-11	Overburden to 4 ft Granite 4-34 Decomposed granite 34-68 Gravel/sand cemented 68-96 with water-bearing fracture at 90 Granite with soft zones 96-200 – water bearing fractures at 125, 154 & 187	SWL 87	Screened 140-200
19190 - Long 20-19-10bcdb1	2775	Cactus View Drive	1978-11-16	Decomposed granite to 20 ft Brown clay 20-45 Solid granite 45-85 Granite fractured 85-100	SWL 55 below LSE 5066	Screened 80-100
19319 **See # 20989 & 28313** 20-19-10bcad1	2580	Knob Hill Drive	1979-1-26	Topsoil to 6 ft Firm decomposed granite 6-200 DG & granite 200-210	SWL 130 below LSE 5075.46	Screened 170-210
20293	2780	Cactus View Drive	1979-9-4	Topsoil to 3 ft Red clay & gravel 3-50 Conglomerated fractured rock 50-76	SWL 15	Screened 56-76
20989 **See # 19319 & #28313**	2580	Knob Hill Drive APN 88-040-36	1980-4-22	Top soil to 1.5 ft Brown clay 1.5-65 Green rock with clay layers 65-129 Gray granite with fractures 129-198	SWL 93	Screened 156-198
25545	2785	Cactus View Drive	1984-7-13	DG to 10 ft Green granite with some weathered 10-65 Gray granite 65-156 Fractured granite 156-178 Green granite 178-190	SWL 55	Screened 160-190
28313 – **Deepened See # 19319 & 20989**	2605	Knob Hill Drive	1986-11-18	Granite 210-240 with fractures 220-240	SWL 85 below LSE 5075.46	Extended well below casing 30 ft – hot water up heated on casing 60 ft good well. Backfilled with coarse rock in bottom of casing well will make 30 GPM.

29068	2760	Cactus View Drive	1987-9-3	DG to 4 ft Hard DG with boulders 4-38 Granite 38-61 Cemented gravel 61-89 Red clay 89-95 Fractured granite 95-138	SWL 55	Screened 100-138
30797	6510	Meyers Avenue	1988-12-21	Brown sandy clay with some gravel to 89 ft Soft zone – no water 89-93 Brown sandy clay with some gravels 93-149 Soft sandy clay 149-183 Brown sandy clay with gravels 183-245 Weathered green granite 245-295 Fractured granite 295-338 Green granite 338-350	SWL 255	Screened 279-339
33120	9215	N Virginia Street	1990-3-1	Multi-colored gravels with fine sand and clays to 76 ft Brown sticky clay 76-84 Multi-colored gravel with some brown clay 84-223 Blue-green rock with some fine sand 223-257 Brown sticky clay with gravels & sand 257-282 Green clay with some fine sand 282-362 Blue green white & red rock with some glue clay and fine sand 362-367 Blue clay 367-441 Blue black red & tan coarse gravels with some fine sand 441-477	SWL 320	Screened 337-357 & 457-477
36249	332	Lemmon Drive	1991-4-1	Clay & gravel to 28 ft Fractured granite 28-125	SWL 35	No screened interval noted on log
39853	9050	N Virginia Street	1992-10-24	Brown clay, cobbles, silt & broken rock to 42 ft Sands & gravel 42-64 Brown clay w/ broken rock 65-92 Sands & gravel 95-121 Brown clay sands with broken rock 121-200 Light blue clays sand w/ broken rock 200-239 Blue broken rock, brown clay, green clay layers 239-325 Blue clay, blue rock chips 325-630 Light blue rock, fractures w/brown silt clay 630-770	SWL 63	Screened 210-350 & 390-430 & 470-510 & 320-570 & 590-730 & 750-770

Appendix B: Precipitation at Reno International Airport (KRNO)

Monthly and annual precipitation at Reno International Airport recorded in inches of water equivalent.

Recorded January 1937 through September 2023.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1937	M	M	0.04	0.18	0.01	0.04	0.22	0	0.17	0.24	0.87	1.64	3.41
1938	0.28	3.44	1.82	0.17	0.3	1.37	0.37	0.01	0.08	0.14	0.14	0.13	8.25
1939	1.14	0.22	0.67	0.06	0.61	0.04	0.62	0.48	0.84	0.72	0.06	0.27	5.73
1940	3.07	1.35	0.58	1.1	0.02	0.62	0.24	0	0.79	0.43	0.55	1.48	10.23
1941	0.6	0.85	0.14	0.5	0.09	0.54	0.26	1.22	0.04	1.06	0.13	2.21	7.64
1942	1.46	0.64	0.33	0.2	0.32	0.08	T	0	0.02	0.07	0.96	0.56	4.64
1943	4.05	0.56	1.81	0.44	T	0.18	0.6	T	T	0.32	0.29	0.76	9.01
1944	0.77	1.48	1.13	0.2	0.37	0.18	0.28	0	0.07	0.64	1.58	0.27	6.97
1945	0.25	1.88	0.97	0.31	0.24	0.97	0.1	0.23	0	2.14	0.17	1.58	8.84
1946	0.19	0.33	0.97	0.05	0.17	0	0.84	T	0.1	0.51	2.04	0.39	5.59
1947	0.16	0.51	0.12	0.03	0.3	0.07	0	0.12	T	0.17	0.06	0.01	1.55
1948	0.01	0.3	0.07	0.67	1.25	0.52	0	0.08	0.01	0.17	T	0.72	3.8
1949	0.76	0.32	0.74	0.29	1.64	0.13	0.8	0.11	0.18	0.11	1.28	0.17	6.53
1950	1.54	0.3	0.96	0.5	0.2	0.73	0.04	0.07	1.02	1.56	1.43	1.26	9.61
1951	0.98	0.43	0.24	1.07	0.71	0.67	0	0.13	0.37	0.96	0.61	1.95	8.12
1952	1.89	0.62	2.02	1.63	0.02	0.09	0.72	0.01	0.67	0.04	0.5	1.68	9.89
1953	0.81	0.22	0.34	0.41	1.2	0.77	0.21	0.17	0.05	0.1	0.17	0.12	4.57
1954	0.86	1.49	1.81	0.21	0.02	0.24	0.08	T	0	T	0.74	1.49	6.94
1955	0.64	0.63	0.25	0.17	1.03	T	0.35	T	0.62	0.04	0.21	5.25	9.19
1956	2.58	0.53	0.05	1.38	0.75	0.02	0.49	T	0.35	0.89	T	0.05	7.09
1957	1.2	0.8	0.26	0.21	0.83	0.06	0.03	0	0.61	1.27	0.58	1.52	7.37
1958	0.78	1.7	1.76	2.04	0.25	0.45	0.22	0.56	0.49	T	0.38	0.24	8.87
1959	0.64	2.8	0.07	T	1.84	0	0.05	0.09	0.04	T	0	0.45	5.98
1960	1.21	1.19	0.59	0.05	T	T	0.87	T	T	0.18	1.45	0.24	5.78
1961	0.8	0.3	0.4	0.27	0.91	0.56	0.3	0.47	0.39	0.15	0.64	0.18	5.37
1962	0.35	3.69	0.84	T	1.4	0.04	0.38	0.08	0.1	1.55	0.02	0.6	9.05
1963	2.51	1.09	0.41	0.82	2.89	1.1	T	0.17	0.18	0.24	1.44	0.08	10.93
1964	0.68	0.01	0.72	0.53	1.79	0.29	0.13	0.02	0	0.04	0.63	2.89	7.73
1965	1.64	0.01	0.98	0.27	0.18	1.31	0.35	1.65	0.5	0.02	1.62	1.19	9.72
1966	T	0.2	0.04	0.03	0.33	0.03	T	0.02	0.1	T	1.07	1.45	3.27
1967	2.11	T	1.93	0.95	0.47	0.59	0.57	1.22	0.82	0.04	0.22	0.55	9.47
1968	1.11	0.92	0.84	0.02	0.3	0.16	0.05	0.13	0.15	0.01	0.73	1.03	5.45
1969	4.13	1.74	0.07	0.1	0.2	1.29	0.17	T	0.01	0.4	0.04	2.07	10.22
1970	1.73	0.32	0.19	0.6	T	0.88	0.05	0.02	0.01	0.03	1.47	1.65	6.95
1971	0.75	0.33	1.54	0.59	2.38	0.09	1.06	0.09	0.1	0.44	0.24	2.97	10.58
1972	0.37	0.14	0.03	0.14	1.02	0.18	0.01	0.14	0.3	1.3	1	0.89	5.52
1973	1.54	1.66	0.73	0.13	0.75	0.07	0.27	0.48	0.01	0.56	1.74	1.27	9.21
1974	1.6	0.34	1.16	0.23	0.01	T	0.33	0.19	0	0.69	0.27	0.56	5.38
1975	0.32	1.74	1.59	0.62	0.21	0.21	0.03	1.03	0.92	0.15	0.12	0.01	6.95
1976	0.16	1.2	0.36	0.2	0.1	T	0.96	0.62	1.1	0.28	0.07	0.01	5.06
1977	0.67	0.71	0.19	T	1.24	1.03	0.07	0.01	0.01	0.14	0.23	2.54	6.84
1978	1.66	0.98	1.49	0.2	0.31	0.07	0.19	0.15	0.68	0.08	1.3	0.82	7.93
1979	0.66	0.82	0.52	0.41	0.16	T	0.58	0.38	T	0.31	0.17	2.02	6.03

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1980	2.77	1.9	0.76	0.51	0.78	0.12	0.54	0.32	0.48	0.14	0.28	0.6	9.2
1981	0.85	0.21	0.58	0.21	0.57	T	0.01	0.36	0.07	0.64	2.13	1.05	6.68
1982	1.2	0.41	1.14	0.34	0.1	1.07	0.04	0.09	2.31	1.65	1.71	1.04	11.1
1983	1.72	1.58	1.31	1.35	0.21	0.53	T	0.78	0.84	0.36	3.08	1.47	13.23
1984	0.36	0.22	0.2	0.24	0.06	0.34	0.45	0.02	0.04	0.6	1.68	0.07	4.28
1985	0.24	0.68	1.07	T	T	0.12	T	0.01	0.63	0.46	1.23	0.55	4.99
1986	0.4	4.84	0.88	0.77	0.26	0.31	0.86	0.07	0.28	0.06	0.02	0.19	8.94
1987	0.49	0.78	0.8	0.49	2.29	1.12	0.01	0.01	0.01	0.54	0.37	0.59	7.5
1988	0.5	0.02	T	0.95	0.12	0.59	0.22	0.01	0.04	0.02	1.99	0.84	5.3
1989	0.2	0.8	0.46	0.03	1.33	1.53	0	0.82	1.19	0.43	0.55	T	7.34
1990	0.62	1.98	0.07	0.33	0.19	0.03	0.86	0.21	0.31	0.06	0.15	0.45	5.26
1991	0.01	0.21	1.42	0.47	0.5	0.39	0.04	0.24	0.6	0.23	0.89	0.15	5.15
1992	0.13	0.45	0.69	0.06	0.1	1.12	0.15	0.28	T	0.45	0.06	1.87	5.36
1993	2.42	1.27	0.55	0.01	0.27	0.35	T	T	T	1.42	0.13	0.16	6.58
1994	0.06	0.62	1	0.03	1.39	0	0.09	0	0.15	0.23	1.47	0.16	5.2
1995	3.31	0.2	2.87	0.4	1.81	1.29	0.22	T	T	0	0.19	2.27	12.56
1996	1.33	2.3	1.63	0.16	1.07	0.71	0.2	0.16	0.45	0.28	0.89	3.03	12.21
1997	3.32	0.71	0.01	0.22	0.13	1.17	0.04	T	0.55	0.16	0.86	0.58	7.75
1998	1.1	2.59	2.21	0.6	0.82	1.39	T	T	2.17	0.34	0.77	0.04	12.03
1999	0.76	1.25	0.11	0.55	0.2	0.06	0.1	0.82	0.07	0.42	0.01	0.07	4.42
2000	2.14	0.98	0.38	0.34	0.23	0.23	0	0.79	0.04	0.04	0.4	0.14	5.71
2001	0.31	0.18	0.15	0.66	T	0.09	0.07	T	0.09	0.14	0.83	1.83	4.35
2002	0.59	0.24	0.42	1.21	0.2	0.1	0.12	0.82	T	0.12	1.08	2.18	7.08
2003	0.17	0.23	0.31	0.83	0.04	0.38	0.23	1.01	0.01	0.03	0.12	1.22	4.58
2004	0.96	1.56	1.26	T	0.32	0.2	T	0.28	0.01	1.58	1.53	1.71	9.41
2005	1.78	0.84	0.42	0.61	0.59	0.37	0.59	0.1	T	0.03	0.18	3.88	9.39
2006	1.6	1.04	0.92	1.88	0.31	T	0.34	T	0	0.42	0.25	0.41	7.17
2007	0.13	1.01	0.03	0.18	0.16	0.12	T	0.16	0.44	0.19	0.25	1.06	3.73
2008	2.8	0.78	0.07	T	0.56	T	0.34	T	0.01	0.11	0.92	0.5	6.09
2009	0.51	0.21	1.61	0.35	0.5	1.52	0.01	0.01	T	1.5	0.24	1.79	8.25
2010	0.95	2.18	0.18	0.68	0.3	T	0.34	0.13	0	2.65	0.45	1.39	9.25
2011	0.1	1.45	1.28	0.11	0.4	1.35	T	T	0.03	0.24	0.06	0	5.02
2012	1.54	0.6	0.11	0.07	0.3	T	0.02	0.01	0.08	0.08	0.85	2.11	5.77
2013	0.12	T	0.29	0.23	0.67	0.16	0.49	1.08	0.02	0.06	0.49	0.41	4.02
2014	0.38	0.69	0.08	0.31	0.54	T	0.2	1.08	0.29	0.18	0.31	0.93	4.99
2015	0.06	1.43	0.01	0.35	1.01	0.93	0.51	0.11	0.16	1.1	2.1	0.75	8.52
2016	1.7	0.42	0.97	0.96	1.16	T	0	0.04	T	2.43	0.15	1.21	9.04
2017	5.57	3.42	0.87	0.68	0.61	0.12	0.04	0.16	0.69	0.28	1.18	0.11	13.73
2018	0.67	0.2	2.35	0.54	1.84	0.1	1.29	T	T	0.26	0.92	1.09	9.26
2019	2.92	3.84	1.12	0.24	0.39	T	0.25	T	0.29	T	0.4	1.69	11.14
2020	0.13	0.04	0.79	0.38	0.05	0.09	0.24	0.13	0	0	0.59	0.28	2.72
2021	1.3	0.12	0.06	T	0.13	0.14	0.3	T	0.09	3.14	0.11	3	8.39
2022	0	0.44	0.03	0.25	0.01	T	0	1.72	0.25	0.01	0.4	5.23	8.34
2023	2.44	1.07	1.95	0.18	2.44	0.63	0	0.42	0.21				9.34

APPENDIX C: SELECTED REFERENCES

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ANALYSIS AND EFFECTS OF THE 1948 EARTHQUAKE AT VERDI, NEVADA

BELL, Elaine J., Broadbent, Robert, and Szumigala, Amy, Department of Geology, Mackay School of Mines, University of Nevada, Reno, Nevada 89507

The Verdi earthquake of December 29, 1948, occurred at 12:53:27 Gmt with an estimated Richter magnitude of 6.0 and a maximum Modified Mercalli intensity of VII. Based on newspaper accounts, the earthquake was felt over an area of about 70,000 square miles from Eureka, San Francisco and Fresno, in California, to Winnemucca, Nevada.

Significant transitory and permanent effects of the earthquake were generally restricted to within a 25 mile radius of the epicenter and were probably due entirely to seismic shaking as no surface faulting was detected. In addition to localized ground breakage, the earthquake affected highways, buildings, water facilities, and communication systems. The severity of the damage was related to both epicentral distance and the local geologic environment.

By comparison of the Verdi earthquake arrival times at distant stations with the 1966 Truckee earthquake arrival times at the same stations, the Verdi earthquake epicenter was relocated to 39°33' North latitude and 120°03' West longitude. This epicenter is at the intersection of the northwest trending Last Chance Fault and a northeast trending lineation in Dog Valley which was detected on aerial photographs and side-looking radar.

Definition and Development in Expansive Rock of the Peavine-Wedekind District, Reno, Nevada

Bell EJ, Louisell RH and Vestbie NS. 1986. Definition and Development in Expansive Rock of the Peavine-Wedekind District, Reno, Nevada. Geological Society of America, Abstracts with Programs, volume 18(2), page 84.

DEFINITION OF AND DEVELOPMENT IN EXPANSIVE ROCK OF THE PEAVINE-WEDEKIND DISTRICT, RENO, NEVADA

№ 100948

BELL, Elaine J., Pezonella Associates, Inc., 1030 Matley Lane, Reno, NV 89503; LOUISELL, Richard H., Mackay School of Mines, University of Nevada, Reno, NV 89557; VESTBIE, Nicholas S., Pezonella Associates, Inc., 1030 Matley Lane, Reno, NV 89503

Urban growth in the Reno area has rapidly encroached upon the Peavine-Wedekind District, resulting in the identification of a unique engineering problem. Locally, the problem is referred to as expansive rock.

The District is characterized by minor gold, silver and copper mineralization that was subject to limited mining activity during the late 1800's and early 1900's. At least two episodes of hydrothermal activity have produced alteration and brecciation of the silicic and intermediate volcanic rocks in zones with both lateral and vertical continuity of varying dimensions. The resultant advanced argillic alteration products are significant from an engineering geologic perspective due to their physical properties.

Based on laboratory testing, these expansive rock materials exhibit anomalously high plasticity, with Plastic Indexes ranging from 50 to 75 and Liquid Limits of 75 to 95. Expansion potential measured by oedometer testing of undisturbed samples under nominal loads ranged from approximately 20 to 25 percent for samples initially at field moisture contents of approximately 24 to 26 percent. These values exceed the typical ranges for clay soils in all environments examined in the Reno area.

Case studies indicate two major areas of concern for the engineering geologist: 1) the difficulty of predicting the behavior of the altered volcanic rock material in the field without adequate laboratory testing and 2) achieving a balance between the engineering measures appropriate for these expansive rock materials and the recommendations provided to the client who seeks a cost-effective approach to the development of property within the Peavine-Wedekind District.

FEATURE

Pluvial Lakes of the Great Basin

Elaine J. Hanford

Left: Present-day Tooele City, Utah, looking south toward the Oquirrh Mountains with Interstate 80 and the Great Salt Lake in the foreground. Right: This reconstruction shows Lake Bonneville between 19,000 and 15,000 years ago, at a highstand of 5,090 feet elevation, submerging the Tooele Valley. Source: Used with the permission of the *Tooele Transcript Bulletin*.

ANYONE WHO HAS LIVED IN THE GREAT BASIN OF THE Western United States has vivid memories of the impacts of the Pineapple Express (a.k.a., atmospheric rivers). Torrential rains that spawned mudslides and debris flows or epic snowstorms that enhanced the snowpack by tens of feet and supported skiers well into the summer months are memorable because they bring vast amounts of precipitation to a currently water-stressed region. More recent headlines have bemoaned the impacts of drought on the Great Salt Lake in Utah and the demise of Lake Abert in south-central Oregon.

The vagaries of weather can vary from season to season, year to year, or even decade to decade. But geology and hydrology remind us that we must view such conditions in the longer term, by understanding the history of pluvial lakes in the Great Basin as climate has fluctuated. Scientific understanding of the changes over geologic time can help minimize unintended consequences of human activities and support more sustainable interactions with our environment.

The Echoes of Past Lakes

The Great Basin lies between the Sierra Nevada and Cascade Mountains to the west and the Wasatch Mountains to the east. The pluvial lakes in the Great Basin date to the Pleistocene Epoch, which lasted from roughly 2.5 million years ago until about 11,700 years ago. The Pleistocene was characterized by a series of Ice Ages interrupted by short warming periods known as interglacials, when pluvial lakes periodically occupied portions of the Great Basin. These pluvial lakes—in contrast to, say, the Great Lakes or the ancient Lake Agassiz—were not formed directly by glacial ice. Rather, they were created by excessive rain (*pluvia* is Latin for rain) that collected in closed basins with no drainage outlet under temperature regimes that supported low rates of evaporation. Successive pluvial lake formation during interglacials tended to mask surficial evidence of prior episodes.

The Great Basin is hydrographically closed and encompasses smaller internally drained basins. In other words, what precipitates in the Great Basin stays in the Great Basin. In total, as many as 120 pluvial lakes inundated more than 103,600 square kilometers (sq km), which means more than 20% of the Great Basin was flooded. It has been estimated that more than 80% of nearly 200 drainage basins within the Great Basin contain remnants of extensive pluvial lakes that existed during the late Pleistocene Epoch.

The last Ice Age in North America, called the Wisconsinan, lasted from about 75,000 to about 11,000 years ago. It featured several vast ice sheets, including the Cordilleran Ice Sheet, covering what is today western Canada, and the Laurentide Ice Sheet, stretching across

Figure 1. Generalized extent of the Cordilleran and Laurentide Ice Sheets across North America during the Last Glacial Maximum. Adapted from **Quora**.

today's central and eastern Canada and the Great Lakes region (Figure 1).

The continental ice sheets caused changes in the prevailing global wind patterns, influencing local and regional climates. Across North America, the jet stream crossed what is now the Western United States and continued across the southern tier toward the Atlantic Ocean, bringing precipitation to rates that were likely 1.5 to 2.4 times greater than under modern conditions. Furthermore, about 25,000–23,000 years ago, when the Last Glacial Maximum occurred, roughly 30% of Earth's landmass was covered by snow and ice, whose reflectivity helped cool the planet. These cooler temperatures in turn significantly reduced rates of evapotranspiration.

In the Great Basin, the increase in precipitation and decrease in evapotranspiration resulted in the formation of pluvial lakes that reached their maximum extents—their highstands—between about 18,000 and 14,000 years ago, following the Last Glacial Maximum. Lake Bonneville and Lake Lahontan were the two largest of these pluvial lakes.

As the continental ice sheets waned following the Last Glacial Maximum, the position of the polar jet stream shifted northward, resulting in rising and fluctuating water levels in the pluvial lakes. The lakes across the Great Basin did not achieve highstands all at once. Local and regional factors—including hydrogeologic setting, El Niño-Southern Oscillation, and convergence of moisture-laden air masses—would have also influenced lake levels.

To write the history of the three main pluvial lakes in the Great Basin—Bonneville, Lahontan, and Chewaucan (Figure 2)—geologists can draw on a range of tools. Evidence is derived from outcrops, geomorphology, core samples, pollen, and isotopic studies. Direct evidence of lake levels, changes in lake margins, and geologic events such as catastrophic floods, drainage-basin changes, and isostatic rebound—that is, the rise in landmass after the weight of ice sheets or water is removed—is combined with proxies for changes in lake level, water temperature and chemistry, and ecological conditions.

The resulting history provides a glimpse of the dramatic changes that have taken place across the Great Basin in the past 20,000 years.

What precipitates in the Great Basin stays in the Great Basin.

Lake Bonneville

At its maximum extent, Lake Bonneville occupied multiple basins in central and northwestern Utah,

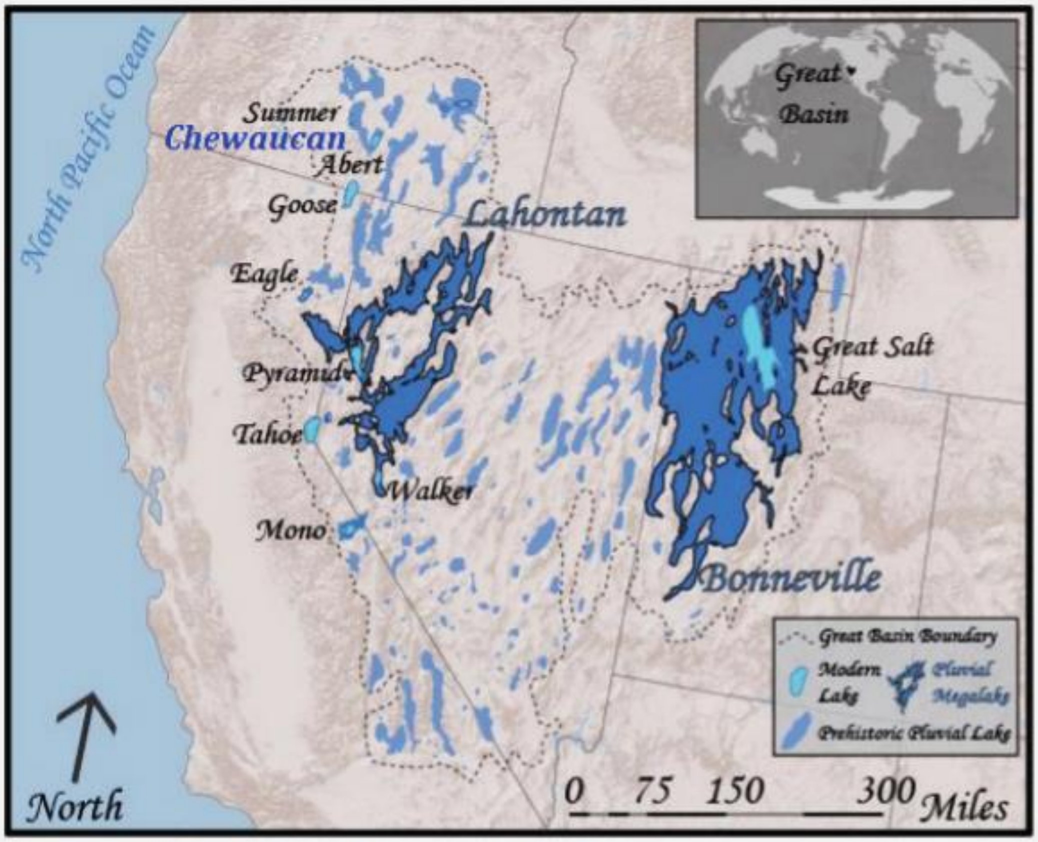

Figure 2. Pluvial lakes of the Great Basin. Adapted from **Lakeshore**.

northeastern Nevada, and southern Idaho, including the Bonneville Basin and the Sevier Basin. It encompassed more than 51,000 sq km and was more than 300 meters deep at its deepest. The lake's initial rise was quite rapid, potentially because the basin was capturing river water. Given its large size, Lake Bonneville may have influenced precipitation within its watershed and become partially self-sustaining.

Three distinct shorelines reflecting the expansion and receding of the lake over time can be traced throughout the basin. The lake did not occupy a completely closed basin; at times, its water overflowed into adjoining basins.

The lake was at its highest level between 19,000 and 15,000 years ago. Catastrophic flooding of an estimated 5,000 cubic kilometers of water into the Snake River Basin occurred prior to 18,000 years ago. About 15,000 years ago overflow ceased, and with continued regression, Lake Bonneville split into Lake Gunnison in the Sevier Basin and the Gilbert-episode lake that encompassed the modern Great Salt Lake. Isostatic adjustment and recovery—the sinking and lifting of the landmass—continue to influence the elevation of Lake Bonneville's shorelines, with maximum elevation of the highest shoreline in the central part of the basin more than 64 meters higher than the south and north ends.

Lake Lahontan

At its largest, Lake Lahontan covered more than 22,000 sq km in western Nevada and northeastern California, with a maximum depth of about 270 meters at present-day Pyramid Lake. The lake reached a brief highstand about 15,700 years ago and had a consistent shoreline at 1,256 meters elevation. By about 13,250 years ago, the lake had fallen to 1,206 meters, and as the lake shrank its waters were limited primarily to the Pyramid and Winnemucca Subbasins. Modern remnants include Walker Lake, Pyramid Lake, and the Carson and Humboldt Sinks. Winnemucca Lake has been dry since the 1930s, and Honey Lake periodically dries out. The decline of Pyramid Lake was exacerbated by diversions of irrigation water from the Truckee River starting in the early 1900s. A similar fate has afflicted Walker Lake because of irrigation diversions from the Walker River.

It has been estimated that more than 80% of nearly 200 drainage basins within the Great Basin contain remnants of extensive pluvial lakes that existed during the late Pleistocene Epoch.

Lake Chewaucan

Lake Chewaucan occupied four subbasins in southern Oregon: Summer Lake, Upper Chewaucan Marsh, Lower Chewaucan Marsh, and Lake Abert. At its maximum, the lake covered roughly 1,240 sq km with a maximum depth of 115 meters. Sometimes the subbasin lakes were connected, depending on the level of the lake. After an episode of desiccation around 17,000 years ago, the lake's highstand occurred between 14,000 and 13,000 years ago at an elevation of 1,356 meters. Then the lake began to shrink. Lake Abert and Summer Lake are modern remnants that dry up during mid- to late summer each year. Lake Abert has become a true saline lake whose desiccation is related to a number of factors, including overuse and restriction of inflow by human activities.

Beginning of the End or a Short Intermission?

The warming trend and northward migration of the jet stream began in the late Pleistocene about 21,000 years ago, followed by an abrupt change about 18,000 years ago to warmer conditions that generally persisted until a return to cold conditions during the Younger Dryas from 12,800 to 11,700 years ago. Since then, warmer conditions have persisted throughout most of the Holocene Epoch, with increased temperatures and decreased precipitation causing pluvial lakes to become playa lakes that appear seasonally. Human activities in the 20th century have exacerbated this transition. Will pluvial lakes once again return to the Great Basin with the onset of the next Ice Age? ■

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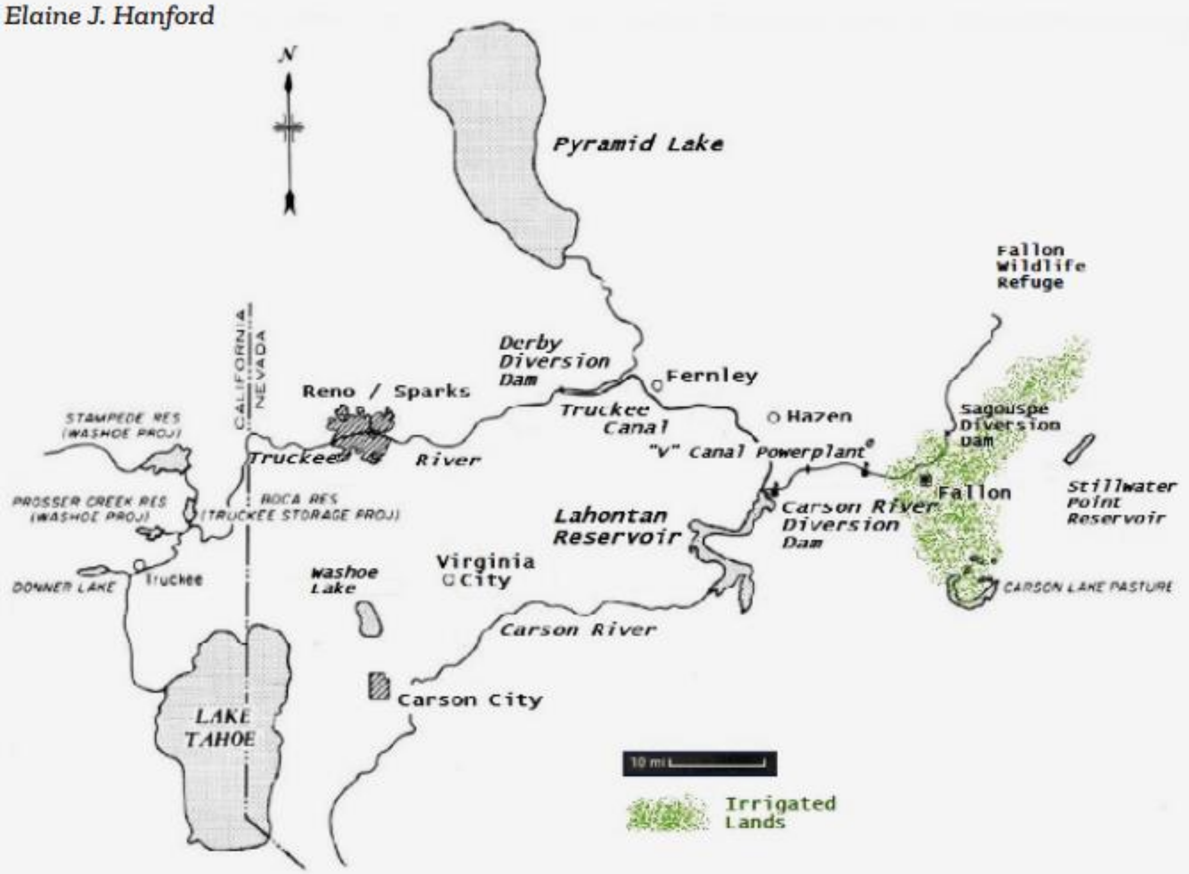
The Newlands Project

Elaine J. Hanford



The Newlands Project, one of the earliest projects of what became the Bureau of Reclamation, is a sprawling complex of dams and canals designed to use the waters of Lake Tahoe to irrigate farmland in west-central Nevada. Source: Author, based on Google satellite imagery.

You could not remove a single grain of sand from its place without thereby . . . changing something throughout all parts of the immeasurable whole.

— Johann Gottleib Fichte, *The Vocation of Man (1800)*

ON JUNE 17, 1902, THE U.S. CONGRESS PASSED THE Reclamation Act. This moment marked the start of a new era in the American West, when millions of acres of arid land would be "reclaimed" for use by farmers, ranchers, and cities and towns. One of the first federally legislated outcomes was the Newlands Project, a complex of dams and canals in west-central Nevada that has helped provide livelihoods for generations of farmers and ranchers. Not only did this project mark the launch of the organized retention, diversion, and delivery of water resources in the West, but it also reflected the shifting of power and control over water resources in the region from local authorities to the federal government.

As Johann Fichte noted in so many words, one thing leads to another. How did the Newlands Project come into existence? Let us delve into a bit of history, starting arbitrarily with the miners who ventured west along with many others under the banner of Manifest Destiny. The arrival of settlers and gold miners led over time to agriculture, ranching, and eventually the Newlands Project.

Settlers Pour West

The discovery of gold nuggets at Sutter's Mill, California, in early 1848 enticed many early settlers to pass through Nevada on their way to seeking their fortune in the Golden State. Though the Gold Rush peaked by 1852, California continued to draw settlers. In June 1859, the first major discovery of silver ore in the United States occurred near Virginia City, Nevada, and drew fortune seekers and miners from California and the East to the Comstock Lode—as well as providing the impetus for the creation of the Nevada Territory in 1861 and statehood in 1864.

Mining practices and the clearing of forests for timber for use in the mines initiated a long period of declining water quality. In heavily logged areas, increased runoff over bare earth caused soil erosion and a high sediment load in local streams. Consequently, both the Truckee and Carson Rivers fluctuated between droughts and floods.

Beginning in the 1860s, many settlers turned to agriculture, for which they needed a stable water supply. A haphazard system of diversion canals was dug to control flooding and direct river waters. But potential was limited by the few settlers and cattlemen who controlled much of the land around surface water sources.

Irrigation Potential? Yes. Action? No.

In 1888, John Wesley Powell, director of the U.S. Geological Survey, submitted a plan for an irrigation survey to assess the water resources of the Far West. The 1888–1890 Powell Irrigation Survey encompassed three parts: topographic determination of drainage areas to locate lands most suitable for irrigated agriculture and reservoirs; hydrographic determination of available water supplies, principally through stream gauging; and engineering to plan irrigation and design dams, canals, and other necessary structures. The survey found that the Truckee River, which drained from Lake Tahoe, could be diverted though a canal to the Lahontan Valley.

The Powell Irrigation Survey was significant in transferring reclamation of arid lands from the local level to the federal government, initiating political squabbling between East and West that dominated the issue until the early 1900s. In the arid West, lack of precipitation required settlers to divert water from streams, but demand outstripped supply. Settlers wanted to increase supply by storing "wasted" runoff from rains and snowmelt. Private and state-sponsored ventures mostly failed because of lack of funding and engineering skill.

Nevada senator Francis Griffith Newlands was the principal sponsor of reclamation legislation in Congress. Source: Library of Congress.

Since Congress had already invested in roads, river navigation, harbors, canals, and railroads in other parts of the country, Westerners demanded that the federal government invest in irrigation projects. Despite the findings of the Powell survey, no viable action was immediately taken.

Enter Francis Griffith Newlands

Francis Griffith Newlands, a trustee of extensive landholdings in Nevada, moved to Carson City in 1888 and began acquiring his own land along the Truckee River. As he expanded his holdings, he commissioned surveying and engineering parties to examine reservoir and canal sites. Newlands used reclamation as an issue in his successful bid for political office, serving as a U.S. representative from 1893 to 1903 and as a senator from 1903 to 1917.

Though his proposed reclamation legislation was turned down by the Nevada Legislature and later brushed aside by President William McKinley, President Theodore Roosevelt embraced the project. Roosevelt

Derby Dam was posted to the National Register of Historic Places on April 26, 1978. Source: US Bureau of Reclamation.

authorized, with an additional 20 projects authorized over the next five years.

Turning on the Tap: The Newlands Project Gets Underway

One of the first projects authorized under the Reclamation Act began with a construction contract issued in 1903 for Derby Dam and the Truckee Canal. Originally known as the Truckee-Carson Project, this undertaking was renamed the Newlands Project in 1919.

On October 2, 1903, construction began on the Derby Diversion Dam. The dam was designed to divert Truckee River water that would otherwise flow to Pyramid Lake (and to Winnemucca Lake, which dried up by the 1930s) toward the Lahontan area in a canal to provide water to Fernley and Hazen. Work crews finished Derby Dam in less than two years, with construction completed on May 20, 1905. Derby Dam is 31 feet high with a crest length of 1,331 feet. The total cost to build Derby Dam was $85,390. It has nine canal gates and 18 river gates, with flanking spillway sections.

believed that land should be usable and settled by farming families and that water in western rivers, if not being used to help people, was wasted.

The Newlands Reclamation Act authorized the federal government to commission water diversion, retention, and transmission projects in arid lands in 16 arid and semi-arid states. Within a year, five projects were

Because seepage from the 31-mile-long Truckee Canal provides recharge to nearby domestic wells, plans to line the canal with concrete have generated lawsuits. Source: U.S. Geological Survey, Nevada Water Science Center.

Carson River Diversion Dam was posted to the National Register of Historic Places on March 25, 1981. Source: William Hoffknecht.

Northside Main Canal ("T" Line) and the Southside Main Canal ("V" Line) supply about 75% of agricultural water in the Fallon area. Water-thirsty alfalfa was the principal crop. Farmers also grew wheat, barley, potatoes, sugar beets, and garden truck, including the famous Fallon Hearts O' Gold cantaloupes. Fallon agriculture still centers primarily on livestock and alfalfa hay.

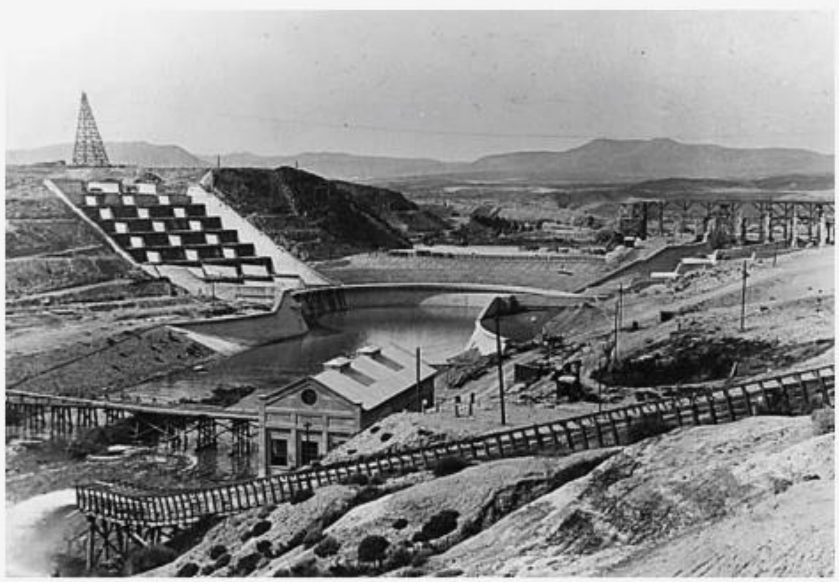
Lahontan Dam and Reservoir were not part of the initial authorization, but construction was initiated in 1911 and completed in 1915. Lahontan Dam is an earth and gravel fill dam that is 162 feet high and 1,700 feet long, the largest earth-filled dam of its time. Storage capacity to the spillway of Lahontan Reservoir is 290,000 acre-feet, and total capacity is 319,400 acre-feet. The reservoir stores natural flows of the Carson River and waters diverted from the Truckee River and is named after pluvial Lake Lahontan. The site also includes hydroelectric generators with total capacity of 4,000 kilowatts.

The reservoir, irrigated farmlands, and associated wetlands are an important waterfowl breeding and migratory site along the Pacific Flyway. In addition, with 69 miles of shoreline, the reservoir and its surrounding area support numerous recreational opportunities.

The Truckee Canal was constructed in two additional phases. Four tunnels were built over a seven-mile span between the dam and Fernley. The shortest tunnel extended 50 yards, while the longest tunnel stretched along the mountainside for 1,515 feet. The final phase consisted of an 18-mile canal from the Fernley area to a chute near Lahontan. Now the Truckee Canal runs for 31 miles and has a carrying capacity of 1,200–1,500 cubic feet per second.

Historically, fish ladders, constructed between 1905 and 1941 to bypass the dam, were ineffective and periodically damaged by flooding. Currently, a $34-million fish screen is being installed at Derby Dam, the final phase of a fish passage project to restore habitat connectivity for native Lahontan cutthroat trout along the Truckee River between Pyramid Lake and Lake Tahoe.

The next element of the Newlands Project was Carson River Diversion Dam, a replica of Derby Dam, built across the Carson River in 1904–1905. Constructed on a natural bed about 13 miles west of Fallon, the dam is a concrete structure 23 feet high and 241 feet long. Two main project canals, the



Lahontan Dam was posted to the National Register of Historic Places on March 25, 1982. Source: The Clio, https://theclio.com/entry/76267.

Looking to the Future

Today the Newlands Project covers lands in Churchill, Lyon, Storey, and Washoe Counties and provides water for irrigated land in the Lahontan Valley near Fallon and bench lands near Fernley. Overall, the project has 68.5 miles of main canals with a combined diversion capacity of 2,000 cubic feet per second. In addition to the primary canals, the project includes more than 300 miles of laterals and almost 350 miles of drains to prevent alkali damage to land and crops from rising groundwater levels. In an average year, the project delivers about 215,000 acre-feet of water, primarily for agricultural use, to about 2,500 users. Its dams, canals, laterals, and drains allow for irrigation of about 57,000 acres of farmland, wetlands, and pasture.

Not surprisingly, disputes continue over who owns the rights to Truckee and Carson River waters. For the past 115 years, seepage from the Truckee Canal has provided recharge to domestic wells in Fernley, Nevada. Current U.S. Bureau of Reclamation plans to line the canal with concrete have spurred lawsuits that claim the bureau is failing to consider the expected harm to the Fernley municipal water supply and hundreds of private well users with binding water allotments dating to World War II. Charges fly back and forth and commonly make headlines: "Feds Want to Fix Canal, but Nevada Town Lives off the Leaks." A mega-drought now threatens water resources in Nevada and across the Southwest, ensuring many new chapters in the history of the Newlands Project.

As grains of sand shift in the grand scheme of human intervention, the political and physical landscape upon which we live and make our living will continue to evolve to meet our incessant and ever-changing demands on this dynamic planet. Fichte was right. ■

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