

City of Big Bear Lake Department of Water and Power Analysis of Potential Groundwater Resources in the Arrastre Creek Drainage



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Analysis of Potential Groundwater Resources in the Upper Arrastre Creek Drainage

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

Prepared by

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1 Introduction

1.1 Background

This report presents an investigation of potential groundwater resources in the Upper Arrastre Creek Drainage (the Project Area), located immediately east of the Erwin Hydrologic Subunit of the Baldwin Lake Watershed (see Figure 1). The Project Area is outside the Hydrologic Subunits of Big Bear Valley that have previously been investigated for potential water resources. Furthermore, with the exception of groundwater production from one well, operated by YMCA Camp Oakes, the water resources of the area have not been developed. Given its proximity to Lake William, it may be beneficial to develop the groundwater resources of the Upper Arrastre Creek Drainage as a future source of water supply to this community, which is within the City of Big Bear Lake Department of Water and Power's (BBLDWP's) service area.

1.2 Purpose and Scope

The purpose of this investigation was to evaluate the available groundwater resources in the Upper Arrastre Creek Drainage to assess the potential for future production wells in this area.

The scope of work to address the project objective included:

- Defining the portion of the Arrastre Creek Drainage for inclusion in the investigation;
- Obtaining background geological and hydrogeological data for the Project Area;
- Field inspection of the Project Area, including measurement of stream flow in Arrastre Creek;
- An evaluation of groundwater recharge in the Project Area using precipitation/evapotranspiration/runoff relationships;
- An evaluation of the feasibility of a new well on the Camp Oakes property including potential drilling locations; and
- Preparation of this report summarizing the findings.

1.3 Project Area

The focus of the investigation was the upper portion of the drainage area encompassing Arrastre Creek, located immediately east of the Erwin Hydrologic Subunit of the Baldwin Lake

Watershed (see Figures 1 and 2). This drainage area is bounded on the south by a high elevation ridge that includes Onyx Peak and Onyx Summit, on the east by an unnamed ridge extending north from Onyx Peak and Broom Flat, and on the west by the Erwin Hydrologic Subunit, which includes Gocke Valley and Camp Oakes. The northern portion of the drainage area was delineated to correspond to the section of Arrastre Creek directly downstream of Camp Oakes. The total surface area of the drainage is 7.9 square miles (5,072 acres). This area is hereafter referred to as the Upper Arrastre Creek Drainage and/or Project Area.

2 Hydrogeologic Setting of the Upper Arrastre Creek Drainage

The Upper Arrastre Creek Drainage area is located on the upper northern slope of the San Bernardino Mountains of southern California (see Figure 1). Elevations in the Project Area range from approximately 7,000 ft above mean sea level (amsl) at the lowermost drainage outlet to approximately 9,000 ft amsl near Onyx Peak. The topography on either side of Arrastre Creek is generally steep and rugged (see Figure 2). However, relatively flat areas exist to the west (Gocke Valley) and east (Broom Flat) of the creek.

2.1 Hydrology

Arrastre Creek is the primary surface water feature in the Project Area and is the confluence of multiple tributary drainages from the area. United States Geological Survey (USGS) topographic maps show that at least two springs (Deer Spring and Missed Spring) feed the creek upgradient of Camp Oakes. Other ephemeral drainages that periodically drain into Arrastre Creek include Balky Horse Canyon and the drainage from Broom Flat. Although the drainage channel between Onyx Summit and Missed Spring was dry at the time of the field reconnaissance (see Figure 2), the lowermost section of the creek east of Camp Oakes was flowing.

2.2 Geology

The surface geology of the Upper Arrastre Creek Drainage consists predominantly of very old metamorphic rocks with smaller outcrops of Mesozoic granitic rock and localized areas of young alluvium (see Figures 3 and 3a). The oldest surficial rocks in the area consist of ortho- and augen- gneiss of the Baldwin Gneiss (Pbg), which has been dated to 1.7 billion years before present. The other dominant rock type in the area is quartzite of the late Proterozoic (approximately 540 million to 1 billion years before present) Wildhorse Formation (Pwh). Cretaceous (65 to 145 million years before present) granitic rock (Mzp) outcrops in the southernmost portion of the Project Area.

Unconsolidated to semi-consolidated sediments in the Upper Arrastre Creek Drainage occur in the vicinity of Camp Oakes, in the Broom Flat area, and within the drainage channel of Arrastre Creek (see Figure 3). The oldest of these sediments are mid- to late-Pleistocene age (approximately 12,000 to 1.5 million years before present) and shown as Qof on Figures 3 and

3a. These older sediments consist of fluvial and debris flow fan deposits that are moderately to well consolidated. The sediments consist of sand to boulder size clasts consisting primarily of granitic rock and quartzite weathering from the surrounding highlands. Younger alluvial fan deposits (Qyf) have been mapped in the center of Gocke Valley, in the vicinity of Camp Oakes, and along the drainage of Arrastre Creek.

In the vicinity of Camp Oakes, the unconsolidated to semi-consolidated sediments extend to depths ranging from 200 to 275 ft below ground surface (bgs). The borehole log from one BBLDWP exploratory test hole located approximately 2,300 ft northwest of Camp Oakes (Camp Oakes BH-2; see Figure 4) provided the nearest information on subsurface lithology. At BH-2, subsurface sediments consist of interbedded sand, silt and clay in varying proportions (Geoscience, 2004b). Metamorphic bedrock of the Baldwin Gneiss was encountered at a depth of approximately 275 ft bgs. The borehole log shows approximately 60 ft of aquifer material below the groundwater, which was observed to be approximately 75 ft bgs. The borehole logs for the Camp Oakes production wells were not available for review.

2.3 Hydrogeology

Groundwater in the Gocke Valley area (west of Camp Oakes) flows towards the center of Gocke Valley and then to the east towards Camp Oakes (see Figure 4). Based on available data, it appears that groundwater outflow from Gocke Valley occurs at the drainage outlet in the northeast corner of the valley. However, it is possible that some subsurface outflow occurs from Gocke Valley into the Arrastre Creek drainage along the eastern edge of the Erwin Subunit (see Figure 4). Groundwater levels in the Camp Oakes area are between 111 and 134 ft bgs based on groundwater elevations presented in Geoscience, 2004a.

Groundwater production from the existing Camp Oakes production wells is estimated to be approximately 15 acre-ft/yr (Geoscience, 2004a). Most of this production is used to fill the lake near the camp. It is not clear how much production is from Camp Oakes Well No. 1 (located in the Arrastre Creek Drainage) and how much is from Camp Oakes Well No. 2 (located in the Erwin Subunit).

Groundwater quality observed in samples from the Camp Oakes wells is very good with no constituents exceeding State or Federal maximum contaminant levels (MCLs) for drinking water (Geoscience, 2004a). Total dissolved solids (TDS) concentrations range from 110 to 130 milligrams per liter (mg/L). Both nitrate and fluoride concentrations in groundwater from these wells are well below their respective MCLs (see Table 1).

3 Analysis of Potential Groundwater Resources

3.1 Methodology

Potential groundwater resources in the Upper Arrastre Creek Drainage were evaluated using the procedure for estimating natural water loss and recoverable water described in Crippen, 1965. Natural water loss, as used in this analysis, is water lost to the atmosphere through evapotranspiration (ET). Recoverable water is the sum of surface water runoff and groundwater recharge. The relationship between natural water loss (i.e. ET) and recoverable water is given as:

$$\text{Natural Water Loss} = \text{Precipitation} - (\text{Surface Runoff} + \text{Groundwater Recharge})$$
$$[\text{Recoverable Water}]$$

Groundwater recharge can be estimated from this relationship based on evapotranspiration, precipitation distribution, and surface water runoff data specific to the Project Area.

3.2 Delineation of the Upper Arrastre Creek Drainage Area

The Upper Arrastre Creek Drainage area was defined using Geographic Information System (GIS) software with topographic maps and digital elevation maps of the area. The boundaries of the drainage area represent surface water drainage divides. For this analysis, it is assumed that the surface water drainage divides also represent groundwater flow divides. The northern boundary was selected so that the drainage area encompasses the proposed well location near Camp Oakes (see Figure 2). The total area of the Upper Arrastre Creek Drainage is approximately 7.9 square miles (5,072 acres).

The northern drainage boundary was also chosen to correspond to a bedrock constriction where all surface water is assumed to flow out of the drainage (see Figure 3). Surface water flow measurements at this location represent the surface runoff factor for the governing equation in the analysis.

3.3 Evapotranspiration Estimates

Evapotranspiration (i.e. water loss) estimates used in the analysis represent potential ET based on evaporation pan records from the Big Bear area. Potential ET is the water loss that would occur if the water was available and the water requirement of plants was fully met (Thornwaite, 1944). Potential ET can be approximated from evaporation pan data adjusted for a free water surface (Crippen, 1965). Typical adjustment factors (also referred to as pan coefficients) range from 0.7 to 0.75 (Viessman et al., 1977).

The closest evaporation pan with the longest period of record is the Big Bear City Community Services District (BCCSD) evaporation pan located on the west side of Baldwin Lake near Well 4A (see Figure 1). The average annual evaporation rate as measured in this pan for the period between 1993 and 1997 was 42.4 inches/yr (Geoscience, 1999). Pan evaporation was converted to potential ET for water loss estimates by applying pan coefficients ranging from 0.7 to 0.75 (Viessman et al., 1977; Crippen, 1965). The corresponding potential ET range used for recoverable water estimates ranged from 29.7 to 31.8 inches/yr.

3.4 Precipitation Distribution

Average annual precipitation distribution for the Upper Arrastre Creek Drainage Area was based on County of San Bernardino Flood Control District (SBFCD) Records. The precipitation distribution was based on a SBFCD isohyetal map developed from precipitation records between 1870 and 1970 (see Figure 5). The isohyets are generally consistent with long-term precipitation records at the Green Canyon Creek precipitation station, located approximately three miles to the west of the Project Area (see Figure 1). Average annual precipitation at this location for the period 1962 to 2008 is approximately 14 inches/yr. The long-term average precipitation across the Project Area ranges from approximately 14 to 18 inches/yr with the highest precipitation in the highest elevations of the drainage.

The precipitation value used in recoverable water calculations was the weighted mean precipitation across the Arrastre Creek Drainage based on the isohyetal map. The weighted mean precipitation across the drainage area is 15.69 inches/yr (see Table 2).

3.5 Stream Flow in Arrastre Creek

The reach of Arrastre Creek that occurs in the northern portion of the Project Area appears to flow perennially. TH&Co staff inspected the stream on November 9, 2009. The creek channel was dry between approximately Onyx Summit and Missed Spring (see Figure 2). Although the exact location where surface water begins to flow was not observed, it appears that the stream begins to flow somewhere north of Deer Spring (see Figure 2). Given that the field inspection occurred in the dry portion of the precipitation year and no significant precipitation events had occurred near the time of the inspection, the flow conditions were considered indicative of low flow conditions in the creek.

During the field inspection, TH&Co obtained measurements of flow at two locations along the flowing portion of Arrastre Creek. The first stream flow measurement location was at the intersection of an unimproved jeep trail and Arrastre Creek as shown on Figure 2. The second stream flow measurement location was at the furthest downstream portion of the Arrastre Creek Drainage at the bedrock constriction (see Figure 2). Stream flow measurement locations were selected in areas where the stream was relatively straight, all or most of the flow could be accounted for in the channel, and the flow had a minimum of turbulence.

Stream flow measurements were approximated manually by measuring the cross sectional area of the stream and surface water flow rate at each of the two locations. The cross sectional area was measured using a tape and staff gauge. The flow rate was estimated by measuring the travel time of a floating leaf along a known distance of the creek channel. The measurements are considered approximate because the stream channel bottom is variable and the flow in the stream was not perfectly laminar. Further, there is a possibility that some stream flow was bypassing the measurement location at the first location. However, the flow estimates are considered a good first order approximation of surface water outflow from the Arrastre Creek Drainage area.

Estimates of stream flow rate ranged from approximately 0.06 ft³/sec (26 gallons per minute) at the first measurement site (upstream location) to 0.15 ft³/sec (67 gallons per minute) at the second measurement site (downstream location). The downstream location is considered more representative of actual stream flow because it appeared to account for the total flow in the stream.

3.6 Estimates of Groundwater Recharge

Groundwater recharge estimates for the Upper Arrastre Creek Drainage were obtained using the procedure for estimating natural water loss and recoverable water described in Section 3.1. The equation for this analysis is:

$$\text{Natural Water Loss} = \text{Precipitation} - (\text{Surface Runoff} + \text{Groundwater Recharge})$$
$$[\qquad \qquad \text{Recoverable Water} \qquad \qquad]$$

Where:

$$\text{Natural Water Loss} = \text{Potential ET [29.7 to 31.8 in/yr]}$$

$$\text{Precipitation} = \text{Weighted Mean Precipitation} = [15.69 \text{ in/yr}]$$

$$\text{Surface Runoff} = [0.15 \text{ ft}^3/\text{sec}; 109 \text{ acre-ft/yr}]$$

Groundwater recharge was estimated from the above relationship and analysis of the recoverable water for the Arrastre Creek Drainage area using the method of Crippen, 1965. The recoverable water analysis is summarized in Table 2. For the analysis, the drainage area was divided into five precipitation zones based on the isohyetal map of the area (see Figure 5). An average annual precipitation value was assigned to each zone. The ratio of precipitation to ET (P/ET) was then used to determine the ratio of recoverable water to ET (R/ET) using charts provided in Crippen, 1965. The initial recoverable water estimate for each precipitation zone was then determined from the R/ET ratio for that zone.

The initial recoverable water estimate was adjusted to account for the geology of the Upper Arrastre Creek Drainage area. The adjustment factor is based on runoff and retention characteristics of the various rock types found in the mountains of southern California (Crippen, 1965). The predominant rock type of the Arrastre Creek Drainage is Precambrian metamorphic rock, with lesser coverages of Quaternary alluvium, Tertiary sediments, and Mesozoic granitic rock (see Figure 3). Based on these rock types, the initial recoverable water estimates for each precipitation zone were adjusted by a factor of 0.6.

Based on this analysis, recoverable water for the Upper Arrastre Creek Drainage area is estimated to range from 618 to 657 acre-ft/yr. The range is dictated by the range in potential ET used in the analysis.

Groundwater recharge was estimated for the Upper Arrastre Creek Drainage by subtracting surface water runoff measured in Arrastre Creek from the recoverable water estimates. This is based on the assumption that the surface water flow measurements conducted in November 2009 are representative of baseflow conditions in the creek. The resulting groundwater recharge estimates for the Upper Arrastre Creek Drainage range from 509 acre-ft/yr to 548 acre-ft/yr. Given that less than 15 acre-ft/yr of groundwater production currently occurs from this area, it is concluded that there are available groundwater resources available for development.

4 Feasibility Analysis of a New Well at Camp Oakes

TH&Co evaluated the feasibility of drilling, constructing and operating a new BBLDWP production well on the Camp Oakes property, which is located on the northwestern edge of the Upper Arrastre Creek Drainage. Constraints that guided the selection of a new well site included:

1. It must be located within the Arrastre Creek Drainage;
2. It must be north of the U.S. Forest Service boundary, which is the southern boundary of the Camp Oakes property;
3. It should be as far away as possible from bedrock outcrops in the northern and eastern portions of the Camp Oakes property in order to maximize alluvial thickness and, presumably, well yield. It is assumed, for this analysis, that potential production wells will be completed in alluvial aquifers only.

The most promising sites for a new well are in the central and southern portion of the Camp Oakes property (see Figure 6). Specific criteria for evaluating the feasibility of a new well in this area included:

- Potential well yield
- Acceptable groundwater quality
- Potential for interference with the existing well
- Potential for environmental constraints
- Drilling rig access

The criteria were evaluated in the context of the hydrogeologic evaluation presented in this study, a site reconnaissance on November 9, 2009, and evaluation of aerial photos.

4.1 Potential Well Yield

Potential well yield in the Camp Oakes area was evaluated in the context of the thickness and permeability of the aquifer system. Currently available data suggest the aquifer is approximately 100 ft thick in the Camp Oakes area. However, borehole logs from the existing well weren't available to confirm the aquifer thickness and assess the types of sediments that make up the aquifer system. Further, no instantaneous production data was available from the existing well.

In order to assess potential production, it will be necessary to collect additional data from one or more test boreholes within the southern portion of the Camp Oakes property (see Section 5.2).

4.2 Groundwater Quality

Based on historical records of groundwater quality from Camp Oakes Well No. 1, the quality of the groundwater is favorable for use as a municipal supply source. No water quality constituents have been detected above their respective MCLs. It was noted during the site reconnaissance that horse stables are located in the northern portion of the Camp Oakes property. Although there is no evidence in groundwater quality samples of nitrate impacts from the horse stables, any future well site should be located as far from the stables as possible.

4.3 Potential for Interference with the Existing Camp Oakes Well

Camp Oakes Well No. 1 is located as shown on Figure 6. Given the constraints of the drainage area boundary to the west, the Forest Service Boundary to the south, bedrock outcrops to the north and east and the horse stables to the north, it will be necessary to site the new well within 500 ft of the existing Camp Oakes Well No. 1. This may result in pumping interference. Based on available data, it is not possible to determine the amount of interference that can be expected. Future test drilling should include a pumping test to determine this.

4.4 Potential for Environmental Constraints

No significant environmental constraints are expected from drilling and constructing a new well in this area. The southern portion of the Camp Oakes property has already been altered by roads and other manmade features. However, other impacts may need to be considered, including pumping impacts on the surface water resources in Arrastre Creek. Once a specific site(s) has been identified, it is recommended that the BBLDWP retain an environmental consultant to inspect the site and conduct an appropriate analysis prior to drilling to ensure compliance with California Environmental Quality Act (CEQA) requirements.

4.5 Drilling Rig Access

The Camp Oakes property has ready access for a drilling rig to drill either test boreholes or a full-scale municipal well. No overhead obstructions were observed during the field reconnaissance although it will be necessary to confirm the existence/absence of underground utilities.

5 Conclusions and Recommendations

5.1 Conclusions

The analysis of potential groundwater resources in the Upper Arrastre Creek Drainage has resulted in the following conclusions:

- The Upper Arrastre Creek Drainage encompasses an area of approximately 7.9 square miles (5,072 acres);
- Based on San Bernardino County Flood Control District records, precipitation across the drainage area ranges from approximately 14 to 18 inches/yr with a weighted mean of 15.62 inches/yr;
- Potential ET (i.e. water loss) is estimated to range from 29.7 to 31.8 inches/yr.
- Baseflow in Arrastre Creek at the outlet of the drainage, based on field measurements, is estimated to be 0.15 ft³/sec, which is approximately 109 acre-ft/yr;
- Recoverable water (runoff plus groundwater recharge) for the Upper Arrastre Creek Drainage is estimated to range from approximately 618 to 657 acre-ft/yr;
- Groundwater recharge is estimated to range from 509 to 548 acre-ft/yr;
- Given that less than 15 acre-ft/yr of groundwater production currently occurs from this area, it is concluded that there are available groundwater resources for development;
- The central and southern portions of the Camp Oakes property are the most feasible for a future BBLDWP production well. This area is on private property within the Upper Arrastre Creek Drainage and is located away from bedrock outcrops on the east and the north.

5.2 Recommendations

Test drilling is recommended at one or more locations within the southern portion of the Camp Oakes property in order to verify the feasibility of a full-scale municipal well in this area. The depth and character of the alluvial aquifer system is largely unknown and is likely variable based on the proximity to bedrock outcrops in the area. It will be beneficial to verify that the well location is in an area of the greatest alluvial thickness and the sediments are permeable. Test drilling will enable the collection of borehole lithologic and hydrogeologic data necessary to confirm the hydrogeologic conditions specific to the site prior to constructing a well.

Three potential test drilling locations have been identified, as shown on Figure 6. It is envisioned that test boreholes can be drilled using a dual-tube reverse air drilling rig. The types of data to be collected would include (but not necessarily be limited to) soil type and characteristics, grain-size distribution, and geophysical logs. All boreholes would be drilled to the consolidated bedrock surface.

A pumping test is also recommended during test drilling to assess potential interference with the existing Camp Oakes Well No. 1. This could be accomplished by using the Camp Oakes Well No. 1 as the pumping well and completing one of the test boreholes as a monitoring well. If possible, it would be beneficial to conduct both step-drawdown and constant rate pumping tests. In the event that the permanent pump in Camp Oakes Well No. 1 is not a variable frequency type pump, then it may only be possible to conduct a constant rate test. The pumping test data will enable the estimation of aquifer properties that can be used to assess potential well yield. Drawdown in the monitoring well would be used to assess potential pumping interference that could be expected from operating two wells in close proximity.

Upon completion of the pumping test, it is recommended to collect groundwater samples from Camp Oakes Well No. 1 and have them analyzed for a full Title 22 suite of water quality constituents. This would confirm if the water quality meets regulatory requirements for municipal supply.

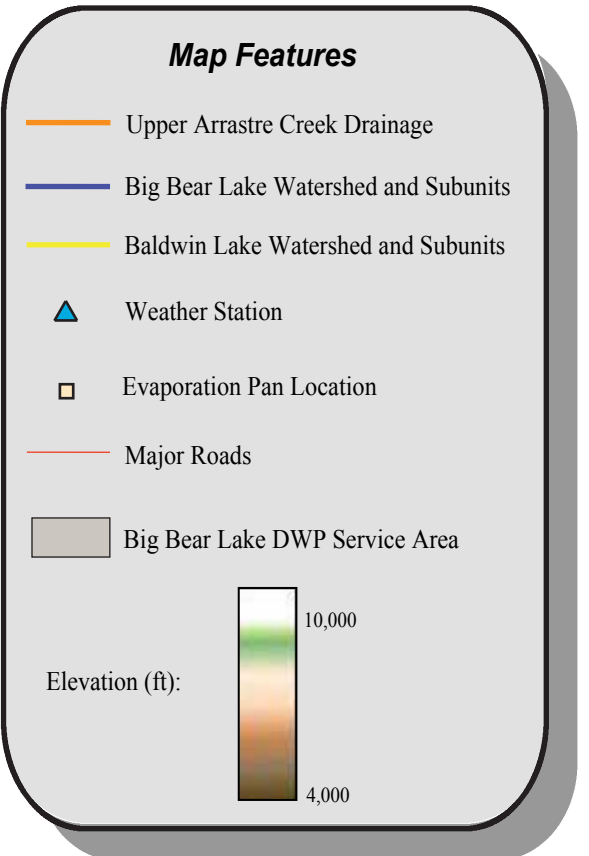
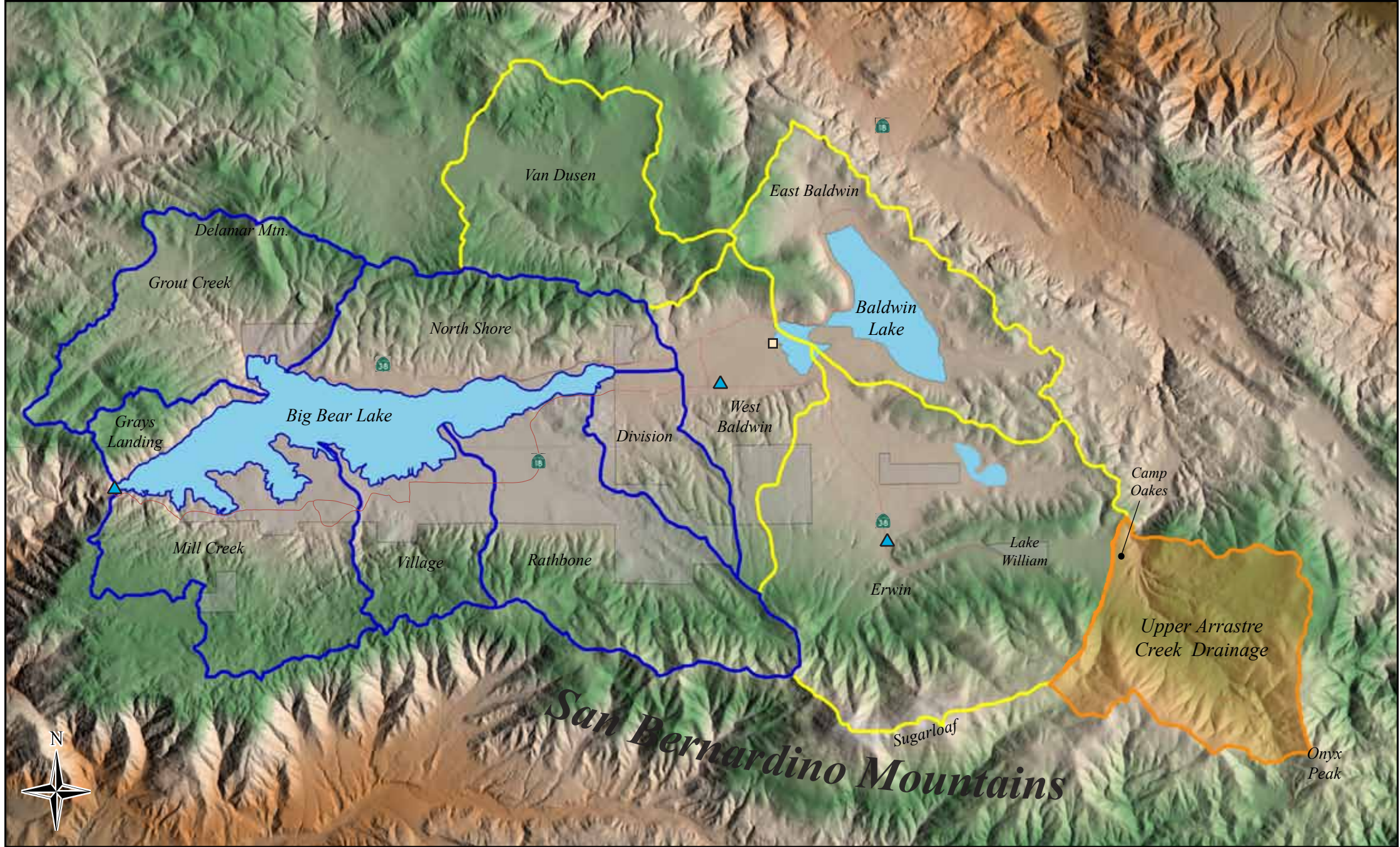
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Figures

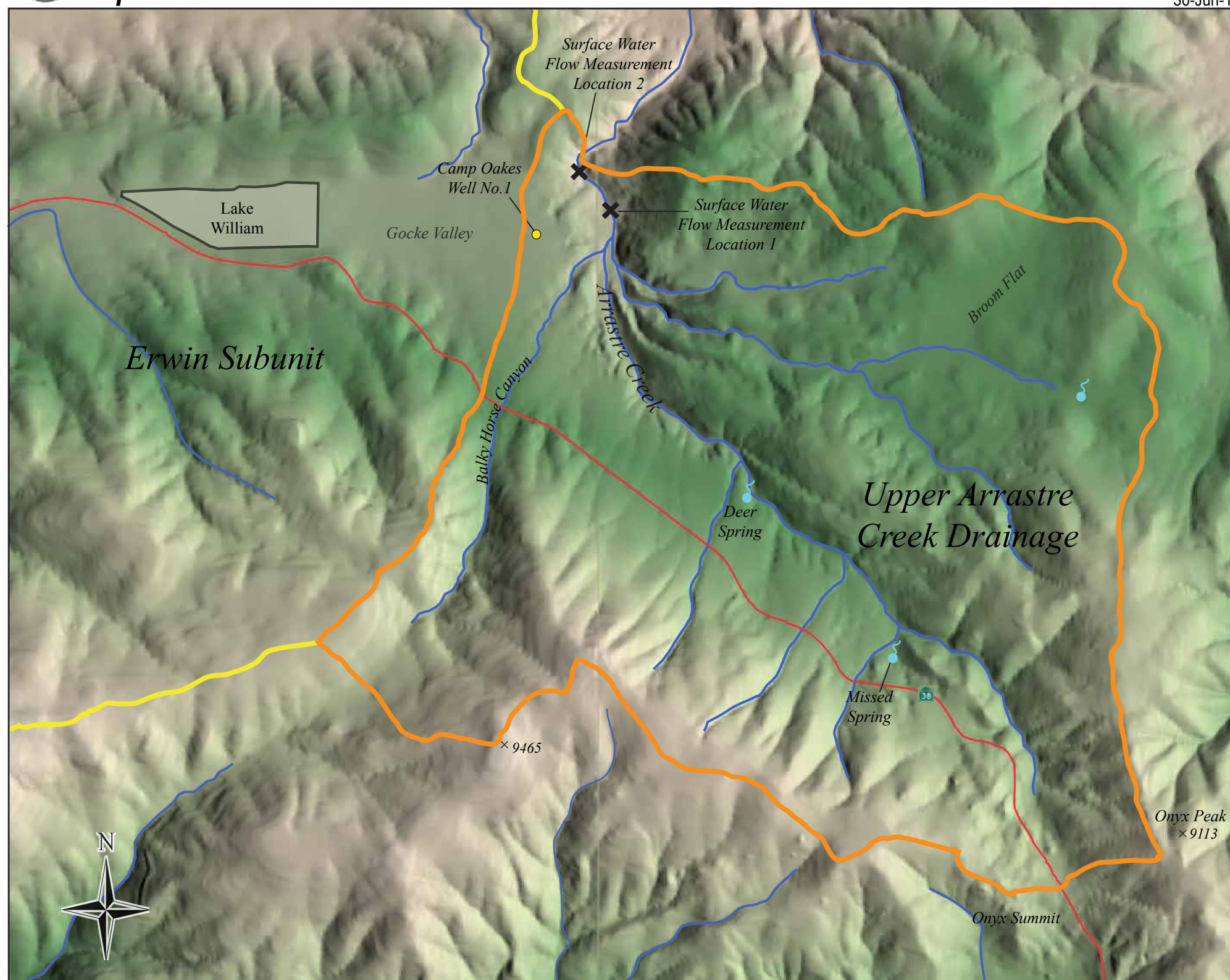


Analysis of Groundwater Resources
Upper Arrastre Creek Drainage



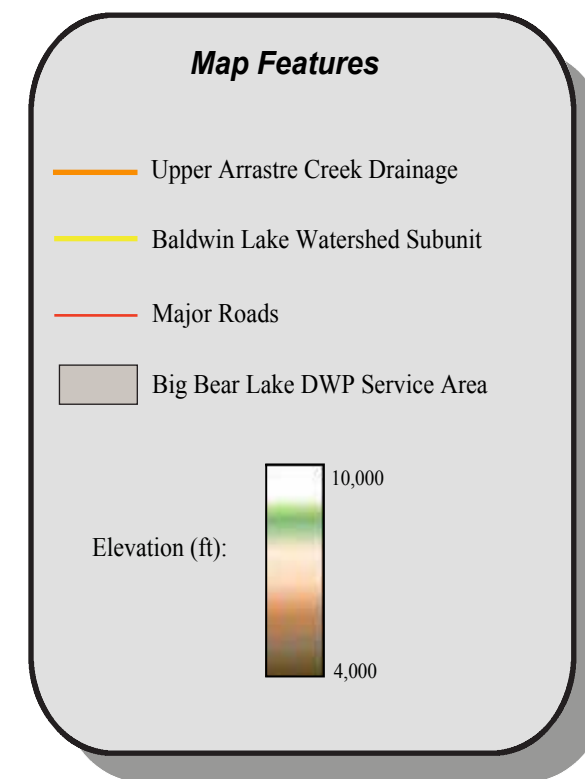


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0 Miles
NAD 27 UTM Zone 11 N.
Central Meridian: -117

Analysis of Groundwater Resources Upper Arrastre Creek Drainage



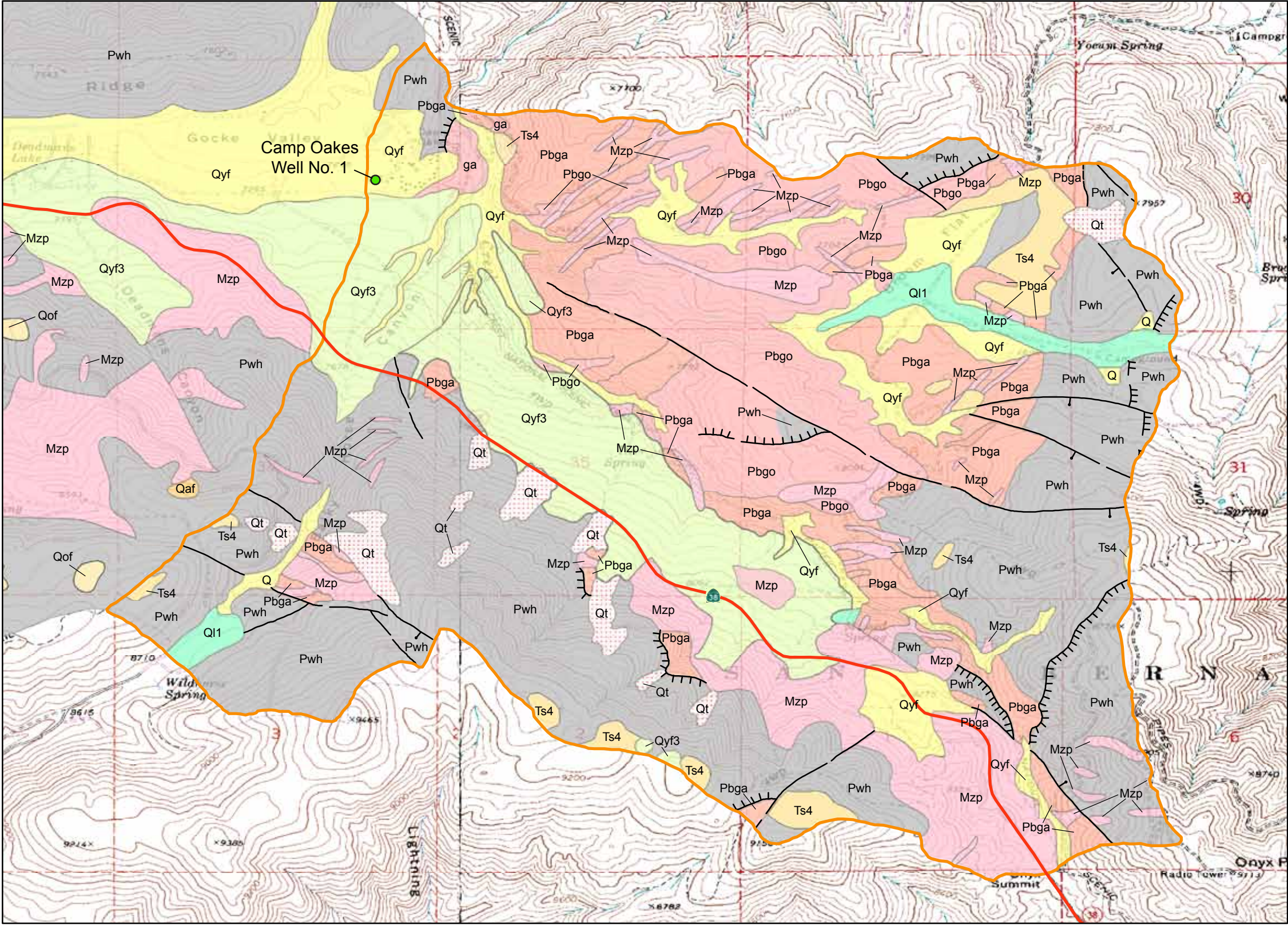
Area Setting



Upper Arrastre Creek Drainage
Figure 2



30-Jun-10



Map Features

- Upper Arrastre Creek Drainage
- Camp Oaks Well No. 1
- Fault
- Highway 38

Area Setting

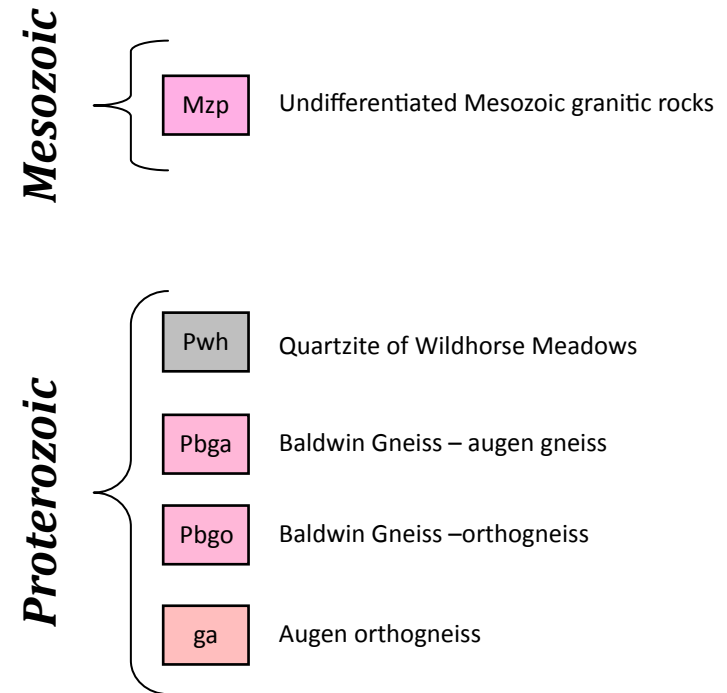
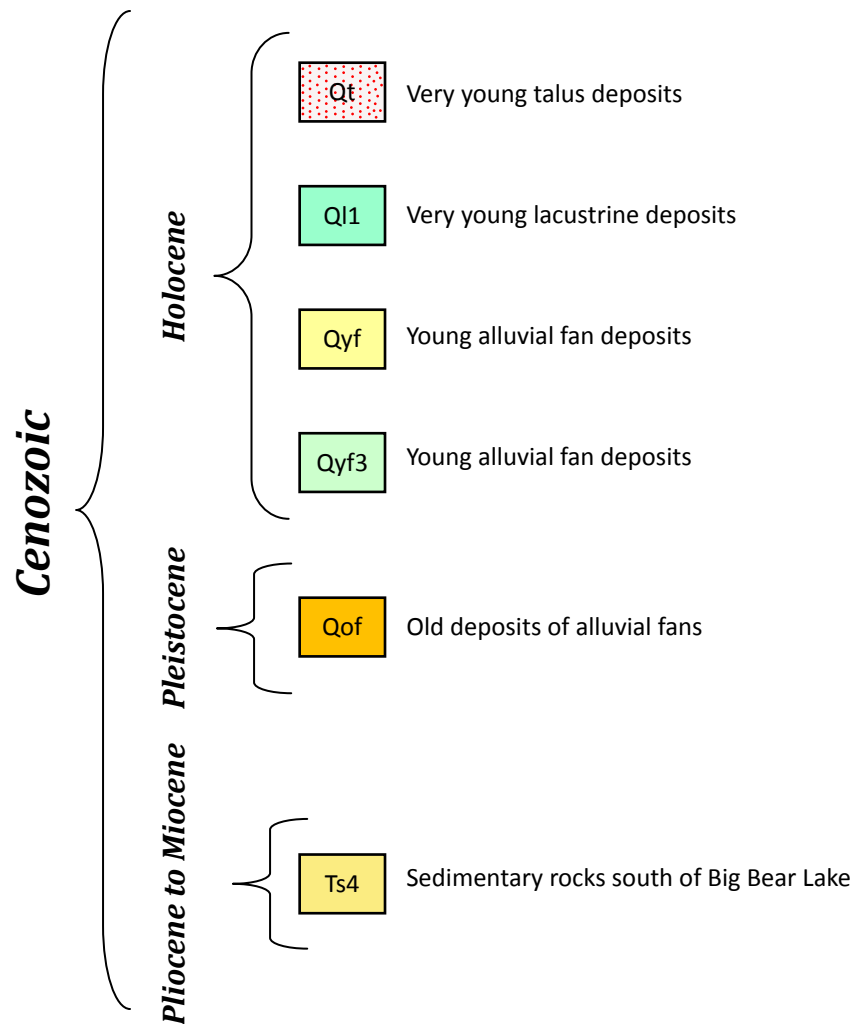




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Department of Water and Power

Analysis of Groundwater Resources
Upper Arrastre Creek Drainage

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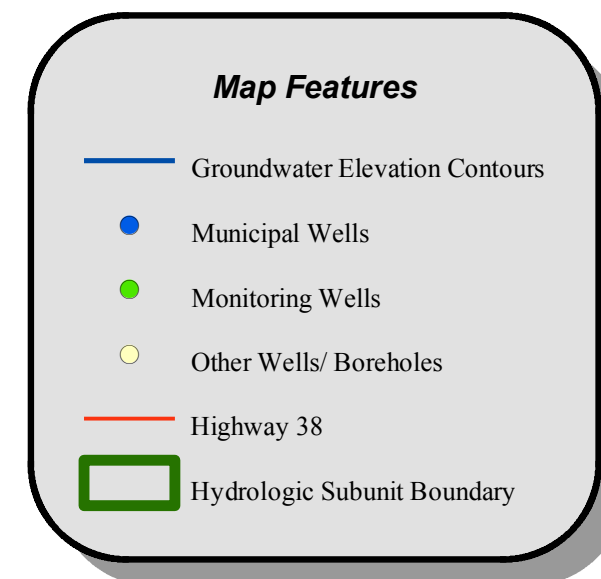
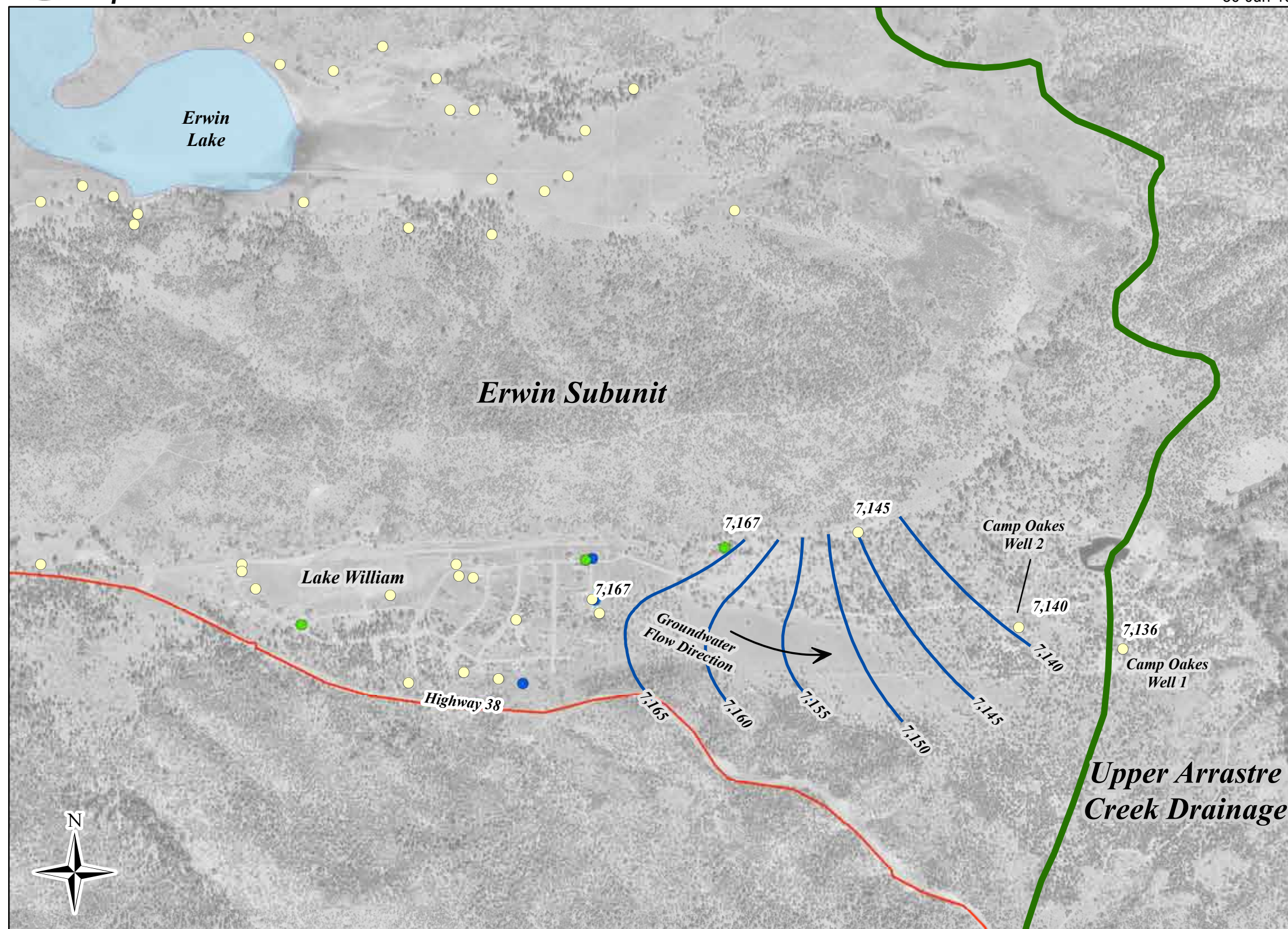


Explanation of Geologic Map Units

Figure 3a



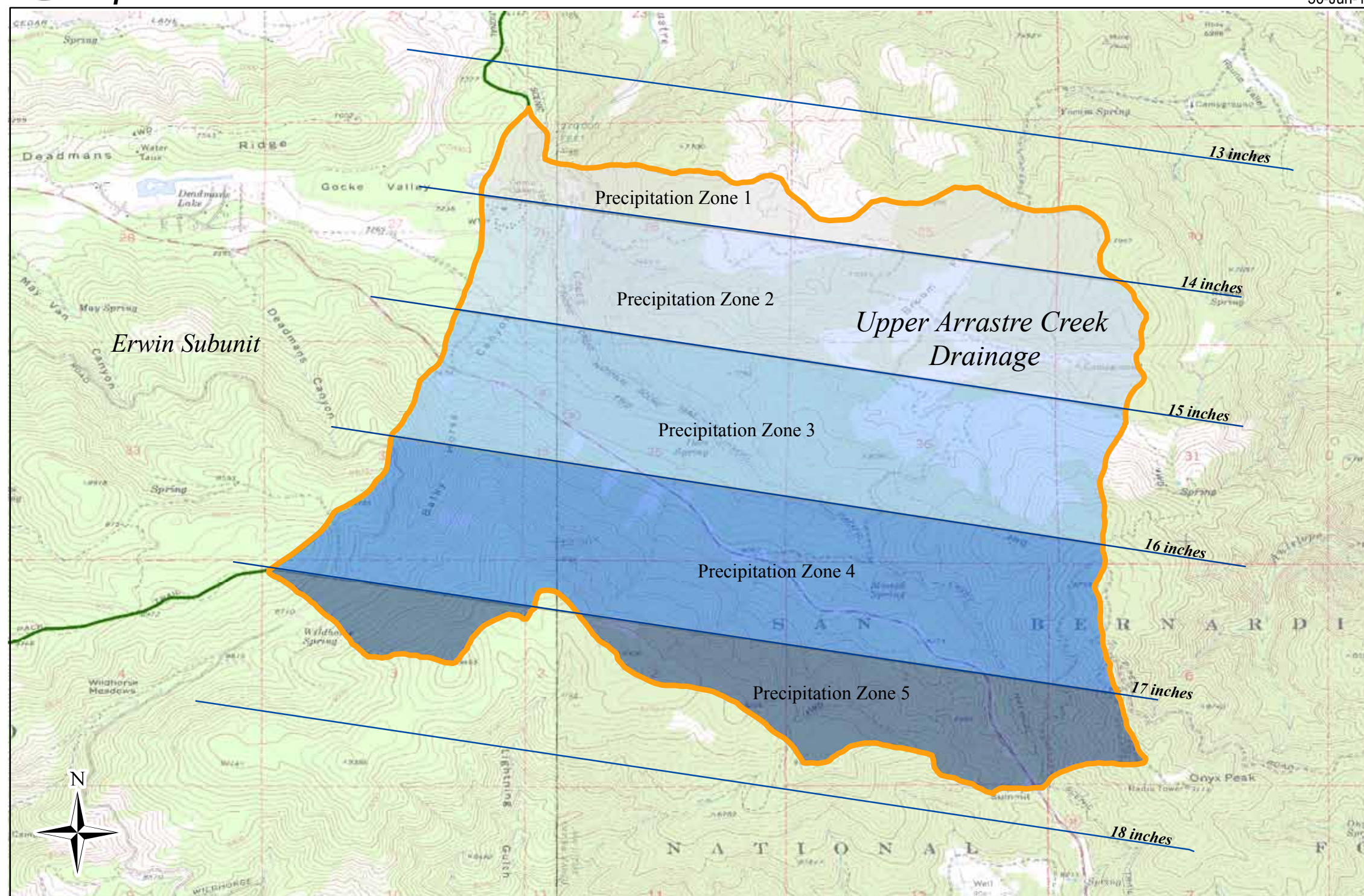
30-Jun-10



0 750 1,500 3,000 Feet
NAD 83 UTM Zone 11
Central Meridian: -117



30-Jun-10



0 0.375 0.75 1.5
Miles

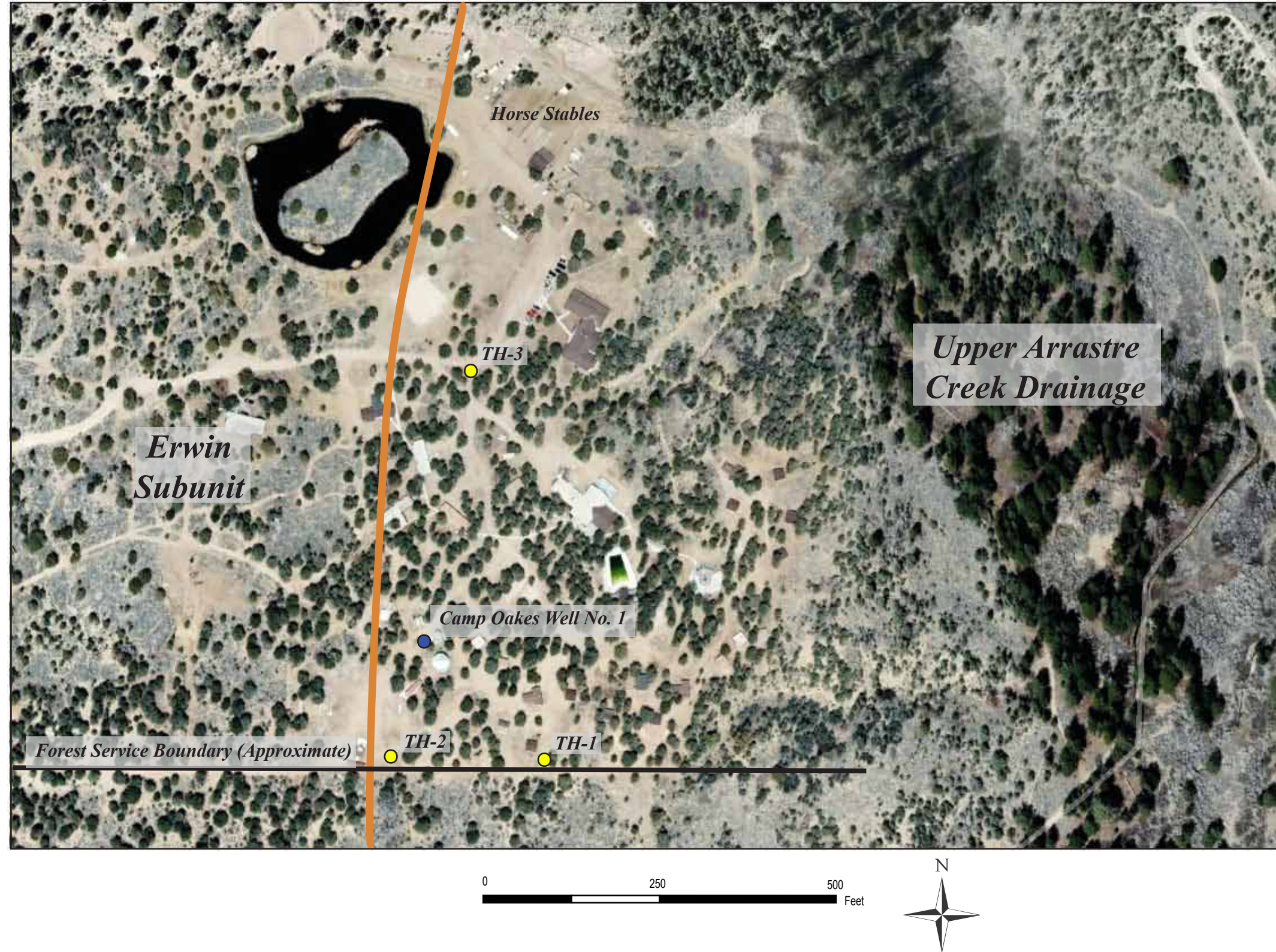
NAD 83 UTM Zone 11
Central Meridian: -117

Map Features

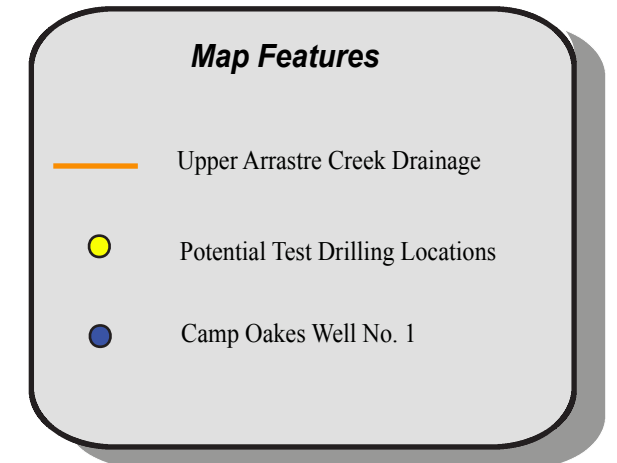
- Upper Arrastre Creek Drainage
- Isohyets
- Precipitation Zone 1
- Precipitation Zone 2
- Precipitation Zone 3
- Precipitation Zone 4
- Precipitation Zone 5

Area Setting





Analysis of Groundwater Resources Upper Arrastre Creek Drainage



Basemap Source: Google Earth, 2010

Area Setting



Tables

**Summary of Selected Water Quality Data¹
 Camp Oakes Wells**

Well Name	Collection Date	Nitrate as NO3 (mg/L) ²	Fluoride (mg/L) ²	Total Dissolved Solids
Camp Oakes Well No. 1	18-Nov-03	1.90	0.10	110
	1-Oct-03	<2	0.13	110
Camp Oakes Well No. 2	18-Nov-03	1.60	0.50	130
	1-Oct-03	2.00	0.14	110
MCL or Action Level		45 ³	2.0 ³	1,000 ⁴

Notes:

1- Source: Geoscience, 2004

2 - Milligrams per liter

3 - California Department of Public Health (DPH) Primary Maximum Contaminant Levels

4 - California DPH Secondary Maximum Contaminant Levels

Summary of Recoverable Water Estimates
Upper Arrastre Creek Drainage

Precipitation Zone ¹	Precipitation Zone Area (acres)	Percent of Drainage within Precipitation Zone	Estimated Average Annual Precipitation (in)	Potential Evapotranspiration Range ² (in)	P/ET ³	R/ET ⁴	Recoverable Water (in)	Adjusted Recoverable Water ⁵ (in)	Adjusted Recoverable Water (acre-ft/yr)	
1	444	8.75	13.75	29.7	0.463	0.075	2.228	1.337	49	
				31.8	0.432	0.055	1.749	1.049	39	
2	1,098	21.65	14.5	29.7	0.488	0.078	2.317	1.390	127	
				31.8	0.456	0.057	1.813	1.088	100	
3	1,263	24.90	15.5	29.7	0.522	0.090	2.673	1.604	169	
				31.8	0.487	0.078	2.480	1.488	157	
4	1,511	29.79	16.5	29.7	0.556	0.092	2.732	1.639	206	
				31.8	0.519	0.088	2.798	1.679	211	
5	756	14.91	17.25	29.7	0.581	0.094	2.792	1.675	106	
				31.8	0.542	0.093	2.957	1.774	112	
Total Drainage Area:	5,072	Weighted Average Precipitation (in):	15.69						Totals:	657
										618

Notes:

1 - See Figure 5

2 - Derived from pan evaporation rates at the BBCCSD station located as shown on Figure 1.

3 - Ratio of average annual precipitation to potential evapotranspiration (ET).

4 - Ratio of recoverable water to potential evapotranspiration (ET). Derived from charts provided in Crippen, 1965.

5 - Recoverable water was adjusted to account for geologic factors that effect the retention and runoff of surface water.
The geologic adjustment factor for recoverable water estimates was 0.6, based on Figure 10 in Crippen, 1965.

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