
*Geohydrologic Evaluation of the
Maximum Perennial Yield of the
Lake Williams Area, Baldwin Lake Watershed*



Prepared for: City of Big Bear Lake Department of Water and Power

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**GEOHYDROLOGIC EVALUATION
OF THE MAXIMUM PERENNIAL YIELD OF THE
LAKE WILLIAMS AREA, BALDWIN LAKE WATERSHED**

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1.0 EXECUTIVE SUMMARY

The Lake Williams area is located within the Erwin Hydrologic Subunit of the Baldwin Lake Watershed in the San Bernardino Mountains of western San Bernardino County, California. The City of Big Bear Lake Department of Water and Power (BBDWP) produces ground water from three municipal supply wells within the Lake Williams area: the Monte Vista Well, Onyx Well, and Skyview Well. A recent period of dry climatic conditions (starting in 1999) has necessitated a reduction in the pumping rate of the Monte Vista well to maintain pumping ground water levels above the pump intake, which is near the bottom of the well. Reliance on the other two wells (Onyx and Skyview) has been limited due to high concentrations of fluoride. Given these conditions, additional wells are necessary in the Lake Williams area to meet future municipal water demand.

In order to evaluate the feasibility of additional ground water production wells in the Lake Williams area from a water supply standpoint, GEOSCIENCE conducted a focused evaluation of the maximum perennial yield and ground water storage capacity of the drainage catchment surrounding Lake Williams, which is a tributary of the larger Erwin Hydrologic Subunit. The smaller drainage catchment is referred to as the Lake Williams Tributary Subarea.

Maximum perennial yield was evaluated in the context of the total average annual ground water recharge within the Lake Williams Tributary Subarea. Ground water recharge is the total amount of water that reaches the aquifer (i.e. ground water reservoir) through natural processes,

such as deep percolation of precipitation falling on the land surface and infiltration beneath flowing stream channels. In the development of ground water resources for municipal supply, however, not all of the natural recharge that any given aquifer receives on an average annual basis can be developed.

Maximum perennial yield is defined as:

The maximum quantity of ground water perennially available if all possible methods and sources are developed for recharging the basin. This quantity depends on the amount of water economically, legally, and politically available to the organization or agency managing the basin (Todd, 1980).

By definition, the maximum perennial yield is some portion (i.e. subset) of the total amount of ground water recharge that the aquifers receive from precipitation on an average annual basis. Not all of the water that reaches the ground water aquifer can be developed for beneficial use because either it is not economically feasible, or there is no legal right to the water, or political constraints prevent or inhibit development. In the case of the Lake Williams area, a portion of the ground water contains concentrations of naturally occurring fluoride that exceed regulatory levels for municipal supply. The volume of ground water that exceeds regulatory levels for fluoride cannot be included in the maximum perennial yield estimate.

Average annual ground water recharge was estimated for the Lake Williams Tributary Subarea using a watershed hydrologic model. The ground water recharge was also evaluated in the context of ground water level trends and ground water production data from the BBDWP wells in the Lake Williams area. When possible, measured data was used as input for the analysis of ground water recharge. Measured data included:

- Long-term precipitation records from a weather station within the Baldwin Lake watershed,

- Evapotranspiration data from an evaporation pan within the watershed,
- Ground water levels, and
- Ground water production.

Most of the input parameters that are required for a detailed evaluation of the average annual ground water recharge had to be estimated or assumed from data collected outside the Baldwin Lake Watershed due to lack of measured data in the area. Although the assumed values are published and are from reliable sources (i.e. the U.S. Environmental Protection Agency, United States Geological Survey, etc.), they are not specific to the area of interest. Numerous additional monitoring features can be developed to collect the data necessary to refine the ground water recharge estimates. However, priority should be given to the construction of monitoring wells and the development of a reliable ground water level baseline for the area.

Based on the analyses presented in this report, the following have been concluded regarding the maximum perennial yield of the Lake Williams Tributary Subarea:

- The Lake Williams Tributary Subarea is delineated based on surface water drainage divides.
- Ground water storage in the Lake Williams Ground Water Basin (i.e. the alluvial portions of the subarea) is approximately 3,600 acre-ft. However, only approximately 50 percent of this storage is available for development due to well/pump operation constraints and water quality concerns (higher fluoride concentrations at depth within the ground water basin).
- The range of average annual ground water recharge for the Lake Williams Tributary Subarea, based on the watershed model, is approximately 45 to 67 acre-ft/yr with a midpoint of approximately 56 acre-ft/yr. The midpoint of the range is approximately

3.5 percent of precipitation for the subunit, which is within the range of accepted recharge estimates for other ground water basins in southern California (3 to 7 percent).

- The low end of the long-term average annual ground water recharge estimate (45 acre-ft/yr) is considered a realistic estimate of maximum perennial yield for the Lake Williams Tributary Subarea, given the available data. A portion of the ground water within the subarea contains high concentrations of fluoride, which cannot be used for municipal supply and it is not economical to develop the ground water in the bedrock areas surrounding the subarea. Furthermore, significant short-term ground water level impacts have occurred during drought periods at production rates near 45 acre-ft/yr.
- Recent ground water production within the Lake Williams Tributary Subarea includes approximately 28 acre-ft/yr from BBDWP, 3 acre-ft/yr from private wells, and 15 acre-ft/yr at YMCA Camp Oakes for a total of approximately 46 acre-ft/yr.
- The limited ground water storage capacity of the subarea could result in a significant impact on ground water levels during periods when ground water production is maintained near the long-term average annual recharge but precipitation is below the long-term average (i.e. drought conditions).
- Current average annual production slightly exceeds the maximum perennial yield of 45 acre-ft/yr.
- Approximately 20 acre-ft/yr of return flow recharge from applied irrigation and septic system effluent is estimated for the Lake Williams area and is included within the 45 acre-ft/yr perennial yield estimate. Without this return flow, ground water level impacts would likely be greater than currently observed and the maximum perennial yield would have to be reduced.

It is recommended that future ground water development planning be based on the maximum perennial yield estimate of 45 acre-ft/yr. However, as ground water production continues in the subarea, it will be very important to monitor ground water levels in dedicated non-pumping monitoring wells located in areas from which ground water is extracted. Ground water production and development should be managed based on ground water levels in key monitoring wells and established ground water level thresholds rather than the perennial yield estimates.

Recent average annual ground water production from the Lake Williams Tributary Subarea slightly exceeds the maximum perennial yield estimate. However, almost all of the BBDWP ground water production is from one well. Given this, and assuming a new source of supply is not brought into the subarea from elsewhere, it is recommended to construct additional production wells within the subarea but outside the existing service area to distribute ground water level impacts across the ground water basin. Additional wells that are strategically located throughout the ground water basin would enable a more even distribution of ground water level impacts from pumping, enable the BBDWP to more fully utilize the maximum perennial yield, and maximize the available ground water in storage during extended periods of below-normal precipitation. At least two additional wells are recommended.

2.0 INTRODUCTION

2.1 Background

The Baldwin Lake Watershed, located in the San Bernardino Mountains of western San Bernardino County, California (see Figure 1), has previously been divided into four hydrologic subunits based on surface water drainage divides (Glenn A. Brown & Associates, 1974; GEOSCIENCE, 2001). These hydrologic subunits are: West Baldwin, East Baldwin, Van Dusen and Erwin. The Lake Williams area is located within the southeastern portion of the Erwin Hydrologic Subunit (see Figure 2).

The City of Big Bear Lake Department of Water and Power (BBDWP) produces ground water from three municipal supply wells within the Lake Williams area: the Monte Vista Well, Onyx Well, and Skyview Well. Since 1996, combined ground water production from these wells has averaged approximately 28 acre-ft/yr. Ground water production in 2003 was approximately 27.5 acre-ft. While this amount of production did not significantly impact ground water levels during years of above-average precipitation, the recent period of dry climatic conditions (starting in 1999) required a reduction in the pumping rate of the Monte Vista well to maintain pumping ground water levels above the pump intake, which is near the bottom of the well. Furthermore, reliance on the other two wells (Onyx and Skyview) has been limited due to high concentrations of fluoride. Given these conditions, additional wells are necessary in the Lake Williams area to meet future municipal water demand.

In order to evaluate the feasibility of additional ground water production wells in the Lake Williams area from a water supply standpoint, GEOSCIENCE conducted a focused evaluation of the maximum perennial yield and ground water storage capacity of the drainage catchment surrounding Lake Williams, which is a tributary of the larger Erwin Hydrologic Subunit. The smaller drainage catchment is referred to as the Lake Williams Tributary Subarea.

2.2 Purpose and Scope

The purpose of this report is to summarize the methodology, analysis, and findings of a focused evaluation of the maximum perennial yield and volume of ground water in storage in the Lake Williams Tributary Subarea of the Erwin Hydrologic Subunit. The scope of this evaluation included:

- Updating the existing geohydrologic database for the hydrologic subunit,
- Delineating the Lake Williams Tributary Subarea,
- Evaluating the maximum perennial yield of the subarea,
- Evaluating aquifer storage capacity, and
- Preparing this report of findings from the analysis.

The geohydrologic database was updated with well production and ground water level data from the BBDWP and precipitation data from the Big Bear City Community Services District (BBCSD). In addition, the following reports were consulted for the analysis and in the preparation of this report:

- Re-evaluation of the Maximum Perennial Yield Big Bear Lake Watershed and a Portion of Baldwin Lake, GEOSCIENCE (2001).
- Estimating Hydrology and Hydraulic Parameters for HSPF, United States Environmental Protection Agency (EPA) 2000.
- An Interactive Database of HSPF Model Parameters, Version 1.0, EPA, Donigan et al. (1999).
- Geohydrology of Big Bear Lake and Baldwin Lake Drainage Areas, Glenn A. Brown & Associates (1974).
- Specific Yield – Compilation of Specific Yields for Various Materials (Table 29); USGS Water Supply Paper 1662-D, Johnson (1967).

3.0 METHODOLOGY

3.1 Maximum Perennial Yield Analysis

Maximum perennial yield was evaluated in the context of the total average annual ground water recharge within the Lake Williams Tributary Subarea. Ground water recharge is the total amount of water that reaches the aquifer (i.e. ground water reservoir) through natural processes, such as deep percolation of precipitation falling on the land surface and infiltration beneath flowing stream channels. In the development of ground water resources for municipal supply, however, not all of the natural recharge that any given aquifer receives on an average annual basis can be developed.

Maximum perennial yield is defined as:

The maximum quantity of ground water perennially available if all possible methods and sources are developed for recharging the basin. This quantity depends on the amount of water economically, legally, and politically available to the organization or agency managing the basin (Todd, 1980).

By definition, the maximum perennial yield is some portion (i.e. subset) of the total amount of ground water recharge that the aquifers receive from precipitation on an average annual basis. Not all of the water that reaches the ground water aquifer can be developed for beneficial use because either it is not economically feasible, or there is no legal right to the water, or political constraints prevent or inhibit development. In the case of the Lake Williams area, a portion of the ground water contains concentrations of naturally occurring fluoride that exceed regulatory levels for municipal supply. The volume of ground water that exceeds regulatory levels for fluoride cannot be included in the maximum perennial yield estimate.

Estimating the average annual ground water recharge involves relating geohydrologic and ground water basin operational factors in a quantitative form. It requires a detailed understanding of the basin's inflow terms (including all precipitation, infiltration, and other recharge), and outflow terms (including ground water extraction, evapotranspiration, and losses to the surface and/or adjacent ground water reservoirs). When possible, inflow and outflow terms are obtained from measured data, such as:

- Long-term precipitation records from weather stations within the Baldwin Lake watershed,
- Evapotranspiration data from evaporation pans and weather stations within the watershed,
- Ground water levels, and
- Ground water production.

Aside from the measured data, many of the factors that affect the inflow and outflow terms that are required for a detailed evaluation of the ground water recharge have to be estimated or assumed from data collected outside the Erwin Subunit or outside the Baldwin Lake Watershed. Although the values are published and are from reliable sources (i.e. the U.S. Environmental Protection Agency, United States Geological Survey, etc.), they are not specific to the area of interest.

The primary method for evaluating average annual recharge in the Lake Williams Tributary Subarea was through the use of a watershed model. Ground water levels and production data from the Monte Vista, Onyx and Skyview Wells were also evaluated to assess changes in ground water levels in response to long-term pumping trends. The methods employed for the analysis are described in more detail in the following subsections.

3.1.1 Delineation of the Lake Williams Tributary Subarea and Ground Water Basin

Prior to conducting the maximum perennial yield analysis, the boundaries of the Lake Williams Tributary Subarea were identified within the Erwin Hydrologic Subunit (see Figure 3). A tributary subarea is a smaller surface water drainage within the larger hydrologic subunit. Thus, the boundaries of the subarea represent surface water drainage divides. It is assumed that the surface water drainage divides also represent ground water flow divides, particularly in areas where bedrock is exposed at the ground surface.

The Lake Williams Tributary Subarea was determined through hydrological analysis of a digital elevation model using a Geographic Information System (GIS). The Lake Williams Tributary Subarea is approximately 1,226 acres.

The Lake Williams Ground Water Basin is defined as the ground water reservoir that is located within the unconsolidated alluvial portions of the Lake Williams Tributary Subarea. The lateral boundaries of the ground water basin were determined to be the alluvium/bedrock boundary as defined by Sadler, 1982 (see Figure 3). The bottom of the ground water basin was estimated based on the logs of boreholes within the area that were deep enough to penetrate bedrock, as described in Section 3.2.

3.1.2 Watershed Model

The watershed model is a computer tool that assists in solving the water balance, or hydrologic budget, for the tributary subarea. The water balance takes into account all of the quantifiable hydrologic variables that affect the water resources of the catchment. These variables include daily precipitation, surface water infiltration, surface water runoff, evapotranspiration, and deep percolation (see Figure 4). The deep percolation term given by the watershed model is considered an estimate of the average annual ground water recharge.

The model code used for the Lake Williams Tributary Subarea model was the Hydrological Simulation Program – Fortran (HSPF; EPA, 1997). This program uses measured precipitation and potential evapotranspiration¹ (PET) to estimate surface water runoff, actual evapotranspiration² (ET), and ground water recharge within the watershed. Input data were formatted for the model using the code Generation and Analysis of Model Simulation Scenarios (GenScn). Input parameters for the model were selected according to the most recent EPA guidelines for estimating hydrology and hydraulic parameters specific to HSPF (EPA, 2000).

3.1.2.1 Conceptual Watershed Model

As any given volume of precipitation falls within a watershed or, in this case, tributary subarea, it is ultimately subject to multiple fates as shown on Figure 4. Interaction of precipitation with the ground surface will generally determine the volume of streamflow within the subarea. Among the processes that actively govern streamflow at the ground surface are initial abstraction, infiltration, and overland flow. Ground water recharge occurs if the amount of infiltration exceeds the capacity of the soil to hold the water.

3.1.2.1.1 Initial Abstraction

A portion of the precipitation falling on the watershed tributary subarea is intercepted by vegetation and other above-ground objects, such as buildings, and is defined as interception. Part of the intercepted precipitation wets and adheres to these objects before returning to the atmosphere through evaporation. This mechanism is called “interception loss”.

¹ The amount of water that would be lost to the atmosphere through evaporation and uptake by plants (transpiration) under a given climatic condition if there were unlimited soil moisture.

² The amount of water that would be lost to the atmosphere through evaporation and uptake by plants (transpiration) under a given climatic and soil moisture condition.

The water that does reach the ground during precipitation events can follow several pathways that do not necessarily result in ground water recharge. Almost immediately, some of the water is evaporated from the soil surface. Some precipitation is temporarily stored in topographic depressions (i.e. “depression or surface detention storage”) where it can slowly infiltrate into the subsurface or evaporate. Some precipitation infiltrates into the shallow subsurface where it is either evaporated back out of the soil zone or is utilized by plants. The effects of vegetation interception, transpiration, evaporation, and depression storage are combined to determine a volume of water that is referred to as “initial abstraction” or “initial loss.”

In summary, of the precipitation that reaches the ground surface within any given watershed, a substantial portion is prevented from percolating to the ground water due to:

- Interception by impermeable surfaces (rocks, concrete, etc.) and evaporated,
- Evaporation directly off of the ground surface,
- Evaporation out of the shallow soil zone, and
- Interception and utilization by plants.

3.1.2.1.2 Infiltration and Interflow

A portion of the precipitation that reaches the ground surface infiltrates into the shallow subsurface. This infiltration is a function of many variables, including (but not limited to) soil permeability, vegetation type and cover, surface slope, precipitation intensity and duration, and the ambient moisture content of the soil. If the supply rate of precipitation is greater than the capacity of the soil to accommodate it, infiltration will occur into the shallow subsurface.

Movement of infiltrating water in the shallow subsurface is known as interflow. Infiltration rate is highly dependent on soil permeability and, if low permeability layers exist above the water table, infiltrating water can temporarily pond in these areas (a condition known as interflow detention storage). Depending on the permeability of the soil and the amount of infiltrating

water, some of the water will evaporate back out of the soil and some will percolate to the ground water as recharge.

3.1.2.1.3 Overland Flow

If the volume of precipitation that reaches the ground surface exceeds the initial abstraction, overland flow occurs and collects to form small rivulets, which eventually lead to streams (known as routing). Because infiltration occurs at the same time as overland flow, the relationship between the two processes must be considered. For example, spatial variations in the infiltration characteristics of the ground cover will allow overland flow in some areas and not others.

3.1.2.1.4 Ground Water Recharge

If the volume of water in the shallow soil zone exceeds the field capacity (the amount of water that can be held by the soil particles without draining away) and the amount that is evaporated or consumed by plants (ET), it will percolate to the ground water surface as recharge. Depending on the depth to ground water, some of this water may still be subject to ET.

3.1.2.2 Model Input

After delineating the Lake Williams Tributary Subarea, hydrologic parameters (i.e. topographic characteristics, precipitation, and ET) unique to the subarea were then assigned to the watershed model and simulated.

3.1.2.2.1 Precipitation

The only inflow term into the watershed model is precipitation because all of the Baldwin Lake Watershed's available water resources are from precipitation. The amount of precipitation that falls on the Baldwin Lake Watershed, on an average annual basis, is greatest in the highest elevations at the southern end of the catchment, decreasing to the north (see Figure 5).

A summary of annual precipitation data from the BBCSD Weather Station, which is located in the western portion of the Baldwin Lake Watershed (see Figure 5), is provided in Table 1. Average annual precipitation at the BBCSD weather station, was 13.67 inches between 1950 and 2002 (see Figure 6). Cumulative departure from mean precipitation for the BBCSD Weather Station shows that the periods from approximately 1955 to 1975, 1988 to 1990, and 1999 to present were relatively dry. The periods of 1979 to 1984 and 1991 to 1998 have been relatively wet periods.

From the isohyetal map, a long-term weighted mean precipitation was assigned to the Lake Williams Tributary Subarea (see Figure 5). This long-term weighted mean precipitation was the basis for input into the watershed model. However, because the watershed model requires daily precipitation, daily precipitation input values had to be calculated for the Lake Williams Tributary Subarea. Daily precipitation input was calculated as the daily precipitation from the BBCSD Weather Station multiplied by an adjustment factor to account for the difference in average annual precipitation between the BBCSD Weather Station and the Lake Williams area (see Figure 6). The adjustment factor is the long-term weighted mean annual precipitation of the Lake Williams Tributary Subarea divided by the measured mean annual precipitation of the BBCSD Weather Station.

The long-term weighted mean precipitation for Lake Williams Tributary Subarea is 14.6 inches per year. The long-term average precipitation for the BBCSD District Weather Station is 13.9 inches per year. The adjustment factor for daily precipitation input to the watershed model is 14.6 divided by 13.9 or 1.05. Thus, the daily precipitation values assigned to

the Lake Williams Tributary Subarea are the daily precipitation values from the BBCSD Weather Station each multiplied by 1.05.

3.1.2.2.2 Potential Evapotranspiration

Daily potential evapotranspiration (PET) for the Lake Williams Tributary Subarea area was estimated based on monthly evaporation records from the BBCSD evaporation pan (see Figure 5 for evaporation pan location). Average annual evaporation, as measured from the BBCSD pan, is 42.4 inches (see Table 2). Average monthly evaporation ranges from 0.16 inches in February to 8.4 inches in July.

3.1.2.2.3 Other Input Parameters

In addition to measured and calculated input parameters, HSPF requires additional parameters that must be assumed for areas where measured hydrologic data are not available. For the Big Bear area, 18 of the 20 required input parameters were estimated from ranges of values published in United States Environmental Protection Agency (EPA) guidelines because measured data for those parameters were not available (EPA, 2000). The EPA guidelines are based on a database of measured data for each parameter collected from sites across the continental United States. Thus, the published values are not specific to any particular area.

Published parameter values from the EPA guidelines include a typical maximum and minimum range and a possible maximum and minimum range (see Table 3). Statistically, it is more likely that any given parameter for a specific area of the United States would fall into the “typical” range of values. However, the “possible” range is included to consider areas where non-normal conditions could exist. For the Lake Williams watershed model, the average of the “typical” and “possible” ranges of input parameters provided the range of input values used in the model.

3.1.2.3 Model Output

3.1.2.3.1 Surface Runoff

The precipitation that reaches the ground surface (after interception) is separated into infiltration, interflow storage, surface detention storage, or runoff. The amount of water allotted to infiltration and interflow storage is a function of the infiltration characteristics of the soils within the model subarea and the slope of the land surface.

When precipitation amounts exceeded soil infiltration capacity, the balance of available water was separated into surface runoff, which was estimated using the Chezy-Manning equation (Crawford and Linsley, 1966) and an empirical expression that relates runoff depth to depression storage. The rate of surface runoff is determined by the following equation:

$$R = (t)(r)(D_s)(1+0.6(D_s/D_{se})^3)^{1.67}$$

where:

R = Surface Runoff, [inches/t]

t = Time Interval, [hr/interval]

r = Routing Variable, [unitless]

D_s = Mean Surface Detention Storage Over the Time Interval, [inches]

D_{se} = Equilibrium Surface Detention Storage (inches) for Current Supply Rate

The routing variable is given by the following equation:

$$r = 1,020\sqrt{S_{LS}/(n)(l)}$$

where:

S_{LS} = Slope of the Runoff Surface, [ft/ft]

n = Manning Friction Coefficient, [unitless]

l = Length of the Runoff Surface, [ft]

3.1.2.3.2 Evapotranspiration

Actual ET calculated by the watershed model is represented as a function of the potential ET (PET) described in Section 2.3.2.3 and the sum of ET from surface water, interception storage, the upper soil zone, shallow ground water, and the lower soil zone (i.e. vadose zone). Total PET demand is met from these sources, starting with surface water and proceeding through the other sources in the order listed. For example, the surface water in the model (not including interception storage) will be used up until the PET demand is met. Remaining PET will then be satisfied from interception storage. If interception storage does not meet the PET demand, then water from the upper soil zone will be utilized, etc. The actual ET calculated by the model is the sum of the ET sources used to fulfill the PET demand.

3.1.2.3.3 Ground Water Recharge

The watershed model calculates ground water recharge (deep subsurface percolation) by subtracting runoff and actual ET from the total precipitation applied to the model area.

3.1.3 Analysis of Ground Water Levels and Production History

The potential ground water yield of any particular ground water basin can be assessed by evaluating ground water elevation trends and ground water production for a selected period of time. Ideally, the selected time period should extend over multiple dry and wet precipitation

cycles to include climatic variations encountered in the area of interest. If the mean ground water elevations at the beginning of the selected time period match those at the end, the average production during the same time period is considered within the maximum perennial yield of the ground water basin because ground water levels can be maintained within that pumping regime.

For the Lake Williams Tributary Subarea, a general analysis of ground water levels and pumping history was conducted. The relatively short period of record for the ground water level data and the limited amount of data within the period of record precluded a detailed evaluation of perennial yield. However, the available data suggest that ground water levels have fluctuated in the historical past (prior to extensive ground water production) in response to available precipitation. Furthermore, recent (i.e. 1998 to the present) increases in ground water production in the area have greatly accentuated ground water level declines that would have otherwise occurred from below-normal precipitation during the same period. All of the data suggest that the available ground water in storage in the Lake Williams Tributary Subarea is relatively limited.

3.2 Aquifer Storage Analysis

The total potential aquifer storage capacity for the Lake Williams Tributary Subarea was estimated based on the following relationship:

$$\text{Aquifer Storage Capacity} = (\text{Volume of Saturated Sediments}) * (\text{Effective Porosity})^3$$

The volume of saturated sediments was estimated from the area of the ground water basin within the Lake Williams Tributary Subarea, a ground water elevation contour map generated from recent ground water levels (see Figure 7), and a contour map of the top of buried bedrock (see Figure 8) generated from drillers logs and data from exploratory boreholes drilled in the Gocke

³ Also called specific yield or “drainable porosity”.

Valley area in September 2003. Effective porosity was estimated from the types of sediments encountered in the exploratory boreholes drilled in Gocke Valley and published data (Johnson, 1967).

The following procedure was followed to estimate the ground water storage of the ground water basin within the Lake Williams Tributary Subarea:

- The boundary of the Lake Williams Tributary Subarea were digitized based on land surface elevation from United States Geological Survey (USGS) digital elevation models of the area (10 meter resolution).
- The bedrock elevation map is based on water well driller's logs from the California Department of Water Resources (DWR) and detailed lithologic logs of BBDWP test boreholes that intercept the bedrock.
- GIS was used to subtract the ground water elevation surface from the bedrock elevation surface across a 10 meter by 10 meter grid. This resulted in an estimate of the volume of saturated sediments in the basin.
- An average effective porosity was calculated from available lithologic logs. Each lithologic interval was assigned an effective porosity based on published values (Johnson, 1967).
- The volume of saturated sediments was then multiplied by the effective porosity to obtain the aquifer storage capacity estimate.

4.0 LAKE WILLIAMS TRIBUTARY SUBAREA

4.1 Location

The Lake Williams Tributary Subarea is located in the southeast portion of the Erwin Hydrologic Subunit, which is located in the southeast portion of the Baldwin Lake Watershed (see Figure 1). The total surface area of the Erwin Hydrologic Subunit is approximately 9,715 acres, and the surface area of Lake Williams Tributary Subarea is approximately 1,226 acres. Land surface elevations within the tributary subarea range from approximately 7,200 ft above mean sea level (amsl) in the northeastern portion of Gocke Valley to approximately 8,785 ft amsl in the mountains that define the southern portion of the subarea.

4.2 Geohydrology

4.2.1 Geology

The predominant rock types within the Lake Williams Tributary Subarea are Mesozoic granitic rock (Mzp), and Saragosa quartzite (SLW), which are exposed at the surface in the higher elevations of the drainage catchment (see Figure 9). Unconsolidated alluvial fan gravel sediments (Qaf) consisting predominantly of sand and gravel are deposited along the southern portion of the tributary subarea. Alluvial sediments consisting predominantly of sand with minor interbedded silt and clay are deposited within the northern portion of the tributary subarea and throughout most of Gocke Valley. Alluvial thickness ranges from approximately 25 ft in the west to more than 210 ft thick in the eastern portion of the subarea (in the vicinity of Camp Oakes Monitoring Well).

4.2.2 Hydrogeology

Ground water in the Lake Williams Tributary Subarea generally occurs in the unconsolidated alluvial deposits on the lower slopes of the surrounding mountains, Gocke Valley, and in the fractures and weathered portions of the bedrock. Ground water in the alluvium occurs at depths ranging from approximately 10 ft bgs in the western portions to approximately 100 ft bgs in the eastern portion of the subarea near Camp Oakes Test Borehole No. 2. Ground water in the Lake Williams Tributary Subarea generally flows toward Gocke Valley and then northeasterly toward a drainage outlet in the northeast portion of the subarea (see Figure 7). Surface and ground water drains through this outlet toward Erwin Lake.

4.2.2.1 Ground Water Levels

Ground water levels in the Monte Vista well increased slightly from the time of well construction (1979) to 1988 and then began declining from 1988 to 1992, corresponding to dry climatic conditions in the late 1980s/early 1990s coupled with increased production from the well during that time (see Figure 10). Ground water levels recovered to historical high levels from 1993 through 1999 (period of above average precipitation) at which time they declined again to historical low levels in 2003. The significant drop in ground water levels between 1999 and 2003 can be attributed to dry climatic conditions and increased pumping demand on the well (see Figures 6 and 10; Table 4).

A relatively low ground water level measured at the time the Onyx well was constructed (1968) reflects the relatively prolonged dry climatic period that began in 1955 and ended in 1977 (see Figures 6 and 10). Ground water levels reached a historical high level in 1993 but dropped to a historical low level in December 2002. Recent low ground water levels can be attributed to dry climatic conditions and the start of ground water production from this well in 1998 (see Table 4).

Ground water levels in the Skyview well show greater fluctuations than the Onyx or Monte Vista wells, which may be due to its location at the base of the mountain range to the south where ground water recharge is likely taking place (see Figure 10). In addition, the relatively low ground water levels in the Skyview well in 1993 (which corresponds to an above-average precipitation year) and the very high “spikes” in ground water levels in 1995 (above average precipitation year but not as high as 1993) may reflect the localized nature of precipitation events in this portion of the Baldwin Lake Watershed.

The Monte Vista monitoring well, with a similar perforation interval as the Monte Vista production well, is located approximately 50 ft southeast of the Monte Vista Well (Figure 3). The well was constructed in 2003 to serve as a key well for measuring ground water levels in the Lake Williams area. Ground water level data obtained from this well after construction are plotted on Figure 10.

4.2.2.2 Ground Water Recharge and Discharge

Ground water recharge within the Lake Williams Tributary Subarea likely occurs as deep percolation of runoff through the younger alluvium and fractures in the bedrock during periods of prolonged precipitation.

The primary sources of ground water discharge within the Lake Williams Tributary Subarea are underflow and ground water pumping from wells within the tributary subarea. The BBDWP currently operates three municipal production wells within the tributary subarea (Monte Vista, Skyview and Onyx Wells). Combined average annual ground water production from BBDWP wells between 1982 and 2002 was approximately 20 acre-ft/yr. However, increasing demand has resulted in an increase in average annual ground water production such that the average production from 1996 through 2002 was approximately 28 acre-ft/yr (see Table 4). Approximately 88 percent of the production is from the Monte Vista Well. Pumping data for the 15 private wells in the tributary subarea were not available. However, assuming that they are

domestic sources and that an average single family home uses approximately 200 gpd/yr, it is estimated that production from these wells is approximately 3.4 acre-ft/yr. YMCA Camp Oakes operates two wells (see Figure 3). Although no ground water production records are available, staff at the Camp estimates that their production demand is approximately 15 acre-ft/yr, which includes water used to fill and maintain the water level in the recreational lake. Thus, the total annual ground water production from the Lake Williams ground water basin (BBDWP, private and Camp Oakes production) is approximately 46 acre-ft/yr.

4.2.2.3 Ground Water Volume in Storage

The volume of ground water in storage in 2003 within the unconsolidated alluvial sediments in the Lake Williams Tributary Subarea ground water basin was estimated using the procedure described in Section 3.2⁴. The known saturated alluvial thickness within the ground water basin ranges from zero feet at the bedrock outcrops to approximately 165 ft at Camp Oakes test borehole No. 2. The saturated alluvial thickness at the Monte Vista Well is currently approximately 10 ft. Based on an effective porosity of aquifer sediments of 14 percent and ground water surface contours based on data collected in fall 2003, the total volume of ground water in storage was estimated to be approximately 3,600 acre-ft (see Figure 11).

The ground water in storage in the Lake Williams Ground Water Basin is relatively small and does not provide significant operational storage during prolonged periods of below-normal precipitation. This will result in a significant impact on ground water levels during periods when ground water production is maintained near the long-term average annual recharge but precipitation is below the long-term average, such as occurred during 2003. Furthermore, not all of the ground water in storage can be developed for municipal supply due to poor water quality and well/pump operational constraints (i.e. ground water levels drawn below well screens or pump settings). Approximately 50 percent of the ground water in storage should be relied on for

⁴ Ground water volume in storage in the bedrock portions of the Lake Williams Tributary Subarea was not estimated due to lack of data.

development. Future development and management of the ground water resource in the Lake Williams Tributary Subarea should take these factors into account, as described in Section 4.4.

4.2.2.4 Ground Water Quality

Ground water quality within the Lake Williams ground water basin is generally very good with the exception of localized areas where high concentrations of naturally occurring fluoride have been detected. Total dissolved solids (TDS) concentrations in ground water increase from east to west, ranging from 110 milligrams per liter (mg/L) in the eastern portion of the subarea (Camp Oakes Well No. 1) to 210 mg/L in the western portion of the subarea (Ploense private well). Ground water in the Lake Williams Ground Water Basin is calcium bicarbonate type with the exception of ground water in the vicinity of the Camp Oakes Monitoring Well, where ground water is enriched in sodium and sulfate, relative to the other wells (see Figure 12). With the exception of fluoride, no water quality constituents have been detected above their respective maximum contaminant levels (MCLs) for drinking water.

A summary of nitrate, fluoride, and TDS concentrations in selected wells in the Lake Williams Ground Water Basin is shown in the following table:

**Selected Water Quality Data from Wells
In the Lake Williams Ground Water Basin**

	Collection Date	Nitrate as NO ₃ [mg/L]	Fluoride [mg/L]	Total Dissolved Solids [mg/L]
Ploense Well	16-Sep-03	11	1	210
Monte Vista Well	22-May-90	5.8		
	4-Sep-90	5.2	0.8	186
	5-Oct-93	9.8		
	15-Oct-96	14.6		
	12-Oct-99	16.5		
	15-Oct-00	16		
	15-Oct-02	16	1	190
Skyview Well	22-May-90	1		
	4-Sep-90	1.8	0.2	198
	5-Oct-93	1		
	15-Oct-96	3.2		
	21-Jan-97	2		
	15-Oct-00	2.8		
	15-Oct-02	2.8	0.18	190
Onyx Well	21-Jan-97	5.2		
	12-Oct-99	5.45		
	30-Oct-00	5.9		
	30-Oct-02	5.9	2.6	180
Camp Oakes Monitoring Well	18-Nov-03	<0.88	8.2	160
Camp Oakes Well No. 1	18-Nov-03	1.9	0.1	110
	1-Oct-03	< 2.0	0.13	110
Camp Oakes Well No. 2	18-Nov-03	1.6	0.5	130
	1-Oct-03	2	0.14	110
MCL or Action Level		45 ¹	2.0 ¹	1,000 ²

¹ California Department of Health Services (DHS) Primary Maximum Contaminant Levels.

² California DHS Secondary Maximum Contaminant Levels.

Naturally occurring fluoride has been detected in ground water from some wells within the Lake Williams Ground Water Basin at concentrations that exceed the 2.0 mg/L MCL for this constituent. Fluoride concentrations detected in BBDWP's Onyx Well range between 2 and 3 mg/L. Further to the east, fluoride has been detected in the Camp Oakes monitoring well (test borehole No. 1) at concentrations ranging from 7.5 to 8.2 mg/L.

In the Gocke Valley portion of the Lake Williams Ground Water Basin (eastern portion), recent test borehole data indicate that fluoride concentrations in ground water are depth-specific. At Borehole No. 1 (the Camp Oakes Monitoring Well), fluoride was detected at a concentration of 7.4 mg/L in ground water at a depth of 195 ft below ground surface (bgs) but was only detected at a concentration of 1.4 mg/L at a depth of 315 ft bgs. At Borehole No. 2, located to the east of the Camp Oakes Monitoring Well, fluoride was detected at concentrations of 0.6 mg/L (195 ft bgs), 0.7 mg/L (255 ft bgs), 2.2 mg/L (355 ft bgs), and 6.2 mg/L (475 ft bgs). Bedrock at both locations was between approximately 210 and 220 ft bgs. These data suggest that ground water in bedrock is higher in fluoride in the eastern portion of Gocke Valley than in the western portion of the same valley. However, the presence of high concentrations of fluoride in the ground water appears to be site-specific and the drilling of future wells should include depth-specific ground water quality sampling as a criteria for well design.

Another significant water quality parameter within the Lake Williams Ground Water Basin is nitrate. Although nitrate has not been detected above the MCL of 45 mg/L, it has been detected in BBDWP production wells at concentrations above background levels, which are essentially non-detect. Recent nitrate concentrations in ground water range from 2.8 mg/L in the Skyview Well to 16 mg/L in the Monte Vista Well. Nitrate detected at the Monte Vista well has increased from 5.2 mg/L, detected in the well in 1990. The source of the nitrate is likely septic systems in the Lake Williams area. These data are significant because they suggest that septic system effluent is recharging the ground water. Focused monitoring of nitrate in ground water and strategic land use planning in the area will be required to prevent concentrations from exceeding the MCL in the future.

4.3 Average Annual Ground Water Recharge

4.3.1 Precipitation Recharge

The watershed model described in Section 3.1.2 was used to assess the average annual ground water recharge for the Lake Williams Tributary Subarea. Assumed input parameters for the watershed model for which no measured data were available were obtained from the EPA database of hydrologic parameters (EPA, 2000) as described in Section 3.1.2.2.3 and summarized in Table 3.

Based on the watershed modeling results, the maximum perennial yield for the Lake Williams Tributary Subarea ranges from approximately 45 to 67 acre-ft/yr with a midpoint of approximately 56 acre-ft/yr. This range of recharge is approximately 3 to 4 percent of average annual precipitation for the subunit, which is within the range of accepted recharge estimates for other ground water basins in southern California (Metropolitan Water District of Southern California (MWD), 1999). The midpoint of the range is approximately 3.5 percent of precipitation for the subunit.

4.3.2 Return Flow Recharge

Return flow recharge refers to water that reaches the ground water from deep percolation of applied irrigation water or septic system effluent. Estimates of the volume of applied irrigation water in the Lake Williams area can be assumed from monthly ground water production records. Ground water production from April through September of each year is typically approximately 7 acre-ft more than ground water production from October to March. The difference is assumed to be irrigation demand. Return flow recharge from irrigation is estimated to be 30 percent of the applied water, which, in the case of the Lake Williams area, would be approximately 2 acre-ft/yr (30 percent of 7 acre-ft). Return flow recharge from septic system leach fields has been estimated to be approximately 86 percent of the effluent. Thus, if it is assumed that all of the

non-irrigation water demand in the Lake Williams area (21 acre-ft/yr) is discharged to the subsurface as septic effluent, it is estimated that approximately 18 acre-ft/yr recharges the ground water as return flow. Thus, the combined return flow recharge is estimated to be approximately 20 acre-ft/yr (2 acre-ft/yr from irrigation return flow and 18 acre-ft/yr from septic system return flow).

4.4 Maximum Perennial Yield

As stated earlier, the maximum perennial yield is the maximum quantity of ground water perennially available if all possible methods and sources are developed for recharging the basin. This quantity depends on the amount of water economically, legally, and politically available to the BBDWP.

In consideration of the factors involved for determining maximum perennial yield and based on the data available at this time, the lower end of the range of average annual recharge estimates (45 acre-ft/yr) is the most realistic estimate of maximum perennial yield for the Lake Williams Tributary Subarea. First, some portion of the ground water within the subarea is impacted by fluoride at levels that render it unusable for municipal supply. Second, a portion of the average annual recharge is within the bedrock surrounding the ground water basin where it is not currently economically or legally developed. Finally, due to the limited volume of ground water in storage within the ground water basin, a significant impact on ground water levels will result during periods when ground water production is maintained near the long-term average annual recharge but precipitation is below the long-term average (i.e. drought periods).

The impact of the limited ground water storage capacity on ground water levels has been apparent in the Monte Vista Well, where ground water levels dropped to historical low levels in August 2003 and required a reduction in pumping rate in the well to maintain pump submergence. As stated earlier, the ground water levels are a result of increased production during a 5-year period of below average precipitation. The ground water level impacts occurred

despite an estimated 20 acre-ft/yr of irrigation and septic system return flow. Thus, the ground water level data from this well suggests that, while ground water levels may recover at the current production rates during prolonged periods of average to above-average precipitation, during periods of below average precipitation, the portion of the ground water basin within the BBDWP service area cannot sustain the maximum perennial yield of 45 acre-ft/yr, which is near the recent average annual production from the subarea).

It should be noted that almost 90 percent of the BBDWP ground water production from the Lake Williams Tributary Subarea is from the Monte Vista production well and that this focused pumping likely results in a localized pumping depression that may not be indicative of the entire subarea. More distributed pumping throughout the subarea would help mitigate the localized pumping depression around the Monte Vista well.

Ground water level monitoring will be a critical aspect of the future management of the ground water resources within the Lake Williams Tributary Subarea. Two dedicated, non-pumping monitoring wells have been constructed in key areas of the subarea for this purpose. An unused private well (Burdette) is also being used for monitoring water levels. As ground water level data are collected from these wells, ground water level thresholds should be established from which to manage the ground water resources in the area. Future management of the ground water in the Lake Williams Tributary Subarea should rely more on these established ground water level thresholds than the perennial yield estimates.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the analyses presented in this report, the following have been concluded regarding the maximum perennial yield of the Lake Williams Tributary Subarea:

- The Lake Williams Tributary Subarea is delineated based on surface water drainage divides;
- Ground water storage in the Lake Williams Ground Water Basin (i.e. the alluvial portions of the subarea) is approximately 3,600 acre-ft/yr. However, only approximately 50 percent of this storage is available for development due to well/pump operation constraints and water quality concerns (higher fluoride concentrations at depth within the ground water basin);
- The range of average annual ground water recharge for the Lake Williams Tributary Subarea, based on the watershed model, is approximately 45 to 67 acre-ft/yr with a midpoint of approximately 56 acre-ft/yr. The midpoint of the range is approximately 3.5 percent of precipitation for the subunit, which is within the range of accepted recharge estimates for other ground water basins in southern California (3 to 7 percent);
- The low end of the average annual ground water recharge estimate (45 acre-ft/yr) is a realistic long-term estimate of maximum perennial yield for the Lake Williams Tributary Subarea, given the available data. A portion of the ground water within the subarea contains high concentrations of fluoride, which cannot be used for municipal supply and it is not economical, and in some cases legal, to develop the ground water in the bedrock areas surrounding the subarea. Furthermore, significant short-term ground water level impacts have occurred at the Monte Vista Well during drought periods at production rates in the Lake Williams Subarea near 45 acre-ft/yr;

- The limited ground water storage capacity of the subarea will result in a significant impact on ground water levels during periods when ground water production is maintained near the long-term average annual recharge but precipitation is below the long-term average (i.e. drought periods);
- Recent ground water production within the Lake Williams Tributary Subarea includes approximately 28 acre-ft/yr from BBDWP, 3 acre-ft/yr from private wells, and 15 acre-ft/yr at YMCA Camp Oakes for a total of approximately 46 acre-ft/yr. Thus, current average annual production slightly exceeds the maximum perennial yield of 45 acre-ft/yr;
- Approximately 20 acre-ft/yr of return flow recharge from applied irrigation and septic system effluent is estimated for the Lake Williams area. Without this return flow, ground water level impacts would likely be greater than currently observed and the maximum perennial yield would have to be reduced.

It is recommended that future ground water development planning be based on the maximum perennial yield estimate of 45 acre-ft/yr. However, as ground water production is initiated, it will be very important to monitor ground water levels in dedicated non-pumping monitoring wells located in areas from which ground water is extracted. Future ground water production and development should be managed based on ground water levels in key monitoring wells and established ground water level thresholds rather than the perennial yield estimates.

Recent average annual ground water production from the Lake Williams Tributary Subarea slightly exceeds the maximum perennial yield estimate. However, almost all of the ground water production is from one well. Given this, and assuming a new source of supply is not brought into the subarea from elsewhere, it is recommended to construct additional production wells within the subarea to distribute ground water level impacts across the ground water basin.

Additional wells that are strategically located throughout the ground water basin would enable a more even distribution of ground water level impacts from pumping and enable the BBDWP to more fully utilize the maximum perennial yield and available ground water in storage during drought periods. At least two additional wells are recommended at the approximate locations shown on Figure 11.

6.0 REFERENCES

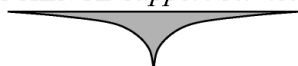
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FIGURES

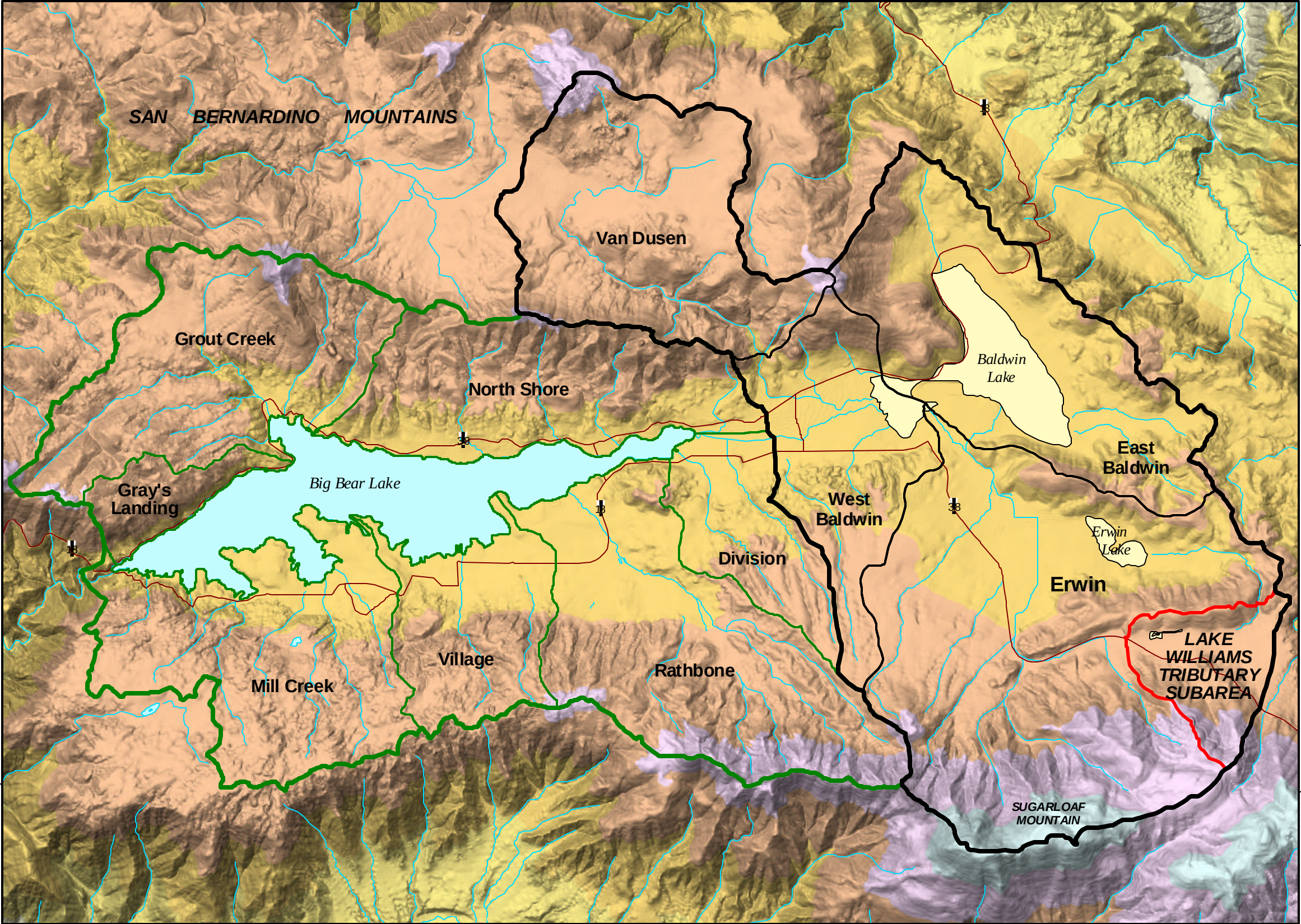
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LOCATION OF
BIG BEAR VALLEY

EXPLANATION

- Baldwin Lake Watershed Boundary with Hydrologic Subunits
- Baldwin Lake Hydrologic Subunit Boundaries
- Lake Williams Tributary Subarea Boundary
- Big Bear Lake Watershed Boundary with Hydrologic Subunits
- Big Bear Lake Hydrologic Subunit Boundaries
- Road
- Surface Water
- Mountain Playa Lake
- Creek or Stream



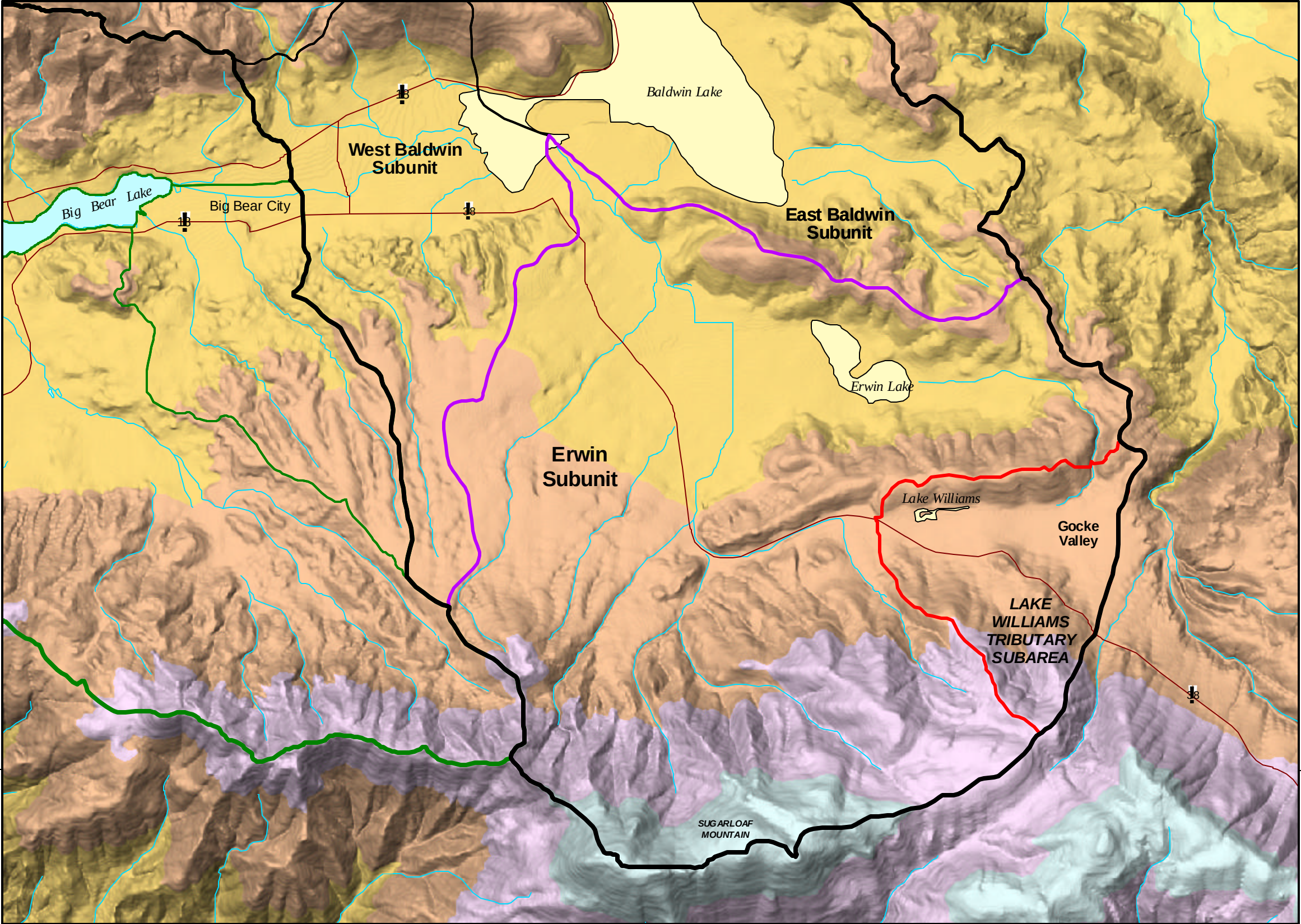
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Figure 1

Map Projection:
UTM Zone 11, NAD27
Central Meridian: -117 degrees

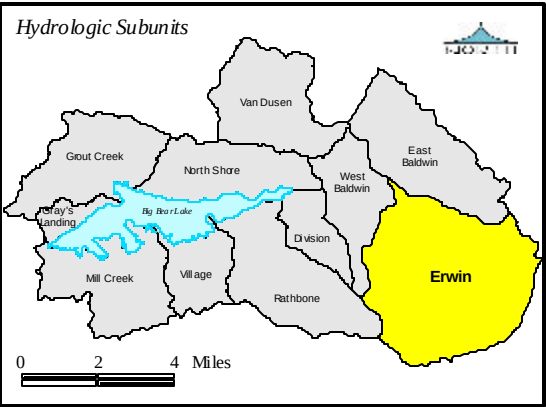




ERWIN HYDROLOGIC
SUBUNIT

EXPLANATION

- Baldwin Lake Watershed Boundary with Hydrologic Subunits
- Baldwin Lake Hydrologic Subunit Boundaries
- Erwin Subunit Boundary
- Lake Williams Tributary Subarea Boundary
- Big Bear Lake Watershed Boundary with Hydrologic Subunits
- Big Bear Lake Hydrologic Subunit Boundaries
- Road
- Surface Water
- Mountain Playa Lake
- Creek or Stream



T.2 N.
T.1 N.

Prepared by: DWB

R.1 E. | R.2 E.

27-JAN-04

Map Projection:
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Figure 2

LAKE WILLIAMS
TRIBUTARY SUBAREA

EXPLANATION

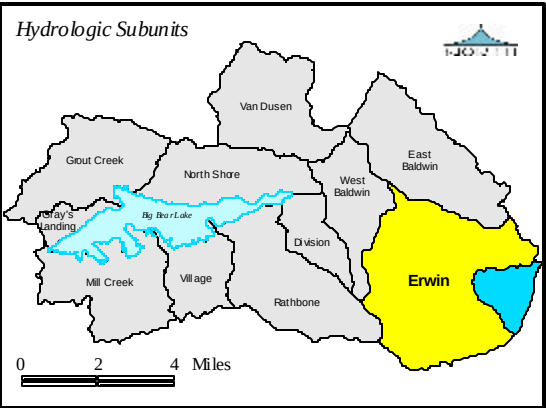
-  Baldwin Lake Watershed Boundary
-  Lake Williams Tributary Subarea Boundary

Well Use Classification and Name

S	Monitoring		Private
'	Municipal	0	Test Borehole

Well locations were determined from City of Big Bear Lake Department of Water and Power, and DWR Well Drilling Logs.

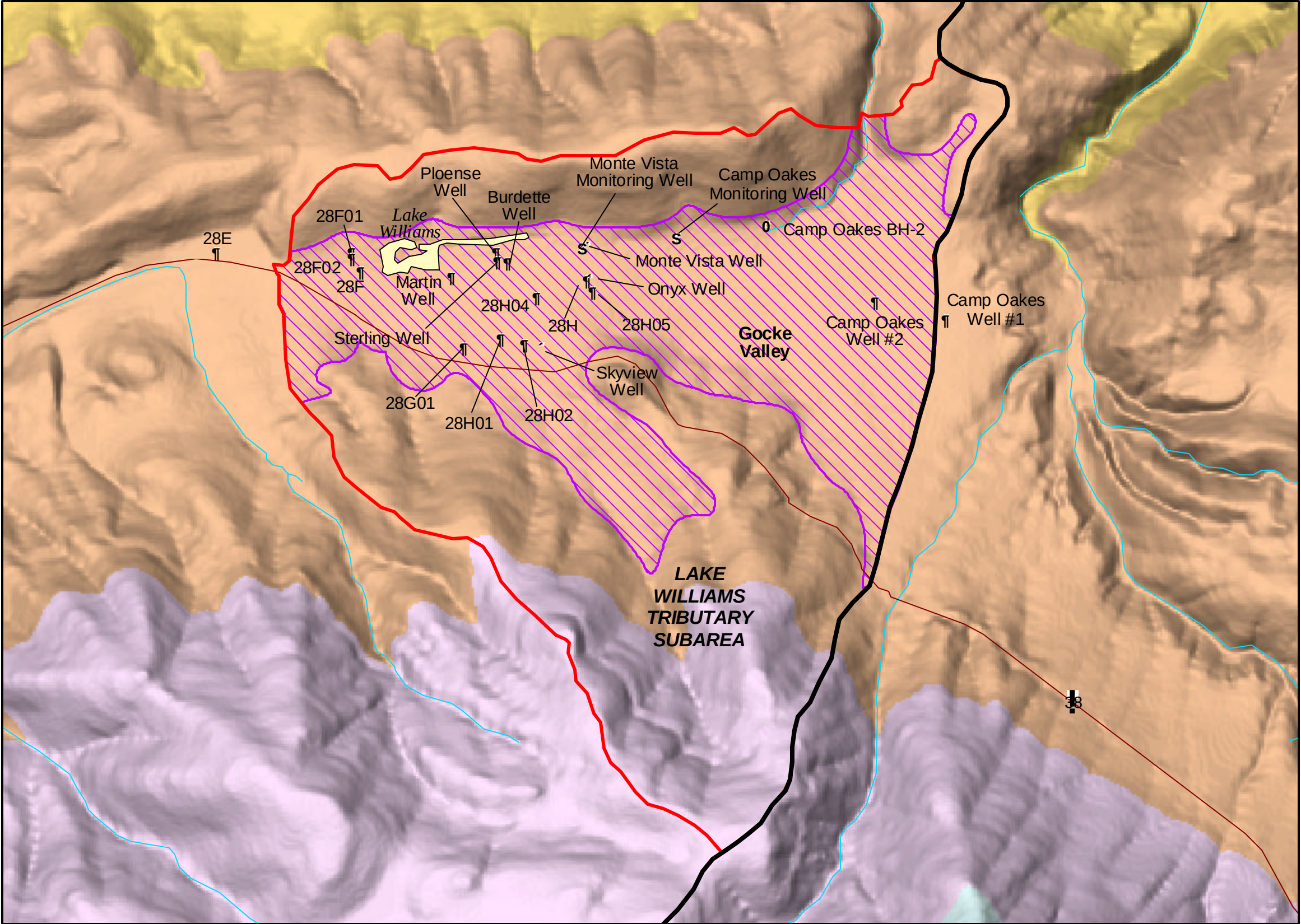
-  Lake Williams Ground Water Basin
-  Road
-  Surface Water
-  Creek or Stream



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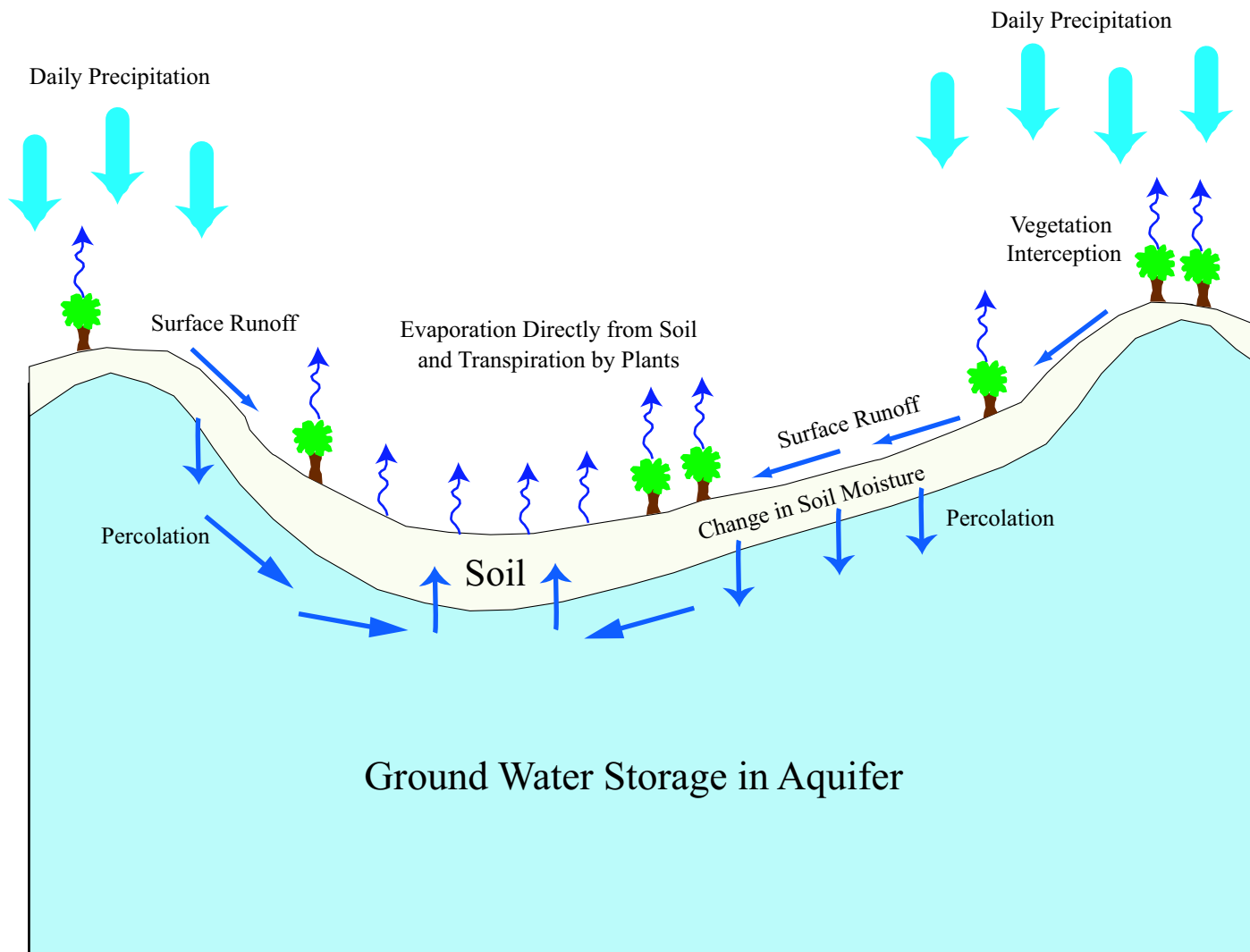
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Figure 3



T.2 N. R.2 E. 27-JAN-04

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Central Meridian: -117 degrees



**Figure
4**

Drawn: DWB

Checked: TH

Approved: DEW

Date: 27-JAN-04

CITY OF BIG BEAR LAKE DEPARTMENT OF WATER AND POWER

SCHEMATIC DIAGRAM OF WATERSHED MODEL

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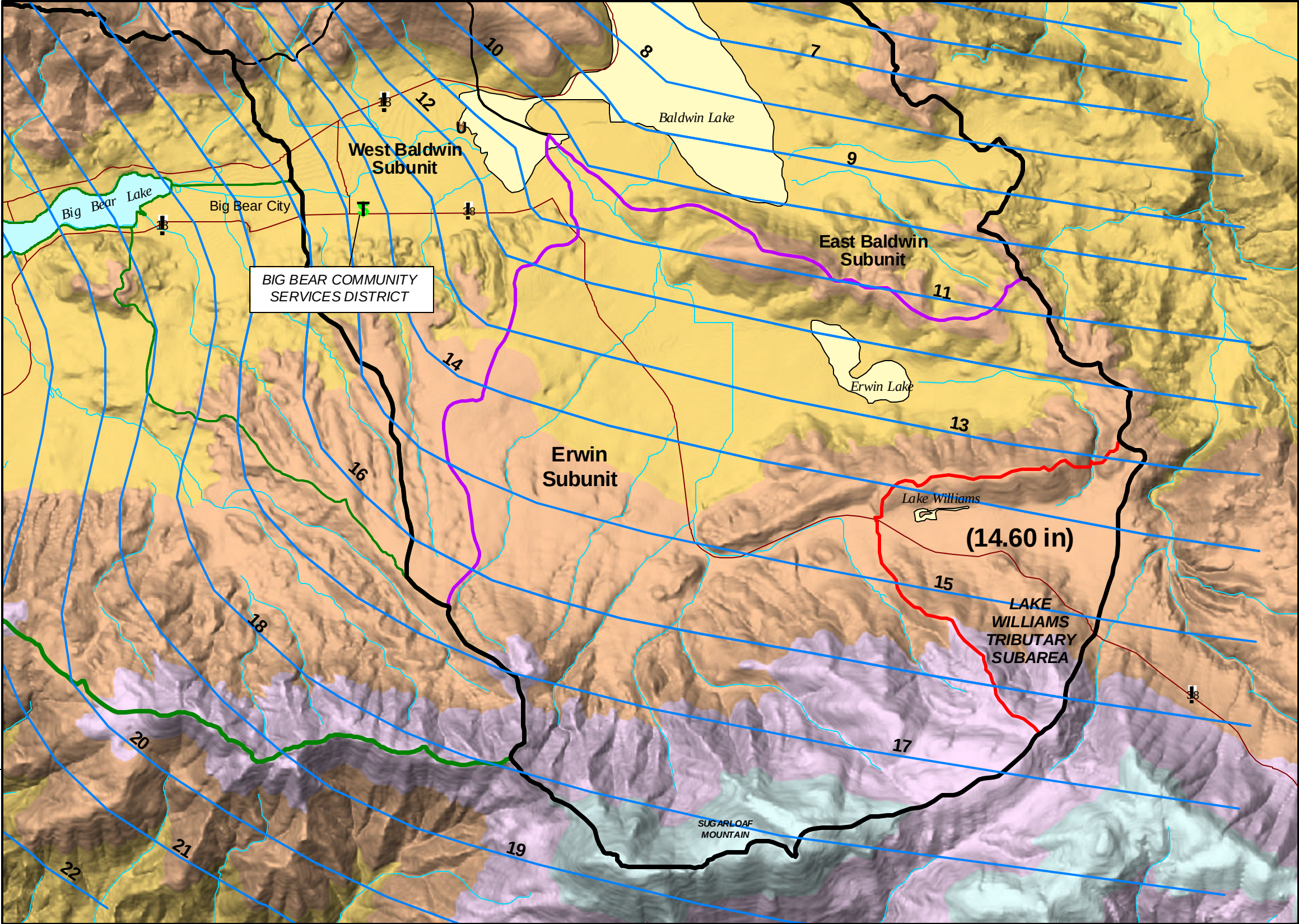
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ISOHYETALS IN THE
VICINITY OF THE
ERWIN HYDROLOGIC
SUBUNIT

EXPLANATION

- 17 Average Annual Precipitation (in.)
1870 - 1970
(Source: San Bernardino County
Flood Control District)
- (14.60 in) Lake Williams Tributary Subarea
Weighted Mean Annual
Precipitation (in.)
- Weather Station
San Bernardino County Flood
Control District
- Evaporation Pan Location
- Baldwin Lake Watershed
Boundary with Hydrologic Subunits
- Baldwin Lake Hydrologic Subunit
Boundaries
- Erwin Subunit Boundary
- Lake Williams Tributary Subarea
Boundary
- Big Bear Lake Watershed
Boundary with Hydrologic Subunits
- Big Bear Lake Hydrologic Subunit
Boundaries
- Road
- Surface Water
- Mountain Playa Lake
- Creek or Stream



Prepared by: DWB

R.1 E. | R.2 E.

27-JAN-04

Map Projection:
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Central Meridian: -117 degrees



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Figure 5

Precipitation and Cumulative Departure From Mean Precipitation Big Bear City Community Services District Weather Station

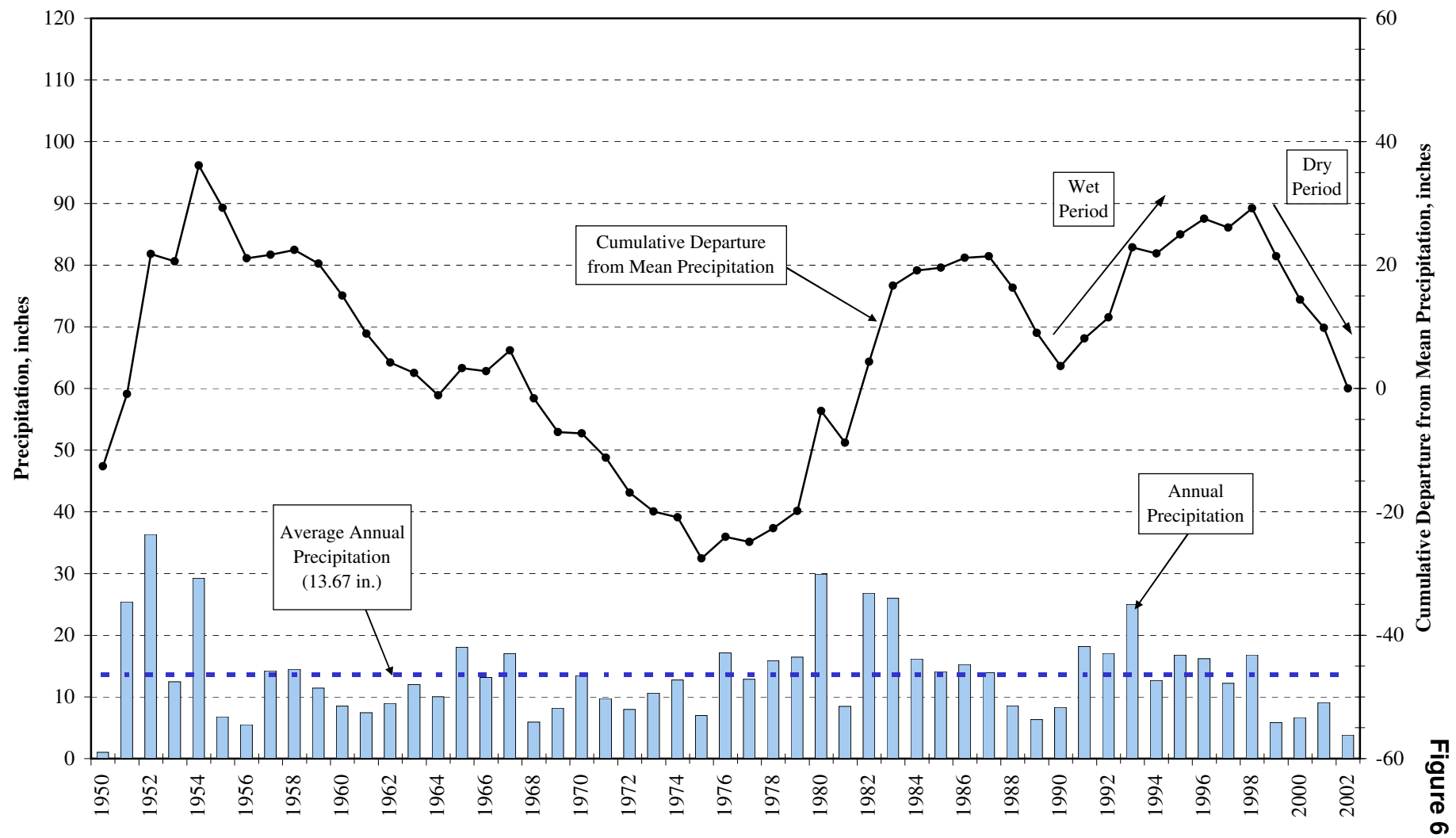


Figure 6

LAKE WILLIAMS
GROUND WATER
ELEVATIONS
FALL 2003

EXPLANATION

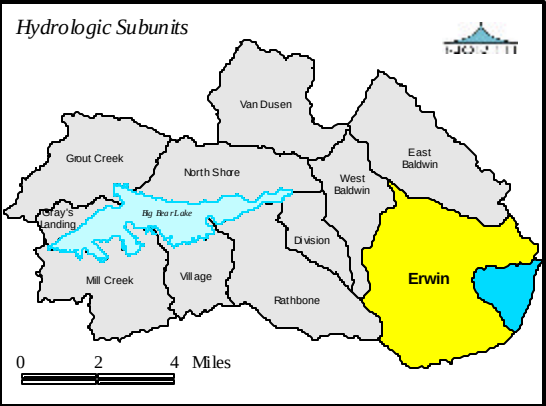
- 7500** Ground Water Elevations (Fall 2003)
(Note: dashed lines inferred based on topography)
- Baldwin Lake Watershed Boundary
- Lake Williams Tributary Subarea Boundary

Well Use Classification and Name

S	Monitoring		Private
'	Municipal	0	Test Borehole

Well locations were determined from City of Big Bear Lake Department of Water and Power, and DWR Well Drilling Logs.

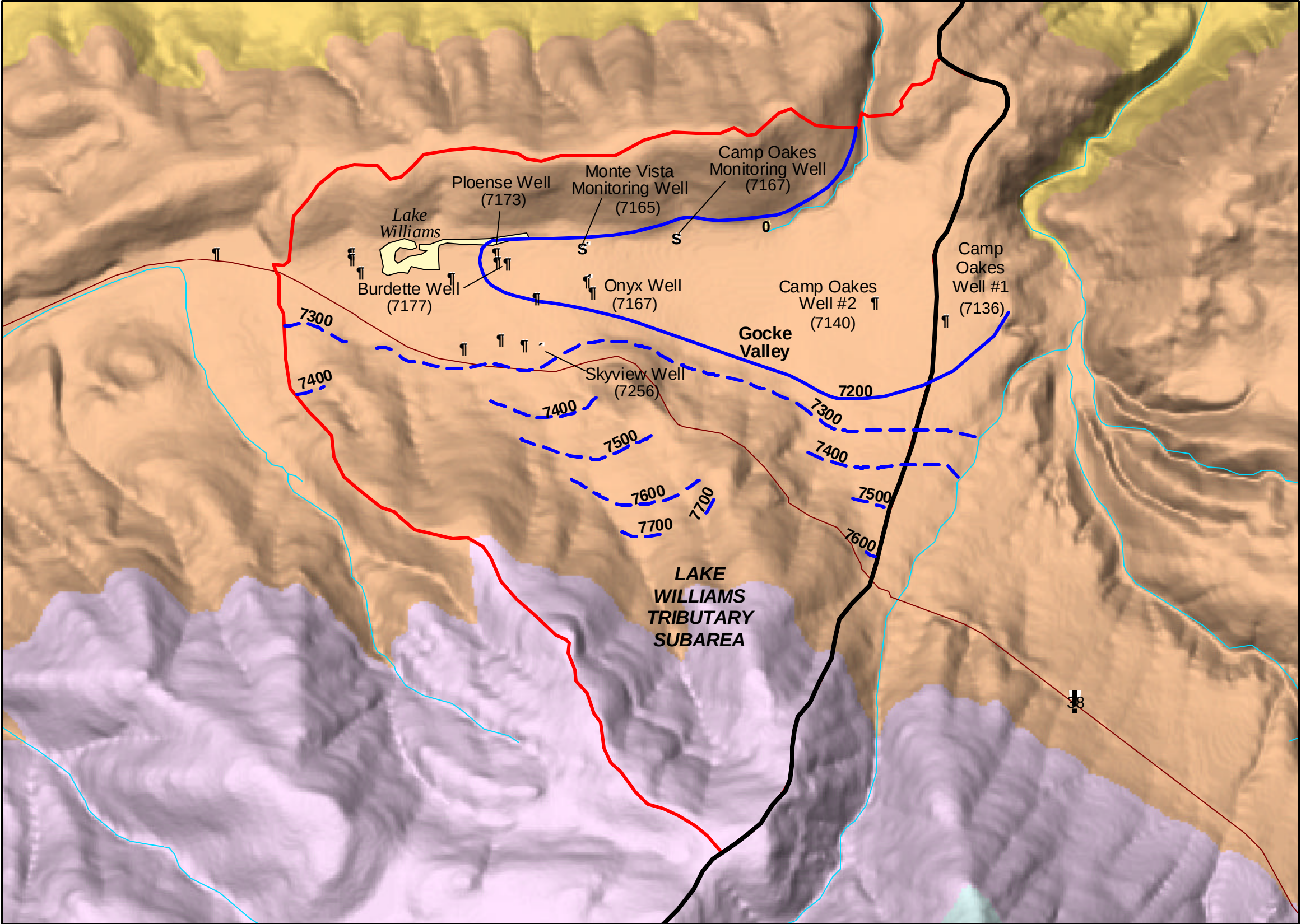
- Road
- Surface Water
- Mountain Playa Lake
- Creek or Stream



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Figure 7



T.2 N. R.2 E. 27-JAN-04

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UTM Zone 11, NAD27
Central Meridian: -117 degrees



LAKE WILLIAMS
TRIBUTARY SUBAREA
BEDROCK ELEVATIONS

EXPLANATION

7200 Bedrock Elevation
(ft above mean sea level)

(7199) Bedrock Elevation Control Point
(ft above mean sea level)

Well Use Classification and Name

S Monitoring P Private
M Municipal O Test Borehole

Baldwin Lake Watershed
Boundary with Hydrologic Subunits

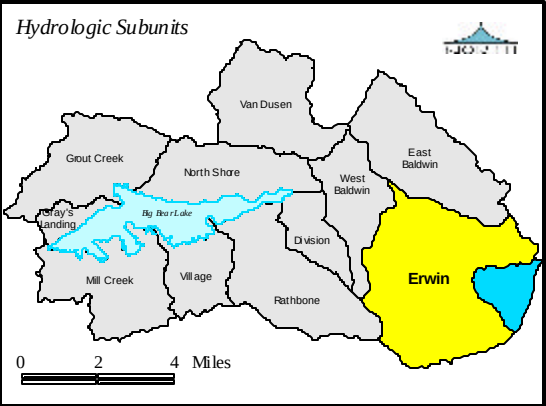
Lake Williams Tributary Subarea
Boundary

Road

Surface Water

Mountain Playa Lake

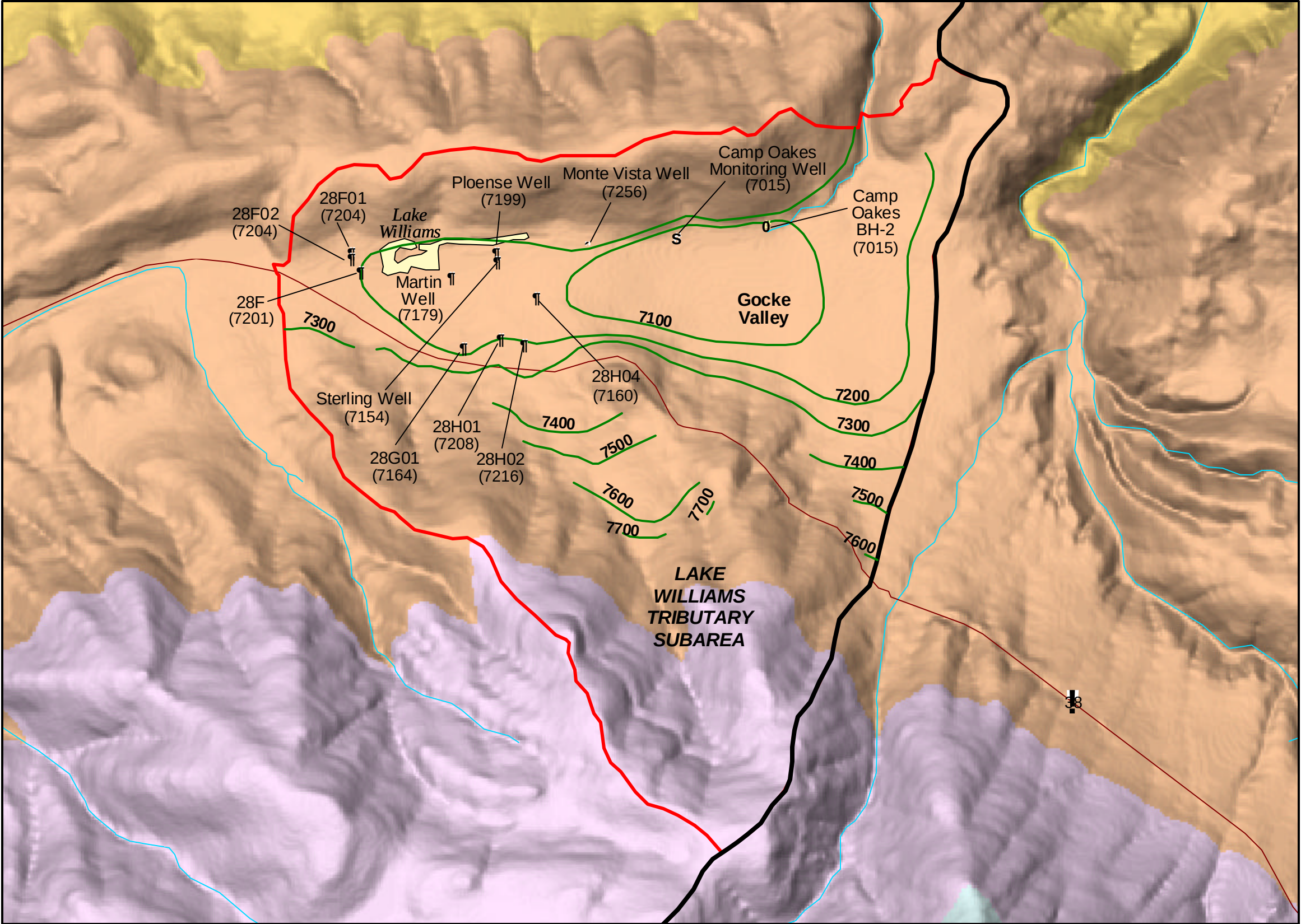
Creek or Stream



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Figure 8



T.2 N. R.2 E. 27-JAN-04

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Map Projection:
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Central Meridian: -117 degrees

GEOLOGY

EXPLANATION

- Geologic Units
- Qaf** Alluvial fan gravel
 - Qaa** Alluvial and colluvial deposits consisting of sand, gravel, silt and clay
 - Qof** Older alluvium, glacial till, terrace and fanglomerate deposits consisting of gravel, sand, silt and clay
 - Mzp** Plutonic rocks, primarily quartz monzonite and quartz diorite
 - SLW** Sargosa Quartzite

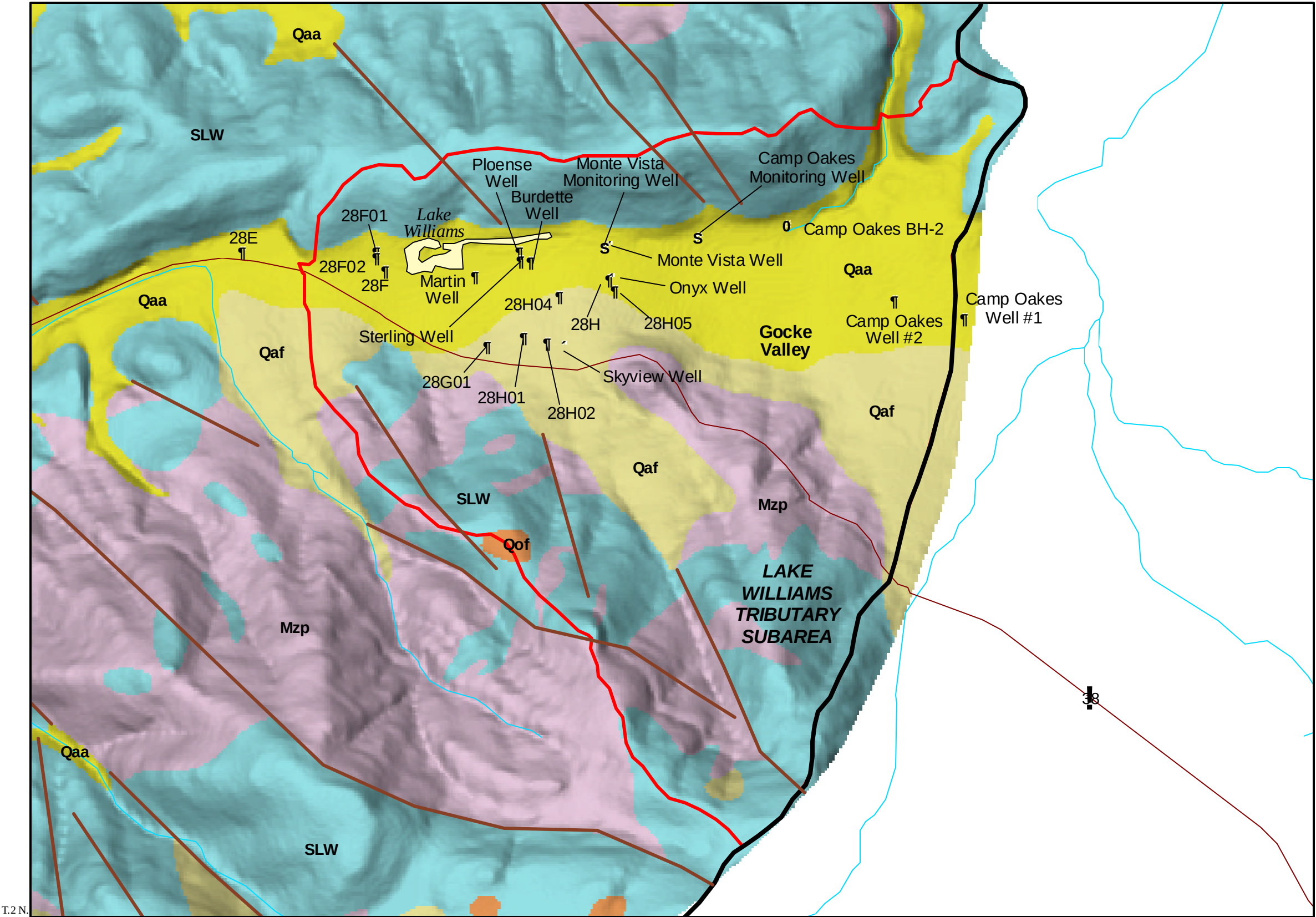
Note: geology shown is extent of geologic mapping.

Fault

- Well Use Classification and Name
- | | | | |
|----------|------------|----------|---------------|
| S | Monitoring | ¶ | Private |
| ' | Municipal | 0 | Test Borehole |

Well locations were determined from City of Big Bear Lake Department of Water and Power, and DWR Well Drilling Logs.

- Baldwin Lake Watershed Boundary
- Lake Williams Tributary Subarea Boundary
- Road
- Mountain Surface Water
- Creek or Stream



T.2 N. R.2 E. 27-JAN-04

Prepared by: DWB
Map Projection:
UTM Zone 11, NAD27
Central Meridian: -117 degrees

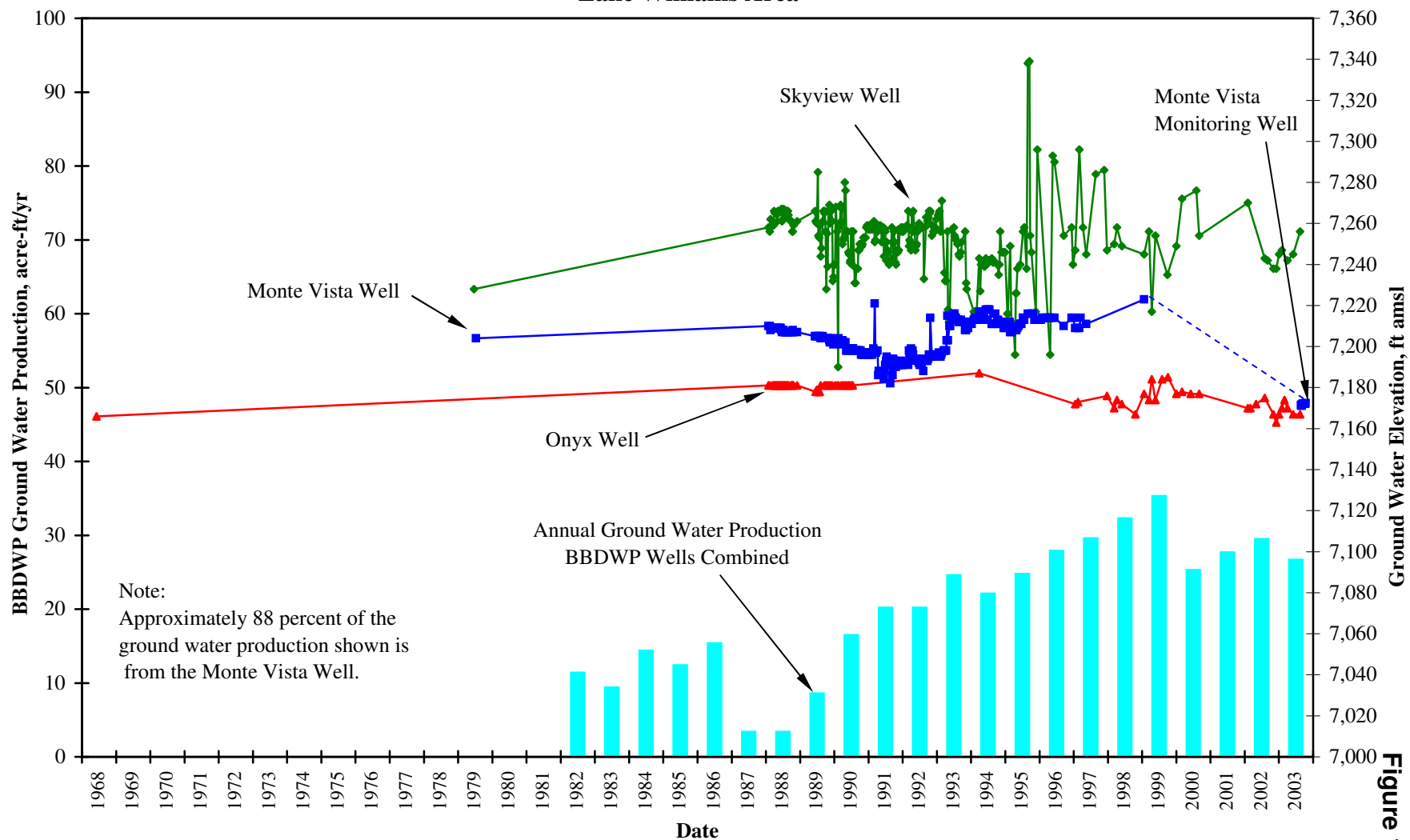
Source of Geology:
Sadler, P.M., 1982. "Geology of the San Bernardino Mountains".
California Division of Mines and Geology Open File Report 82-18LA.



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E mail: email@geosciencewater.com

Figure 9

Ground Water Levels and Production City of Big Bear Lake Department of Water and Power Wells Lake Williams Area

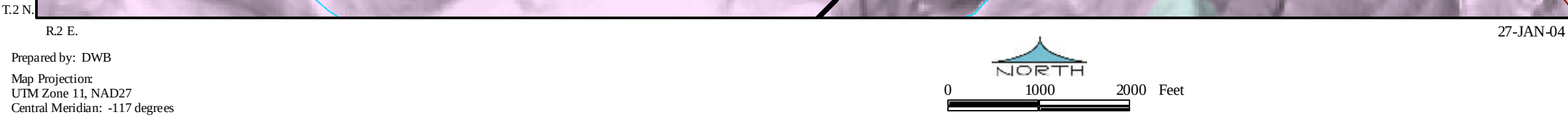
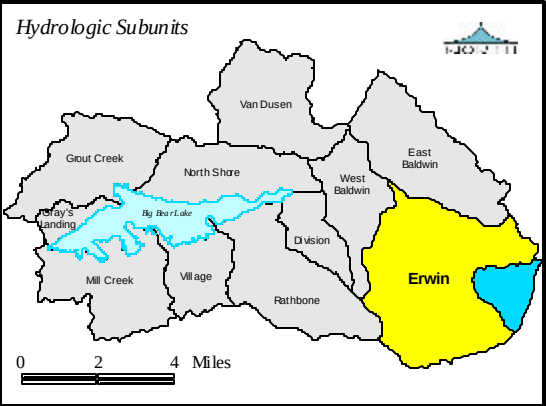


LAKE WILLIAMS
TRIBUTARY SUBAREA
SATURATED ALLUVIAL
THICKNESS AND AQUIFER
STORAGE CAPACITY

EXPLANATION

- 100** Saturated Alluvial Thickness (ft)
- Aquifer Storage Capacity = 3,600 ac-ft
- (152)** Saturated Alluvial Thickness (ft)
(based on DWR well completion reports and water level data collected up to Fall 2003)

- Well Use Classification and Name
- S** Monitoring
- ¶** Private
- Baldwin Lake Watershed Boundary with Hydrologic Subunits
- Lake Williams Tributary Subarea Boundary
- Road
- Surface Water
- Mountain Playa Lake
- Creek or Stream

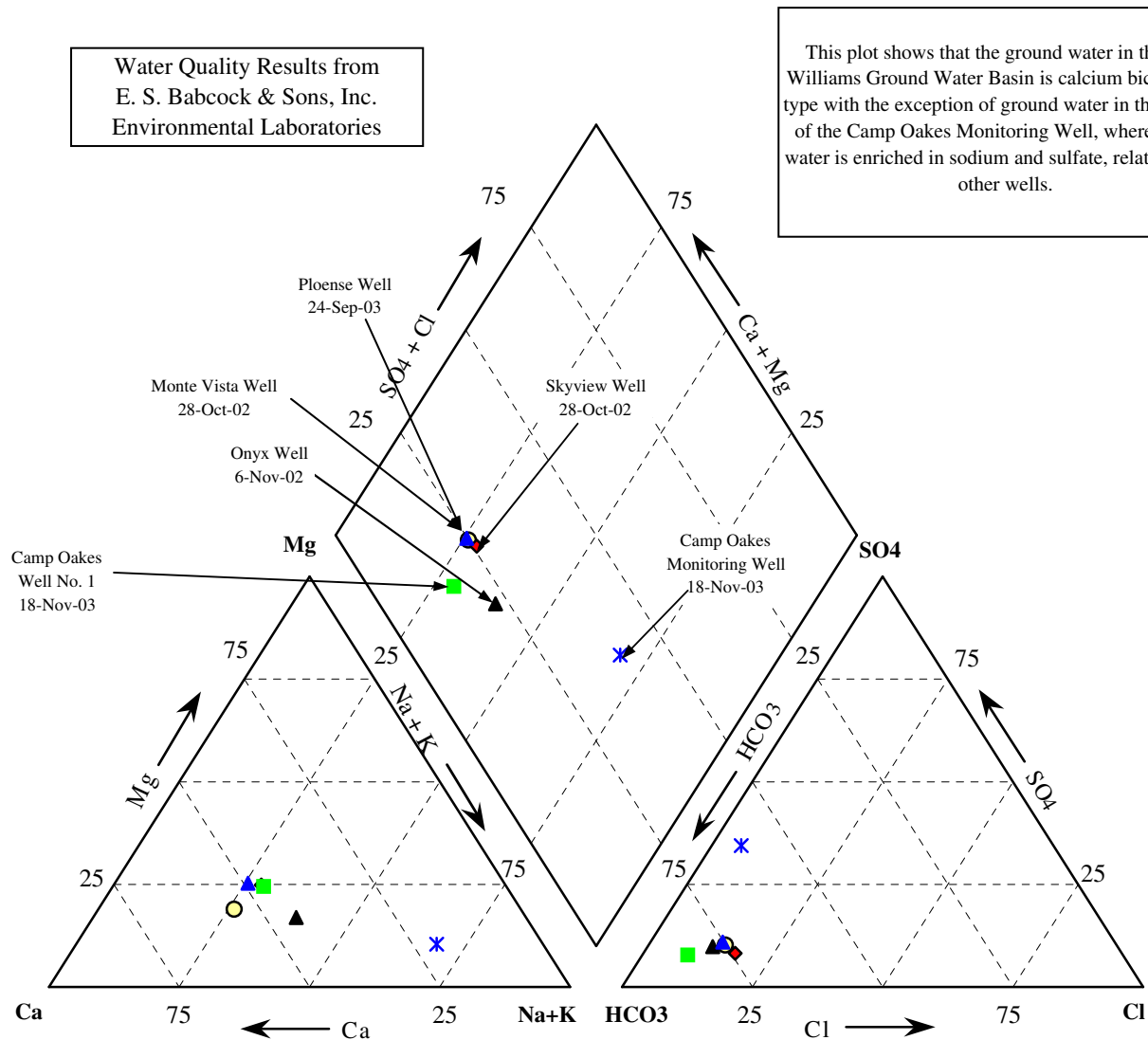


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Figure 11

Trilinear Diagram Water Quality in the Lake Williams Ground Water Basin



PROPOSED PRODUCTION
WELL LOCATIONS

EXPLANATION

 Proposed Production Well Location

 Baldwin Lake Watershed Boundary

 Lake Williams Tributary Subarea Boundary

Well Use Classification and Name

S	Monitoring		Private
'	Municipal	0	Test Borehole

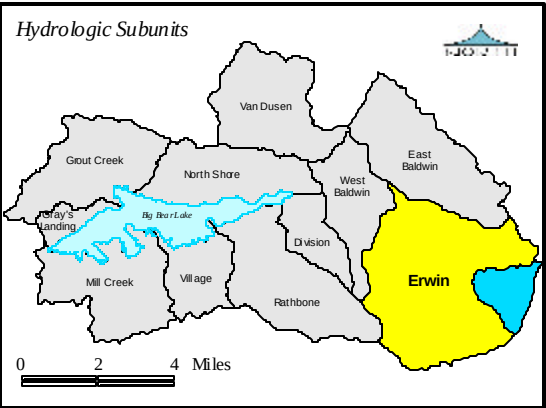
Well locations were determined from City of Big Bear Lake Department of Water and Power, and DWR Well Drilling Logs.

 Lake Williams Ground Water Basin

 Road

 Surface Water

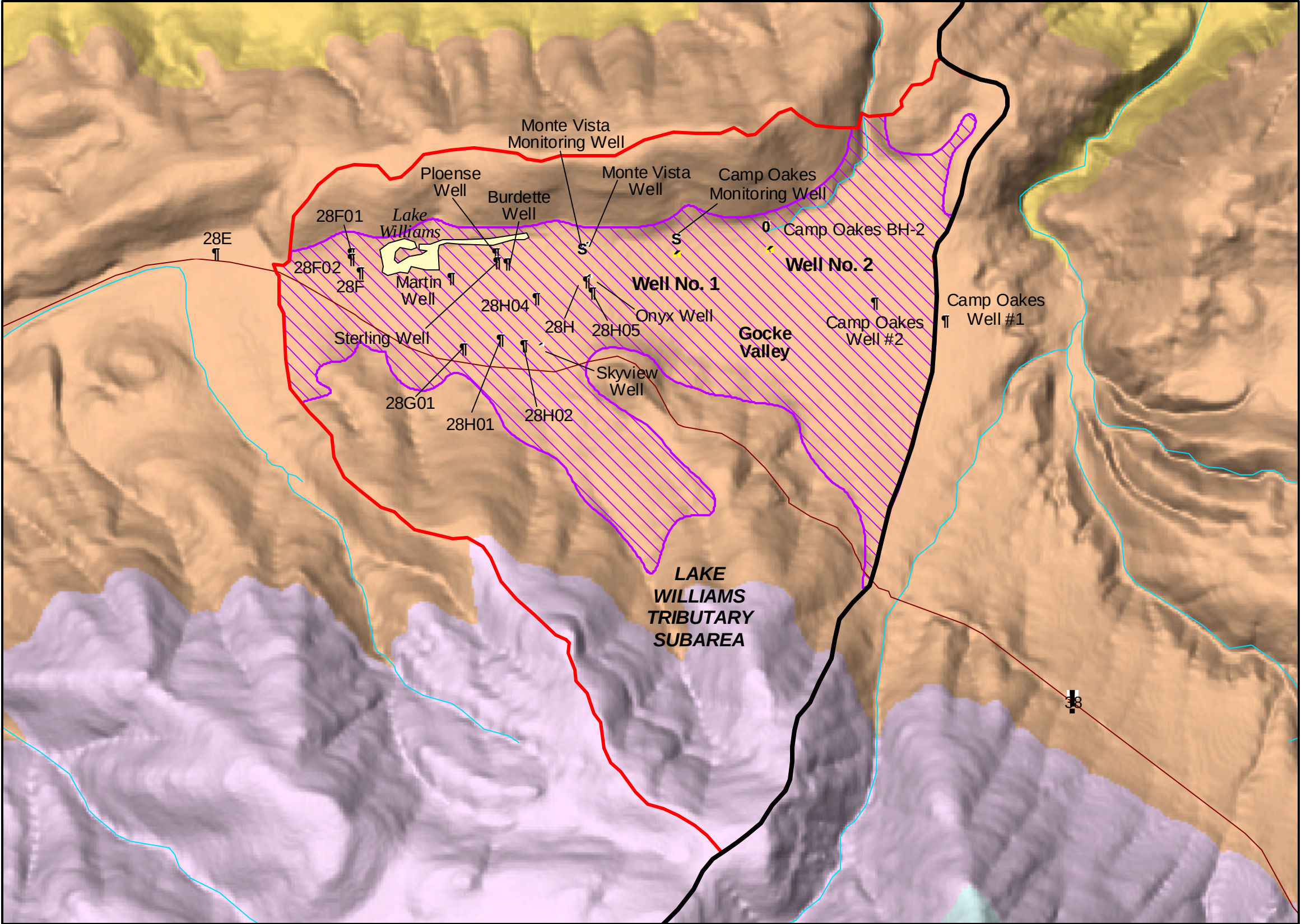
 Creek or Stream



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Figure 13



T.2 N.

R.2 E.

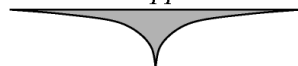
27-JAN-04

Prepared by: DWB
Map Projection:
UTM Zone 11, NAD27
Central Meridian: -117 degrees



TABLES

GEOSCIENCE Support Services, Inc.



**Summary of Annual Precipitation
 Big Bear City Community Services District Weather Station**

Year	Annual Precipitation*
	[inches]
1950	1.02
1951	25.40
1952	36.36
1953	12.47
1954	29.23
1955	6.78
1956	5.51
1957	14.22
1958	14.46
1959	11.44
1960	8.50
1961	7.46
1962	8.98
1963	12.00
1964	10.05
1965	18.05
1966	13.17
1967	17.03
1968	5.93
1969	8.18
1970	13.46
1971	9.73
1972	7.97
1973	10.61
1974	12.73
1975	7.01
1976	17.14
1977	12.87
1978	15.87
1979	16.47
1980	29.89
1981	8.49
1982	26.80
1983	25.99
1984	16.16

**Summary of Annual Precipitation
 Big Bear City Community Services District Weather Station**

Year	Annual Precipitation*
	[inches]
1985	14.11
1986	15.26
1987	13.93
1988	8.55
1989	6.33
1990	8.29
1991	18.16
1992	17.07
1993	25.02
1994	12.67
1995	16.77
1996	16.20
1997	12.23
1998	16.80
1999	5.86
2000	6.67
2001	9.10
2002	3.82
AVERAGE	13.67

Source: San Bernardino County Flood Control District.

* Calendar Years

**Summary of Annual Evaporation Data
 Big Bear City Community Services District Weather Station**

Year	Annual Pan Evaporation
	[inches]
1993	39.0
1994	44.6
1995	44.6
1996	37.1
1997	46.6
1998	NA
1999	NA
2000	NA
2001	NA
2002	NA
AVERAGE	42.4

Source: Big Bear City Community Services District
 NA = Data not available

City of Big Bear Lake Department of Water and Power
 Geohydrologic Evaluation of the Maximum Perennial Yield
 of the Lake Williams Area, Baldwin Lake Watershed

HSPF Watershed Model Input Parameters

Name	Definition	Units	Range of Values					
			Typical			Possible		
			MINIMUM	MAXIMUM	AVERAGE	MINIMUM	MAXIMUM	AVERAGE
LZSN	Lower Zone Nominal Soil Moisture Storage	inches	3.0	8.0	5.5	2.0	15.0	8.5
INFILT	Index to Infiltration Capacity	in/hr	0.01	0.25	0.13	0.001	0.50	0.2505
LSUR	Length of overland flow	feet	200	500	350	100	700	400
KVARY	Variable ground water recession	1/inches	0.0	3.0	1.5	0.0	5.0	2.5
AGWRC	Base ground water recession	none	0.92	0.99	0.955	0.85	0.999	0.9245
PETMAX	Temperature below which evapotranspiration is reduced	deg. F	35.0	45.0	40	32.0	48.0	40
PETMIN	Temperature below which evapotranspiration is set to zero	deg. F	35.0	35.0	35	30.0	40.0	35
INFEXP	Exponent in infiltration equation	none	2.0	2.0	2	1.0	3.0	2
INFILD	Ratio of maximum/mean infiltration capacities	none	2.0	2.0	2	1.0	3.0	2
DEEPFR	Fraction of ground water inflow to deep recharge	none	0.0	0.20	0.1	0.0	0.50	0.25
BASETP	Fraction of remaining evapotranspiration from baseflow	none	0.0	0.05	0.025	0.0	0.20	0.1
AGWETP	Fraction of remaining evapotranspiration from active ground water	none	0.0	0.05	0.025	0.0	0.20	0.1
CEPSC	Interception storage capacity	inches	0.03	0.20	0.115	0.01	0.40	0.205
UZSN	Upper zone nominal soil moisture storage	inches	0.10	1.0	0.55	0.05	2.0	1.025
NSUR	Manning's n (roughness) for overland flow	none	0.15	0.35	0.25	0.05	0.50	0.275
INTFW	Interflow inflow parameter	none	1.0	3.0	2	1.0	10.0	5.5
IRC	Interflow recession parameter	none	0.5	0.7	0.6	0.3	0.85	0.575
LZETP	Lower zone evapotranspiration parameter	none	0.2	0.7	0.45	0.1	0.9	0.5

Source: Environmental Protection Agency (2000)

Note: Average values of EPA's typical ranges and possible ranges were used for the Lake Williams Tributary Subarea

Table 3

GEOSCIENCE Support Services, Inc.

**Lake Williams Tributary Subarea
 Annual Production**

City of Big Bear Lake Department of Water and Power Wells				
	Monta Vista	Onyx	Skyview	TOTAL
	[acre-ft]	[acre-ft]	[acre-ft]	[acre-ft]
1982	7.0	-	1.0	8.0
1983	5.0	-	1.0	6.0
1984	10.0	-	1.0	11.0
1985	8.0	-	1.0	9.0
1986	10.0	-	2.0	12.0
1987	-	-	-	0.0
1988	-	-	-	0.0
1989	4.4	-	0.8	5.2
1990	11.9	-	1.2	13.1
1991	15.6	-	1.2	16.8
1992	15.4	-	1.4	16.8
1993	19.0	-	2.2	21.2
1994	16.8	-	1.9	18.7
1995	19.3	-	2.1	21.4
1996	22.7	-	1.8	24.5
1997	24.6	-	1.6	26.2
1998	26.1	1.2	1.6	28.9
1999	28.4	2.0	1.5	31.9
2000	15.3	5.1	1.5	21.9
2001	26.7	0.5	0.5	27.7
2002	28.9	-	0.6	29.5
2003	23.5	2.7	0.5	26.7
AVERAGE*	24.5	2.3	1.2	28.0

Source of data: City of Big Bear Lake Department of Water and Power (2003).

* Average for 1996 through 2003