3. Existing Groundwater Conditions

3.1. Introduction

The goal of Chapter 3 is to review the potential for impacts to existing water wells in the vicinity of J.C. Boyle, Copco 1 & 2, and Iron Gate Dams, specifically impacts to static water levels (SWL) in the wells and potential increases in pumping head from the removal of the dams. There is no intent in this chapter to discuss potential changes in water quality in the wells or the river resulting from the removal of the dams. Nor is there any intent to discuss potential changes in water temperatures in the wells or river from the removal of the dams. It is assumed that the river and the groundwater system(s) were in equilibrium in terms of water chemistry and temperature before the dams were put into operation, and that they will return to near pre-dam equilibrium conditions once the dams are removed. The post-dam removal equilibrium will of course be modified by all the anthropogenic activities in the project area that have occurred and continue to occur since the dams went into operation.

3.2. Physiographic Setting and Regional Geology

The physiographic setting and regional geology of the Klamath River watershed as it pertains to groundwater is reviewed here. There is also a section on geological conditions as it relates to geomorphology in Section 5.

The Klamath River watershed covers four geomorphic provinces with distinctly different characteristics developed by, and indicative of, their geologic history. The head of the watershed begins in the Modoc Plateau Province (Figure 3-1), and abruptly transitions into the Cascade Volcanics Province (composed of the High Cascades sub-province and the Western Cascade sub-province) just west of Upper Klamath Lake (UKL). West of the Cascade Volcanics Province, in order, are the Klamath Mountains Province and the Coastal Range Province (Oakeshott, 1998). The three dams that are the subject of this report are all in the Cascade Volcanics Province. The Modoc Plateau Province has a strong influence on the character of the water, both surface and subsurface, in the Klamath Basin, and it will be discussed within this chapter as it relates to the occurrence and movement of subsurface water in the study area.

3.2.1. CASCADE VOLCANICS PROVINCE

Cascade Volcanics Province (CVP): is generally divided into two sub-provinces based on age and style of volcanism (Mertzman & Hazlett, 1997; Taylor, 1990): the Western Cascade Sub-Province (WCSP) and the High Cascades Sub-Province (HCSP).

The Western Cascade Sub-Province (WCSP) is the oldest and most eroded of the two sub-provinces (Figure 3-2). It is dominated by calc-alkaline continental margin andesites. The WCSP were extruded beginning some 40 Ma (mid-Tertiary; Oligocene time) in a back arc environment resulting from the subduction of the Juan de Fuca Plate under the North American Plate (Mertzman & Hazlett, 1997). USFS (2002a) describe the WCSP as:

> *The Western Cascades province is characterized as an older, deeply eroded volcanic range lying west of the more recent snow-covered High Cascade Range. They range in elevation from 1700 feet on the western margin to 5800 feet on the eastern margin. The Western Cascades began to form 40 million years ago with eruptions from a chain of volcanoes near the Eocene shoreline. Volcanic activity gradually shifted to the east in the Miocene and Pliocene.*
>
> *The Western Cascades are made up almost entirely of slightly deformed and partly altered volcanic flows and pyroclastic rocks which range in age from late Eocene to late Miocene. These rocks have been heavily dissected by erosion and the only evidence remaining of the many volcanoes from which they were erupted are occasional remnants of volcanic necks or plugs which mark former vents. There are also minor Pliocene to Pleistocene intracanyon lavas derived from the High Cascades or rare local vents (USFS, 2002a).*

The High Cascades Sub-Province (HCSP) is the younger of the two sub-provinces (Figure 3-2). The HCSP is of Quaternary age and is distinguished by lava flows, lava shields, pyroclastic flows, tuffs, cinder cones, and classic cone shaped stratovolcanoes. Volcanics consist primarily of basalt, andesite, and andesitic basalt with minor amounts of dacite and rhyolite although different volcanoes and even different eruptions from the same volcano can vary the proportions of the basalts, andesites, and andesitic basalts. Petrogrraphic analyusis indicates that all the volcanic are dominated primarily by olivine, plagioclase, clinopyroxene and opaques compositions (Robinson, 1995; Gaffney, 1994; Mertzman, 1995; Hill, 1995; Gravely, 1995). USFS (2002b) described the HCSP as:

> *The High Cascades province is characterized by a north-trending belt of upper Miocene to Quaternary volcanic rocks that were erupted on the east margin of the upper Eocene to Miocene Western Cascades province. The late Pleistocene record of this volcanic activity is well preserved on the crest of the High Cascades. The best exposed record of the early Pleistocene, Pliocene and late Miocene Cascade volcanism is found in volcanic and volcaniclastic deposits on the east flank of the range and in the adjacent Deschutes Basin.*
>
> *Upper Pliocene and Quaternary rocks of the High Cascades form a broad platform of chiefly basalt and basaltic andesite volcanoes that fill a structurally subsided zone in the older rocks of the High Cascades. Mt.*

Hood, Mt. Jefferson, Three Sisters-Broken Top, and Mt. Mazama (Crater Lake) are the four major Quaternary volcanic centers along this platform. These major volcanic centers have erupted lava flows and pyroclastic material that ranges in composition from basalt to dacite and with the exception of Mt. Hood have also erupted rhyolite (USFS, 2002b).

3.2.2. MODOC PLATEAU PROVINCE

The Basin and Range Province in south-central and south-eastern Oregon, which includes the Modoc Plateau Province (Figure 3-1), is the northwestern-most extent of the Basin and Range Physiographic Province (Figure 3-3). The Basin and Range Province is dominated by NW-SE tending grabens and horsts resulting from normal faulting associated with extensional tectonics. The grabens are commonly interspersed with lake bed deposits, shield volcanoes, cinder cones, and/or lava flows.

The Modoc Plateau Province is located in north-eastern California and south-central Oregon and is primarily a Californian nomenclature. Although the topographic, geologic, and structural features of the Modoc Plateau extend into Oregon, Idaho, and Nevada it is generally not called the Modoc Plateau in any of those three states. It is bounded to the west by the Cascades Province and to the eastern escarpment of the Modoc Plateau forms the western boundary of the distinctly fault block topography of the Basin and Range Province. The Modoc Plateau structurally resembles the Basin and Range Province in that it consists of NW-SE trending horsts and grabens, but unlike the Basin and Range Province, the grabens of the Modoc Plateau have been essentially filled in with volcanic deposits. Like the Cascades, the area is dominated by volcanic activity, but the volcanics are typical of fissure eruptions and form broad level plains and low shield volcanoes and were generally less explosive than those in the Cascades. The volcanics of the Modoc Plateau lithologically resemble those of the Columbia Plateau more than those of the Cascades or the Basin and Range (Miles and Goudey, 1998). Thus the Modoc Plateau is considered to be a southern extension of the Columbia River plateaus of eastern Oregon and Washington (Michaelsen, 2009; Norris and Webb, 1976). The Modoc Plateau is considered a transitional zone between the upper extent of the Basin and Range Province in Nevada and the southern end of the Cascade Province in northern California and southern Oregon. Shallow lakes (Upper Klamath, Lower Klamath, and Tule lakes) and marshes (Klamath Marsh) are prominent features of the Modoc Plateau’s extent into Oregon.

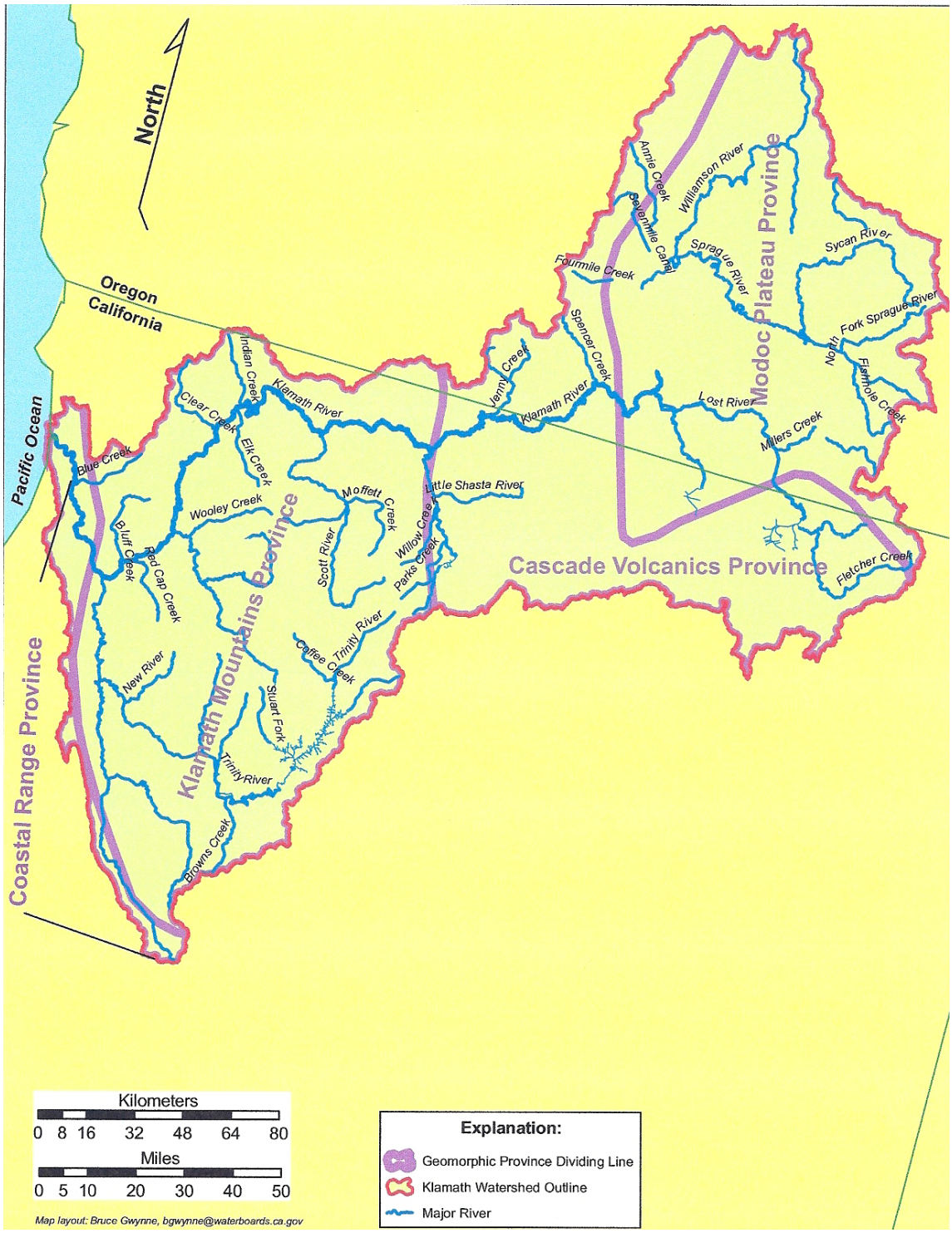


Figure 3-1. Physiographic Provinces of the Klamath River Basin. (after Oakeshott, 1978).

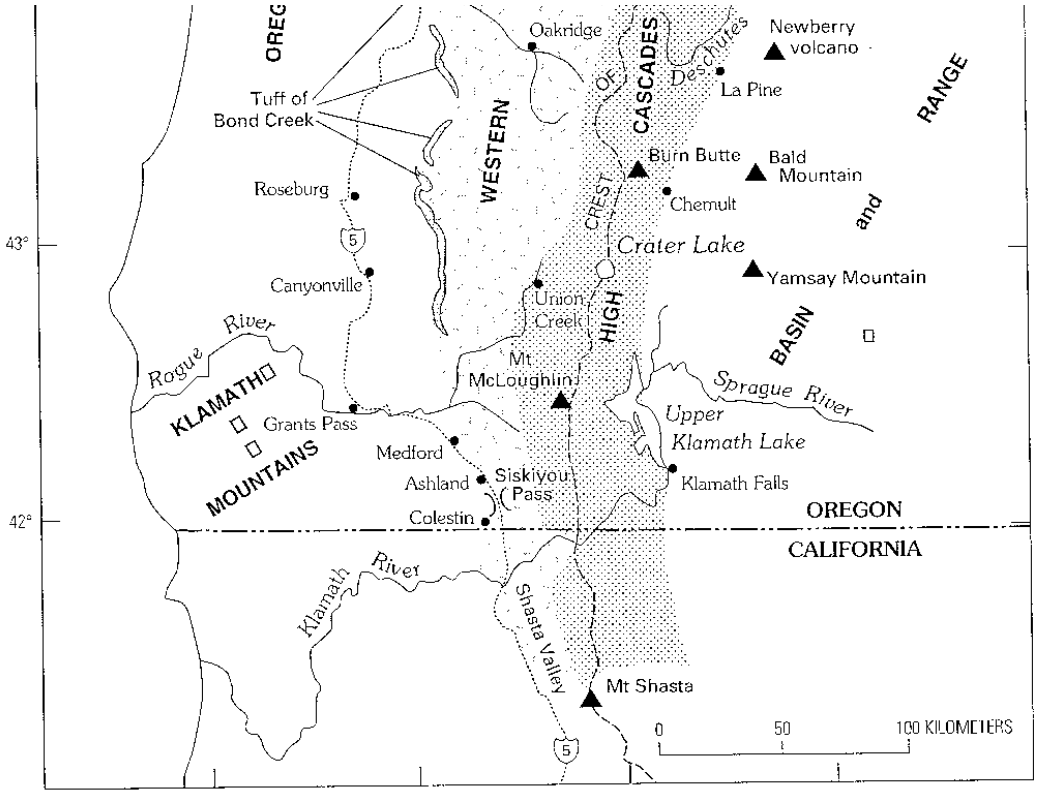


Figure 3-2. Map showing geographic locations, physiographic provinces, and subdivisions in the region of the Oregon-California border. Western and High Cascades sub-province extents are approximate. Modified from Sherrod and Smith, 2000 (Figure 1).

Figure 3-3. Index map of sub-provinces in the western United States. Downloaded from http://geomaps.wr.usgs.gov/parks/province/basinrange.html

3.3. Local Geology

Numerous geologic studies that include the reach of the Klamath River between Keno Dam and Iron Gate Dam were published in the 1970's, 80', and 90's with a significant number also being published between 2002 and 2009. The region is a complex mixture of geologic units (Figure 3-4 and Figure 3-5) that are dominated by extensive volcanic terrains composed of several different and distinct chemical compositions. Sherrod and Smith (2000) state:

> "*The Cascade Range suite of volcanic, volcaniclastic, and nonvolcanic sedimentary rocks is stratigraphically complex compared to miogeoclinal or continental-shelf sedimentary rocks. The complexity results from the intricate way in which volcanic and volcaniclastic rocks were formed, deposited, and reworked in a subaerial arc environment. Hundreds of small overlapping and intertonguing volcanogenic and sedimentary units compose the range; thus, individual lithostratigraphic units are discontinuous and commonly intricately interbedded. In addition, the rocks are poorly exposed in many places, and distinctive widespread marker units are uncommon. Lithologic correlations, even of similar stratigraphic sequences, are unreliable without corroborating isotopic ages or detailed mapping.*"

They continue on to say:

> "*. . . volcaniclastic sediment derived from a major volcano laps onto an older eroded volcano and simultaneously interfingers with contemporaneous deposits that were derived from other volcanoes (fig. 2A). The resulting suite of volcaniclastic rocks represents many different depositional environments and volcanic sources. Intermittently erupted lava flows, highly mobile ash flows, and large-volume debris flows may travel long distances down valleys. Far downstream these flows become interlayered with fine-grained, thin-bedded volcaniclastic deposits that are characteristic of a low-energy depositional environment. Large andesitic to dacitic volcanoes construct aprons of pyroclastic and epiclastic debris derived from dome growth and eruptions higher on their flanks. Basaltic shield volcanoes overlap and interfinger with one another and with volcaniclastic sediment.*

Newcomb (1961) discusses the "Hydrology of Volcanic-Rock Terranes" in the Columbia River Basalt. As the volcanics of the Modoc Plateau have been related lithologically to the Columbia Basalts, Newcomb's descriptions likely apply to the volcanics in the study area. Newcomb describes the average flow as a dense, nearly flintlike, partially fractured rock at the base and grading vertically to dense, massive columnar-jointed rock at its center; and often vesicular – and in some places rubbly at the top. Systems of cooling fractures create irregular columnar, cubical, and platy blocks ranging up to 60 inches across. Water moves through the sequence of flows primarily in the permeable zones at the top of flows which can

be up to 10 feet thick. If a highly jointed flow connects two of these permeable zones then the water bearing unit may be quite thick.

The massive centers of many flows are relatively impermeable, and when several individual flows are stacked successively thick sections of non-water bearing zones are formed. These units can cause perched water tables above the regional water table, or can isolate water-bearing zones so that they have no interconnectivity which can result in water-bearing zones having significantly different piezometric levels.

Water that percolates into these materials will follow the path of least resistance which will be laterally through the permeable layers on the top of some flows and vertically through the highly fractured flows. Newcomb (1961) noted that where the strata are inclined, the water level will lie at or near the level of the principal streams. Water will travel laterally from anticlinal structures to synclinal structures where the water level may lie at or near the drainage level, or be under confined pressures.

Fault zones, vertical barriers such as dikes, termination of the permeable zone on the top of one flow by a later flow, or other processes that can alter or obliterate a permeable layer can impede or stop the flow of water completely. In such a situation, the groundwater will back up behind the barrier and a groundwater 'reservoir' may be created.

In addition to Sherrod and Smith (2000), several other investigators mention features similar to those described by Newcomb (1961). Gaffney (1994) mentions that in her study area "*Most of the units contain more than one flow, which can be seen in the field by a rubbly layer at the base and high vesicularity at the top of the flow*." Hill (1995) states that in her study area ". . . *exposes pyroclastic layers of fine ash, cinder/lapilli, and agglomerate layers with large clasts . . . blocks and bombs are also present and form a lag deposit on the surface where the finer material has weathered away. No lava flows were found . . .*" Norris and Webb (1975), when discussing the structure of the California Cascades, state "*Faulting has been important throughout the development of the California Cascades . . the lowest beds are folded and eroded but the highest are horizontal . . . During andesitic (earlier) volcanism, block faulting occurred, magma emerged along some of the faults, and cones and domes developed. Before and during basaltic (later) flow eruptions, ether was vertical faulting . . . young faults cut the basaltic sequences.*" Norris and Webb also state "*The block faulting that was more or less continuous during early Tuscan deposition produced enclosed drainages in which water collected. Alluvial fan, delta, and lake bed deposits, including water-laid ash, tuff, and diatomite accumulated in the lake basins. Sometimes deposition of the lake sediments was interrupted by lava flows. Many basaltic flows throughout the province show well –developed columnar jointing and possess weathered zones and fossil soils.*" All this suggests that in the study area it cannot be assumed that there is any extensive lateral or vertical connectivity within the

volcanic materials, nor can it be assumed that there is no vertical connectivity between layers.

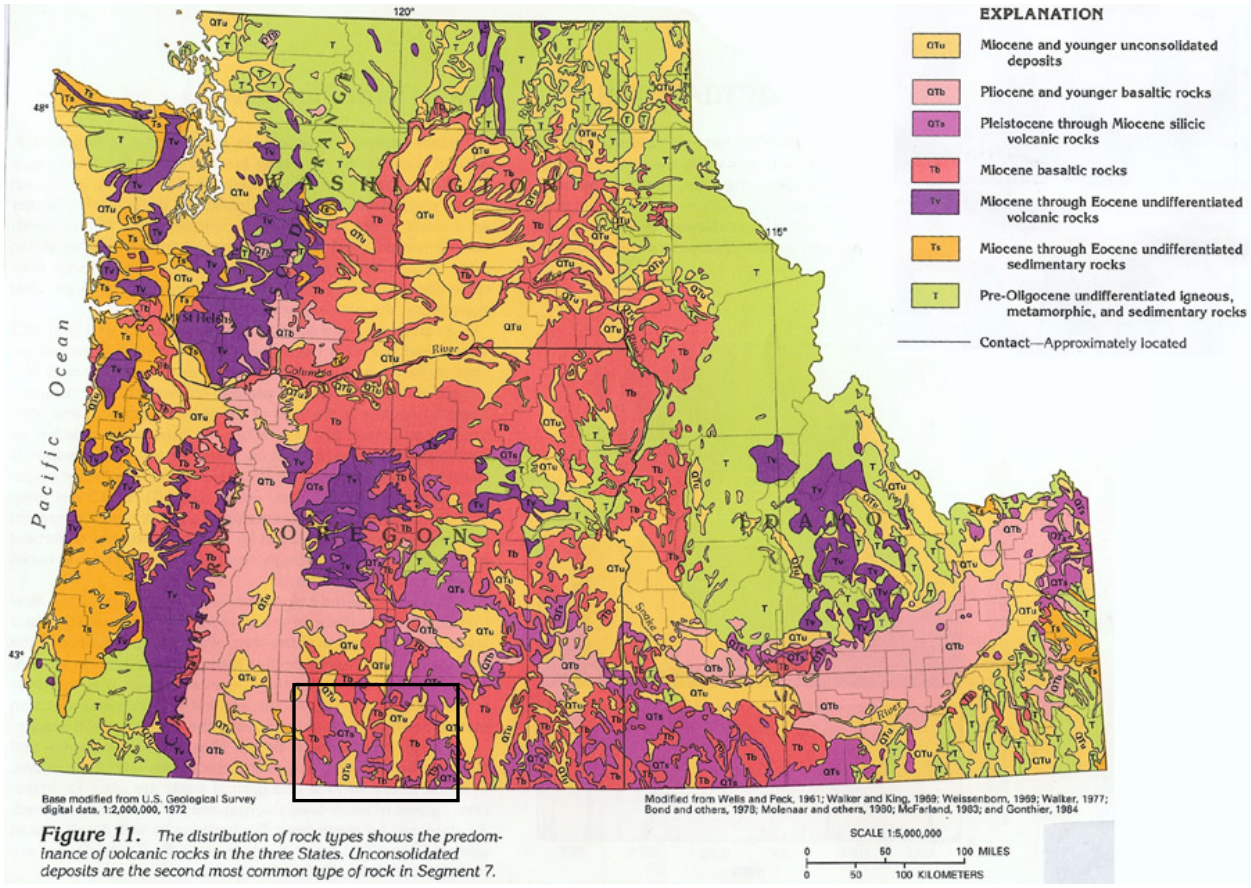


Figure 3-4. Generalized Geology for Washington, Oregon, and Idaho (after Figure 11, USGS Hydrologic Atlas Segment 8, HA 730-H). Box outlines the general region of the Upper Klamath Basin in Oregon in the vicinity of Upper Klamath Lake and Klamath Falls.

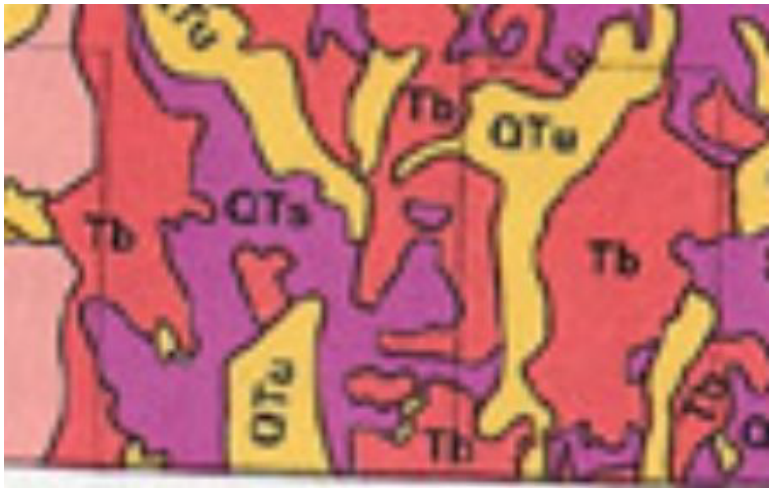


Figure 3-4a. Enlarged view of boxed area in above figure.

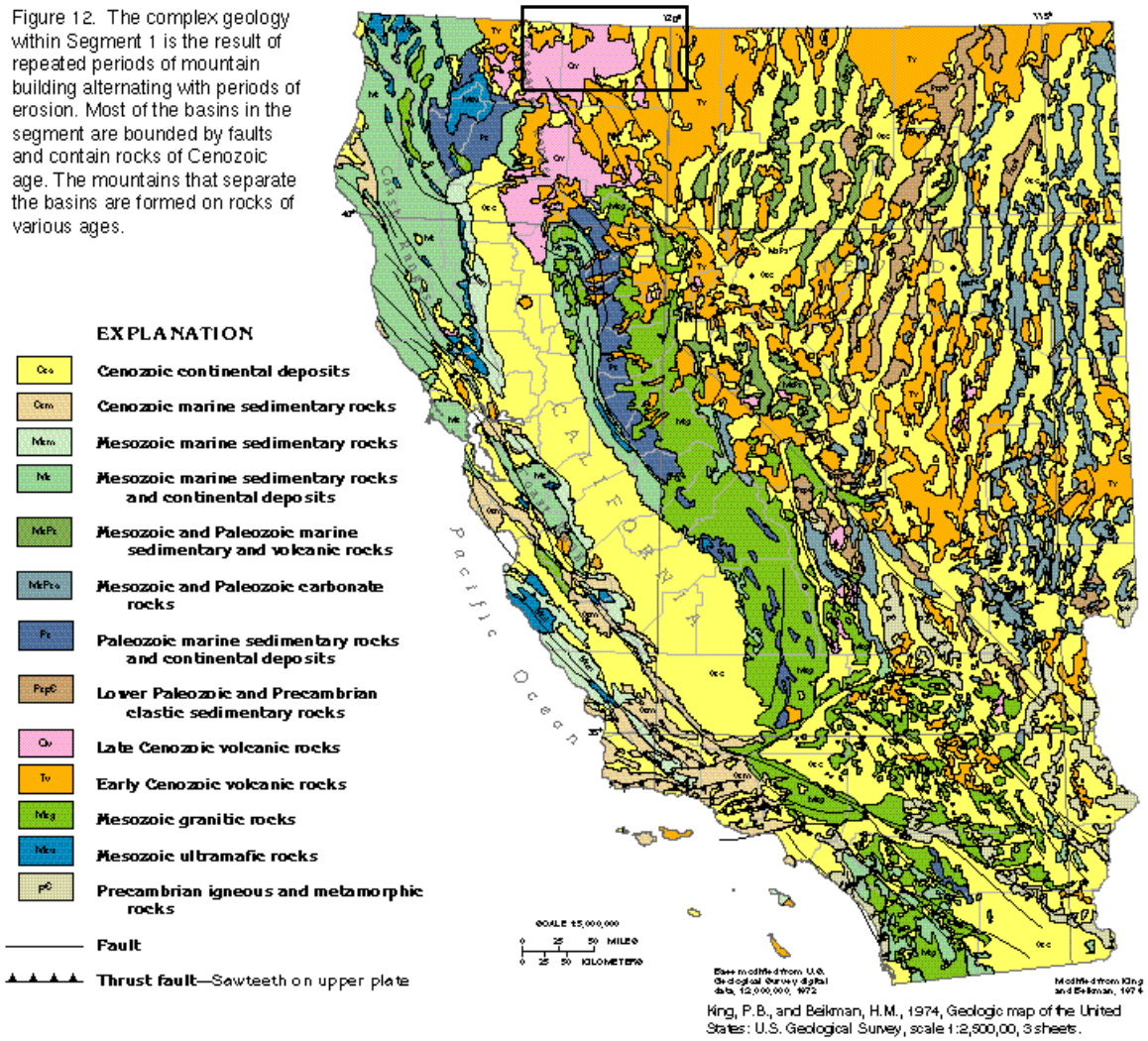


Figure 3-5. Generalized Geology of Nevada and California (after Figure 12, USGS Hydrologic Atlas Segment 1, HA 730-B). Box outlines the general region of the Upper Klamath Basin in California.

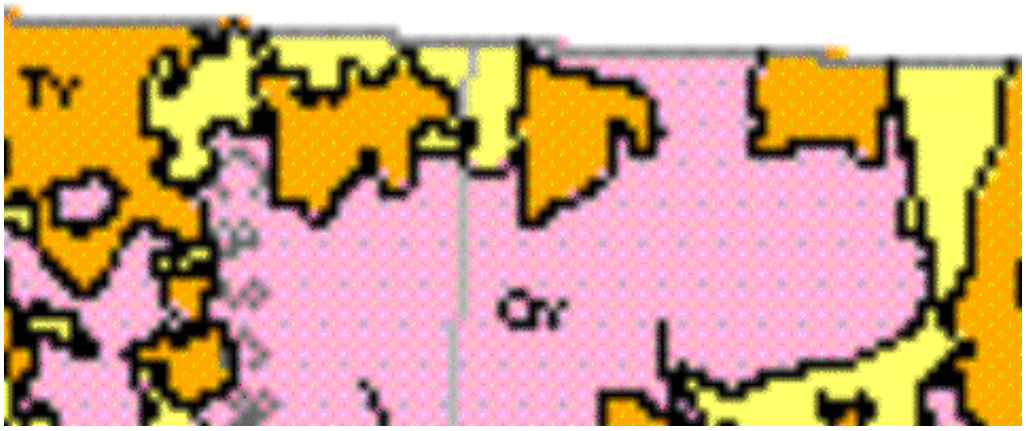


Figure 3-5a. Enlarged view of boxed area in above figure.

3.4. Klamath River Study Area

The river reach within the area that will likely be affected by the removal of the three dams consists of the river between Keno Dam, OR and Iron Gate Dam, CA. Within that reach, there is a section that is known as the Klamath River Gorge, which is generally between Keno and Copco Dams. While just about the entire length of the reach between Keno and Iron Gate Dams has exposures of bedrock it is the Klamath River Gorge section that is reported to have the best exposures (Gaffney, 1994). The best exposures are in a 2-3 km (1.2 – 1.8 miles) stretch identified as 'Long Point'. Within the Klamath River Gorge area, the volcanics have been subdivided many different ways.

Walker (1985) divided the KRG volcanic into two units: an older unit of mildly alkaline basalts, which he informally referred to as the lower Outerson formation; and an overlying younger unit of calc-alkaline basalts, basaltic-andesites, and andesites referred to as the upper Outerson formation. Walker identified the basal contact between these Pliocene lavas and the underlying Western Cascade series as a prominent disconformity marked by a thick soil horizon; the upper contact with the overlying Pleistocene lavas is an angular unconformity. Walker differentiated the mildly alkaline lower Outerson lavas from the overlying calc-alkaline rocks by distinctly higher percentages of P_20_5, $Ti0_2$, iron, and alkalis.

As mentioned previously, Gaffney (1994) identified ten volcanic units in the KRG consisting of basalts and andesites. The most voluminous units come from the Hayden Mountain and Chase Mountain basaltic andesitic cones. The flows from these two volcanic centers interfinger spatially and temporally with flows from the other eight units in the area. Most of the units reportedly consist of more than one flow, where flows can be distinguished in the field by a rubbly layer at the base and high vesicularity at the top of the flow.

Robinson (1995) identified eight distinct units in the area – seven of volcanic origin and one Quaternary alluvium unit. Many if not most, of the studies along and across the river, including studies both upstream and downstream of 'Long Point', have focused on the geochemistry and petrology of the volcanics and generally only have rudimentary geologic descriptions of the units. Few of the studies have descriptions of unit thicknesses, bedding, jointing, faulting, orientation, or other common characteristics usually found in geologic reports.

3.5. Hydrology

3.5.1. GENERALIZED SURFACE HYDROLOGY

For a more detailed discussion of the surface hydrology, see Chapter 2. This chapter will only discuss the surface hydrology as it relates to the groundwater hydrology.

The Sprague and Williamson Rivers drain the Modoc Plateau portion of the upper Klamath Basin (KB) and merge some 10 river miles upstream of, and discharge into, Upper Klamath Lake (UKL). The Klamath River is generally considered to begin at the point of outflow from UKL (Gannett, et al, 2010). The KB is often divided into an upper and lower basin. The boundary between the upper and lower basin has variously been placed near Keno, Oregon or at Iron Gate Dam in California. Placing the boundary near Keno establishes the boundary at the point where the river crosses the transition zone from the relatively flat valleys of the Modoc Plateau Province to the more mountainous terrain of the High Cascades sub-province (Figure 3-1 and Figure 3-2). When placed at Iron Gate dam (Gannett, et al, 2010), the boundary would roughly coincide with where the Klamath River crosses the transition from the Cascade Volcanics Province (including the High Cascade and Western Cascade sub-provinces) to the Klamath Mountains Province (Figure 3-1 and Figure 3-2). This location also corresponds roughly to where the predominantly permeable volcanic terrain of the Cascade Volcanics Province transitions to older, less permeable rocks of the Klamath Mountains Province (Gannett, et al, 2010). By placing the boundary at Iron Gate Dam, the upper basin would include Reclamation's Klamath Project. The convention of placing the boundary between the upper and lower basins at Iron Gate Dam is followed in this chapter.

3.5.2. GROUNDWATER HYDROLOGY

Newcomb and Hart (1958) conducted the earliest investigation into the water resources of the Klamath Basin. The goals of the investigation were three-fold:

1. Recognition and inventory of the ground-water contributions to the surface water in the Klamath Basin and any significant diversions of surface water to the ground-water reservoirs, as well as significant diversions of water from or into the basin through percolation of ground water.

2. Recognition of the principal factors governing the ground-water regime and the water resources available for development.

3. Collection of geologic and hydrologic information pertinent to the development and use of the groundwater resources.

Accordingly, they summarized the primary factors that would influence a water budget including but not limited to: physiography of the basin, rocks composing the basin, surface water drainage, groundwater, population and settlement patterns, vegetation, climate, and geologic setting.
In terms of the hydrologic regime, they described the characteristics of the aquifers. They essentially had four aquifer types; 1) the lower lava rocks, 2) the upper lava rocks, 3) alluvium of Quaternary age, and 4) pumice of Quaternary age. As part of their database, they collected data on many of the springs and wells in the study area and indicated that the "*. . . regional body of ground water*

has a water level near the local base level of the major streams. Although this ground-water body is a single hydrologic unit, interstream divides separate it into four main segments which are treated below as hydrologic subunits. The areas constituting these subunits are (1) the Klamath Marsh area, (2) the Sprague River valley, (3) the Cascade Mountain slope south of Annie Creek valley, and (4) the valleys of the Lost River drainage system in Oregon."

Newcomb and Hart identified the source of the large springs as the upper and lower lava rocks and the pumice of Quaternary age – in the sense that the springs emerge from these units "*. . . where they are exposed at the land surface by faults, erosion, or other geologic conditions*." They also state "*. . . considerable flow is added to the Klamath River from numeroud spring in a 9 mile stretch of the river canyon below the Highway 66 bridge . . . undoubtedly many more springs occur in the river bed, where permeable water-bearing zones of the lower lava rock have been cut through be the canyon. Below that reach the river cuts into older rocks that are practically impermeable; therefore, little or no ground water is believed to enter the river in Oregon downstream from sec. 3, T. 41 S., R. 6 E."* The Highway 66 Bridge is just upstream of J.C. Boyle Dam – which was completed in 1958. Sec. 3, T. 41 S., R. 6 E. is about four river miles downstream of the stretch of river known as 'Long Point' and roughly 3.5 river miles upstream of the Oregon-California border and so would be well upstream of Copco 1 & 2 Dams. Although the authors mention springs in the Klamath River in the reach known as Klamath River Gorge, they do not report any locations or flows for those springs. Likewise, none of the wells that they used for water level measurements were within the Klamath River Gorge downstream of Keno Dam. With the exception of a few wells in and around Keno, there were only two wells 'downstream' of Keno. One was about 1 mile north of the river near Oatman Lake and the other was about 3 miles south of the river just east of Chase Mountain. It would be unlikely that there would be much development around what would become J.C. Boyle Reservoir in 1954 when they collected their water level readings from wells as the dam was just not put into operation until 1958.

Gannett, et al, (2010) completed the first extensive investigation of the groundwater resources in the Upper Klamath Basin. The study area for Gannett, et al. included the entire Upper Klamath Basin above Iron Gate Dam in California (Figure 3-6). As described previously the volcanics in the Klamath River Gorge between Keno and Iron Gate Dams can be divided into many units based on their ages, composition, and style of eruption and/or deposition. That is all well and good for the geochemist or straight geologist – but to understand the hydrologic processes at work in the area, the hydrologic properties of the materials must be identified. Geologic units need to be regrouped according to their hydrologic properties – regardless of their geochemical, age, and/or depositional characteristics. Materials with vastly different characteristics can, and often do, have similar hydrologic properties. Gannett, et al. generalized the many distinct and mappable geologic units in the Upper Klamath Basin into eight hydrogeologic units as shown in Figure 3-7. Figure 3-7a is an enlargement of the area of the Klamath River downstream to Iron Gate Dam and significantly south

of the Oregon-California border. The explanation of the map units is given in Figure 3-7b.

Table 3-1. Generalized hydrogeologic units in the upper Klamath Basin, Oregon and California (after Gannett, et al, 2010, Table 1, pg 12).

Hydrogeo-logic unit	Map symbol	Lithologic and hydrologic characteristics
Quaternary sedimentary deposits	Qs	Fine- to coarse-grained sediments deposited in stream valleys and major lake basins. Permeable coarse-grained deposits occur in stream valleys and locally in the lake basins. The lake basin deposits are, however, predominantly fine grained and have low permeability.
Quaternary volcaniclastic deposits	Qvp	Pyroclastic flows and air fall material (pumice, ash, and lapilli) deposited during the climactic eruption of Mt. Mazama that formed Crater Lake, and debris avalanche deposits of the Shasta River Valley. Air fall deposits are highly permeable. Pyroclastic flows and debris deposits may have low permeability.
Quaternary volcanic rocks	Qv	Basaltic and andesitic lavas and vent deposits occurring in the Cascade Range and around Medicine Lake Volcano. These materials are generally highly permeable, but may not be saturated at high elevations.
Quaternary to late Tertiary sedimentary rocks	QTs	Fine- to coarse-grained unconsolidated to moderately indurated sedimentary deposits. The hydraulic characteristics of this unit are not well known but lithologic descriptions on maps suggest it may be moderately permeable at some locations. This unit has very limited distribution.
Late Tertiary sedimentary rocks	Ts	Predominately fine-grained continental sedimentary deposits including bedded diatomite, mudstone, siltstone, and sandstone. This unit has generally low permeability but contains permeable strata at some locations.
Late Tertiary volcaniclastic rocks	Tvpt	Palagonitized basaltic ash and lapilli deposits associated with eruptive centers. The hydrologic characteristics of this unit are not well known, but springs are known to emerge from basal contact with unit Ts. This unit is most prominent in the Sprague River valley.
Late Tertiary volcanic rocks	Tv	Predominantly basaltic and andesitic lava flows and vent deposits with lesser amounts of silicic domes and flows. This unit has moderate to high permeability and is by far the most widely developed aquifer unit in the study area. Permeability is locally diminished by hydrothermal alteration and secondary mineralization.
Older Tertiary volcanic and sedimentary rocks	Tovs	Miocene and older volcanic and volcaniclastic deposits. The permeability of this unit is generally low due to weathering, hydrothermal alteration, and secondary mineralization. This unit is generally considered a boundary to the regional ground-water system of the upper Klamath Basin.

Gannett, et al (2010) further described the hydrogeologic units as:

> *Early to mid-Tertiary volcanics and sediments (Tovs), the oldest hydrogeologic unit in the study area, comprises Miocene and older lava and volcaniclastic rocks of the Western Cascade subprovince along the western margin of the study area, as well as older volcanic deposits beneath late Tertiary lavas along the eastern margin. The unit also includes older rocks exposed in the Pit River Basin southeast of the study area. The permeability of this unit is generally low due to weathering, hydrothermal alteration, and secondary mineralization. This unit is herein considered a boundary to the regional ground-water system of the upper Klamath Basin.*
>
> *Late Tertiary volcaniclastic deposits (Tvpt) include palagonitized basaltic ash and lapilli deposits associated with eruptive centers. The hydrologic characteristics of this unit are not well known, but springs emerge from basal contact with unit Ts. This unit is most prominent in the Sprague River Valley.*
>
> *Late Tertiary sedimentary rocks (Ts) consist predominately of fine-grained continental sedimentary deposits that include bedded diatomite, mudstone, siltstone, and sandstone. This unit has generally low permeability. These deposits occur throughout the central part of the upper Klamath Basin. They are exposed in uplands in interior parts of the basin and penetrated by wells in the river valleys. Lithologic logs of wells in the Sprague River Valley indicate that the thickness of these sedimentary deposits there locally exceeds 1,500 ft.*
>
> *Late Tertiary volcanic rocks (Tv) consist predominately of basaltic and andesitic lava flows and vent deposits, but the unit includes local silicic domes and flows. This unit is locally affected by hydrothermal alteration and secondary mineralization. This is the most geographically extensive hydrogeologic unit, occurring throughout most of the upper Klamath Basin. The unit has moderate to high permeability and is by far the most widely developed aquifer unit in the study area.*
>
> *Quaternary to late Tertiary sedimentary rocks (QTs) consist of medium- to coarse-grained unconsolidated to moderately indurated sedimentary deposits. The hydraulic characteristics of this unit are not well known, but lithologic descriptions on maps suggest that it is moderately permeable at some locations. This unit occurs locally in the western Wood River Valley, south of Klamath Falls, and in the uppermost Williamson River sub-basin.*
>
> *Quaternary volcanics (Qv) consist primarily of basaltic and andesitic lavas and vent deposits occurring in the Cascade Range and around Medicine Lake Volcano. These materials are generally highly permeable.*

Quaternary volcaniclastic deposits (Qvp) consist primarily of pyroclastic flows and air-fall material (pumice ash and lapilli) deposited during the climactic eruption of Mt. Mazama that formed the caldera encompassing Crater Lake. This unit is most extensive in the Cascade Range around Crater Lake and in the upper Williamson River sub-basin. As mapped (fig. 4), the unit also includes debris avalanche deposits in the Shasta River Valley outside of the study area. Minor Quaternary pyroclastic deposits occur on Medicine Lake Volcano and in Butte Valley. Air-fall deposits are highly permeable.

Quaternary sediments (Qs) include the alluvial deposits in principal stream valleys, glacial deposits in the Cascade Range, and basin-filling sediments in the major lake basins. The basin-filling deposits are generally fine grained and have low permeability. Coarse facies occur at some locations within the basin-filling deposits.

Hydrogeologic unit descriptions from three sub-basins of the UKB (all within the Modoc Plateau Province) – Tule Lake, Lower Klamath Lake sub-basins, and the Butte Valley basin – have very similar descriptions (California Department of Water Resources, California Groundwater, Bulletin 118, 2004a, 2004b, 2004c) and are also similar to the descriptions of Gannett, et al. The principal water-bearing formations in the Tule Lake sub-basin include Tertiary to Quaternary lake deposits and volcanic. The principal water-bearing formations in the Lower Klamath Lake sub-basin include Quaternary alluvium, Tertiary sediments, Tertiary deposits of diatomite, and Tertiary to Quaternary lake deposits and volcanics. The principal water-bearing formations in the Butte Valley basin are Pleistocene to Holocene age alluvial fan, lake deposits, pyroclastic rocks, and Butte Valley Basalt, and Pliocene to Pleistocene volcanic rocks of the “High Cascades”. The water-bearing units and the wider spread confining units are summarized in Table 3-2. For a more detailed description of the units in the three sub-basins, the reader is referred to Bulletin 118.

Table 3-2. Summary of water-bearing and major confining units in the Tule Lake and Lower Klamath Lake sub-basins, and the Butte Valley Basin (after California Department of Water Resources, California Groundwater, Bulletin 118, 2004).

Period		Tule Lake Sub-Basin 1-2.01		Lower Klamath Lake Sub-Basin 1-2.02			Butte Valley Sub-Basin 1-3			
Holocene	Late		Lake Deposits: consist of sand, silt, clay, ash, lenses of diatomaceous earth, and semi-consolidated shale; poorly sorted, very low permeability	Upper Basalt : vesicular olivine flows; extensive fracturing, generally highly permeable	Quaternary Alluvium: consists of gravel, sand, clay, soil, and loess; moderately permeable	Lake Deposits: consist of sand, silt, clay, ash, lenses of diatomaceous earth, and semi-consolidated shale; poorly sorted, very low permeability	Butte Valley Basalt: uniform sheet of vesicular basalt, highly permeable, interfingers with and overlies lakebed deposits	Pyroclastic Rock: typically well consolidated, massive to thin-bedded lapilli tuffs and cindery tuff breccias, generally cross-bedded, include abundant fragments of basalt and scoria	Alluvial Fan Deposits: poorly-sorted volcanic rock debris, cobbles, gravel, sand, and clay from Cascade Range; interfingers with lake deposits at depth	Lake Deposits: consist of sand, silt, clay, ash, lenses of diatomaceous earth, and local stringers of gravelly sand; highly variable permeabilities
	Early									
Pleistocene	Late	Upper Basalt: unweathered, vesicular, olivine basalt; extensive fracturing, generally highly permeable		Intermediate Basalt: thin-bedded flows of diabasic olivine basalt; interfingers with lakebed deposits, columnar jointing, highly permeable			High Cascade Volcanics: successive sheet of basalt, basaltic andesite, discontinuous layers of massive basaltic tuff and tuff breccias, some isolated lapilli tuff and cinder cones deposits			
	Early	Intermediate Basalt: thin-bedded flows of diabasic olivine basalt; interfingers with lake bed deposits, columnar jointing, highly permeable								
Pliocene	Late	Lower Basalt: ophitic olivine basalt to porphyritic basalt, weakly jointed and fractured, highly permeable		Lower Basalt: ophitic olivine basalt to porphyritic basalt, weakly jointed and fractured, highly permeable	Diatomite: often includes interbedded sand, tuff breccia, volcanic ash; generally confining unit					
	Early				Continental Sediments: consist of clay, diatomaceous earth, interbedded fluvial sediments; may include the diatomite deposits					
Miocene	Late									
	Middle									
	Early									

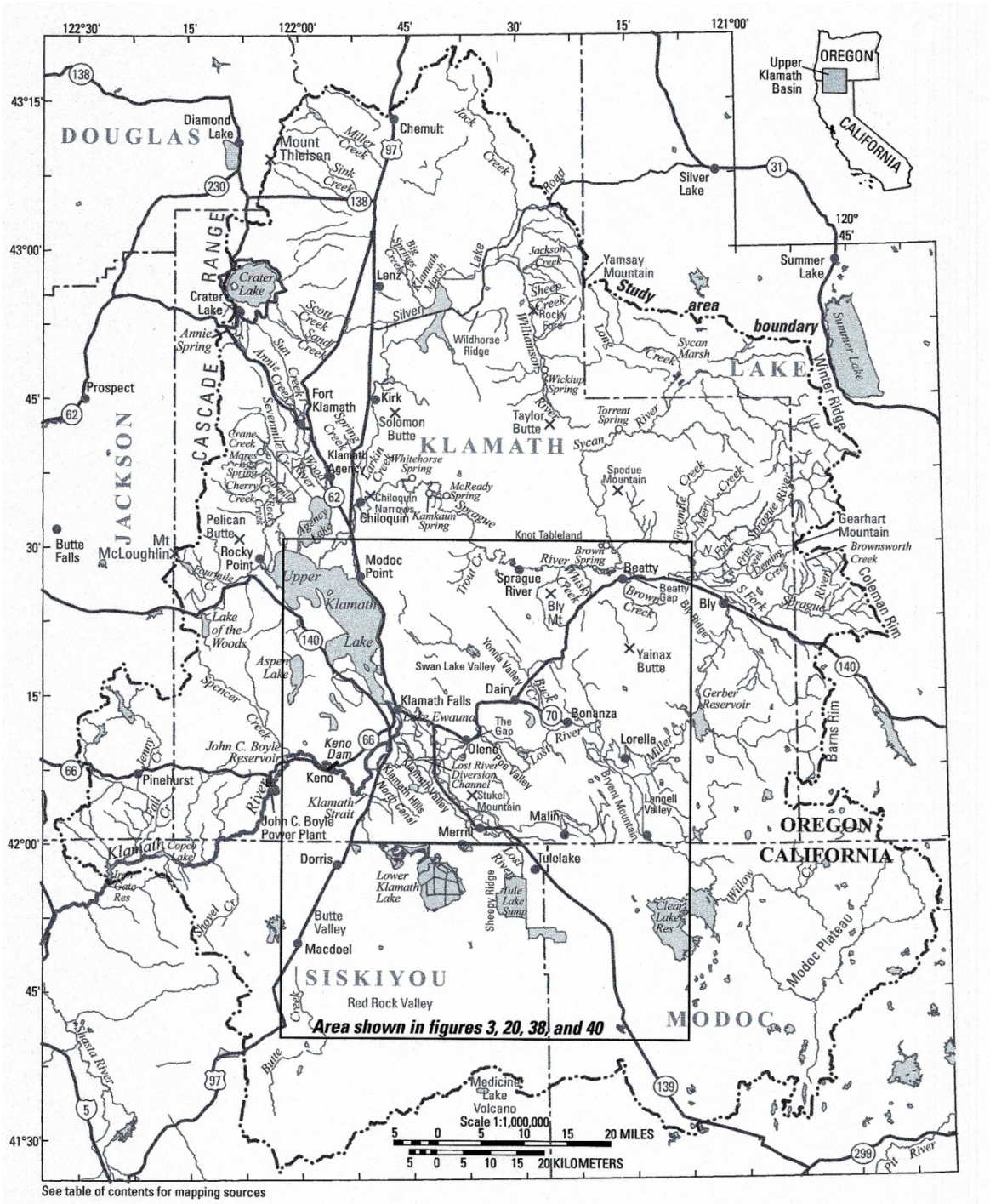


Figure 3-6. Gannett, et al, 2010 study area. Original report dated 2007, revised in 2010.

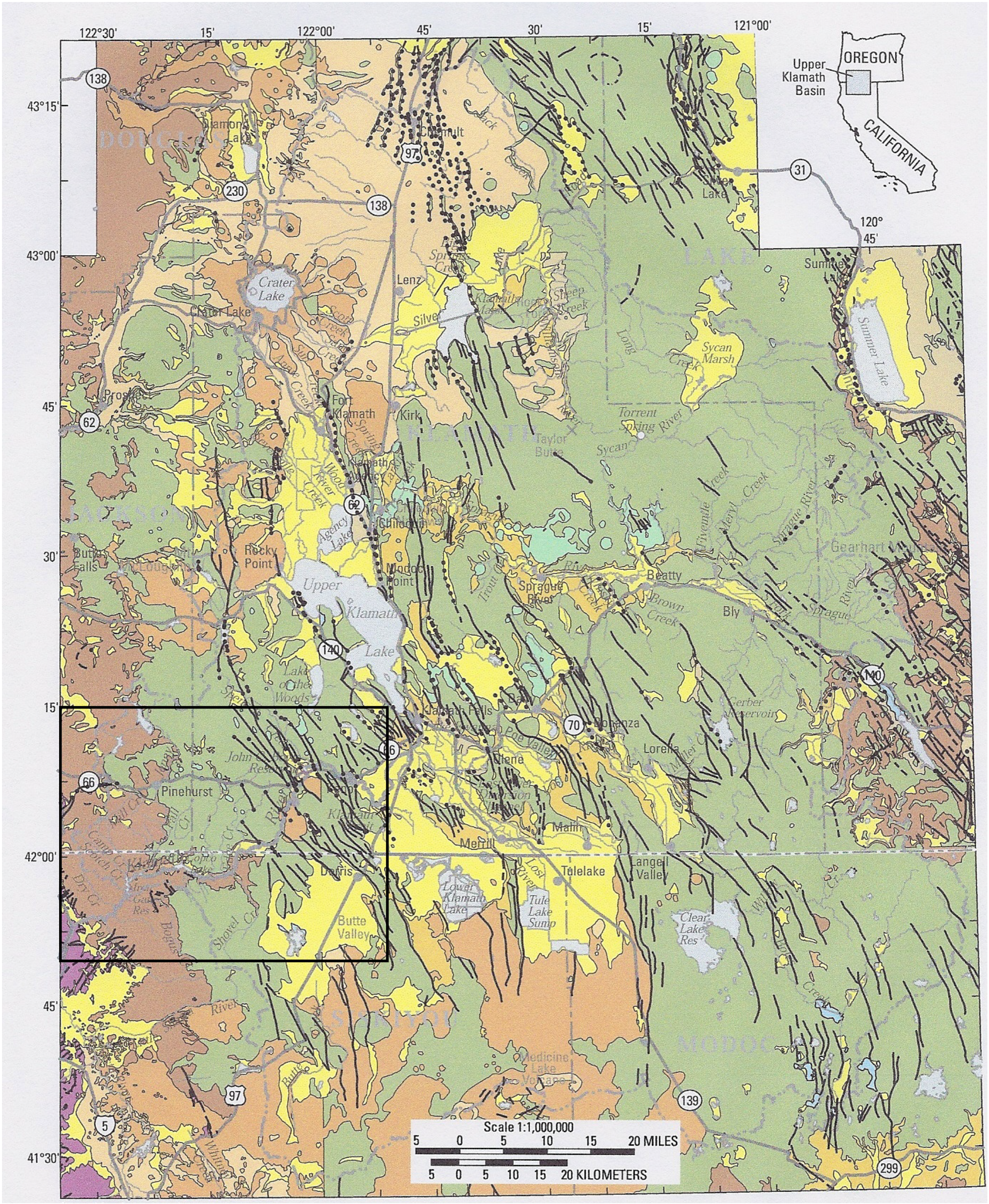


Figure 3-7. Hydrogeologic units of the Upper Klamath Basin, Oregon and California. Boxed area shown enlarged in Figure 3-7a. (after Gannett, et al., 2020, Figure 4).

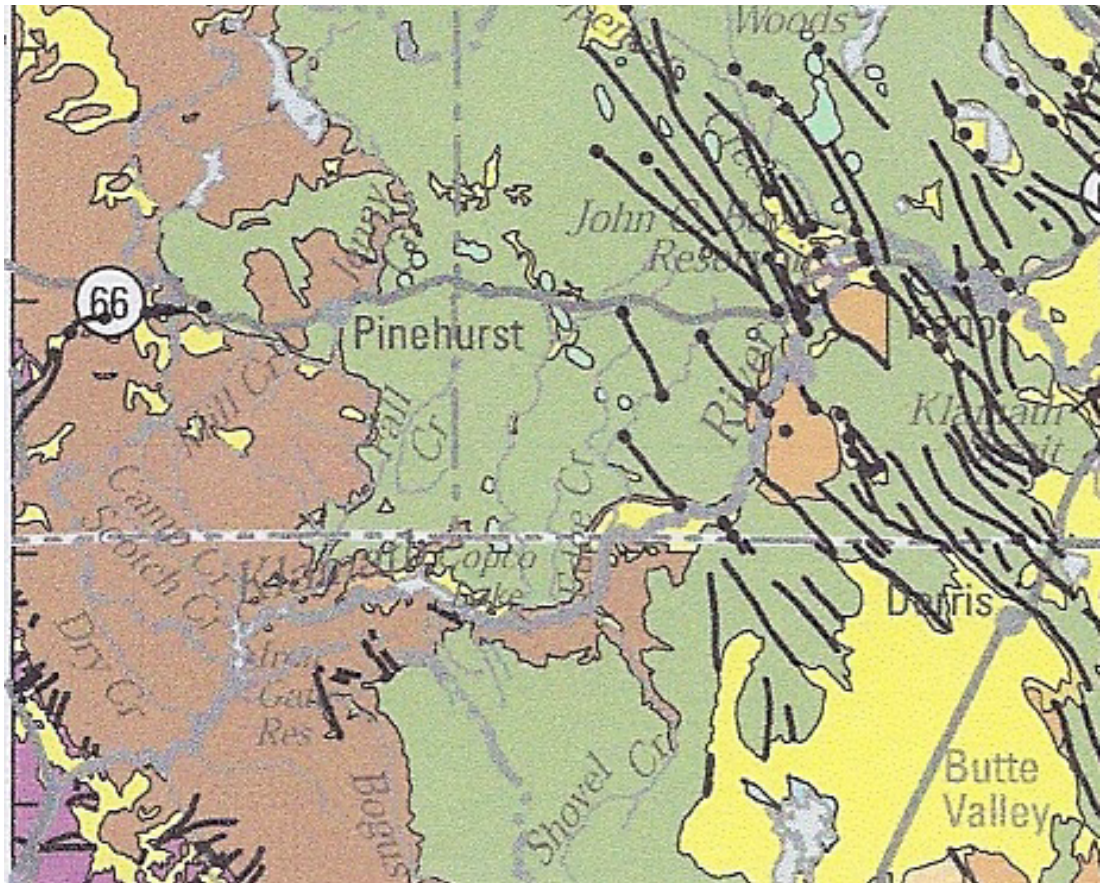


Figure 3-7a. Enlarged image of the hydrogeological units from above Keno Dam to below Iron Gate Dam. (after Gannett, et al, 2010, Figure 4).

EXPLANATION FOR FIGURE 4 3-7

Hydrogeologic unit present at land surface

Qs	Quaternary sedimentary deposits
Qvp	Quaternary volcaniclastic deposits
Qv	Quaternary volcanic rocks
QTs	Quaternary to late Tertiary sedimentary rocks
Ts	Late Tertiary sedimentary rocks
Tvpt	Late Tertiary volcaniclastic rocks
Tv	Late Tertiary volcanic rocks
Tovs	Older Tertiary volcanic and sedimentary rocks
pT	Pre-Tertiary rocks
------	Geologic fault, dashed where inferred, dotted where concealed

Figure 3-7b. Hydrogeologic Unit descriptions for Figure 3-7 and Figure 3-7a.

3.6. Existing Groundwater Conditions

3.6.1. REGIONAL GROUNDWATER CONDITIONS

The project area has few wells that completely characterize groundwater conditions. Gannett, et al, made the first regional attempt to estimate water level gradients and flow patterns in the Upper Klamath Basin – including the area of the Klamath River upstream and downstream of the three dam sites. Figure 3-8 and Figure 3-8a show a generalized groundwater map for the UKB and portions of the LKB. Figure 3-8a indicates that the regional groundwater flow patterns along the Klamath River downstream of Keno Dam are generally from the higher elevations (upland areas, mountain ranges, hills, etc.) toward the Klamath River, and from Keno Dam toward Iron Gate Dam. Gradients are steepest between the Mount Shasta uplands and the Klamath River. Figure 3-8a indicates that there is a possible groundwater divide running NNE-SSW thorough the area at about the Keno Dam. Gradients off the upland between Keno and UKL would trend towards the SE while gradients to the south of Keno coming off the mountain front along the west side of Butte Valley are trending towards the NE. If this groundwater divide exists, it would suggest that groundwater flow from the Modoc Plateau volcanics in Klamath Valley may be limited or restricted and that the hydrogeologic regime in the Modoc Plateau may not have a significant impact on the groundwater regime of the Klamath River as it flows through the Cascade Volcanics Province.

USGS Topographic 7-1/2 minute quadrangles around the reservoirs (Iron Gate and Copco Quadrangles in California, and Spencer Creek and Chicken Hills Quadrangles in Oregon) show varying numbers of springs on both sides of the reservoirs. The Iron Gate Quadrangle shows numerous springs all around Iron Gate reservoir ranging from several 10's of feet to over 300 feet above the reservoir level. The Copco Quadrangle shows fewer springs around Copco reservoir – but the ones that are shown are again several 10's of feet to over 800 feet above the reservoir level. Additionally, a number of the small drainages that empty into Copco reservoir have a spring at the headwater of the drainage. The Spencer Creek and Chicken Hills Quadrangles show very few springs in the vicinity of J.C. Boyle reservoir and those that are shown are only a few 10's of feet above the reservoir level. However, many of the small drainages the empty into JCB reservoir have a spring at the headwater of the drainage (e.g., Spencer Creek (Gannett, et al., 2010). The presence of many springs in the area of the dam sites suggests local groundwater systems, and possibly a regional groundwater system, that are not receiving water from the reservoirs, or at least not directly. The water discharging from the springs above the reservoir levels is obviously not reservoir water. The flows from the springs and the location of the springs could be influenced indirectly by the presence of a reservoir in that the reservoir creates a local base line that in effect would 'back up' the groundwater upgradient of the reservoirs. This could result in a mounding effect near the reservoir that 'artificially' raises the groundwater levels in the local area to the point where spring flow increases, or new springs are created. Whether the spring systems are

hydraulically connected to the reservoir is uncertain, but such a connection is a real possibility.

A spring complex about one mile below J.C. Boyle Dam contributes substantial flow to the River Gannett, et al., 2010). The water discharging at this site could be coming from the local groundwater system, or it could be influenced by seepage from the reservoir that is going around or under the dam and coming to the surface at the spring site. Probably, in this case, the flows from this spring complex are influenced by both the local groundwater system as well as leakage from the reservoir.

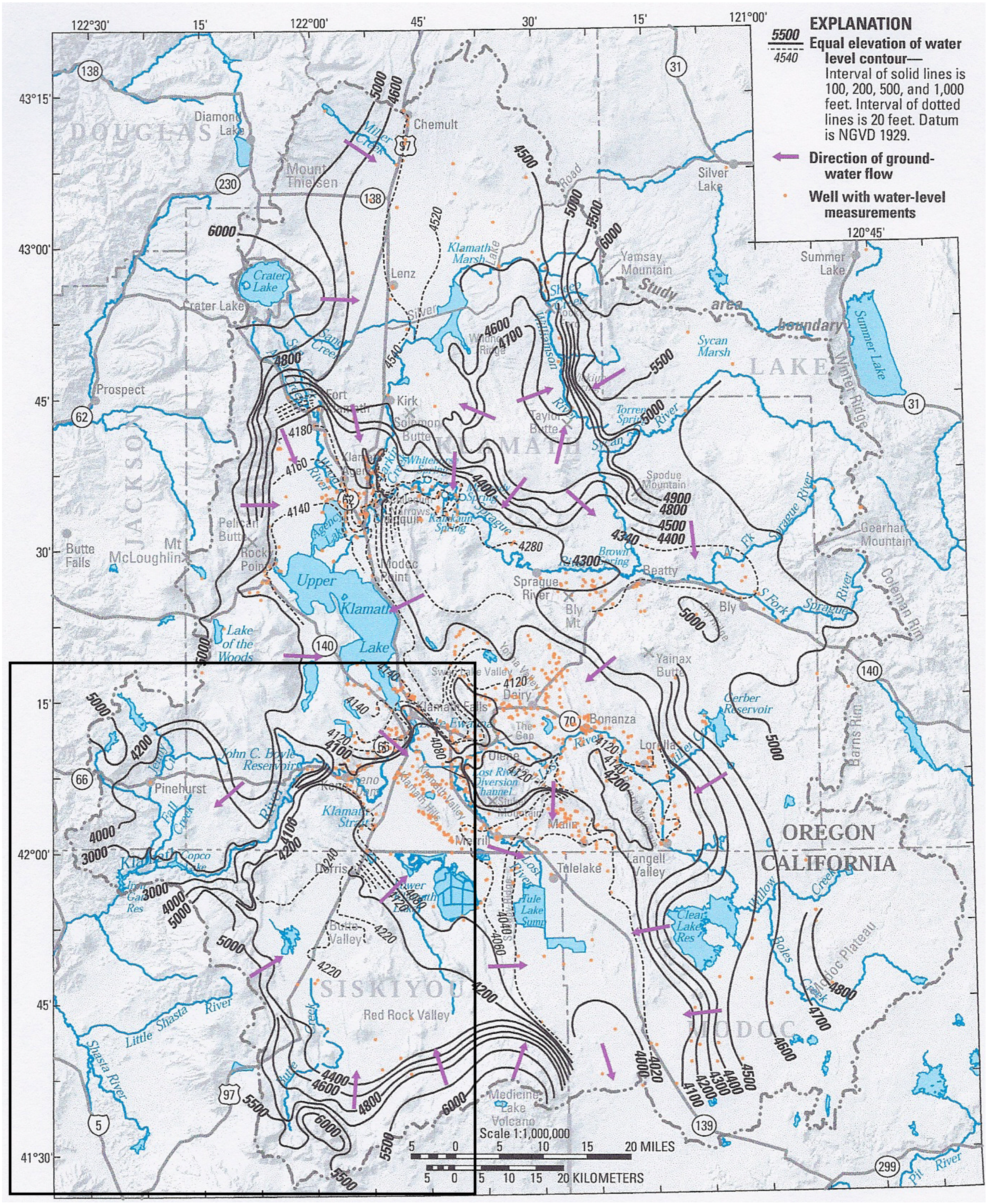


Figure 3-8. Generalized water-level contours and associated directions of regional groundwater flow patterns for the Upper Klamath Basin of Oregon and California. Box shows area enlarged in Figure 3-8a. (after Gannett, et al., 2010, Figure 21)

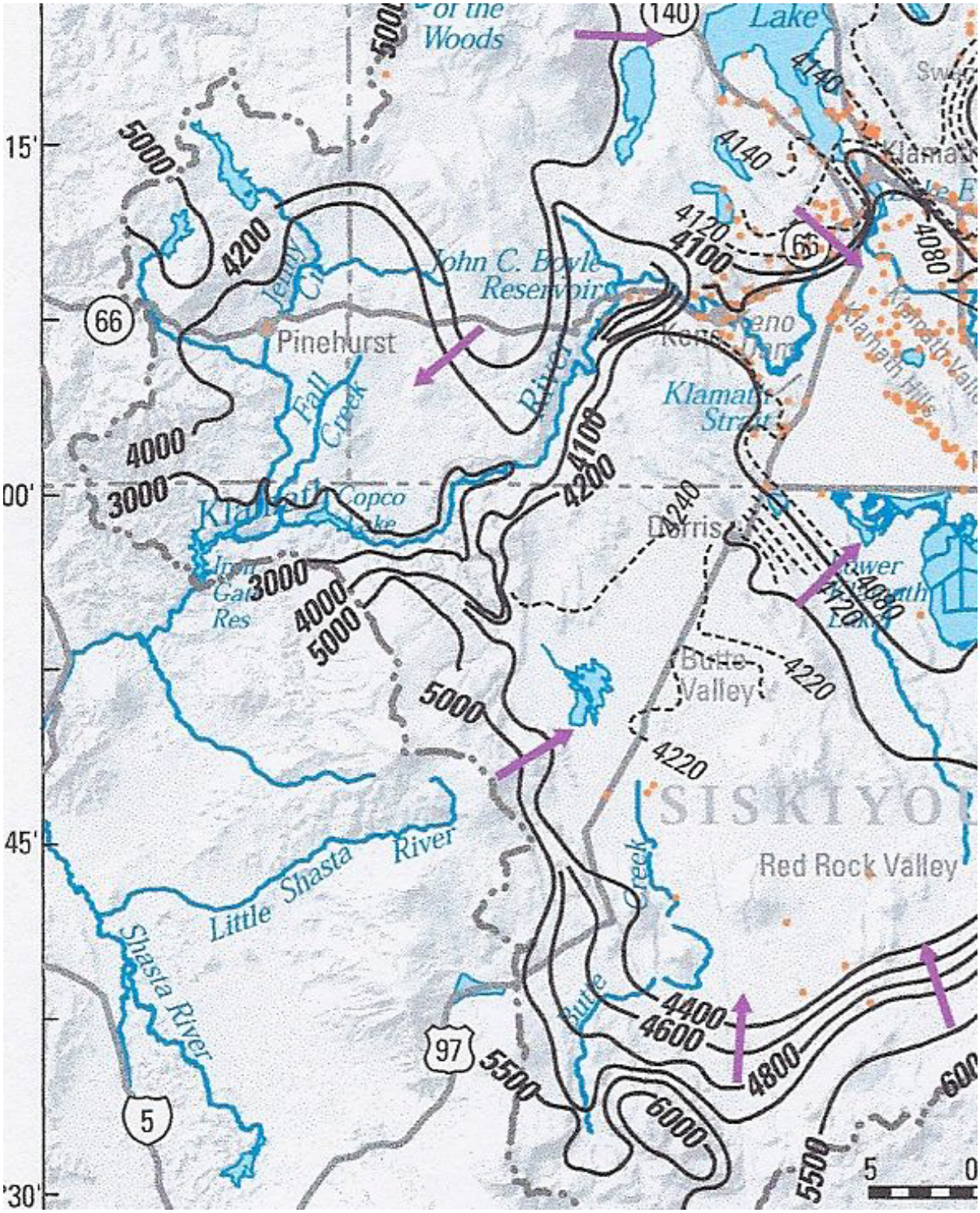


Figure 3-8a. Enlarged area of Figure 3-8 showing the generalized water-level contours and associated flow patterns in the vicinity of the three dam sites. (modified from Gannett, et al, 2010, Figure 21).

3.6.2. SOURCES OF GROUNDWATER IN THE PROJECT AREA

The lack of wells makes characterizing groundwater sources in the project area difficult. Groundwater in the project area is likely fed by percolation of precipitation through the surface materials to the bedrock units. As Figure 3-7a and Figure 3-7b show, groundwater at a regional scale appears to flow into the project area from upland areas toward the Klamath River and the reservoirs. Local groundwater in the project area is also fed by groundwater underflow from these upgradient areas. In the absence of barriers to vertical flow, surface water infiltration is a common source of recharge to groundwater systems. Rivers, lakes and other surface water bodies are common sources of site specific infiltration recharge. Areal precipitation is more of a dispersed, wide extent source of infiltration recharge. Given a regional groundwater flow direction toward the river and reservoirs in the project area, river reaches are more likely receiving water from the groundwater systems than they are losing water to the groundwater systems, while reservoirs are more likely to lose water to the groundwater. However, given the right conditions, the reservoirs could be gaining water from the groundwater system(s).

A large groundwater flow system exists in the Upper Klamath Basin (Gannett et al., 2010). Groundwater is recharged in areas in the Cascade Range and upland areas surrounding the basin. Groundwater flows from these areas toward the interior of the basin and subbasins (Figure 3-7a). Many of the streams in the interior of the basin are at least partially fed by groundwater discharge (Gannett et al., 2010). Some streams are fed predominately by groundwater (baseflow) at a consistent rate throughout the year.

3.6.3. GROUNDWATER SINKS IN THE PROJECT AREA

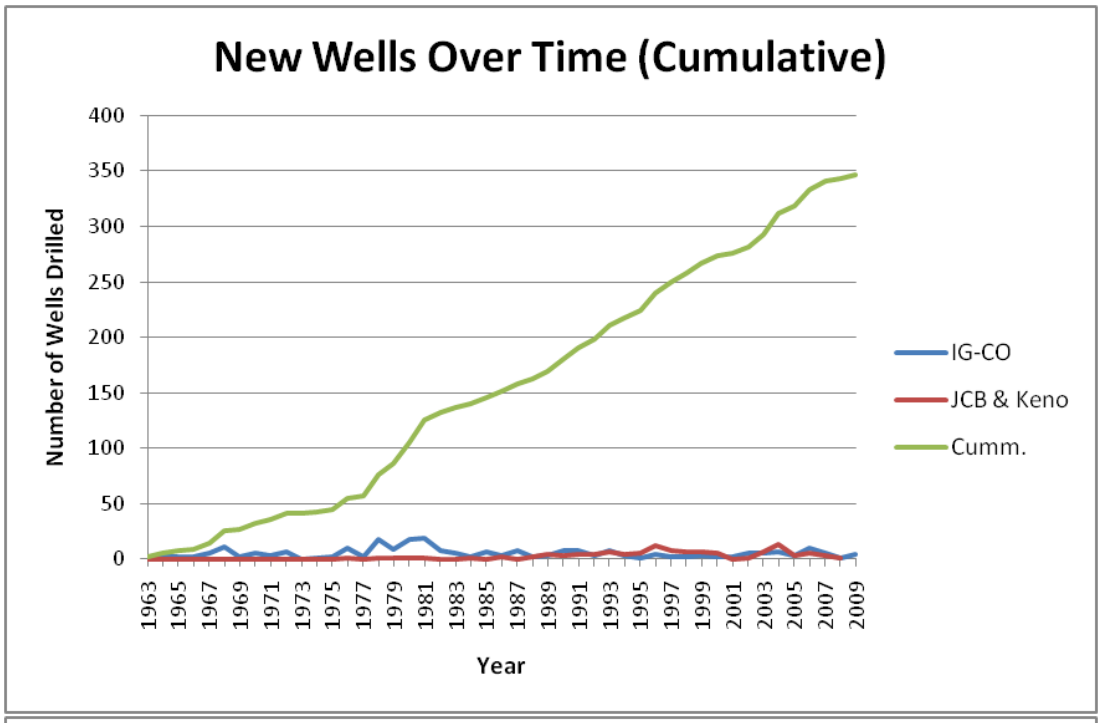
Locations where the bedrock comes into contact with surface water (e.g., rivers, streams, and reservoirs) can be sinks of groundwater to the surface water system if the surface water level is below the groundwater level. Gannett et al. 2010 estimates that groundwater adjacent to the Klamath River discharges to the river in the project area. The USGS estimates an average groundwater discharge of 190 cfs for the reach from Keno Dam to downstream of the J.C. Boyle Powerhouse and 92 cfs for the reach from there downstream to Iron Gate Dam. Based on gage data and changes in reservoir storage, these estimates are calculated for the length of each of these reaches and may include some ungaged tributary inflows.

Groundwater pumping is also a typical groundwater sink in the area. Domestic and some limited amount of irrigation use in the area are the primary uses of pumped groundwater in the project area. Most domestic wells around the reservoirs are probably seasonal residences (owner’s official address is different than the well location address) and are not expected to be a major groundwater sink in the project area. Average well yields in Siskiyou County, CA are just over 19 gpm while in Klamath County, OR the average yield is just over 22 gpm. Based on completion dates on well logs filed with Siskiyou County, an average of

5 new wells per year have been installed in the project area since 1963 (Figure 3-9). In Klamath County the average is about 3 new wells per year since 1976, including the area around Keno and Keno Dam, OR.

Groundwater is used in the Upper Basin to irrigate agricultural land. Groundwater is used as a primary source of irrigation water where surface water is not available and also as a supplemental source when surface supplies are limited (Gannett et al., 2010).

The USGS states that groundwater levels vary in response to both climatic and pumping conditions. Climatic variations can vary the groundwater level by five feet within the basin Gannett, et al., 2010). The typical drawdown and recovery cycles caused by groundwater pumping can be from one to ten feet Gannett, et al., 2010). Groundwater use in the Upper Basin has increased by 50 percent since 2001 Gannett, et al., 2010) primarily in the area surrounding Reclamation's Klamath Project. The increase in pumping has resulted in groundwater levels dropping 10 to 15 feet in portions of this area between 2001 and 2004 Gannett, et al., 2010).



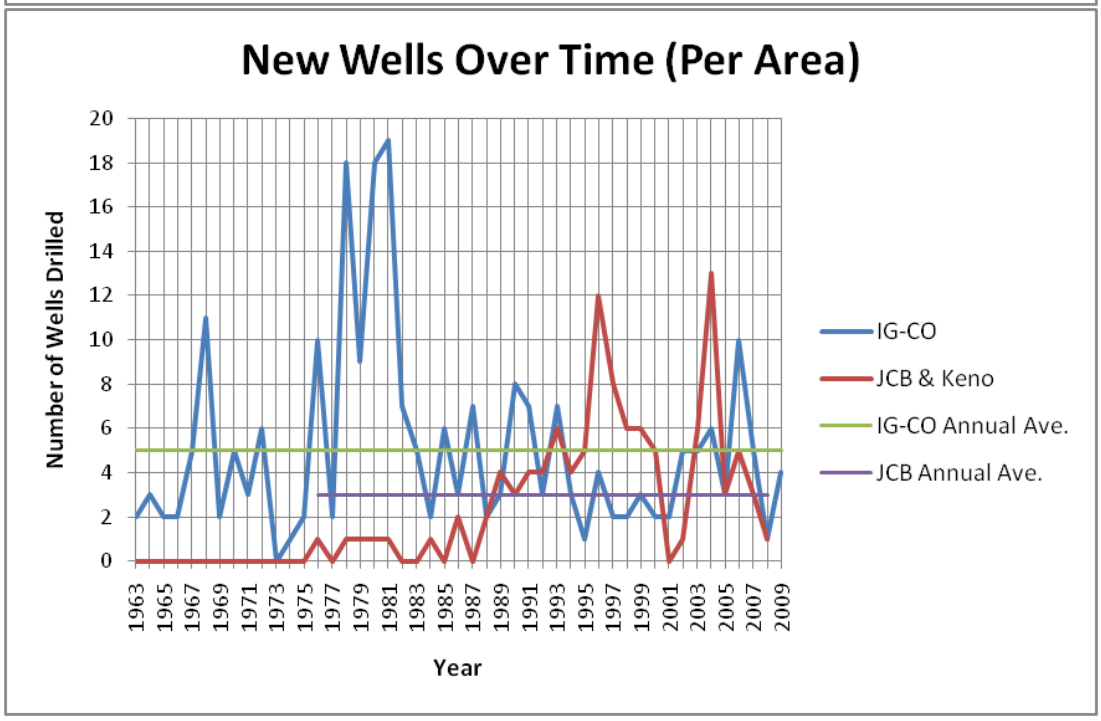


Figure 3-9. Cumulative and Times Series Graphs of new wells over time, by Reservoir based on well logs filed with Oregon and California.

3.6.4. LOCAL GROUNDWATER CONDITIONS

The California DWR *Bulletin 118 – Update 2003, California's Groundwater,* delineates 515 groundwater basins and subbasins throughout the state (DWR 2003). The area of analysis for the Proposed Action and alternatives does not fall within one of these delineated basins. The area is defined as a "groundwater source area" by the California DWR. A "groundwater source area" is "rocks that are significant in terms of being local groundwater sources, but do not fit the [typical] category of basin or subbasin" (DWR 2003). The Klamath River from the Oregon-California Stateline to downstream from Iron Gate Dam is a predominantly non-alluvial river flowing through mountainous terrain. Downstream from the Iron Gate Dam and for most of the river's length to the Pacific Ocean, the river maintains a relatively steep, high-energy, coarse-grained channel frequently confined by bedrock.

A search of wells in the databases of both the Oregon Water Resources Department and the California DWR retrieved well logs for known wells within several miles upstream and downstream of J.C. Boyle, Copco, and Iron Gate Reservoirs. Some of the well logs recorded the static water level at the time the well was completed, and a few logs recorded the well's estimated yield following completion. The drill logs are given in Appendix I. Drill Logs of Groundwater Wells near PacifiCorp Reservoirs.

Of all the retrieved logs for wells within several miles of any part of any of the three reservoirs roughly 83% (percent) of the logs (300 out of 360 logs) had sufficient information to be able to identify with a reasonable amount of certainty where those wells were physically located in relation to the reservoirs. Of the 300 logs where reasonable coordinates could be determined, only 63 were within 2.5 miles of one or more of the three reservoirs – as described below (Figure 3-10). 'Reliable' locations were obtained by comparing physical addresses on the driller logs against GoogleEarth© images of the regions to match an address with the image. When matches were obtained, the coordinates of the property were recorded from GoogleEarth©. When no physical address was included on the driller's log, location maps (if included) were used to locate the property in the same manner – by comparing the location map against the GoogleEarth images. In the absence of both a physical address and a location map, County tax roles were used to match owner's names on the well logs to obtain physical addresses or County/Developer's plat maps. All the data on the well logs were transferred to Excel spreadsheets which were then imported into ARCGIS and georeferenced.

Using the local topography, reservoir bathymetry, and lithologic descriptions on the well logs, representative cross-sections across various spans of the reservoirs were created such that each cross-section intersected at least one known well location. The cross-sections are presented under the discussion of each reservoir below. Each cross-section displays the topography, water surface elevation of the reservoir, well log ID, abbreviated well log lithology, and the static water level in

the well. The water-bearing units in each well are presented in summary tables for each reservoir.

The discussions of potential or possible impacts to the local wells from the proposed action are predicated on the concept that in order to be impacted, the water-bearing unit that each well is tapping must be hydraulically connected to the reservoir – either by having the water-bearing unit daylighting within the reservoir walls or being hydraulically connected to the reservoir through a series of permeable layers between the reservoir and the water-bearing unit.

The potential for impacts to the wells is further predicated on the relative elevation differences between the static water level in the well(s) and the nominal surface elevation of the reservoir. Specifically, since the majority of units in the project area are relatively flat-laying, if the water-bearing unit being tapped by any given well is in hydraulic connection with a reservoir, then the static water level in the well should be similar or close to the water surface elevation in the reservoir. If the static water level is substantially higher or lower than the reservoir level, then it is likely that the water-bearing unit is reflecting a regional or local aquifer flow system as opposed to being influenced by the reservoir. If the water-bearing unit itself is substantially higher than the reservoir water levels, or is substantially deeper than the lowest portion of the reservoir, then it would likely not be in hydraulic connection with the reservoir.

Additionally, given the nature of the flow conditions in the volcanic materials in the region, it is not expected that influences from the reservoir levels would extend laterally very far from the reservoir and the direction in which those influences would likely develop would also be irregular and non uniform spatially.

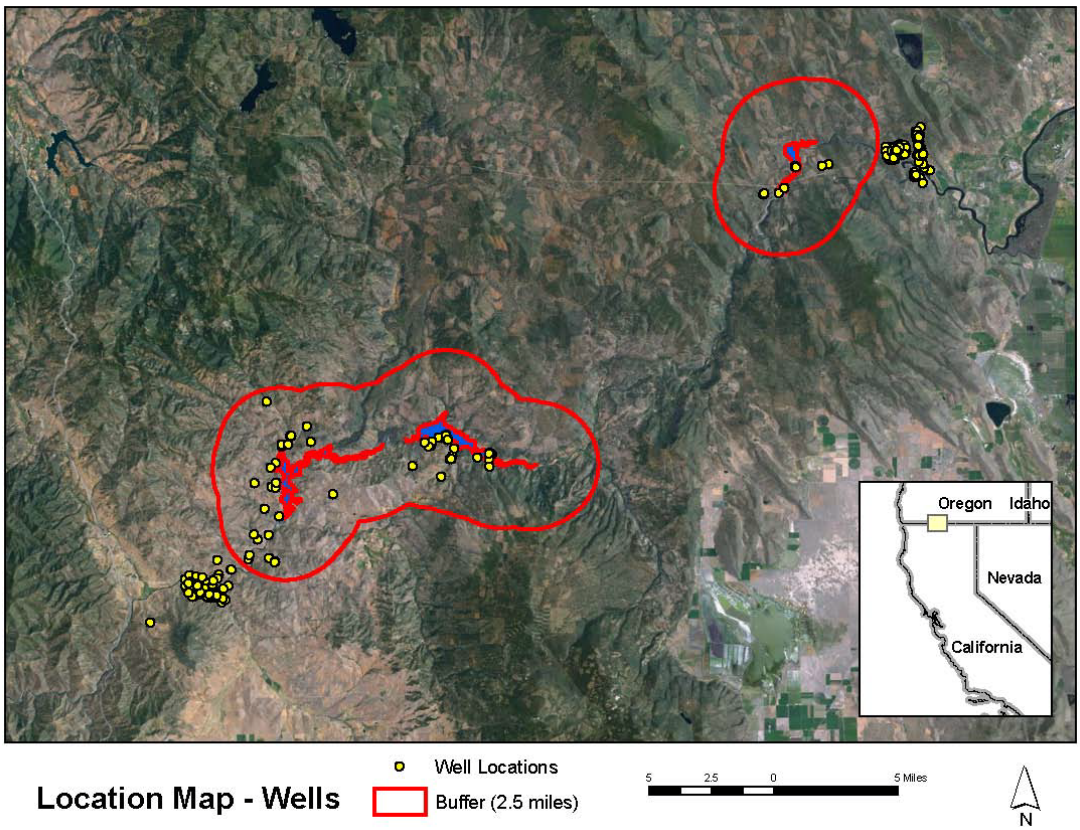


Figure 3-10. Location map showing locations of all the wells retrieved from the Counties' and States' databases of well logs. The red curved line represents a 'buffer zone' that is 2.5 miles from any point on any of the three reservoirs (ARCGIS map image).

3.6.4.1. J.C. Boyle Reservoir

A search of the Oregon Water Resources Department database retrieved 120 well logs around Keno and J.C. Boyle Reservoirs, 50 of which were within 2.5 miles of the reservoir based on T-R-S coordinates. Of those 120 logs, 108 had sufficient information to identify the approximate coordinates of the well, and of those 108 logs, 104 logs had a recorded static water level (SWL). Of the 108 logs, only sixteen were within 2.5 miles of the J.C. Boyle Reservoir (Figure 3-11) and two of those were downstream of the dam and in a tributary drainage basin to the Klamath River. Ten of the sixteen wells were shallow Oregon Department of Transportation borings near bridge footings and were abandoned after drilling. Two of the remaining six wells did not have a recorded SWL. Table 3-3 summarizes the lithology, depth, screened or open interval(s), SWL, and other pertinent data for each of the wells within the 2.5 mile buffer zone for J.C. Boyle Reservoir.

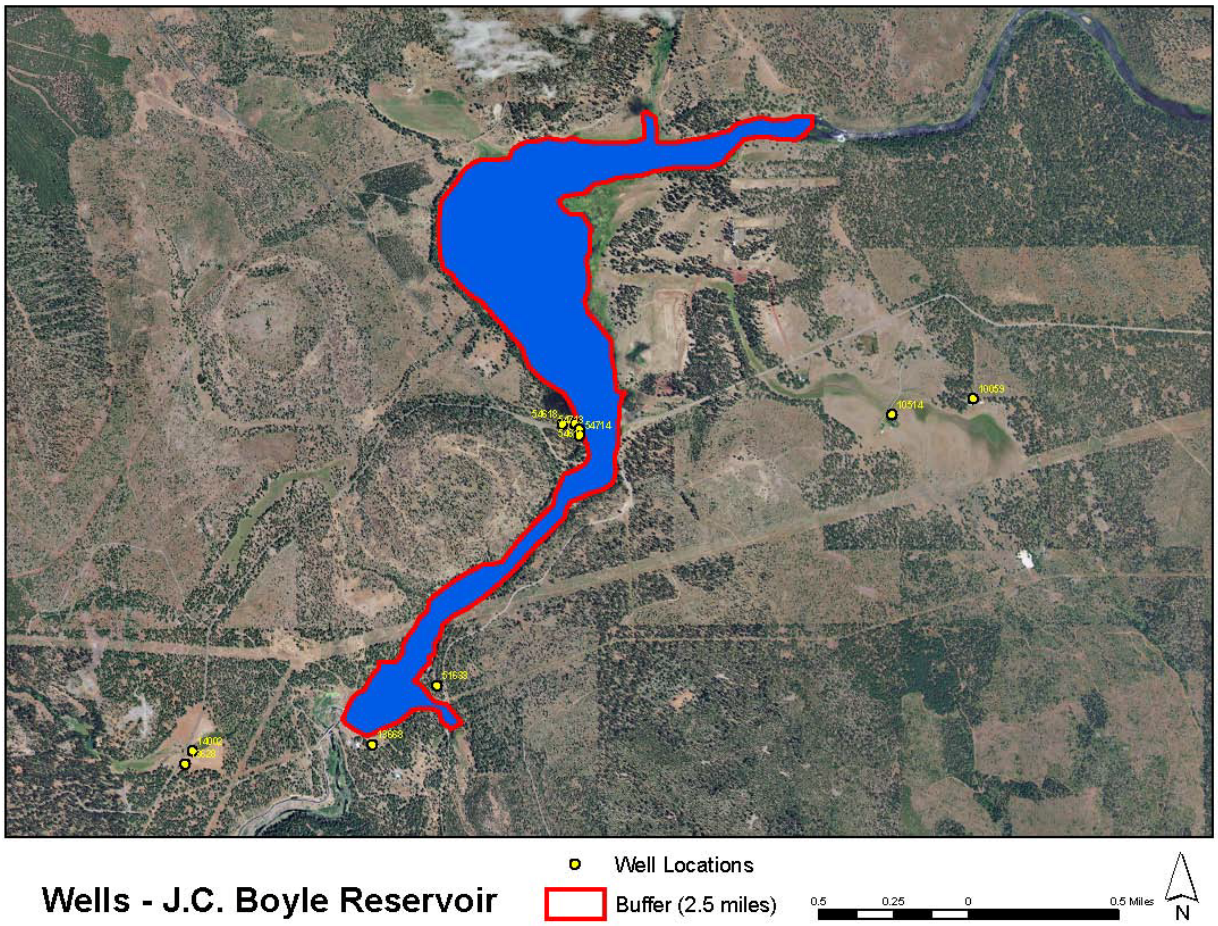


Figure 3-11. Location map showing locatable wells within 2.5 miles of J.C. Boyle Reservoir. Cross-section lines are shown and labeled on Figure 3-12.

Three cross-sections were constructed that intersected at least one of the six wells. These three cross-sections are labeled as J-J', K-K', and L-L' on Figure 3-12 and are shown in Figure 3-13 thru Figure 3-15. The wells within the 2.5 mile zone of J. C. Boyle Reservoir that are along or near a cross-section line are summarized in the following table. In addition to the three cross-sections, a well profile for all the wells within 2.5 miles of J.C. Boyle is shown in Figure 3-16.

As can be seen on the x-sections (Figure 3-13 thru Figure 3-15) and in Table 21-1, the water-bearing units in the wells are below the bottom of the reservoir (3780', 3750', and 3690' respectively) and the SWL in all the wells is 89' to 106' below the reservoir water level elevation of 3787'. In Figure 3-16, with the exception of one well that is 30 ft from the reservoir, all the remaining wells have SWLs below the reservoir water level suggesting that the local gradient is away from the reservoir. If the groundwater gradient is away from the reservoir one would expect to see some influence on the near-by wells. Well 54713 is obviously being influenced by the reservoir levels, but by the time the wells are several hundred feet away any signs of a reservoir influence becomes tenuous.

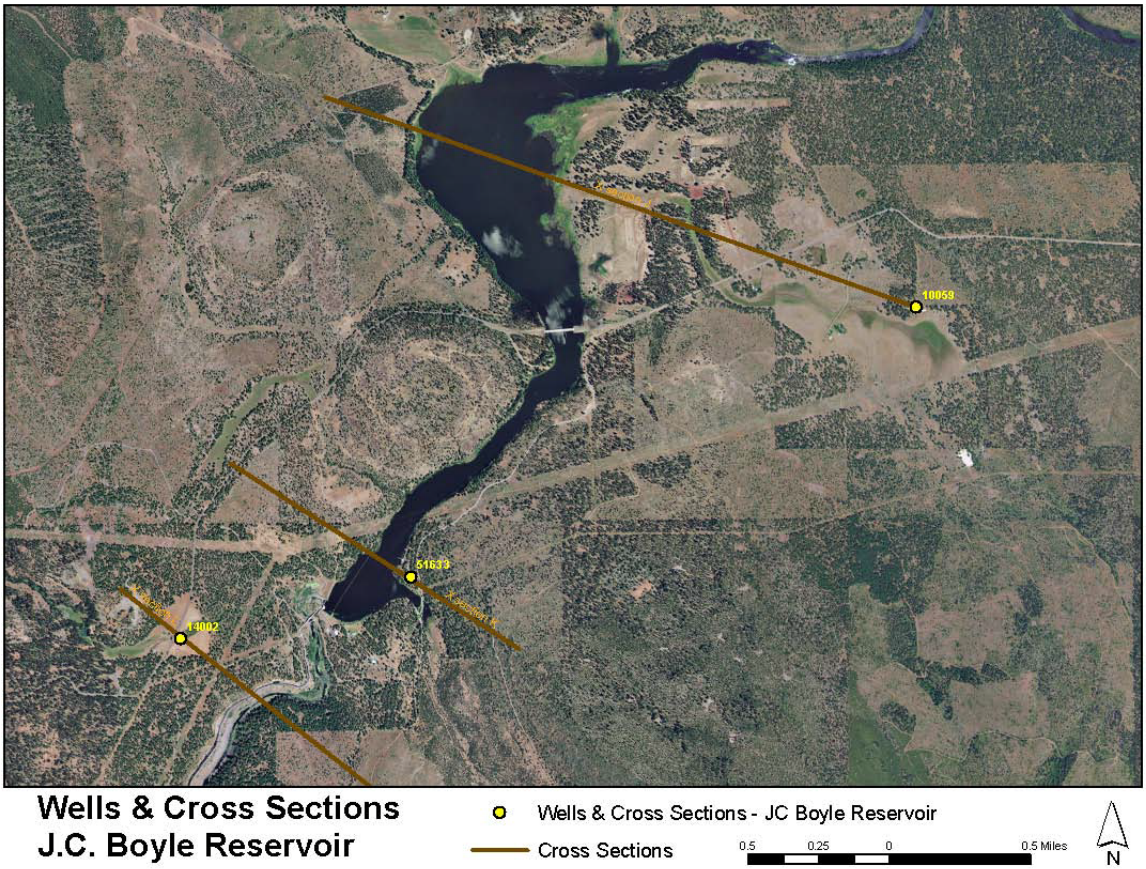


Figure 3-12. Location of cross-sections J – J', K – K', and L – L' on J.C. Boyle Reservoir.

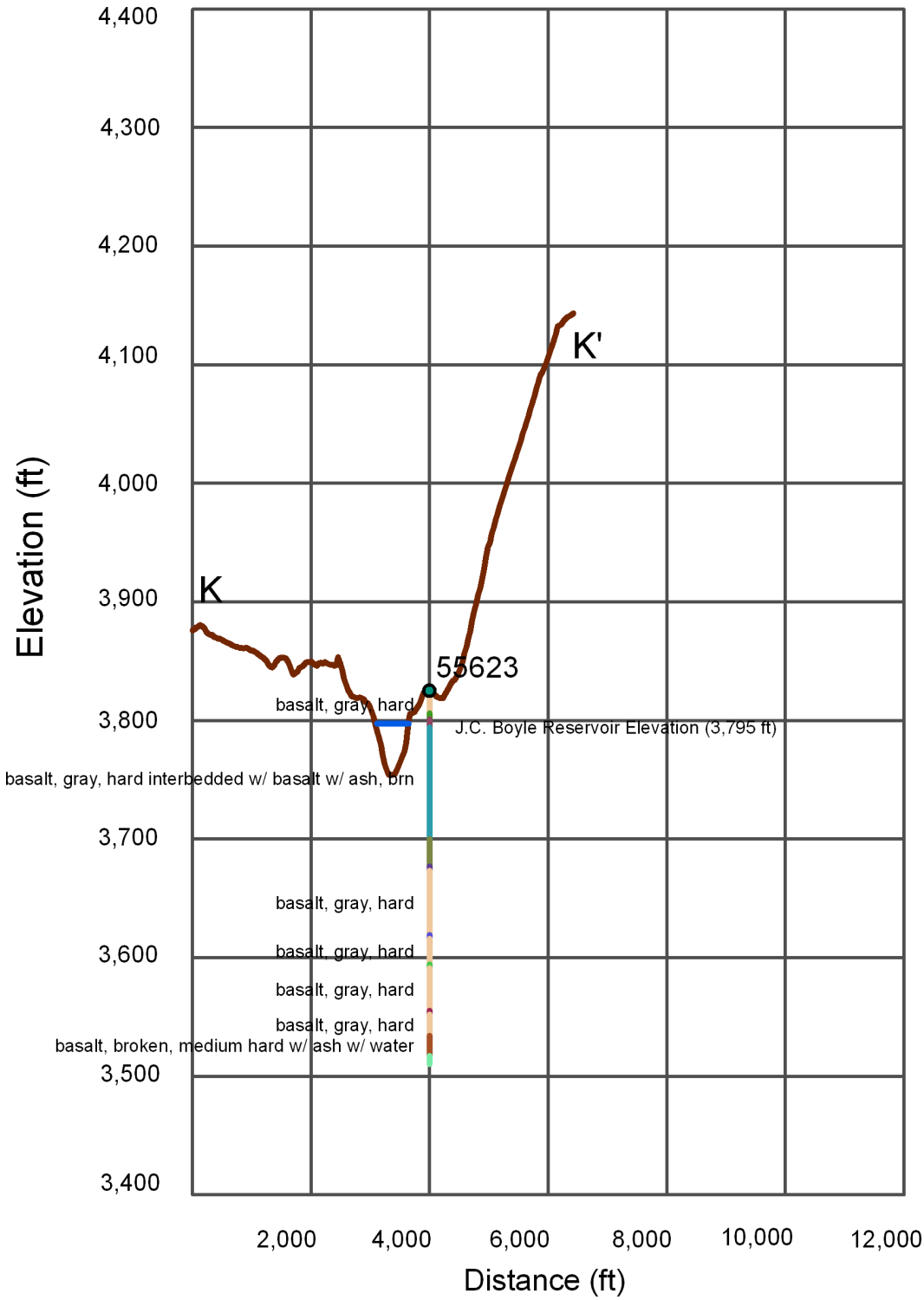


Figure 3-13. Cross section J – J'.

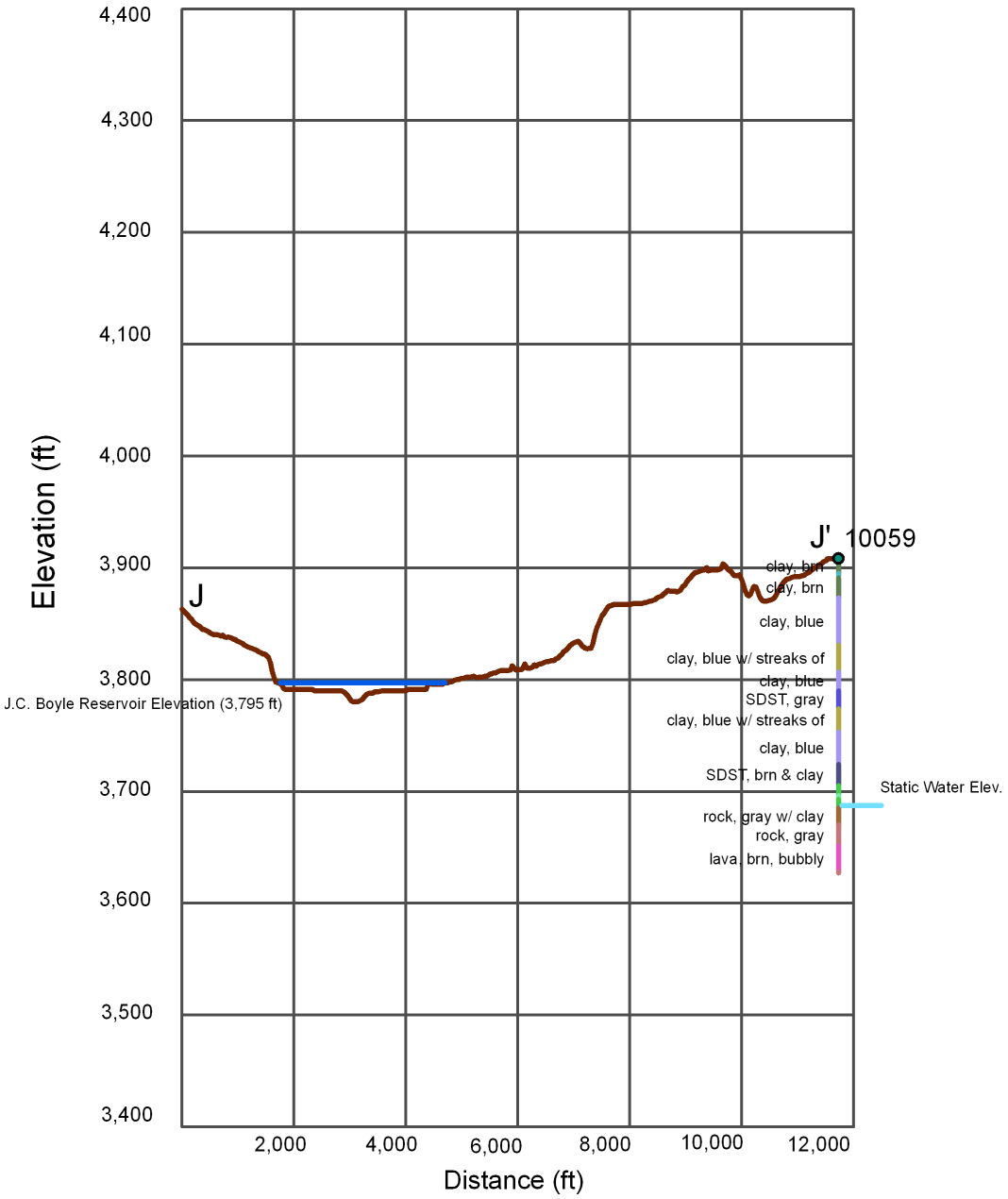


Figure 3-14. Cross-section K – K'.

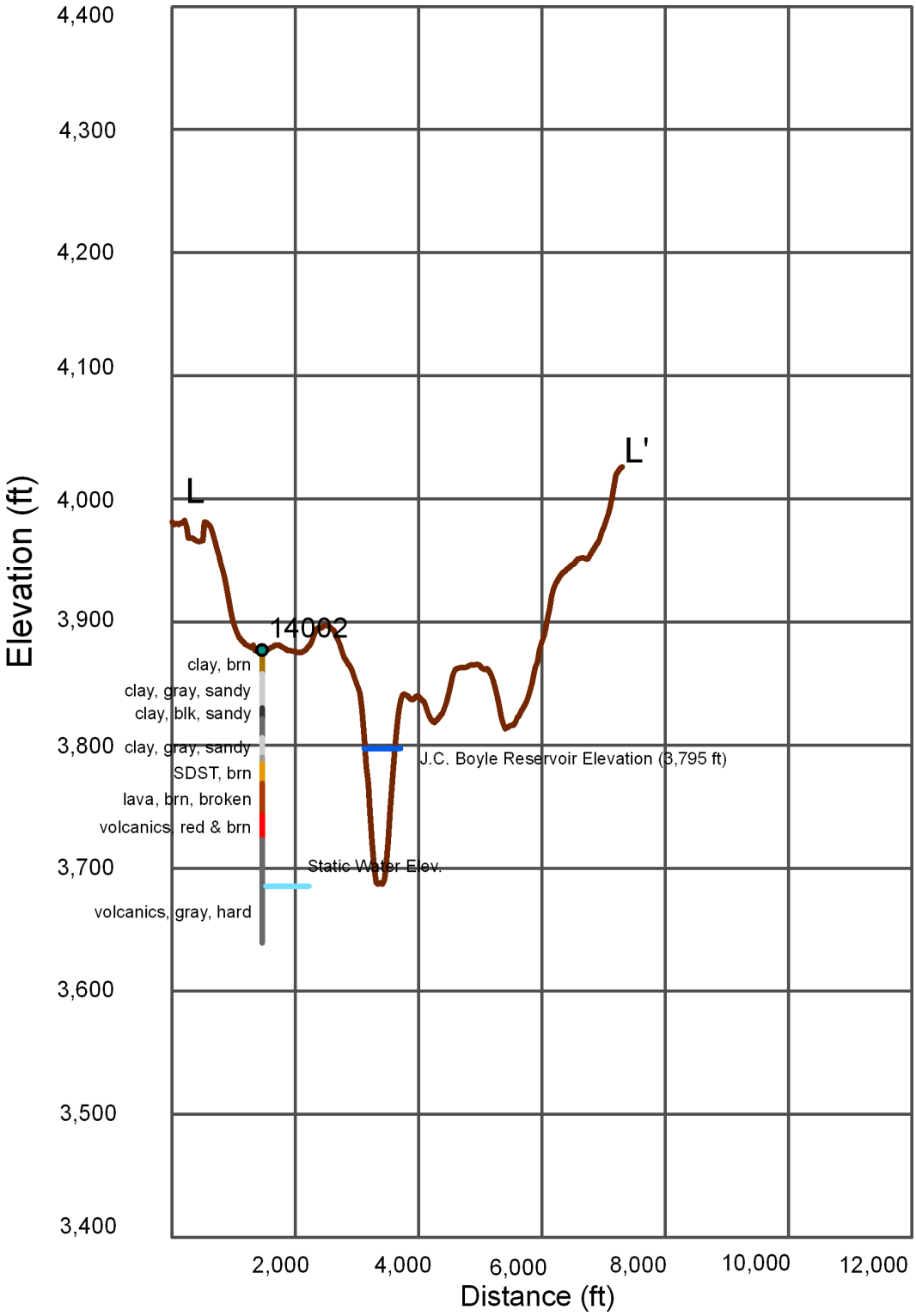


Figure 3-15. Cross-section L – L'.

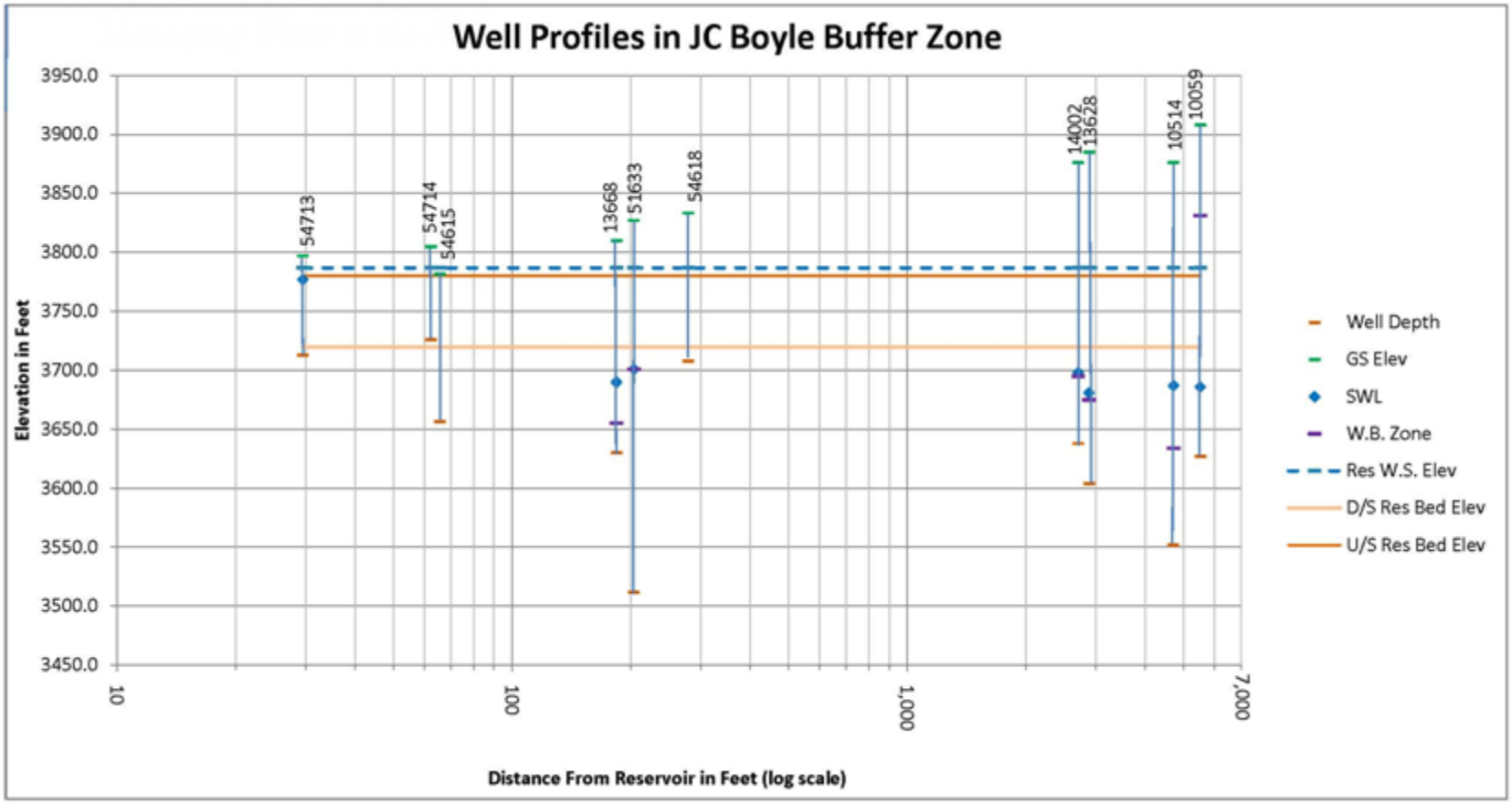


Figure 3-16. Well Profile graph for wells within 2.5 miles of J.C. Boyle Reservoir.

Table 3-3. Well Construction Information for Wells within 2.5 Miles of J.C. Boyle Reservoir (not including Oregon DOT boreholes for bridge footings) (Reservoir stage: 3787 feet AMSL; river bed elevation at dam site: 3720 feet AMSL)

Well ID	Drill Date	Use[1]	Well Diameter (in)	Depth to top of perforated zone or bottom of surface casing in an open well (ft)	Depth to bottom of perforated zone (ft)	Depth of Well (ft)	Depth to 1st Water (ft)	Pumping Rate (gpm)	Depth to Static Water (ft)
10059	06/29/1990	DOM	6	159 [2]	Open	281	77	12	222
10514	07/10/1992	DOM	6	275	315	324	242	40	189
13628	11/10/1989	DOM	4	201	241	281	204	30	204
14002	08/10/1988	DOM	6	99 [2]	Open	238	181	25	178
188972	10/19/2006	DOM	6	280 [2]	Open	315	126	55	126
16836	11/04/1976	DOM	6	22 [2]	Open	180	155	15	120

Notes:
1 - DOM: Domestic
2 - Depth to the bottom of the surface casing or sanitary seal in holes/wells that are open
Key:
in: inches
ft: feet
gpm: gallons per minute

Table 3-4. Water Level Compared to Water-Bearing Unit for Wells within 2.5 Miles of J.C. Boyle Reservoir (Reservoir stage: 3787 feet AMSL; river bed elevation at dam site: 3720 feet AMSL)

Well File #	Cross-Section Line	Static Water Elevation (ft)	Water-Bearing Unit	Elevation of Top of Water-Bearing Unit (ft)
10059	J-J'	3,686	Brown lava and clay from 203 to 223 feet bgs interspersed with black rock from 212 to 215 feet bgs, and gray rock and clay, and gray rock from 223 to 281 feet bgs with bubbly brown lava from 257 to 280 feet bgs	3,705
51633	K-K'	3,701	Gray and brown basalt from 126 to 315 feet bgs interspersed with hard gray baslalt, broken and fractured zones, and two ash layers	3,700
14002	L-L'	3,698	Hard gray volcanic rock from 181 to 238 feet bgs	3,695

The data in Table 3-4 suggests that the relatively flat lying, water-bearing units of volcanic materials are substantially deeper than the bottom elevation of the reservoir (i.e., the pre-reservoir river bed) in well #s 10059 and 51633. The SWL for each of these two wells is between 50 and 100 feet below the bottom of the reservoir. The top of the water bearing layer and the SWL in well # 14002 are just about at the elevation of the old river bed

As discussed in the EIS/EIR Section 3.11 – Geology, Soils, and Geologic Hazards, volcanic deposits in the region are highly variable in their lateral extent, homogeneity or inhomogeneity, degree of fracturing, and primary and secondary vertical permeability. It would be a conservative assumption that some degree of hydraulic connectivity exists between the reservoir and water bearing strata near the reservoir that allows downward migration of reservoir water. There would likely be a zone of similar horizontal hydraulic connectivity around the reservoir – but the extent and degree of connectivity is uncertain based on the limited well data. Both well #s 10059 and 14002 have significant amounts of clay recorded on the logs at depths between the top of their water bearing units and the equivalent depth of the old river bed that probably inhibits or significantly reduces the vertical migration of infiltration water from the reservoir. How extensive these clay units are is also uncertain.

Comparison of the elevations of the SWL in the six wells near J.C. Boyle reservoir shows that two wells downstream of the dam have SWL 20 to 40 feet below the pre-dam river bed elevation (at the dam site); the two wells furthest

away from the reservoir (at 4,721 feet and 5,518 feet from the reservoir) have SWL elevations nearly 100 feet below the pre-dam upstream river bed elevation; and the two wells just about on the shore of the reservoir have SWL elevations 20 to 30 feet below the pre-dam river bed elevation at the dam site. The SWL elevations in the wells furthest from the reservoir are near or below the SWL elevations for the wells closer to the reservoir. No clear determination of any trends in vertical head gradients can be drawn from the data of these six wells.

3.6.4.2. Copco Reservoir

An estimated 80 percent of the reservoir area is on a portion of the Klamath River that was formerly a lower-gradient zone. The change in stream gradient resulted from previous geologic activities related to cinder cones and lava flows (See See Section 5.2). Thus, geologic conditions in Copco 1 Reservoir are different than those in J.C. Boyle Reservoir, even though the bedrock beneath and surrounding both reservoirs consists primarily of rocks formed from older volcanic flows overlain by younger lava flows. Sediment depositions and/or delta formations are present at the mouths of the larger streams in the reservoir (See Section 5.2).

Copco 2 Reservoir is a relatively short impoundment (extending just over 0.25 miles) that lies immediately downstream from Copco 1 Dam. The reservoir is narrow and confined by a narrow bedrock canyon formed by lava flow (See Section 5.2). Similar to Copco 1 Dam, rock at the Copco 2 Dam consists of a combination of lava flows and shallow intrusions. The bedrock surrounding and underlying the reservoir is comprised of basalt and andesite, steep slopes of volcanic cobbles and boulders lie along both sides.

A search of the California Department of Water Resources database retrieved 260 well logs around Copco and Iron Gate Reservoirs. Of those 260 logs, 192 had sufficient information to identify the approximate coordinates of the well, and of those 192 logs, 109 logs had a recorded static water level (SWL). Of the 192 logs, twenty-two were within 2.5 miles of the Copco Reservoir (Figure 3-17). Table 3-6 summarizes the well logs for wells within 2.5 miles of Copco Reservoir.

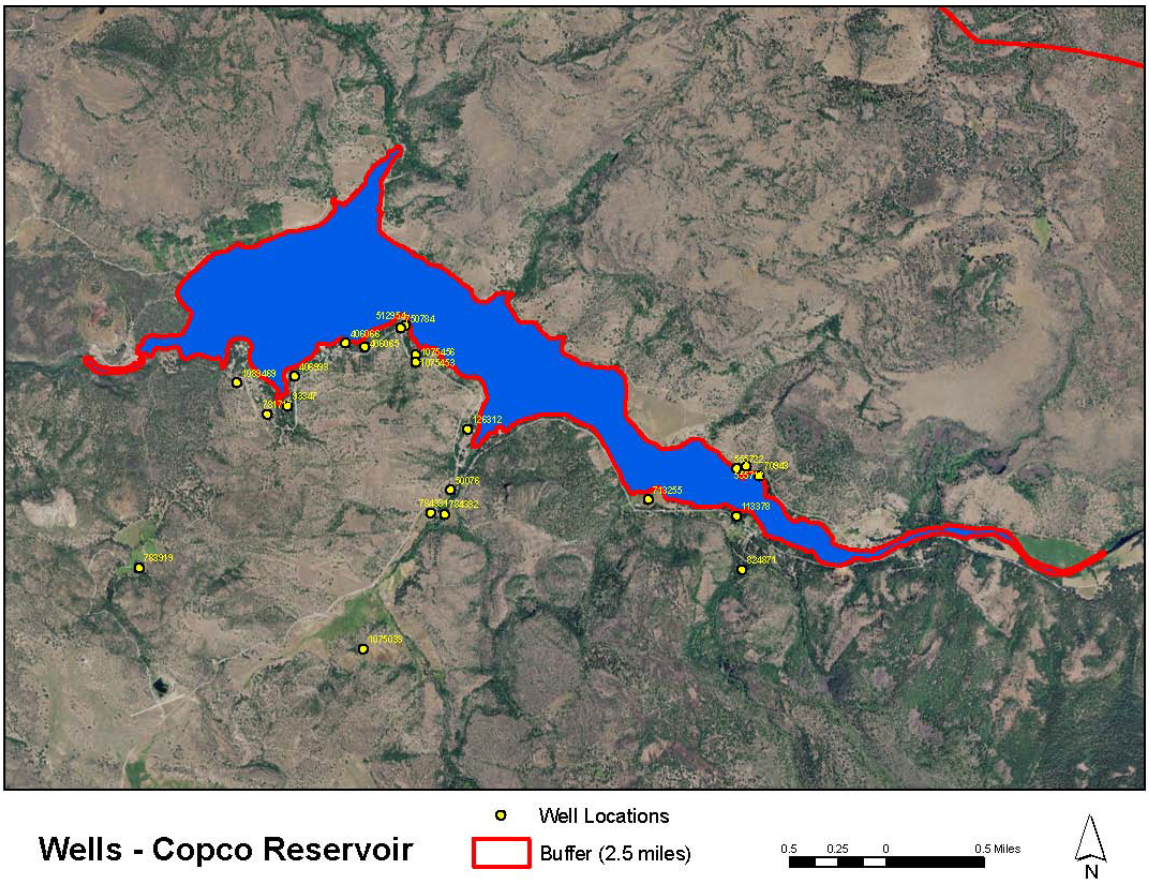


Figure 3-17. Location map showing locatable wells within 2.5 miles of Copco Reservoir. Cross-section lines are shown and labeled on Figure 3-18.

Four cross-sections were constructed on Copco Reservoir that intersected at least one of the six wells. These four cross-sections are labeled as A-A', B-B', C-C', and D-D' on Figure 3-18 and are shown in Figure 3-19 thru Figure 3-23. The wells within the 2.5 mile zone of Copco Reservoir used to generate the x-sections are summarized in the following table. Figure 3-24 shows a well profile of the wells within 2.5 miles of Copco Reservoir.

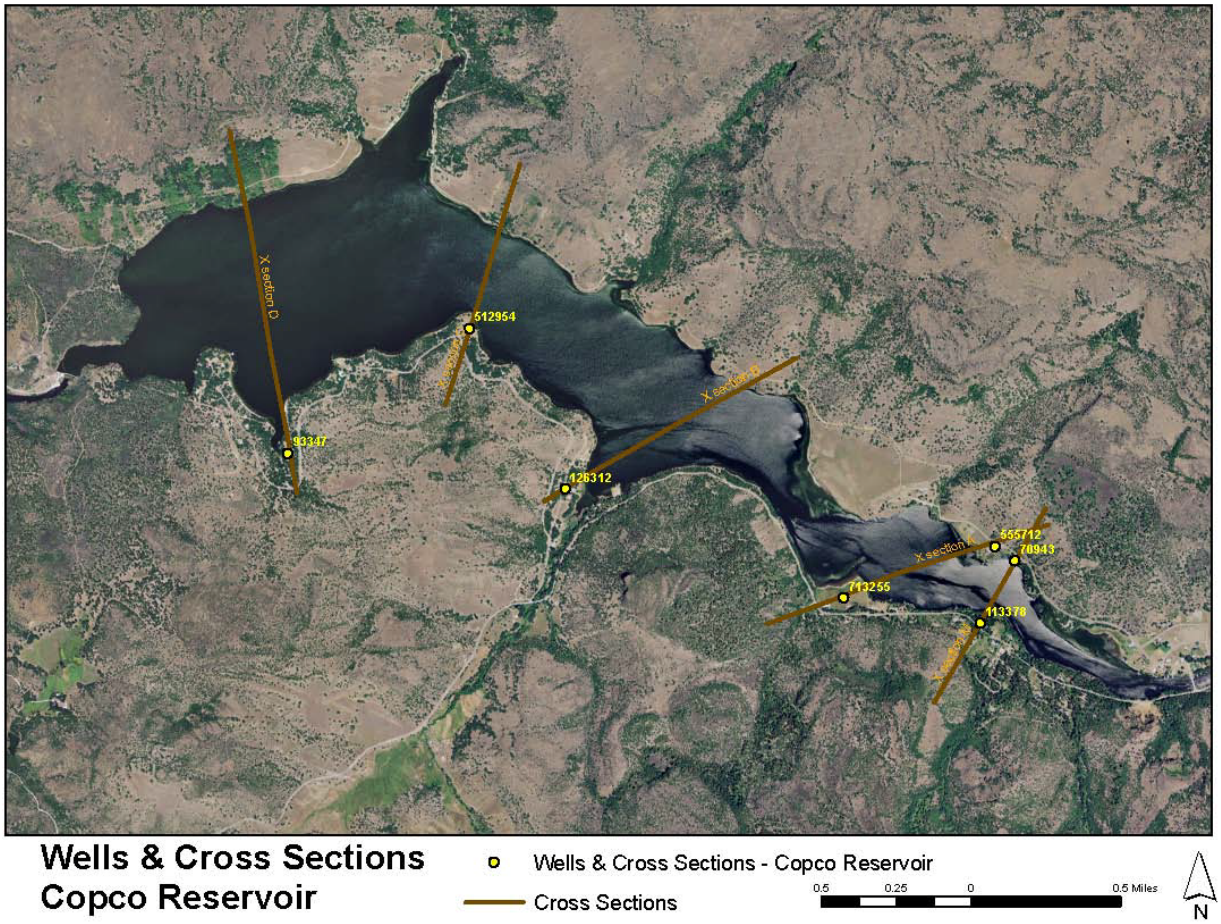


Figure 3-18. Location of cross-sections A – A', B – B', C – C', D – D', and M – M' on Copco Reservoir.

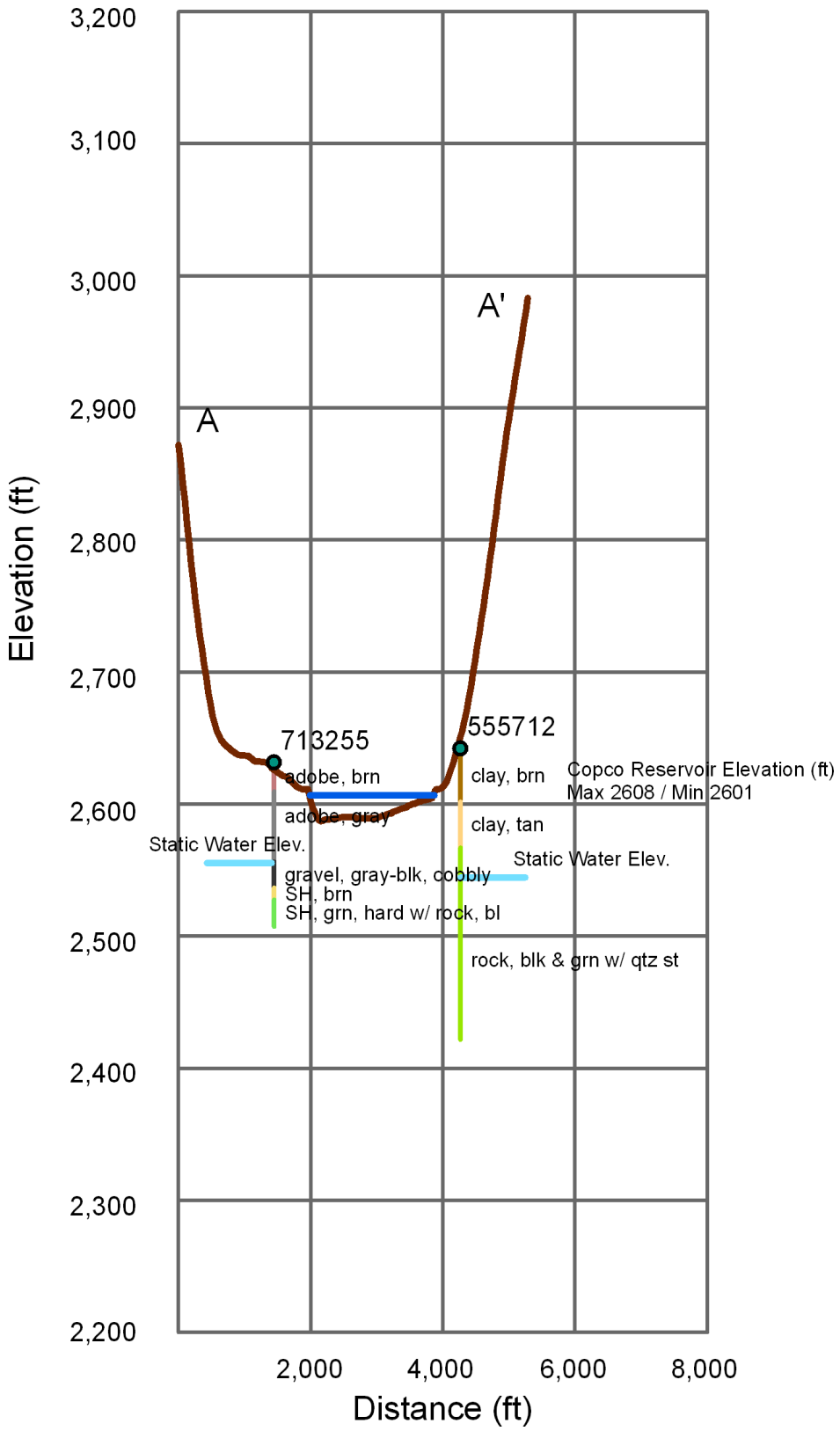


Figure 3-19. Cross-section A – A'.

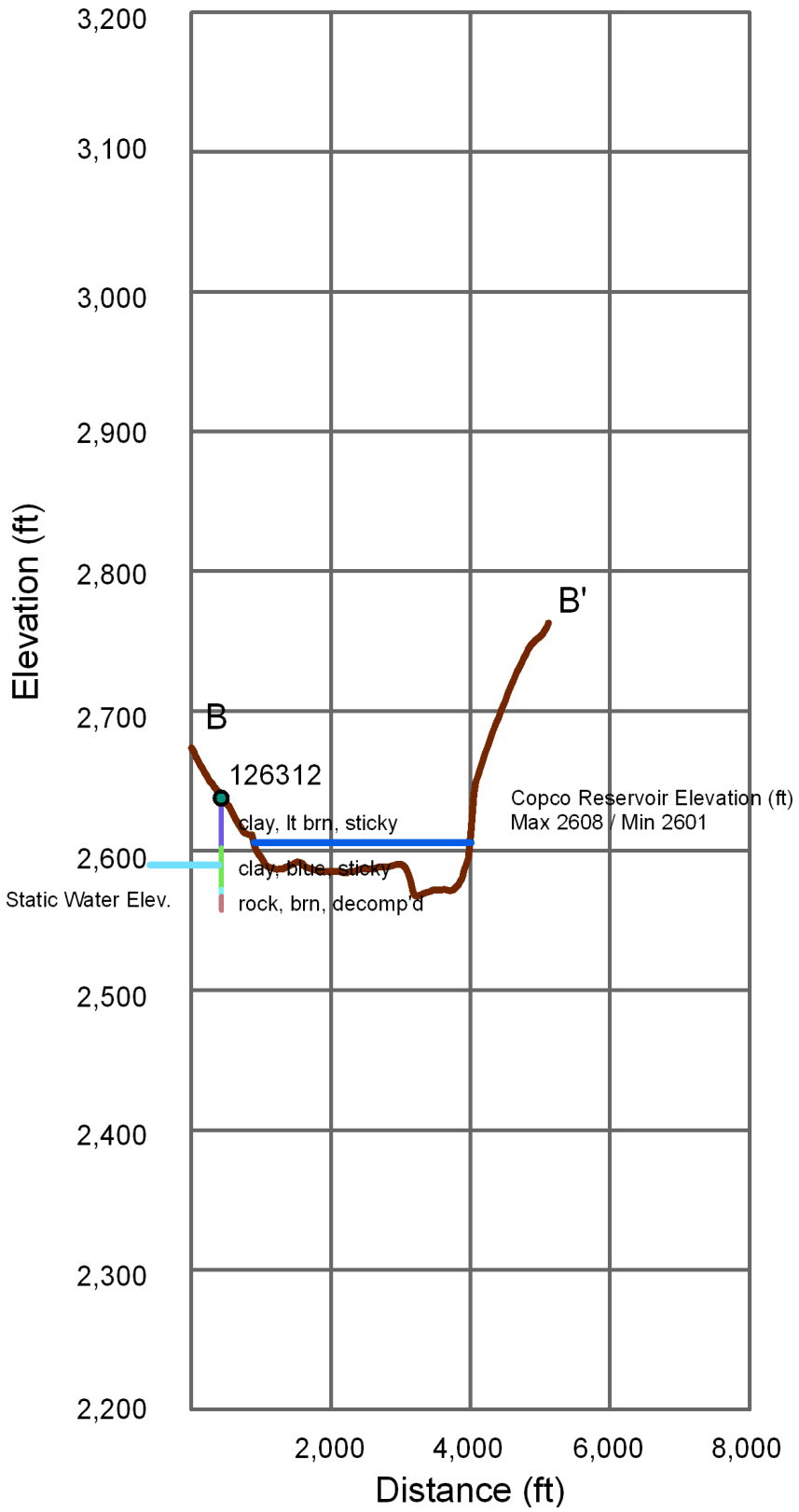


Figure 3-20. Cross-section B – B'.

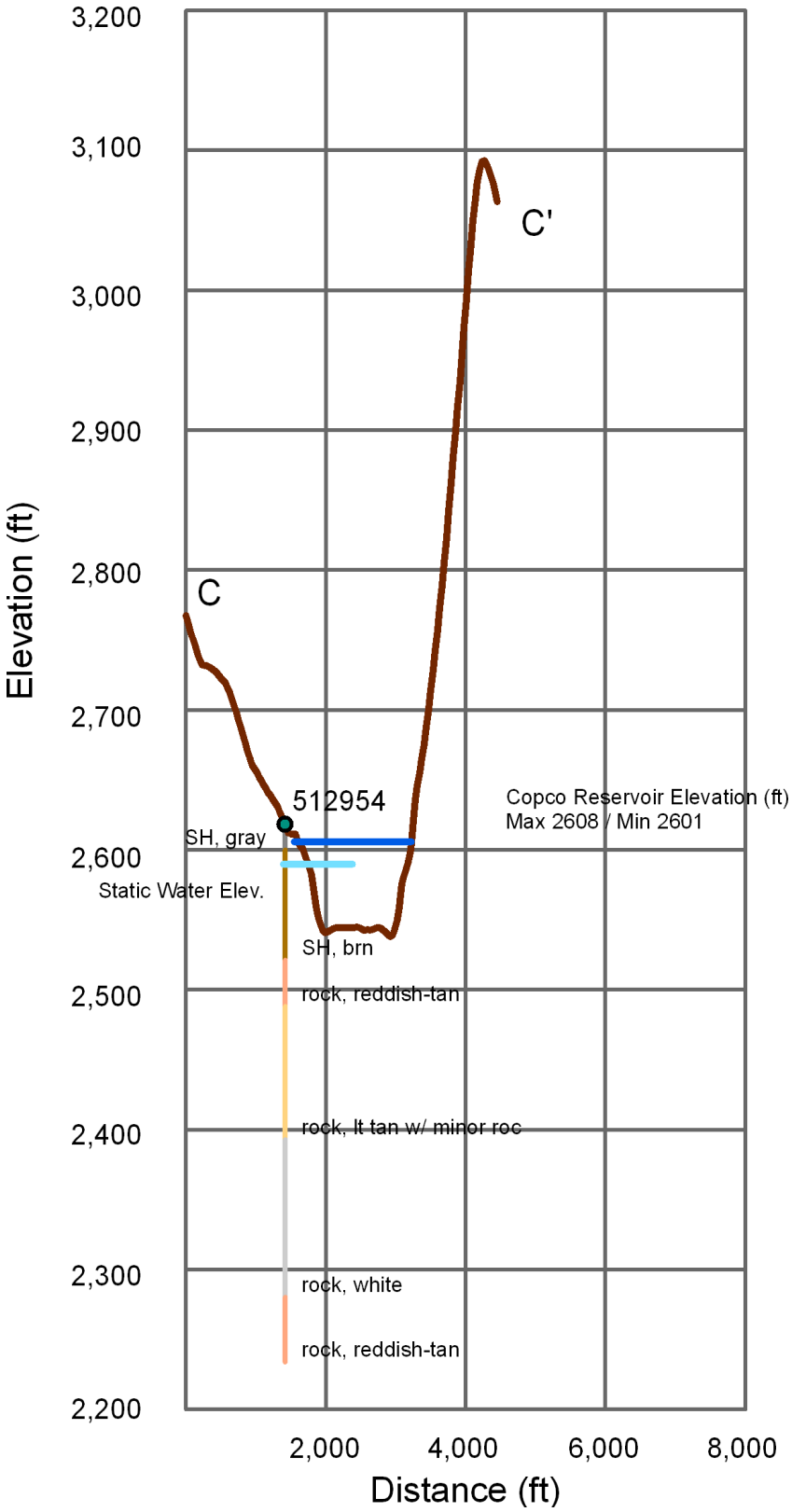


Figure 3-21. Cross-section C – C'.

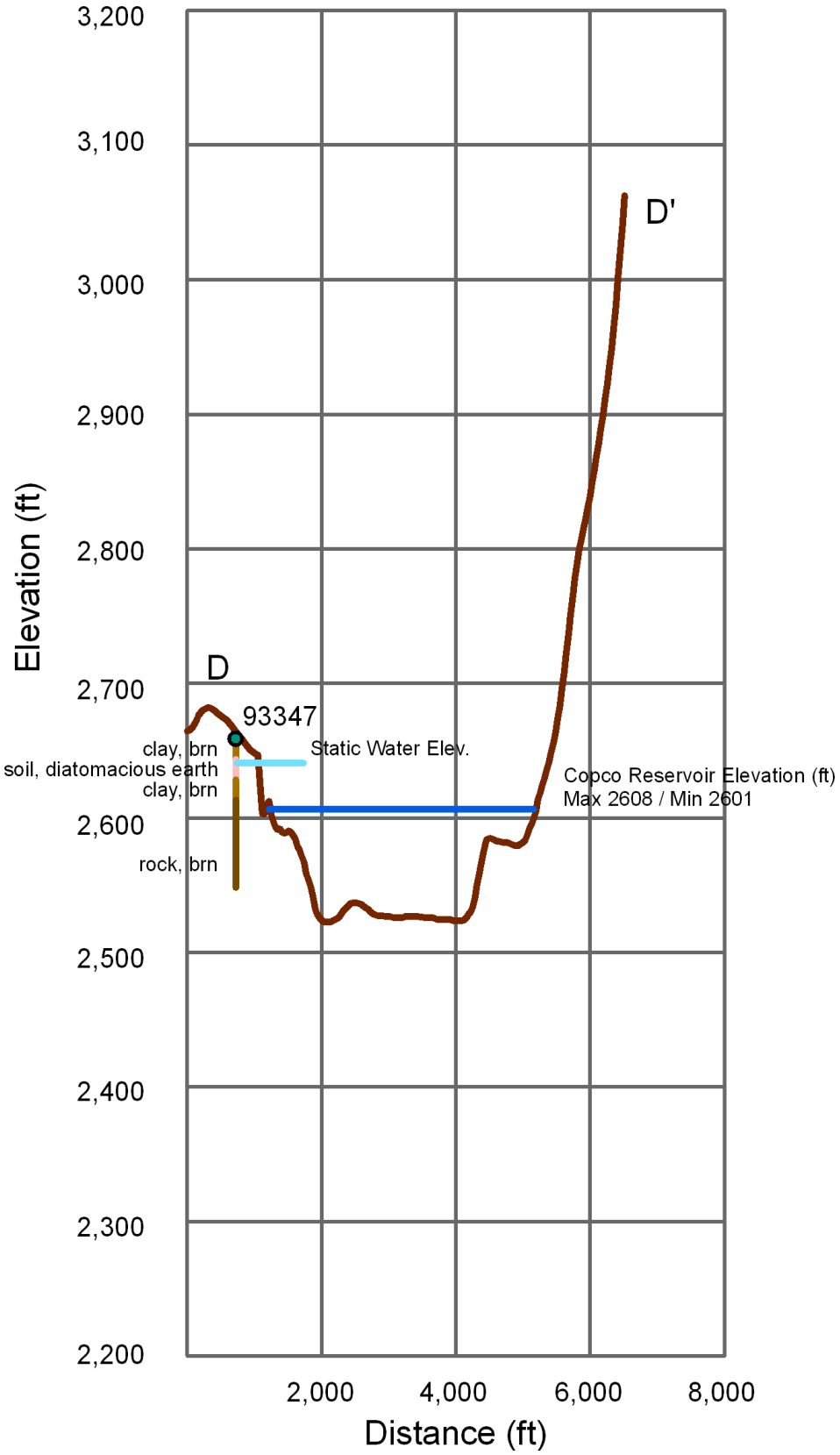


Figure 3-22. Cross-section D – D'.

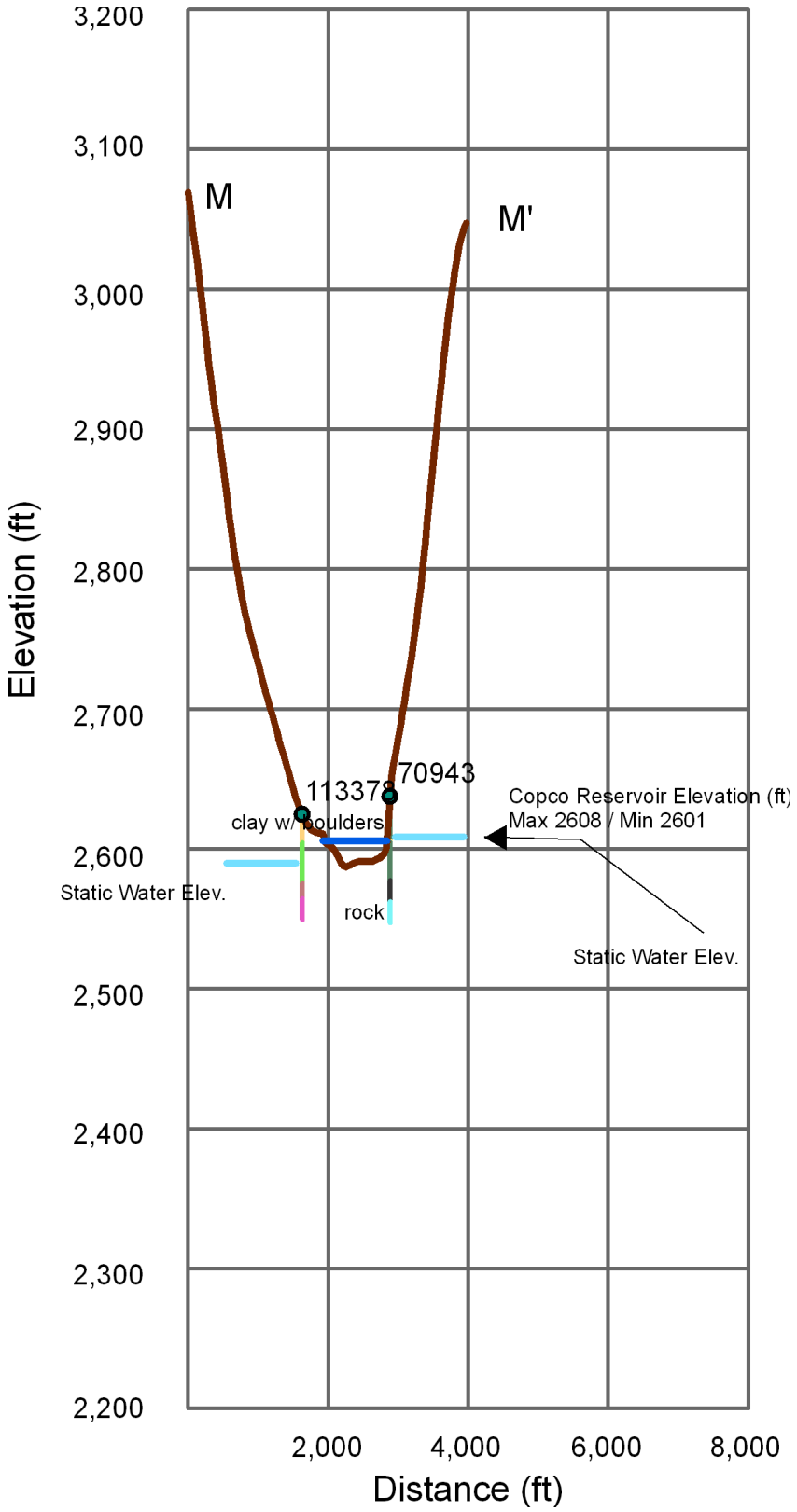


Figure 3-23. Cross-section M – M'.

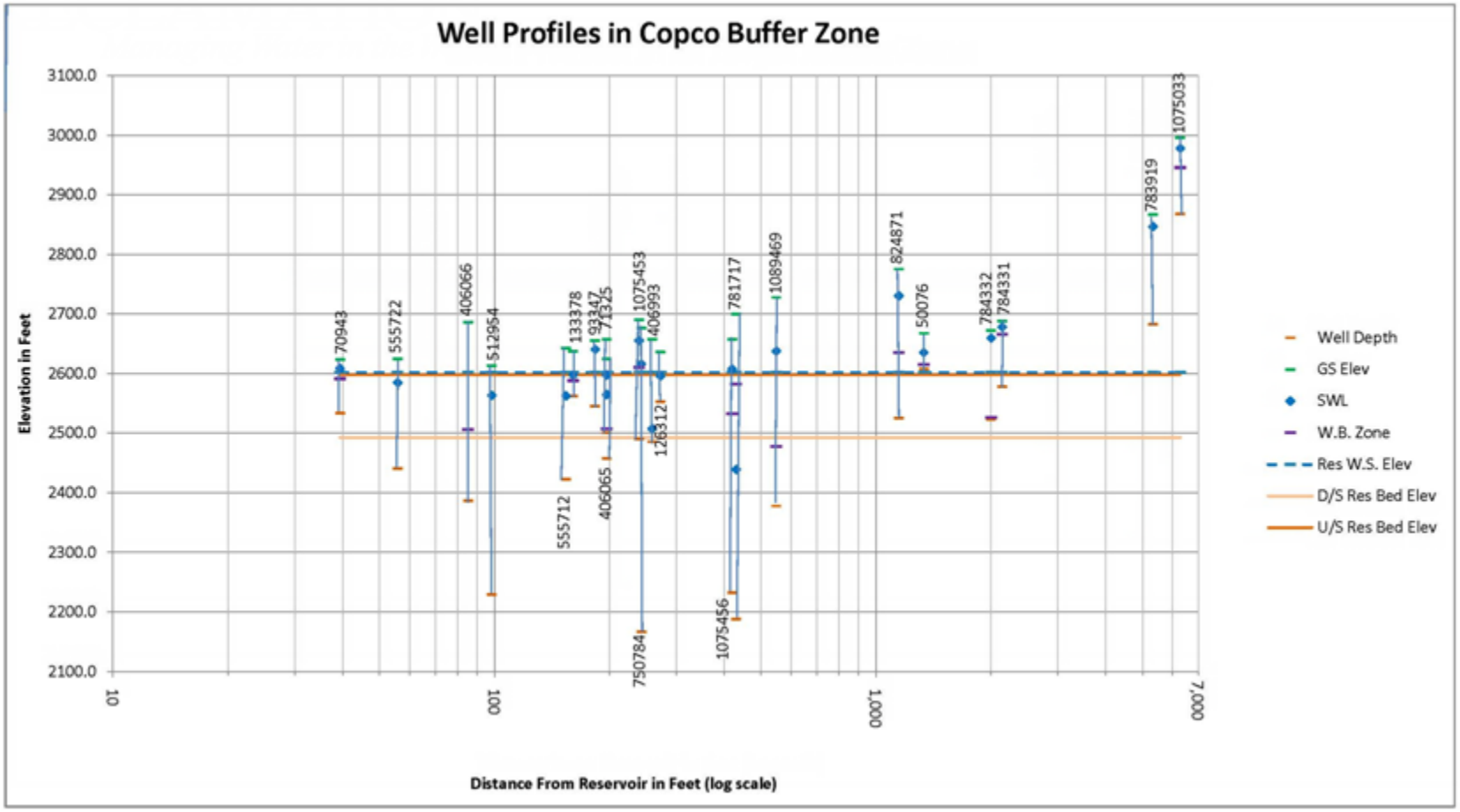


Figure 3-24. Well Profile graph for wells within 2.5 miles of Copco Reservoir.

Table 3-5. Well Construction Information for Wells within 2.5 Miles of Copco Reservoir (Reservoir Stage: 2,602 feet AMSL; River bed elevation at dam site: 2,493 feet AMSL)

Well ID	Drill Date	Use[1]	Well Diameter (in)	Depth to top of perforated zone or bottom of surface casing in an open well (ft)	Depth to bottom of perforated zone (ft)	Depth of Well (ft)	Depth to 1st Water (ft)	Pumping Rate (gpm)	Depth to Static Water (ft)
93347	08/05/1975	DOM	6	45 [2]	Open	110	N/R	20	15
126312	07/14/1976	DOM	6.625	63	83	83	55	10	40
512954	07/08/1998	DOM	6	75	225	384	N/R	2	50
555712	08/31/1994	DOM	6	100	120	220	N/R	15	80
713255	06/15/1999	DOM	6	104 [2]	Open	124	N/R	30	60
113378	08/01/1965	DOM	8	16	75	75	49	25	40
70943	06/20/1964	DOM	4.5	70	84	90	32	N/R	15

Notes:
1 - DOM: Domestic
2 - Depth to the bottom of the surface casing or sanitary seal in holes/wells that are open
Key:
in: inches
ft: feet
gpm: gallons per minute

Table 3-6. Water Level Compared to Water-Bearing Unit for Wells within 2.5 Miles of Copco 1 and Copco 2 Reservoirs (Reservoir Stage: 2,602 feet AMSL; River bed elevation at dam site: 2,493 feet AMSL)

Well File #	Cross-Section Line	Static Water Elevation (ft)	Water-Bearing Unit	Elevation of Top of Water-Bearing Unit (ft)
DWR-713255	Near A on A-A'	2,565	Hard green and black rock, 104 to 124 feet below ground surface (bgs)	2,521
DWR-555712	Near A' on A-A'	2,564	Black/green rock w/quartz stringers, 100 to 120 feet bgs	2,544
DWR-126312	Near B on B-B'	2,597	Tight blue cemented sand, 55 to 70 feet bgs, brown decomposed rock, 70 to 80 feet bgs	2,582
DWR-512954	Near C on C-C'	2,566	Reddish tan rock, lighter tan rock, white rock, reddish tan rock	2,541
DWR-93347	Near D on D-D'	None recorded	Rock, 45 to 110 feet bgs	2,608 (est.)
DWR-113378	Near M on M-M'	2,597	Small boulders, 49 to 60 feet bgs	2,588
DWR-70943	Near M' on M-M'	2,608	Gravel, 32 to 33 feet bgs	2,591

The data for the wells in the x-section indicate that the water-bearing unit is above the bottom of the reservoir at the dam site, as are the SWLs. In fact, all the wells near Copco Reservoir, with the exception of one, have SWLs that are below the reservoir stage but above the river bed elevation at the dam site. Similarly, all the wells but one has elevations for the top of the water bearing unit below the reservoir stage and above the river bed elevation at the dam site. The two exceptions are two different wells. In some cases, the top of the water bearing formation was not identified on the log, so the elevation at which water was first encountered in the drilling is used as a substitute for the top of the water bearing unit.

As can be seen on the x-sections A-A', B-B', and C-C' (Figure 3-19 thru Figure 3-21) and in Table 3-4, the SWL in the wells is below the reservoir water level of 2602', and the water bearing unit is below the bottom of the reservoir in x-sections A-A' and B'B' (2585' and 2565' respectively). In x-section C-C' the top of the water-bearing unit is just about the same elevation as the bottom of the reservoir (2640') although the SWL is some 36' below the reservoir water level elevation of 2602'. So in the case of Well 512954 in x-section C-C' it is uncertain

if the water-bearing unit 'daylights' in the reservoir or is just below the original channel bed (or maybe the channel had started to incise into the unit).

In x-section D-D' (Figure 3-22) the estimated top of the water-bearing unit (in this case the estimate is based on the bottom of the blank casing installed in the well) is well about the bottom of the reservoir at 2520'. Presumably, the water-bearing unit in this well is in direct contact with the reservoir – i.e. the unit 'daylights' in the reservoir. The case for a direct connection between the reservoir and the water-bearing unit could be verified if a SWL reading had been recorded.

The average SWL for all wells less than 300 feet from the reservoir is 2,591 feet while the average SWL for all wells greater than 400 feet from the reservoir is 2,680 feet. This suggests that there is a vertical downward head gradient component closer to the reservoir. This would also suggest that the reservoir does not have a significant lateral influence on groundwater levels.

The SWLs in the wells were recorded upon completion of the wells, which was in 1999, 1994, 1976, 1998, and 1975 respectively. Additionally, the water level elevation of Copco Reservoir is an average elevation over an unknown number of years, so there is little correlation between the reservoir level and the SWL in any of the wells. Even so, for any of these wells to be influenced by the water level in the reservoir the water-bearing unit in each well would have to have some connection with the reservoir. In case of Wells 713255, 555712, and 126312 (x-sections A-A' and B-B') the relatively flat laying or gently eastward dipping units of volcanic materials are deeper than the bottom elevation of the reservoir (the pre-reservoir river bed). The well profile for Copco Reservoir (Figure 3-24) suggests that the gradient near the reservoir is away from the reservoir – i.e. the reservoir is losing water and that far away from the reservoir the gradient is towards the reservoir, while at intermediate distances there are about as many SWLs above the reservoir level as there are below it. The wells more than about 1000 feet away from the reservoir appear to be responding to a regional or localized groundwater system that is higher than the reservoir level,

In the case of wells 512954 and 93347 that could have a connection to the reservoir, the lower SWL could simply reflect a lower water surface elevation in the reservoir when these two wells were completed. No subsequent SWL readings have been obtained that could be compared to the reservoir water surface elevation obtained at the same time in order to verify whether or not the water levels in these wells are responding to water levels in the reservoir.

3.6.4.3. Iron Gate Reservoir

Like Copco 1 Reservoir, Iron Gate Reservoir overlies the transition on the Klamath River with the upstream area being steeper. The downstream portion of Iron Gate Reservoir is a lower-gradient area where the valley floor widens, and the channel is less restricted by the localized basalt lava flows. The reservoir has relatively steep side-slopes and a narrow channel with numerous side drainages. Wells located within 2.5 miles are shown in Figure 3-25.

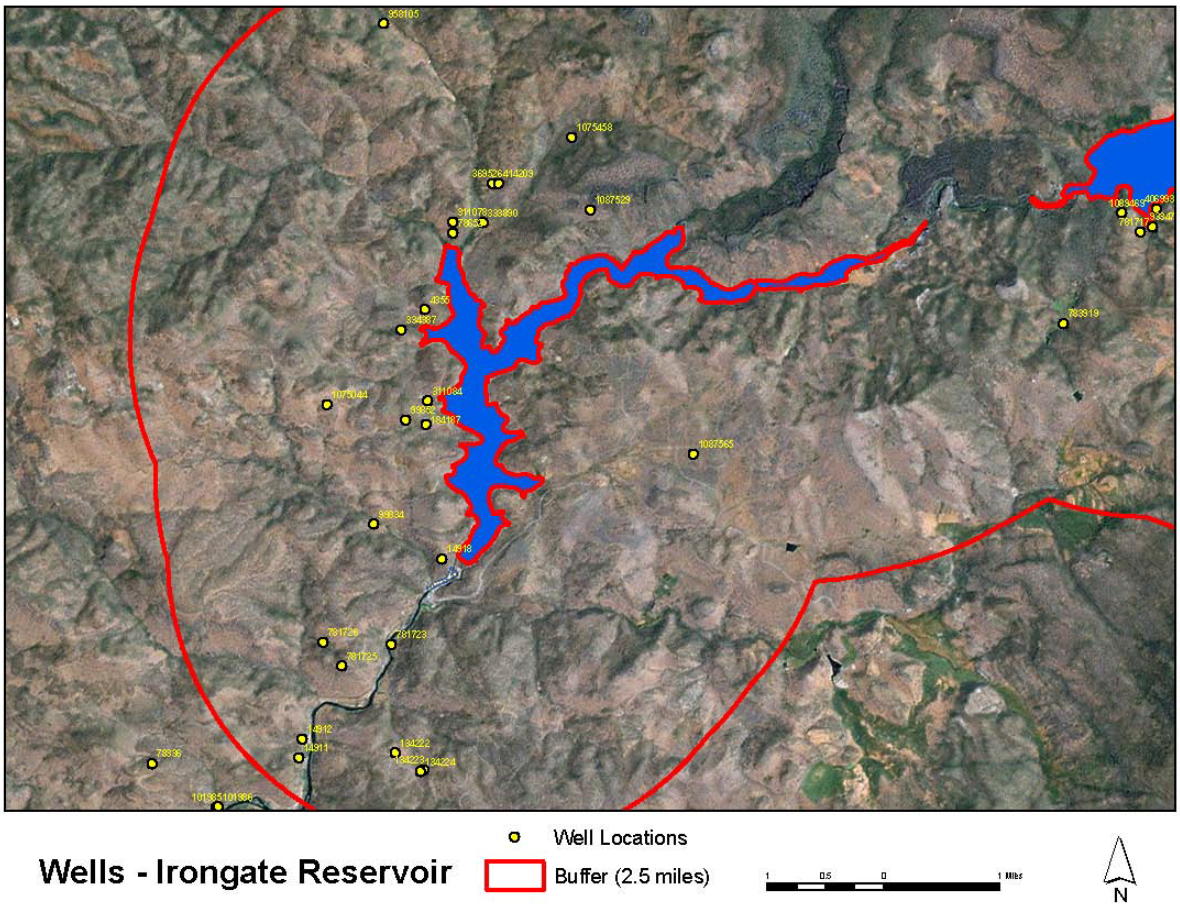


Figure 3-25. Location map showing locatable wells within 2.5 miles of Iron Gate Reservoir. Cross-section lines are shown and labeled on Figure 3-26.

Four cross-sections were constructed for Iron Gate Reservoir that intersected at least one of the twenty wells that are within 2.5 miles of the reservoir. These four cross-sections are labeled as E-E', F-F', G-G', and H-H' on Figure 3-26 and are shown in Figure 3-27 thru Figure 3-29. The wells within the 2.5 mile zone of Iron Gate Reservoir used for the x-sections are summarized in the following tables. Additionally, a well profile for Iron Gate was generated (Figure 3-30).

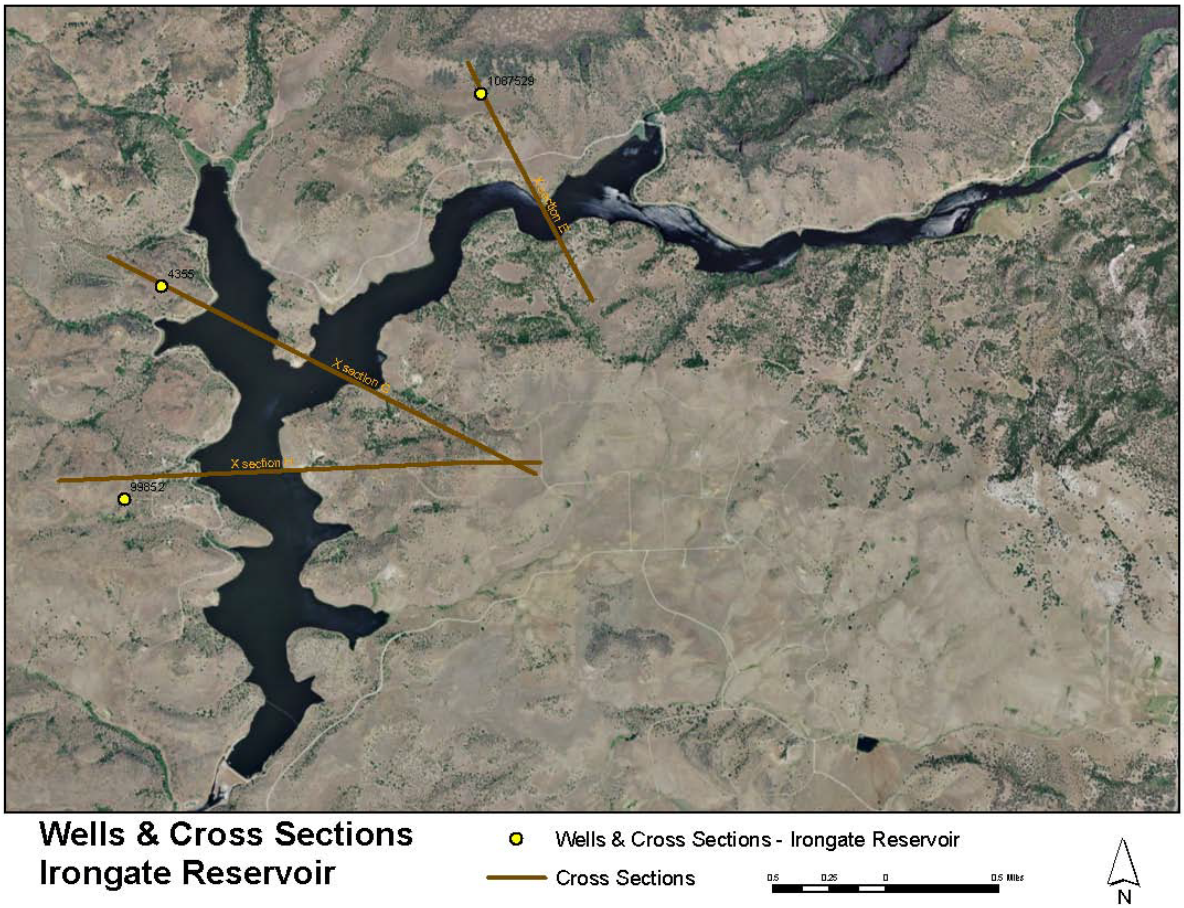


Figure 3-26. Location of cross-sections A – A', B – B', C – C', and D – D' on Copco Reservoir.

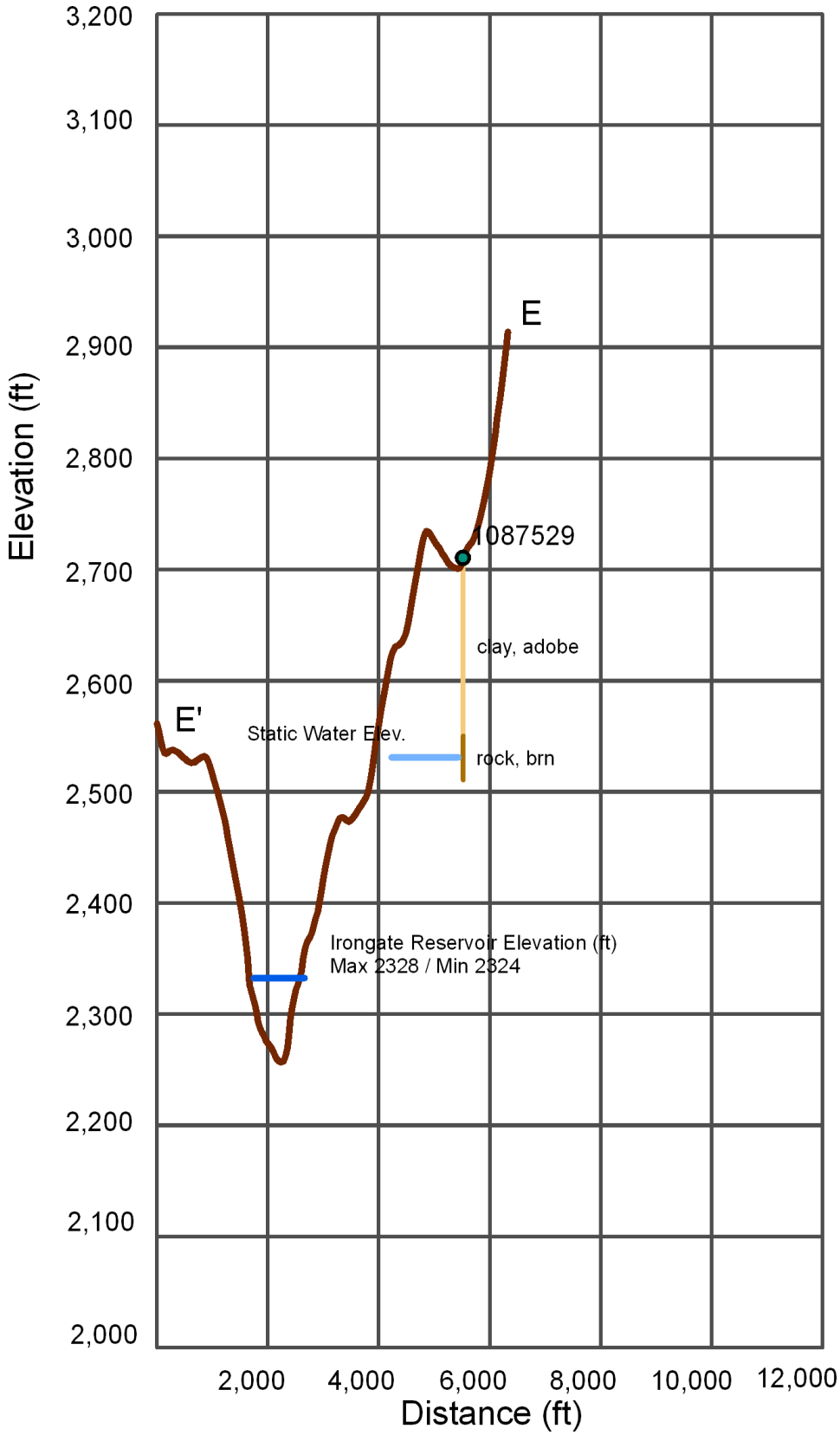


Figure 3-27. Cross-section E – E'.

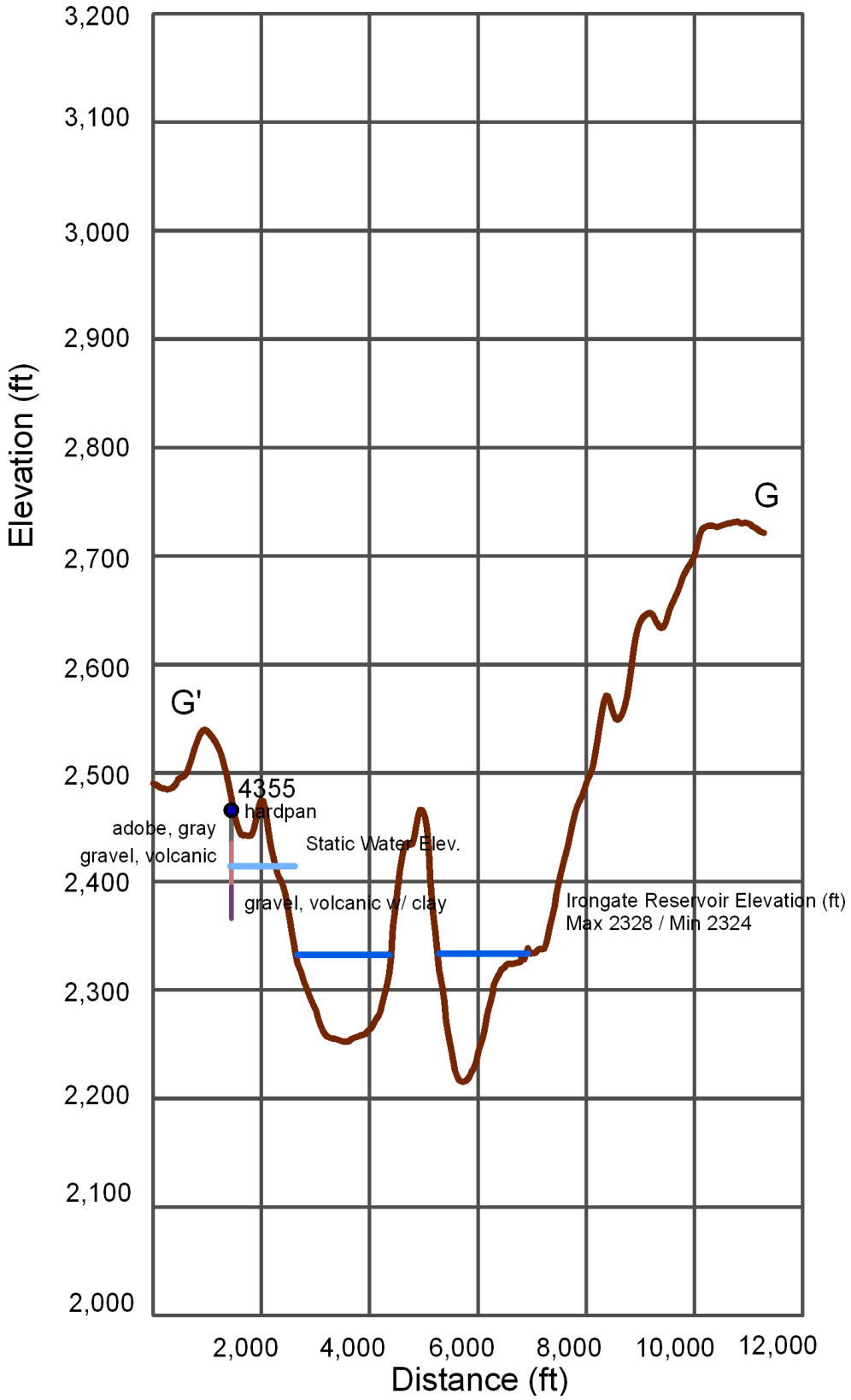


Figure 3-28. Cross-section G –G'.

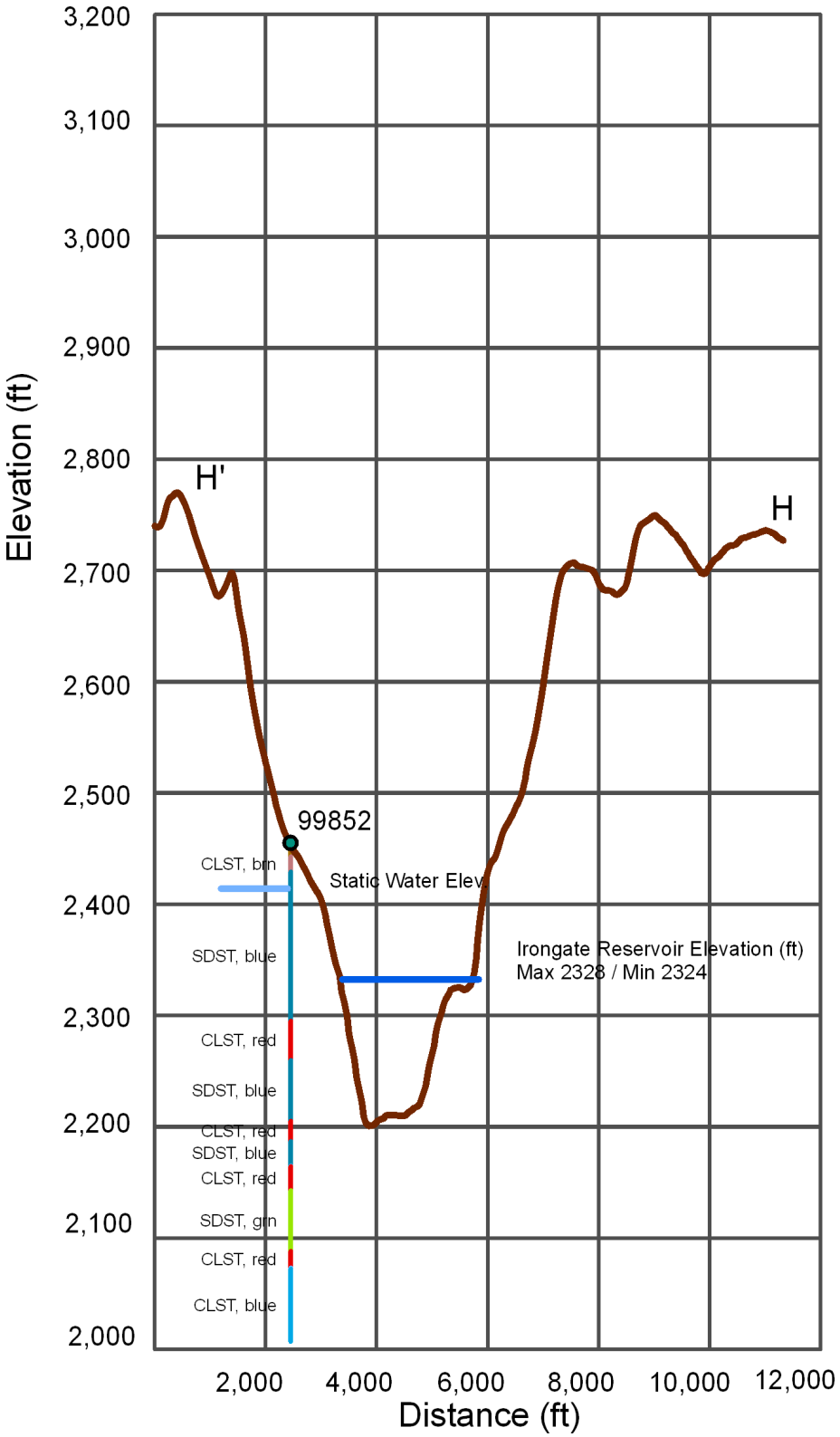


Figure 3-29. Cross-section H – H'.

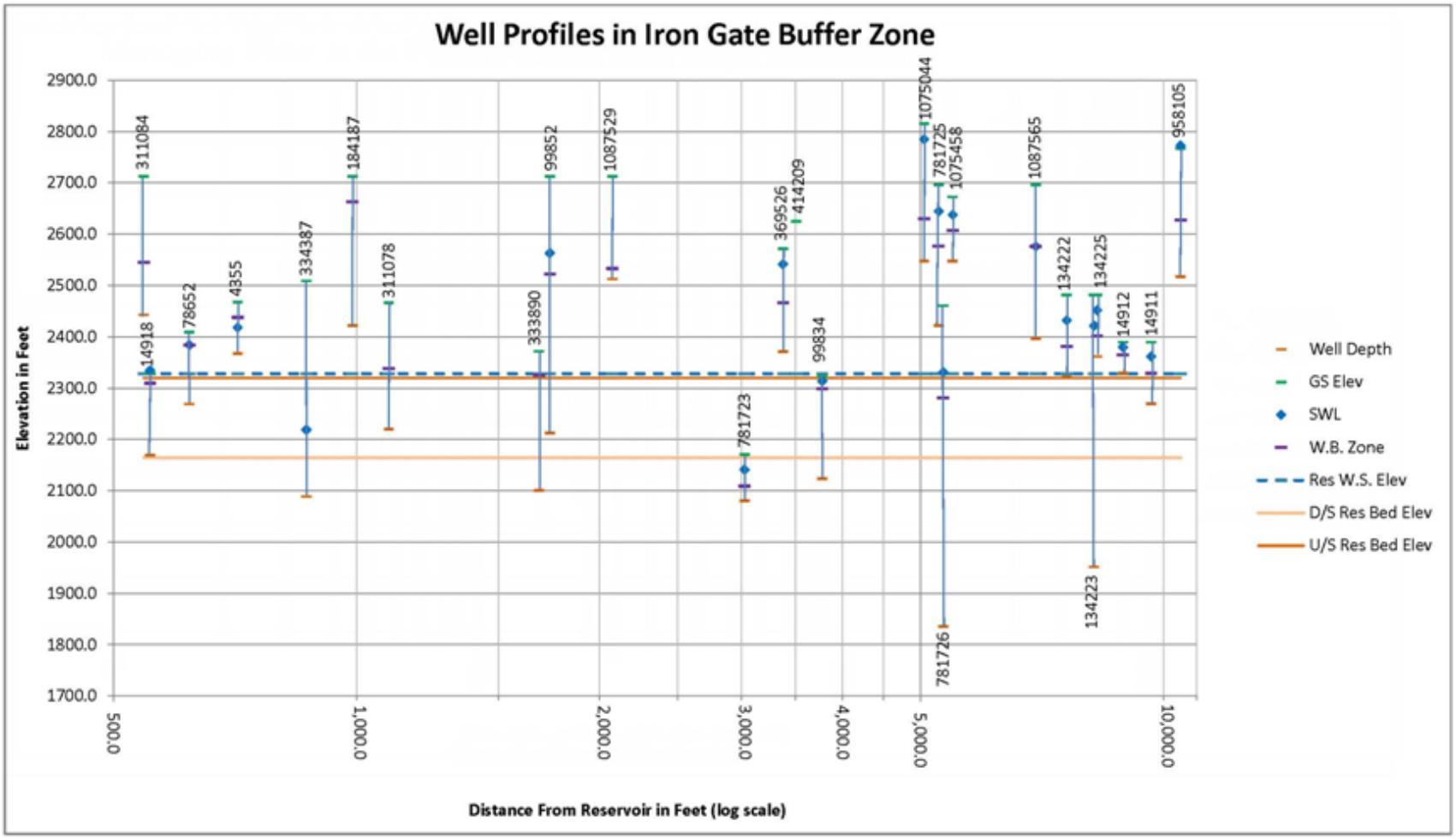


Figure 3-30. Well Profile graph for wells within 2.5 miles of Iron Gate Reservoir.

Table 3-7. Well Construction Information for Wells within 2.5 Miles of Iron Gate Reservoir (Reservoir stage – 2328 feet AMSL; river bed elevation at dam site – 2165 feet AMSL).

Well ID	Drill Date	Use[1]	Well Diameter (in)	Depth to top of perforated zone or bottom of surface casing in an open well (ft)	Depth to bottom of perforated zone (ft)	Depth of Well (ft)	Depth to 1st Water (ft)	Pumping Rate (gpm)	Depth to Static Water (ft)
4355	06/14/1966	DOM	8	12	70	100	30	10	50
14911	10/01/1980	DOM	6	100	120	120	N/R	50	28
14912	10/01/1980	DOM	6	40	60	60	N/R	50	10
14918	12/18/1980	DOM	6	40 [2]	Open	160	20	40	0
134222	09/01/1982	DOM	6	120	160	160	N/R	20	50
134223	09/01/1982	DOM	6	20 [2]	OPEN	530	N/R	1	60
78652	07/05/1983	DOM	4	80	140	140	25	6	25
99852	08/25/1981	DOM	6.625	30 [2]	Open	500	191	5	150
184187	04/13/1987	DOM	4	271 [2]	291	291	281	15	N/R
311078	05/09/1990	DOM	6	22 [2]	Open	246	N/R	12	N/R
134224	09/01/1982	DOM	6	80	120	120	N/R	15	30
311084	05/03/1990	DOM	6	52 [2]	Open	270	250	25	N/R
333890	07/09/1990	DOM	6	23 [2]	Open	271	N/R	12	N/R
334387	10/1201990	DOM	6	21 [2]	Open	420	N/R	0.125	290
369526	06/22/1991	DOM	6	36 [2]	Open	200	105	20	30
1075044	10/09/2008	DOM	4	52	260	268	185	30	30
1087529	07/18/2003	DOM/ IRR	8	100	200	200	180	25	N/R
1087565	09/06/2006	DOM	6	140	300	300	120	20	120
781223	02/03/2003	DOM	4	35	90	90	62	75	30
414209	06/22/1991	DOM	0	N/R	Open	0	N/R	0	0
1075458	11/17/2004	DOM	6	40	125	125	65	100	35
781725	01/06/2003	DOM	4	54	265	275	120	7	52
99834	07/28/1981	DOM	6.625	N/R	Open	200	N/R	25	10
781726	08/25/2002	DOM	4	55	530	625	180	12	130
958105	10/25/2006	DOM	4	30	247	250	140	N/R	0*

Notes:
1 - DOM: Domestic; IRR: Irrigation
2 - Depth to the bottom of the surface casing or sanitary seal in holes/wells that are open
Key:
in: inches
ft: feet
gpm: gallons per minute
N/R: Data not Recorded
* SWL at top of well casing, so depth to water is ‘0’.

Table 3-8. Water Level Compared to Water-Bearing Unit for Wells within 2.5 Miles of Iron Gate Reservoir (Reservoir stage – 2328 feet AMSL; river bed elevation at dam site – 2165 feet AMSL).

Well File #	Cross-Section Location	Static Water Elevation (ft)	Water-Bearing Unit	Elevation of Top of Water-Bearing Unit (ft)
1087529	Near E on E-E'	None recorded	Brown rock, 160 to 200 feet below ground surface (bgs)	2,532
4355	Near G' on G-G'	2,424	Volcanic gravels, 30 to 70 feet bgs	2,444
99852	Near H' on H-H'	2,563	Blue sandstone from 195 to 250 feet bgs	2,518

The data in Tables 3-10 and 3-11 show that the SWL (when recorded) is above the reservoir stage with only two exceptions (well #s 781723 and 99834). The SWL for all the wells is also above the elevation of the river bed at the dam site with only one exception (well # 781723). The tables also show that the estimated elevation of the top of the water bearing unit (recorded on 13 of the 25 logs) is above the reservoir stage (and by default also above the reservoir bottom) in 10 of the 13 wells. In two wells, the top of the water bearing unit is between the reservoir stage and the reservoir bottom. In only one well is the top of the water bearing unit below the reservoir bottom (well # 781723).

Wells further away from Iron Gate Reservoir have higher SWLs and generally higher top of water bearing unit elevations than well closer to the reservoir. This indicates a head gradient towards the reservoir which is in agreement with the regional groundwater gradients (Gannett, et al, 2010). Where recorded, wells within 2,000 feet of the reservoir have SWL very close to the reservoir stage or above (with one exception, well # 334387). The current well data is not sufficient to determine whether or not Iron Gate reservoir has any downward or horizontal seepage.

As can be seen on the x-sections E-E', G-G', and H-H' (Figures 3-27, -28, and -29) and in Table 3-7, both the SWL and the water-bearing units in the wells are significantly above the reservoir water level of 2328'. In fact, the bottom of each bore hole is also well above the reservoir level. It is obvious from these x-sections that the water-bearing units are in no way connected to the reservoir and thus definitely represent the regional groundwater system.

The well profile for Iron Gate Reservoir (Figure 3-30) would suggest that Iron Gate Reservoir has less of an influence on nearby wells than does Copco or J.C. Boyle. It also shows that many private wells are located on highlands overlooking the reservoir as opposed to near the shoreline. The four closest wells to the

reservoir indicate that the local gradient is towards the reservoir so these wells are unlikely to be significantly impacted by the removal of the reservoir.

The SWLs in the wells were recorded upon completion of the wells, which was in 2003, 1966, 1980, and 1990 respectively. Summary
The four dams – J.C. Boyle, Copco #1 & #2, and Iron Gate – are in the High Cascades Province with J.C. Boyle Dam being in the transition zone between the Modoc Plateau and High Cascades Provinces and Iron Gate Dam being in the transition zone between the Western Cascades Sub-Province and the Klamath Mountains Province. The Modoc Plateau Province represents the northern most extent of the Basin and Range Physiographic Province while the Western Cascades and High Cascades Provinces represent volcanic arc processes related to subduction zones. Both processes, however, result in extensive volcanic activities extending back to at least the late Eocene Epoch some 35 - 40 Ma (million years before present).

The geology of the region of the Upper Klamath Basin is very complex with ". . . hundreds of distinct and mappable geologic units . . ." of volcanic and sedimentary processes. However, many of these " . . . distinct and mappable geologic units . . ." have similar or identical origins and properties. As such, these hundreds of geologic units can be grouped into eight hydrologic units based on their hydrogeologic properties. These eight hydrologic units are: Quaternary sedimentary deposits, Quaternary volcaniclastic deposits, Quaternary volcanic rocks, Quaternary to late Tertiary sedimentary rocks, Late Tertiary sedimentary rocks, Late Tertiary volcaniclastic rocks, Late Tertiary volcanic rocks, and older Tertiary volcanic and sedimentary rocks (Gannett, et al., 2010).

Most of these hydrologic units are water-bearing and can form aquifers. The aquifers can consist of vast sheets of vesicular, fractured, and or columnar basalts, layers of weathered and/or reworked volcanic gravels and breccias, lake deposits, alluvial deposits, and loess deposits. Likewise, the aquifers can be restricted in areal extent, thickness, and capacity, or perched. They can also form confining units when they consist of fine-grained materials (such as lake bed clays) and/or are very tight (such as welded tuff, unfractured low vesicular basalts, cemented sandstones, etc). Each of these units can and often do overlay, underlay, and interfinger with all the other units in complex relationships.

Very little specific groundwater data exists for the areas of the three dams and reservoirs as there are no state or USGS monitoring wells in the reach of the Klamath River valley in which the dams are located. A significant number of private domestic wells exist in the river valley from upstream of Keno Dam to downstream of Iron Gate Dam. There are sixteen locatable wells within 2.5 miles of J.C. Boyle Reservoir, twenty-two locatable wells within 2.5 miles of Copco Reservoir, and twenty-five locatable wells within 2.5 miles of Iron Gate Reservoir – all are private domestic wells. No SWLs in any of the wells in the project area have been recorded more than once and no pre-dam SWL measurements were found.

The regional groundwater system generally flows from the higher landforms – hills, ridges, mountains, etc – toward the lower river valley with an overall regional gradient from upstream around Keno Dam downstream toward Iron Gate Dam. The gradients tend to be steepest on the south side of the valley between the Mount Shasta uplands and the Klamath River. Gradients near the reservoirs generally are away from the reservoir and/or vertically downward under the reservoirs – although cases where the gradients are towards the reservoirs or upwards under the reservoir are common.