# Ground Water Hydrology of Four Proposed Project Areas in the Klamath Basin, Oregon

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## Well Location System

The well location system used in this report is based on the rectangular system used for subdivision of public land. Each well location describes the township, range, and section. The letters following the section number indicate the well location within the section, as shown below in Figure 1. The first letter (**c**) represents the quarter section (160 acres), the second letter (**a**) the quarter-quarter section (40 acres), and the third letter (**a**) the ten acre tract.

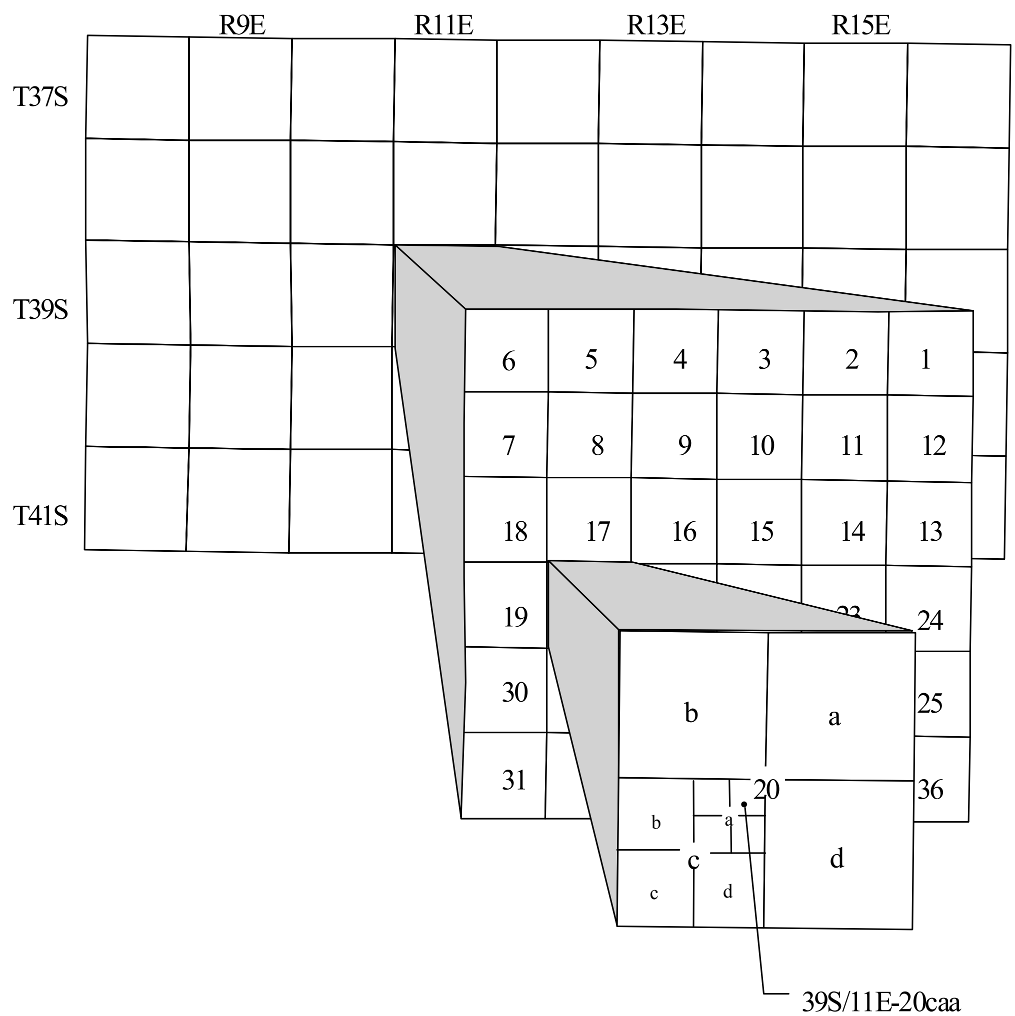



Figure 1. Well Location System.

# EXECUTIVE SUMMARY

## Purpose

Water in the Klamath Basin supports multiple uses. In the past surface water diversions from Upper Klamath Lake and its tributaries, and the Lost River were the primary source of water for irrigated agriculture, livestock, fish, and wildlife refuges. Ground water has been used for domestic supplies and for irrigation in areas not served by surface water supplied projects. These different uses compete for water. Population growth combined with changing public priorities has increased the demand for irrigation water.

The purpose of this study is to investigate options for increasing water supply through ground water development. The report is designed to present an overall review by previous investigators of geologic and hydrologic studies of the Klamath Basin, followed by more detailed sections on the hydrogeologic characteristics and present conditions in the four proposed project areas: the Shasta View Irrigation District, Ady District, Fort Klamath, and Langell Valley areas.

## Geologic Setting

Previous geologic studies of the Klamath Basin have noted the occurrence of extensive volcanic deposits and sedimentary deposits of multiple ages. The primary rock types are older Tertiary basaltic lava flows interspersed with vent deposits, and consolidated sedimentary deposits commonly interbedded within, and overlying, the basalts. Younger Quaternary lava flows and intrusive bodies occur mostly in the northern and western portions of the basin. Recent Pleistocene and Holocene unconsolidated sediments have been extensively deposited in the lowland valley areas.

Extensive faulting has been occurring throughout the past 10 million years. Faulting has produced the well developed horst and graben topography that is prevalent throughout the basin. The major basin bounding faults commonly have displacements in excess of 1000 feet, with numerous subsequent faults having lesser structural offset. These faults often juxtapose different rock types against each other to produce highly variable local hydrogeologic characteristics.

## Hydrogeology

Illian (1970) prepared the most comprehensive investigation of Klamath Basin ground water sources and movement. His study indicated that the lower basalt aquifer occurs throughout most of the sub-basins in the region. The primary source of recharge for this aquifer is from precipitation in the highland regions surrounding the basin. The aquifer owes its permeability to weathered surfaces, scoriaceous interbeds, and fractures in the basalt. Previous investigators have measured high transmissivity values for the lower basalt aquifer throughout most areas of the Klamath Basin. The lower basalt aquifer is the primary formation tapped by irrigation wells.

Illian (1970) noted the ground water flow system is commonly stratified. Ground water circulation in the regional flow system usually flows to depths of thousands of feet. Deep circulation of the regional flow system allows for interbasin ground water exchange from adjacent sub-basins.

Illian (1970), Leonard and Harris (1974), and Gorman (1994), all noted that faulting generally influences ground water flow more locally rather than regionally. They indicated that ground water moves freely across fault zones in most areas, but exceptions do occur.

## Shasta View District

The Shasta View Irrigation District is an excellent area to explore the availability of using ground water as an alternative to surface water supply. The district already has installed an efficient pressurized pipe delivery system. There are also 32 existing irrigation wells in the vicinity of the district.

The primary aquifer in the Shasta View District is fractured Tertiary basalt. Nearly all of the irrigation wells in the area produce water from this basalt aquifer. Wells in this aquifer show good production with yields up to 2200 gpm. Continental sedimentary deposits also occur in the northern district area. The continental sediments yield water to wells but generally this unit acts as a confining layer for the basalt aquifer at depth. The surface sediments are mostly sands and silts. The surface sediments are a poor water producing unit, but yield sufficient quantities of ground water for many domestic wells in the area.

Well log lithology was used to construct geologic cross sections that show the stratigraphic and structural relations of rock units in the area. The cross sections display the faulted structural and stratigraphic characteristics of the continental sedimentary rocks and the underlying basalt strata. These complex relationships suggest that aquifer characteristics may be variable in the Shasta View area.

Forty-one wells were field located and used for data collection and hydrogeologic analysis of aquifer characteristics in the area. Water table maps produced from these wells show that the potentiometric surface elevation of the basalt aquifer ranges from 4021 to 4037 feet. The potentiometric surface is nearly level over most of the area. Water level measurements indicate that the hydraulic gradient of the basalt aquifer is 1 to 2 feet per mile from north to south.

Hydrographs of water level data from wells that penetrate the basalt aquifer show that water levels fluctuate seasonally. Hydrographs of data from the northern part of the district show lower water levels in the fall and a seasonal rise in the spring of up to 8 feet due to the increased recharge. Hydrographs from wells in the southern part of the district show only 1 to 2 feet of seasonal fluctuation, often with their highest level reached in the fall.

Aquifer test data from two separate tests were used to assess the hydrogeologic characteristics of the basalt aquifer. The aquifer test results indicated the transmissivity of the basalt aquifer ranges from 120,000 to 205,000 gpd/ft. These values are moderately high, indicating there is good potential for high production wells in the area. Water quality samples collected showed that water from the basalt aquifer has low concentrations of dissolved solids and is of good quality.

## Ady District

The Ady district area is considered a good candidate for using ground water instead of surface water for its irrigation supply. In the area, ground water is an underutilized resource and the surface water delivery system is inadequate and inefficient.

Cross sections show the geology of the area is characterized by volcanic rock cut by steeply dipping normal faults. Unconsolidated sediments of Lower Klamath Lake are deposited on the basalts in the northern district area. Water levels on opposite sides of faults were at essentially the same elevation suggesting that faults are not a barrier to ground water movement in the area. The fractured basalts should be capable of producing a sufficient quantity of water to irrigate the district, but the absence of good quality production data from wells adds uncertainty to this determination.

Hydrographs of water level data from wells in the area all show a similar trend, higher water levels in the spring and lower water levels in the fall, with a total seasonal variation of about two feet or less. The average water level elevation for the basalt aquifer was 4082 feet (May 1999 data) with little variation between adjacent wells penetrating to different depths. This suggests that wells penetrating the basalt aquifer are hydraulically connected and the basalt strata functions as a single aquifer in the Ady area. Limited long term water level data exist in the area. The long term data that do exist show water levels are presently at the same elevation as they were 60 years ago, suggesting that ground water in the area is an under utilized resource, and has potential as an additional source of water supply for the area.

## Fort Klamath Area

The Nicholson ranch near Fort Klamath was proposed for a cooperative water exchange. Using ground water would reduce the amount of surface water diverted from the Wood River, resulting in more water left in stream.

The Fort Klamath area is characterized by the occurrence of unconsolidated to poorly consolidated lacustrine sediments deposited in a well developed structural graben. The sediments are generally stratified layers of clays, pumice, sands, gravels, and organic deposits. Geophysical data suggests that the sedimentary fill ranges from 1,300 to 3,900 feet in depth before high density rock is encountered (Veen, 1981).

The steeply faulted escarpments that form the valley walls expose the basalt aquifer at land surface. Large quantities of ground water flow from springs in these areas.

In the central valley area water levels in the unconsolidated sedimentary aquifer are nearly coincident with land surface. The potentiometric surface of the sedimentary aquifer occurs at an elevation of 4200 feet in the Fort Klamath area. Most of the wells south of Fort Klamath occur as flowing wells.

The ground water discharged from both the Basalt aquifer along the valley margins and from the unconsolidated sediment aquifer is of excellent quality with very low concentrations of dissolved solids.

The production capacity of the sedimentary aquifer in the central valley is difficult to determine due to the absence of large capacity wells in the area. The absence of large capacity wells is not due to limited production potential, but rather to low demand caused by historically sufficient surface water supplies. The ground water supply from the sedimentary aquifer does not appear to be in overdraft in the Fort Klamath area.

### Langell Valley Area

Historically, sufficient water supply from the Lost River has been available in the Langell Valley area to meet irrigation demands. Required adjustments in surface water management practices to protect endangered species and satisfy instream needs have resulted in a reduction of the amount of surface water available for irrigation.

The primary aquifer for the Langell Valley area is the Tertiary basalt flows. Confining layers of continental sedimentary rock may stratify these basalt flows into shallow and deep aquifer zones (Grondin, in prep). Previous studies have reported high transmissivity values for the basalt aquifer in Langell Valley, demonstrating that water easily moves through the aquifer. However, studies have also shown that ground water levels in the basalt aquifer and discharge from springs are closely linked, limiting the amount of production that can occur from the basalts without injuring surface water rights. In some areas, the continental sedimentary rock and the Tertiary basalts are interconnected and function as a single aquifer (Gorman, 1994). Recent measurements from wells in the area show that ground water levels have recovered to conditions prior to the drought of the early 1990's. This recovery suggests that ground water can be used to supply surface water demands, but the potential for surface water – ground water interference needs to be closely monitored.

# INTRODUCTION

## Purpose

The Klamath Basin Water Supply Initiative is a joint study by the U.S. Bureau of Reclamation and the Oregon Water Resources Department to identify feasible opportunities to enhance water supplies in the Klamath basin. The purpose of this study is to investigate options for increasing water supplies in the Klamath River and Lost River Basins through ground water development in selected areas.

The ground water system in the Klamath Basin is poorly understood and previous work is limited. The ability of the ground water resource to sustain existing irrigation use and accommodate additional development is unknown. This report describes the investigation to-date of the ground water potential in the Shasta View, Ady, Fort Klamath, and Langell Valley areas of the basin.

## Location and Description of Area

The Upper Klamath Basin occupies the lands drained by the Klamath River upstream of Iron Gate Dam. Included in this basin delineation is the Tule Lake sub-basin, a closed basin that receives surface drainage from the Lost River system, but is not connected by surface flow to the Klamath River. Historic evidence shows that there were occasional exchanges of surface water between the Lost River and the Klamath River. Previous investigations have indicated there is a hydrogeologic connection between the two basins.

The Upper Klamath Basin is approximately 8,000 square miles, and is located in south central Oregon and northeastern California (Figure 2). The Oregon portion of the basin is 5,600 square miles, mostly in Klamath County; the California portion is 2,300 square miles in Siskiyou and Modoc Counties (USGS, Upper Klamath Basin Ground water project statement, 1999). The Klamath River originates from the outflow of Upper Klamath Lake and flows southwestward through the Cascade and Klamath Mountains, and discharges to the Pacific Ocean.

Maps 14.6 and 14A.6 (in pocket) are comprehensive maps of the geographic locations in the Upper Klamath River drainage Basin (Oregon Water Resources Board, 1971; Map No. 14.6 and 14A.6). These maps display the major river systems, lakes, springs, mountains, and valleys for the Klamath Basin of Oregon and California. These basin maps are used for all of the locations mentioned in text.

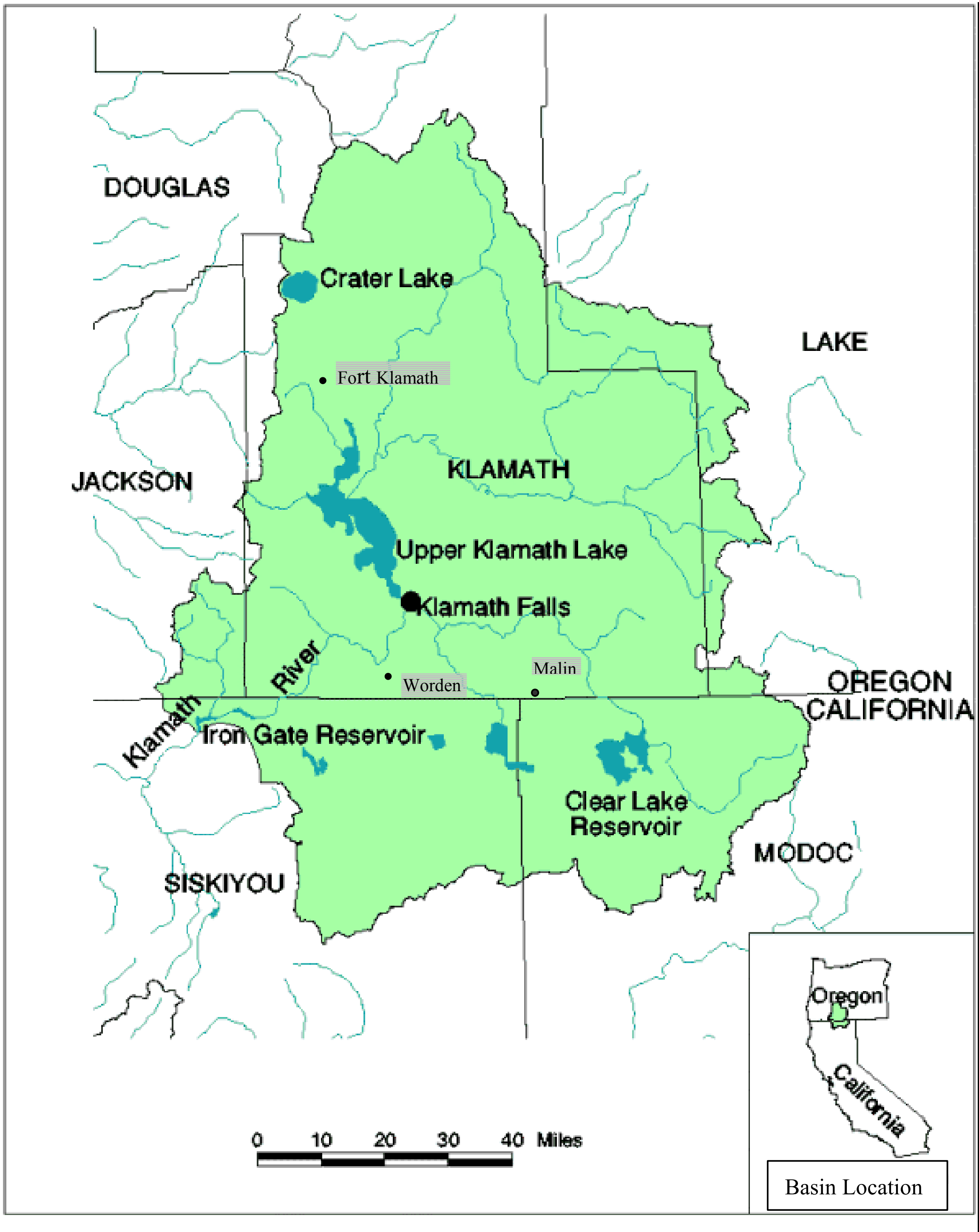



Figure 2. Upper Klamath River drainage Basin (U.S. Geological Survey, Upper Klamath Basin Ground water study project statement, 1999).

The western boundary of the Upper Klamath Basin is formed by the crest of the Cascade Mountains, about 120 miles from the Pacific Ocean. The northern boundary is the volcanic highlands between Miller Mountain and Walker Rim north of Chemult, Oregon, and extends southeastward through the Yamsay Mountain divide to Winter Ridge. The eastern boundary is delineated as the topographic divide near the Klamath and Lake County line of Oregon and extends into northern Modoc County in California. The southern boundary is a poorly defined upland margin along the volcanic highlands of the Medicine Lakes volcanic region. Most of the highland regions surrounding the Klamath Basin reach elevations in excess of 5,000 feet, with higher elevations (up to 9,495 feet) at mountain peaks. The valley lowlands are generally below 4,500 feet elevation. In general, the region has a poorly developed drainage system, including many small streams and internal basins that discharge into marshes or lose their flow into pumice or porous lava beds.

## Previous Work

The subject and scope of selected geologic and hydrologic studies of the Klamath Lake Basin are summarized below. These studies provided substantial data and background information for this investigation.

Meyers and Newcomb (1952) performed the first geologic and hydrologic study of ground water resources in the Klamath Basin. They reported on the "Geology and Ground Water Resources of the Swan Lake – Yonna Valley Area, Klamath County, Oregon." Newcomb (1958) defined the occurrence and described the geology of the Yonna Formation. Newcomb and Hart (1958) compiled extensive information on geology, wells, springs, precipitation, and chemical quality of ground water for the Klamath Basin north of the California border. Phillips (1968) studied the water budget for Crater Lake and calculated inflows and seepage losses from the Lake. A reconnaissance geologic map and a description of mineral resources was compiled by Peterson and McIntyre (1970) for eastern Klamath County and western Lake County. Illian (1970) prepared the "Interim Report on the Ground Water in the Klamath Basin, Oregon." He delineated ground water recharge and discharge areas, interpreted the direction of ground water movement, and described the principal aquifers and their water yielding characteristics. Leonard and Harris (1974) further refined the ground water conditions for six areas in the basin, generally east of the lower Williamson and Upper Klamath Lake drainages. Sammel and Peterson (1976) characterized the hydraulic and thermal characteristics of the geothermal reservoir and constructed a model of the geothermal system. Dicken (1980) studied the paleohydrology and geomorphology of pluvial Lake Modoc. Couch and others (1981) and Veen (1981) used gravity data to describe basin structure and subsurface geometry of the Klamath Basin. McKee, Duffield, and Stern (1983), Pickthorn and Sherrod (1990), and Mallin and Hart (1991) all reported on contributions to stratigraphic geochemistry and chronology of volcanic deposits in the basin. Sherrod and Pickthorn (1992) used data from these recent studies to prepare a geologic map of the west half of the Klamath Falls $1^{o}$ by $2^{o}$ Quadrangle. Wiley and others (1993) analyzed recent seismicity in the Klamath Basin. Gorman (1994) reported on the ground water and surface water conditions in Bonanza and surrounding areas. Studies by Adam and others (1994) and Snyder and Morace (1997) reported on the history of sediments deposited in Upper Klamath Lake.

## Report Scope and Methodology

This report is designed to present reconnaissance level hydrogeologic conditions of four proposed project areas in the Klamath Basin. An overall review of geologic and hydrologic studies by previous investigators is presented for background information, followed by site specific hydrologic conditions for the Shasta View, Ady, Fort Klamath, and Lorella areas.

Ground water data were collected, compiled, and analyzed to determine the hydrologic conditions for three of the four project areas; the Shasta View, Ady, and Fort Klamath areas. Water Level measurements at selected wells in these areas were made periodically to determine ground water fluctuations over time and to observe present ground water conditions. The Langell Valley area is part of a separate Oregon Water Resources Department (OWRD) ground water study currently in progress, and no data for that project is presented in this report.

## Acknowledgements

The cooperation of many local well owners is greatly appreciated for providing access to their wells for data collection. Tom Silbernagel and John Dark allowed their well to be used for an aquifer test. Ron McVay allowed OWRD to install a monitoring well on his property. Mike Zwart and Fred Lissner provided reviews and many valuable ideas. The U.S. Bureau of Reclamation deserves special consideration for their support. Financial contributions were provided through grant 1425-97-FG-20-15800.

# GEOGRAPHIC SETTING

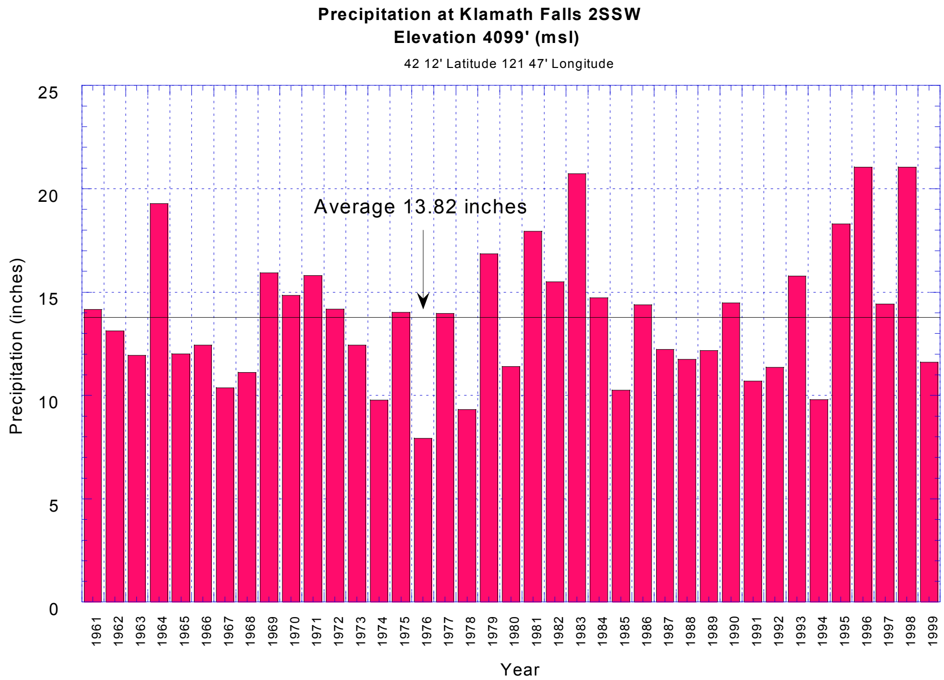
## Drainage System

The primary tributaries to Upper Klamath Lake are the Williamson and Wood Rivers. The Sycan and Sprague Rivers drain a large portion of the northeastern basin. The Sycan River flows into the Sprague, which subsequently discharges into the Williamson River near Chiloquin, Oregon. Many springs and short spring fed creeks also flow into Upper Klamath Lake. The Lost River sub-basin also drains portions of the eastern region and flows into Tule Lake, California. Tule Lake is a landlocked internal drainage basin with no surface outflow, yet previous investigators have indicated that it is hydraulically connected to the main Klamath River drainage system through deep ground water seepage or underflow (Illian, 1970). Upper Klamath Lake is drained by the Link River, which flows into the Klamath River. Lower Klamath Lake is a large wetland area that is also hydraulically connected to the Klamath River drainage system. Historically, Lower Klamath Lake received flood flows from the Klamath River.

## Climatic Conditions

The Upper Klamath River Basin is a semiarid, winter precipitation dominated region, characterized by hot dry summers and wet winters with moderate to low temperatures. Average annual precipitation in the valleys varies from about 14 inches in Klamath Falls to about 18 inches at Chiloquin. The Cascade Range forms a rain shadow and precipitation amounts increase with altitude. Nearly 70 inches of precipitation occurs along the Cascade crest while the high altitude areas in the eastern basin receive nearly 35 inches. Seventy percent of the precipitation in the Klamath Basin falls between October and March, often as snow. Only nine percent of the precipitation falls during the months of July through September. Convective thunderstorms can result in very intense but localized precipitation during the summer.

Figure 3 shows a plot of precipitation at Klamath Falls from 1961 through 1999 and the cumulative precipitation departure from normal for the same time period. Precipitation at Klamath Falls ranged from a minimum of 7.93 inches in 1976 to a maximum of 21.06 inches in 1998. The plot of cumulative departure from normal displays multi-year precipitation cycles over the same period of record. A rising line indicates above average precipitation years and a falling line indicates below average precipitation years.



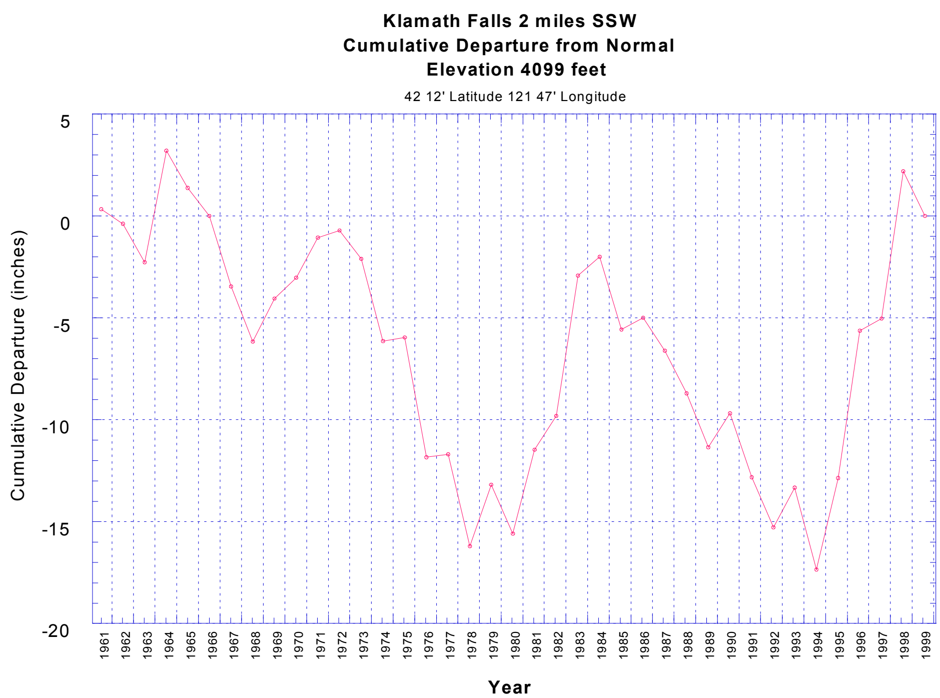




Figure 3. Annual precipitation at Klamath Falls from 1961 through 1999.
Cumulative departure from normal for 1961 through 1999.

# GEOLOGIC SETTING

## Regional Geologic Studies and Geologic Mapping

Meyers and Newcomb (1952) mapped ground water characteristics of the Swan Lake-Yonna Valley area. Nearly all of the irrigation wells were visited and water levels measured. Lithologic logs were obtained for most of the irrigation wells and water samples taken wherever possible. Representative domestic wells and springs were also included. Comprehensive chemical analysis was performed on water samples from four typical wells and from Bonanza springs. Water samples from other wells and springs were analyzed by field methods to determine the hardness and chloride content.

Newcomb and Hart (1958) were the first investigators to perform a basin wide hydrogeologic study of the Klamath Basin. Their study looked at the geology and ground water resources of the Klamath Basin, but did not include areas south of the Oregon-California state line. Their study was similar to the previous work of Meyers and Newcomb but it addressed the hydrogeologic characteristics of the entire Klamath Basin of Oregon. They were also the first investigators to map the geology of the area on a basin scale.

Peterson and McIntyre (1970) reported on the economic potential and mineral resources of eastern Klamath County and Western Lake County, Oregon. Their main contributions to the understanding of the basin geology were: 1) improved understanding of the dating of particular stratigraphic occurrences based on paleontologic evidence; 2) improved understanding of the timing of structural events and; 3) description of the occurrence of anomalous geothermal heat zones.

## Regional Stratigraphy and Timing of Events

Meyers and Newcomb (1952) presented detailed descriptions of the geology and associated stratigraphic position of units in the area. In summary, they indicated that the oldest rocks in the area consist of basalt flows of early Pliocene age. These basalt flows are overlain by lacustrine deposits and fragmental volcanic rocks of middle Pliocene age. These sedimentary rocks are capped by a series of basalt and andesite flows of late Pliocene age. In places where the Tertiary rocks have been downfaulted, they have been partly covered by later deposits of Pliocene and Pleistocene age, and by recent alluvium. They noted that the mountains in the area were produced by faulting with the valleys occupying the downfaulted grabens. The age and correlation of the sedimentary beds were based on paleontologic evidence, mostly of fresh water invertebrates and a few fish fossils. The ages of the igneous rocks were assigned by their stratigraphic and structural position. The assignment of Pliocene age was determined by tracing the upper lava rocks north of the study area where they form the plateau surface upon which rests the younger volcanic cones of the Cascade Range (Meyers and Newcomb, 1952).

Newcomb (1958) defined the occurrence of the Yonna Formation in the Klamath Basin. He described the lithology and areal extent of this formation in greater detail than Meyers and Newcomb (1952). He described the formation as sedimentary deposits consisting of stratified tuff, agglomerate, shale, diatomite, sandstone, volcanic ash, and mixtures of these materials. Most of these deposits were formed in a lacustrine environment, but subaerial deposits also occur.

Generally, the lower stratum of the formation is sedimentary material and the upper stratum is tuffaceous. But Newcomb stated this partitioning of lacustrine versus volcaniclastic origin for the Yonna strata is not clearly established and the deposits do not show a uniform stratigraphic arrangement. He noted the volcanic sedimentary zone ranges in thickness from 0 to 2,000 feet, with common occurrences of 200 to 800 feet thick. He indicated the formation is exposed in large areas of the Yonna, Swan Lake, Sprague River, Williamson River, and Poe Valleys, and the main Klamath graben. The Yonna Formation is overlain with a minor erosional unconformity by late Tertiary and Quaternary lava rocks. Many dikes, sills, and domes of basaltic composition associated with emplacement of the overlying volcanic deposits cut the Yonna Formation. The formation is underlain by older Tertiary lavas.

Peterson and McIntyre (1970) maintained essentially the same stratigraphic and geologic interpretation scheme as Newcomb and Hart (1958). Older Tertiary lava flows were overlain by the Yonna Formation sediments, which then were overlain by younger, well fractured Tertiary and Quaternary lava flows and intrusive bodies. An extensive period of erosion followed during the mid to late Pleistocene with deposition of alluvial deposits in the late Pleistocene lake basins and the occurrence of recent volcanic material produced by Mount Mazama. Their primary contribution to the timing of events was derived from paleontologic data that indicated the lacustrine phase of deposition was mid to late Pliocene age. Also, the eruptions of most volcanic centers ceased by the beginning of the Pleistocene glaciation.

## Stratigraphic Geochemistry and Chronology

McKee, Duffield, and Stern (1983) redefined the occurrence of the extensive Basin and Range basalt lava flows found east of Klamath Falls. The older basalt flows that crop out extensively from Klamath and Lake Counties of Oregon and northern Modoc County of California, termed "lower Basalt" from the previous studies, were redefined using geochemistry to define the age of the flows and address the tectonic environment that led to the emplacement of these basalt flows. They stated the Devils Garden lava field was created by eruptions in a geologically brief period of time (about 5 to 10 million years ago). They estimated a volume of 850 $km^3$ of lava covering 12,400 $km^2$. The coherent age of timing of emplacement along with the lava field's distinctive geochemical composition define these flows as a single geologic unit. The basalt of the Devils Garden is a diktytaxitic olivine tholeiite. The geochemistry of these lavas resembles mid-ocean-ridge basalt, characterized by little or no silica minerals present. These unique geochemical characteristics suggest that these lavas originated in the upper mantle and were erupted through crust thinned by tectonic extension behind the early Cascade Range volcanic arc. This new interpretation about the age and origin of the older basalts reduced the uncertainty previous authors encountered when trying to map and interpret the occurrence of these lava flows.

Pickthorn and Sherrod (1990) performed additional age dating of rock units in the Klamath Basin. They collected samples from basalt and basaltic andesite flows that were in close stratigraphic position with the Yonna Formation sedimentary deposits. The potassium-argon age dating constrained the age of the Yonna Formation deposits to 6.0 to 3.3 million years ago. This corresponds to the latest Miocene to early Pliocene period.

Mallin and Hart (1991) used potassium-argon (K-Ar) age dating to evaluate the distribution and regional structural forces that control the position of mafic lavas in the northwestern Basin and Range – Cascade arc transition area. They sampled two types of basaltic rocks from the Bryant Mountain area and south near Clear Lake, California. The two mafic rock types sampled are calcalkaline basalts/basaltic andesites (characteristic of a Cascade arc source) and high alumina olivine tholeiite (characteristic of a Basin and Range source). The distribution of these two rock types aid in defining the structural forces (and processes) that dominate the region. Their data showed that both rock types were erupting contemporaneously, displayed by the interfingering of both rock types. This close spatial and temporal association of magma generation and structural style supports the concept that the lavas in the region are in a transition zone between the Basin and Range and Cascade provinces.

Sherrod and Pickthorn (1992) used much of the recent geochemical data to prepare a geologic map of the west half of the Klamath Falls one degree by two-degree quadrangle. The geochemical data allowed them to present a more detailed description of the distribution and stratigraphic position of rock units throughout the region. They concluded that the aforementioned Yonna Formation is more accurately described as four mappable units, rather than one large formation. They subdivided the Yonna Formation into older palagonite tuff, younger palagonite tuff, continental sedimentary rocks, and tuff and lapilli tuff. Based on the age dating from recent studies, the continental sedimentary unit was more closely age constrained than previous investigators (Newcomb, 1958) thought, assigning it to the latest Miocene and Pliocene age. The significance of the new geologic work is that the continental sedimentary rocks are coeval with the basalt units, and not younger as previously thought. Based on distinguishing volcanogenic deposits from continental sedimentary rocks, they proposed abandoning the Yonna Formation, reassigning its rocks into the four units mentioned above.

## Regional Tectonics and Structural Geology

Meyers and Newcomb (1952) examined faulting in the region. They noted that all of the faults identified had normal displacement. They attributed this type of structural deformation to tensional forces.

Newcomb (1958) recognized extensive block faulting throughout the Klamath Basin and noted the well developed graben structures of Langell Valley and the Klamath Lake areas. He observed that the Yonna Formation is cut by numerous normal faults.

Newcomb and Hart (1958) further described the tectonic structure and development of the Klamath Basin. The Tertiary age rocks in the western portion of the basin are inclined eastward. The Tertiary age rocks in the eastern highlands, west of the Goose Lake basin, dip westward. The rocks in the northern basin near Walker Rim dip southward into the basin. They indicated that the basin occupies a broad regional syncline with a southward plunge. Also, extensive block faulting has deformed the region. Newcomb and Hart mapped many faults and recognized the consistent pattern of north and northwest trending faults. They recognized the faults had normal displacement with steep fault planes dipping about 60 degrees. This fault pattern is consistent with Basin and Range structures produced by tensional stress. They noted that faulting is prevalent throughout the basin, especially along the steep bounding structures that form the Langell Valley and Klamath Lake grabens.

Peterson and McIntyre (1970) reported on the regional structural trends. They observed that the pre-Pliocene deformational history of the region is difficult to decipher. A northwesterly alignment of a few small eruptive centers and dikes indicates that the prominent regional normal fault pattern was initiated during the Pliocene. They observed most of the area was subjected to post Pliocene normal faulting. The fault frequency and magnitude of displacement appeared to be at a maximum along the areas of anticlinal uplift and diminish inward toward the central structural depression. They also observed a consistent pattern in the direction of dip for the faults. The fault blocks west of Klamath Lake are tilted to the southwest and down dropped to the northeast. East of the main Klamath graben the fault blocks have been tilted to the northeast. In general, the Sycan Marsh-Bly-Beatty area was a broad syncline, and the Goose Lake-Summer Lake graben was an anticline. The Klamath Falls area is also an anticline whose crest subsequently dropped to form the present graben.

Peterson and McIntyre (1970) grouped the faults into two general systems based on relative age, strike trend, and to lesser extent the amount of displacement. The first (earlier) set of faults is characterized by relatively small displacement, close spacing, and consistent strike pattern. The initiation of movement of the first group of faults was assumed to be Pliocene. This age is suggested because faulting is concurrent with lacustrine sedimentation. The climax of activity appears to have occurred during the Pleistocene based on the observation that the faulting occurred after the deposition of the Pliocene sediments and the emplacement of the early Pleistocene basalt flows. Most faults of this group show offsets of less then 500 feet, but exceptions were noted along some of the prominent basin bounding faults such as Bryant Mountain northwest of Malin, the east side of Swan Lake Valley, and Upper Klamath Lake, which have displacements in excess of 1000 feet. The dominant strike trend is northwest.

The second group of faults includes those that have a northerly strike direction and appear to displace faults of the first group. Peterson and McIntyre termed these faults “range” faults because they show large offsets and their pattern of alignment is more consistent with the large scale Basin and Range system structures developed to the east. The earliest movement along the range faults was during the early Pleistocene, at which time the present major topographic basin and intervening fault block uplifts were formed. Subsequent investigations have improved on the interpretation of timing for these two groups of faults.

Sherrod and Pickthorn (1992) presented a tectonic sketch map that displayed their structural interpretation of the Klamath Basin geometry. Many north to northwest trending normal faults were the predominant structural feature in the basin. Displacements are generally less then 100 meters (328 feet) for most of the faults east of the Modoc Ridge area, but increase to as much as two kilometers (6560 feet) on the major fault scarps of the Klamath Lake graben. Exposed fault planes dip $50^{o}$ to $60^{o}$, with slickensides and mullions plunging directly downdip, consistent with normal slip displacement. They noted that extensional tectonic forces produced the composite graben. Extensional strain is probably less then 15 percent although this estimate has uncertainties associated with it because of uncertain fault geometry. East of the main Klamath graben, the decreasing number of faults and lesser displacement along the faults indicates greatly diminished strain.

Sherrod and Pickthorn (1992) described Klamath basin geometry using gravity data from Couch and others (1981), and Veen (1981). They described the southern part of the basin as a simple graben coincident with the original extent of Lower Klamath Lake. In the area near Klamath Falls the graben shallows and Quaternary sediments are deposited against late Miocene and early Pliocene lava flows and sedimentary rocks. In the northern part of the basin the graben structure extends nearly to Crater Lake. The eastern bounding graben fault has 450 meters (1475 feet) of structural relief in the Klamath Falls area. To the north, topographic relief diminishes but structural relief persists. North of Modoc Point, these gravity data suggest 0.4 to 1.2 kilometers (1312 to 3936 feet) of sediment is deposited in the downthrown structural trough. The graben structure is of mostly Pleistocene age, but recent seismic events indicate that Holocene development continues. Sherrod and Pickthorn (1992) mappped faults with probable Holocene displacement along the steep southwest slopes of Stukel Mountain. They also mapped a graben structure with both bounding faults having probable Holocene displacement along the valley floor area northwest of Merrill.

## Recent Seismicity

Recent seismic activity indicates that Holocene faulting is still active. The September 1993 magnitude 5.9 and 6.0 earthquakes located 30 kilometers northwest of Klamath Falls in the West Klamath Lake fault zone attest to the current structural development of the Klamath basin (Wiley and others, 1993). It has been estimated that this fault zone is capable of generating earthquakes as large as magnitude 7.25 (Lienau and Lund, 1994). Geologic evidence for structural development during Holocene time is apparent from the relatively uneroded fault escarpments, and talus deposits exposed in the hanging wall of several exposed fault planes are themselves faulted. Also, Upper Klamath Lake does not have alluvial fans developed along its fault-bounded margins, probably a result of continued structural subsidence. A bathymetric channel along the faulted west side of Upper Klamath Lake is not completely filled in with sediment (Sherrod and Pickthorn, 1992). The absence of Mazama fill sediments suggests that this structure has continued development since the eruption of Mount Mazama about 7,600 years ago (Zdanowicz, Zielinski, and Germani, 1999).

## Pleistocene Geology

High elevation portions of the Klamath Basin were glaciated during the Pleistocene. None of these glaciers reached as far as Upper Klamath Lake, but glacial runoff flowed into the basin. During this time pluvial Lake Modoc covered much of the basin floor (Dicken 1980). This large Pleistocene lake covered an area of 1,096 square miles. When the lake was at its high stand, the shoreline was at an elevation of 4240 feet, about 100 feet above present day Upper Klamath Lake. At maximum extent the northern end was near Fort Klamath and the southern end was south of Tule Lake near the Modoc Lava Beds. Eight major basins were included in the areal extent of the old lake. The largest were Upper Klamath Lake, Lower Klamath Lake, and Tule Lake; smaller basins include Spring Lake, Poe Valley, Swan Lake, Yonna Valley, and Langell Valley. While Lake Modoc occurs within the Basin and Range structural terrain, it is not in the Great Basin province. The location near the Cascade Mountains assured it an abundant supply of water. It also had a continuous surface outlet through the antecedent Klamath River drainage system. Numerous fault block hills and mountains rose above the ancient lake. Some of the smaller hills were islands in the old lake and provide the best-preserved examples of the old shoreline (Dicken, 1980). He noted in the Shasta View area that Turkey Hill immediately north of Malin has shoreline sediments deposited on its northeast side. Lake Modoc dramatically decreased in size about 10,000 years ago leaving several smaller lakes; Upper Klamath Lake in Oregon, and Lower Klamath Lake and Tule Lake in California (Dicken, 1980).

Pleistocene and Holocene alluvial deposits occur along most of the valley floors of the Williamson, Sprague, and Lost Rivers. Alluvium also covers the valley plains of the major lake basins and upland marsh areas. The alluvium is mostly fine grained sediment of clay, silt, sand, and peat with diatomaceous deposits. The thickness of the alluvium is generally less then 300 feet in the valleys drained by the Williamson, Sprague and Lost Rivers. In the major lake basins, the sediment fill may reach up to 6560 feet thickness (Sherrod and Pickthorn, 1992). Newcomb and Hart (1958) noted that estimating the thickness of the alluvial fill is difficult due to the failure of many of the drilling records to distinguish between alluvial deposits and poorly consolidated strata of the underlying Yonna Formation. They stated that in many places the true thickness of the alluvial fill is unknown.

Subsequent studies by Adam and others (1994), and Snyder and Morace (1997), used sediment cores drilled in the wetlands adjacent to Upper Klamath Lake to record the long term and recent history of sediments deposited in Upper Klamath Lake. They noted that a 166-foot core from Wocus Marsh has alternating intervals of highly organic and inorganic sediments that were deposited over a period of perhaps the last 1 million years. Peat deposits are present to a depth of about 85 feet and may be nearly 400,000 years old. A core from Caledonia Marsh has lacustrine clays below about 17 feet in sharp contact with overlying organic rich clay deposited in the marsh. On the basis of estimated sedimentation rates, the change occurred about 11,000 years ago, near the end of the colder climatic conditions and subsequent lowering of Lake Modoc. The lacustrine clays record the past deep water environment of Lake Modoc and the organic rich clays represent the more recent shallow water depositional environment of Upper Klamath Lake. Mazama ash deposits were observed at a depth of 10.5 feet in the Caledonia Marsh core (Snyder and Morace, 1997). Diatomaceous clays and silts, and organic material are presently the most abundant sediment now accumulating in Upper Klamath Lake (Peterson and McIntyre, 1970).

# HYDROGEOLOGY

## Aquifer Units

Meyers and Newcomb (1952) constructed a ground water contour map of the Swan Lake-Yonna Valley area that indicated the direction of flow and slope of the water table is from the upland areas around the valleys to the valley floors with a gradient of about 20 feet per mile. The water table in the two valleys differs in hydraulic gradient. In the Yonna Valley, it has a broad trough-shaped surface with low gradient through the upper part of the valley until it merges with the regional water body from the lower part of the Swan Lake Valley. From there the water table slopes towards the Lost River with a gradient of about two feet per mile.

The regional water table beneath the Swan Lake basin continues the steeper gradient of the upland water surface. Through the valley fill material, the water table has a gradient of about ten feet per mile to the buried talus material along its southern margins. From the valley fill it moves into the bedrock and has a gradient of about two feet per mile. At the southern end of the valley it forms part of the regional water table sloping to the south at the level of the Lost River. Based on the above observations of ground water slope and direction of movement, Meyers and Newcomb (1952) concluded that the main flow from Bonanza springs is not derived from the Yonna Valley regional water body but receives its water from the Langell Valley to the southeast.

Newcomb and Hart (1958) expanded the geologic mapping and hydrologic analysis from the previous investigations to address the hydrogeologic characteristics of the entire Klamath Basin. The oldest rocks they described are the Volcanic Rocks of the Western Cascades. These rocks form a broad belt of partly altered lava flows and interbedded tuffs that extend in a north-south direction along the west slope of the Cascade Mountains in the Rogue River basin. These rocks crop out in the southwest part of the Klamath River basin and continue more extensively in the Klamath River Valley of California. These rocks have undergone low level alteration and been tectonically deformed. Therefore, they are relatively impermeable and considered a non-water bearing formation.

The Tertiary volcanic rocks of the high Cascades were the most prominent rock type mapped and described by Newcomb and Hart (1958). They partitioned the Tertiary volcanics of the high Cascades into three units: an uppermost andesitic unit, underlain by a lower basaltic unit, interbedded within the basaltic unit is the volcanic sedimentary deposits of the Yonna Formation. The upper andesite unit consists of massive and platy lava flows found mostly in the northern upland areas of the basin near Chemult and Klamath Marsh. The total thickness reaches 800 feet. The rock is generally devoid of water but serves as a perching layer. Small to large springs (up to 50 cfs) are common at the downslope contacts with more permeable overlying pumice and alluvial deposits.

The Tertiary high Cascade volcanic sequence is made up of basaltic lava flows and flow breccias; a medial zone of sedimentary strata (the Yonna Formation) of both volcanic and lacustrine origin; and a lower sequence of basalt flows. This sequence of rock underlying the andesitic unit, occurs south of Crater Lake and extends eastward throughout the Klamath Basin east into Lake County, and south into California. These lower units are the most prevailing bedrock occurrence in the Klamath Basin.

The basalt unit above the Yonna Formation is about 50–200 feet thick. This upper basalt unit is fractured and permeable but usually occurs above the water table. Where it occurs beneath the water table, this unit yields large amounts of water to wells and springs.

The basalt flows underlying the Yonna Formation form the base of the Tertiary volcanics of the high Cascades. Measured thickness reaches 800 feet, but since the base of the unit is not exposed, the total thickness is unknown. This sequence of lower basalt flows is fractured and constitutes moderate to good water bearing material, though not as permeable as the upper lava rocks. Wells penetrating the lower basalt unit obtain large supplies of water.

In between the upper and lower basalt units are the volcanic sediments and lacustrine deposits of the Yonna Formation. The Yonna Formation in general is relatively low permeability material, but some of the coarse grained sedimentary tuff layers transmit water, most notably in the Sprague and Williamson River valleys.

Newcomb and Hart (1958) mapped intrusive rocks stratigraphically above the Pliocene volcanic rocks of the high Cascades. They noted that these igneous dikes, plugs and stocks are of basaltic composition and occur at areas of greatest structural flexure such as Gearhart Mountain and Yainax Butte. The intrusive rocks are dense, massive, porphyritic to coarsely crystalline rock bodies. Generally these rocks are tight and non-water bearing.

Quaternary age volcanic lava rocks were mapped and described on a limited scale by Newcomb and Hart (1958). These volcanic flows, cinders, breccias, and pumice were extruded during the Pleistocene (except for recent Mazama pumice) from recently active volcanoes. The lava flows from Mount Mazama constitute the bulk of these rocks. The rocks are andesite and dacite flows and associated fragmentary deposits. These rocks descended from Mount Mazama but did not reach the lowland valley floors. Numerous cinder cones and small lava vents occur near the flanks of the modern high Cascade volcanos. In their mapping, Newcomb and Hart included the large volume of pumice that was ejected from Mount Mazama during Holocene time about 7,600 years ago. They noted that the pumice covers the upland slopes north and east of the Mazama highland and averages about 75 feet thick along highway 97. The pumice plain tapers to a thin edge along the eastern margin of Klamath Marsh. The pumice is excellent material for infiltration and its lateral permeability is moderately high. Together with the underlying lava rocks, the pumice transmits large quantities of groundwater and discharges to large springs, such as Big Springs in Klamath Marsh, the lower Williamson River, and the Wood River. In the Fort Klamath area, the pumice beneath the alluvium is the principal aquifer.

Newcomb and Hart (1958) noted that the Quaternary and Tertiary basalt flows yield significant amounts of water where they occur below the water table. The lower lava rocks contain scoriaceous and fractured interflow zones that readily yield water when penetrated. The porous interflow zones interfinger and overlap sufficiently to allow relatively free movement of water across layers. They also stated that in upland areas of the Cascades and fault block mountains the Quaternary and Tertiary basalts are open to recharge from precipitation. In much of the Klamath Basin, the lower lava rocks serve as a relatively deep layer of transmission for the regional body of ground water (Newcomb and Hart, 1958; Illian, 1970). Hydrologically, the alluvial sediments of the lake basins are poor producers of water. They will yield sufficient quantities of water to wells penetrating a sand or gravel zone of sufficient size, but generally the sediments yield only quantities suitable for domestic wells.

In most lava rocks, the fault zones do not form barriers to the horizontal movement of groundwater. In the Yonna Formation these faults lack the permeability necessary for appreciable movement of groundwater. In the lava rocks the broken and jointed flows readily allow percolation of water, and many of the fault zones provide routes for the emergence of groundwater from springs. Many of the large springs throughout the Klamath Basin are located along the base of fault scarps where the basalt aquifer is exposed by uplift. Examples of this type of fault controlled groundwater discharge occur at the base of the escarpment bounding the Agency Lake graben. Examples include Spring Creek spring, Wood River spring, Crooked Creek spring, and many smaller springs. Bonanza spring, although not at the base of an escarpment, is on a fault that is exposed at land surface along the Lost River.

## Ground Water Sources and Movement

Illian (1970) described the geologic units and structure of the Klamath basin, basing his interpretation on the previous investigations of Newcomb and Hart (1958) and Peterson and McIntyre (1970). His geologic interpretation organized the rock units into four groups based on the hydraulic characteristics of the lithologic units that occur in each group. The four groups are the sedimentary aquifer, the volcanic centers aquifer, the lower basalt aquifer, and the volcanic ash aquifer.

The sedimentary aquifer unit is composed of alluvium, alluvial terrace, and shallow lake deposits with some interbedded basalt, rhyolite tuff deposits, and pumice. The sedimentary aquifer is found throughout the Klamath Basin with the thickest deposits occurring in the major valleys. Wells completed in this aquifer unit have specific capacities of less then 5 gallons per minute per foot of drawdown (gpm/ft) and average 0.45 gpm/ft. Generally, these sedimentary beds yield only sufficient quantities of water for domestic purposes.

The volcanic centers aquifer is composed of basalt and volcanic ejecta (ash, cinders, and agglomerate). These deposits represent eruptive centers of old volcanos. These deposits are most commonly found in mountainous areas but some local exposures are found on the valley floors. Their water bearing characteristics are excellent due to well-sorted coarse cinders, highly fractured lava rock, and scoriaceous interbeds. Wells constructed in these rock types demonstrate a wide range in specific capacity ranging from less than 1 to over 100 gpm/ft. Large producing wells can be constructed in this aquifer unit.

The lower basalt aquifer is the same basalt unit described by Newcomb and Hart (1958). These basalt lava flows occur beneath the sedimentary deposits of the Yonna Formation. The aquifer is highly permeable due to weathered surfaces, scoriaceous interbeds, and fractures in the basalt. Specific capacities commonly range from 33 to 500 gpm/ft and averages 145 gpm/ft. This aquifer occurs throughout most of the valleys of the basin and reaches depths exceeding 1000 feet. It is the most common aquifer tapped by irrigation wells in the Klamath basin and large producing wells have been constructed in this aquifer.

The fourth aquifer unit described by Illian is the volcanic ash aquifer. This unit is composed of volcanic ash, tuff, breccia, volcanic sediments, and occasional basalt flows. This unit is similar to the sedimentary aquifer previously described. It underlies the lower basalt aquifer. The hydraulic characteristics of this unit are poorly defined because few wells penetrate this aquifer (in excess of 1000 feet depth). Generally, production rates are moderate to low and comparable to the sedimentary aquifer described above.

Illian's primary hydrogeologic model focused on stratifying the ground water flow system. He defined the flow systems on the basis of variations in chemical quality, temperature, and water level fluctuations. All of these changes are due to variations of depth, distance, travel time, and geologic materials through which the ground water moves. He divided the flow regimes into three systems dependent on proximity of recharge and discharge areas, flow distances, and common characteristics such as temperature and dissolved solids. This resulted in designation of local, intermediate, and regional ground water flow systems.

The ground water discharged from the local flow systems is recharged in an immediately adjacent recharge area. The local flow systems cover a small-scale area and the water generally circulates to depths of less than 100 feet below the water table. Water discharging from the local flow systems has characteristics of low temperatures ranging from 35$^{o}$ to 50$^{o}$ F. These low temperatures are indicative of shallow circulation. Water from the local systems normally contains low concentrations of dissolved chemical constituents but is more susceptible to surface water contaminants. Wells completed in the local flow system usually show seasonal water level fluctuations.

The regional groundwater flow system receives recharge water from the higher elevations of the basin and discharges the water in the lower regions of the basin. The high elevation recharge areas for the regional flow system include the Cascade Range to the west, Yamsay Mountain and other elevated upland areas to the north, and the high elevation areas that from the topographic divide to the east such as Winter Rim and Quartz mountain. This water may circulate to depths greater than 10,000 feet below sea level under some portions of the Klamath Basin. The regional flow system discharges in the vicinity of Lower Klamath Lake. The evidence for the deep circulation is from the high temperature water discharged along the southern slope of the Klamath Hills. Notable examples are the Liskey well and Osborn well (T40S, R9E, Sec. 4 and T40S, R9E, Sec. 27), discharging water at 200$^{o}$ F and 186$^{o}$ F, respectively, from this region. Chemical evidence also indicates long travel distance and deep circulation for the water discharged from the Lower Klamath Lake area. High concentrations of chloride (50 ppm), sodium (200 ppm), sulfate (400 ppm), and silicate (80 ppm) occur in water discharged from the regional system. Water from both the local and intermediate flow systems also discharge in the regional discharge areas and probably commingle. Therefore, water temperatures and chemical characteristics can be expected to show appreciable variation between closely spaced wells and wells that penetrate variable depths.

Water from the intermediate flow system, as the name implies, occurs between the two other flow systems, and shows intermediate characteristics of size, position, chemical concentrations, and amount of seasonal water level fluctuation. Examples of the intermediate flow system are found in water discharging from the Sprague, Williamson, and Lost River drainage basins. Waters from this system show temperature ranges from 45$^{o}$ to 85$^{o}$ F. The quantity of total dissolved solids ranges from 100 to 800 ppm and averages 100 to 200 ppm. Included in this figure are values for sodium (10 to 200 ppm), chloride (5 to 50 ppm), sulfate (10 to 350 ppm), and silicate (30 to 80 ppm). Chemistry of water pumped from most wells in the Klamath Basin is consistent with these values. Some variation is expected and exists. Water levels in the intermediate flow system can show slight seasonal variation due to the seasonal nature of recharge to the system.

Illian partitioned the Klamath groundwater system into four sub-basins; the Williamson River, Sprague River, Upper Klamath Lake, and Lost River systems. He described the basin boundaries and estimated the ground water budget characteristics of each sub-basin based on precipitation, evaporation, transpiration, and surface runoff. These hydrologic factors allowed him to estimate ground water recharge and discharge in each sub-basin.

## Hydrogeology of the Williamson River Basin

The principal features in the Williamson River basin are the Cascade Range to the west and Klamath Marsh in the central basin area. The Williamson River flows north on the eastern side of the basin and then swings southward through Klamath Marsh and into Upper Klamath Lake. Recharge boundaries are formed by ground water mounds of sufficient size to make ground water flow away from boundary areas. Precipitation infiltration is the only source of ground water to this basin.

Well log coverage in the Williamson basin is sparse, but some aquifer features are apparent. In the Chemult area, water levels in shallow wells that develop water from pumice sands and sediments are at an elevation of about 4,750 feet. Water levels in deep wells completed in broken lavas at depth are at an elevation of about 4,550 feet. The difference in elevation between water levels for the shallow and deep aquifer units shows a decrease in water level elevation with increasing depth indicating that this area is a recharge area.

In the vicinity of Klamath Marsh near Lenz, wells usually penetrate about 75 feet of pumice and sediments before reaching the volcanic rock. Depth to the base of the volcanic rocks, which underlie the sedimentary materials is unknown. Wells completed in the basalt units produce several thousands of gallons per minute with 5 to 50 feet of drawdown. Water levels are very shallow in this area, and many wells flow at land surface at rates of a few to 120 gallons per minute. The Klamath Marsh area is a region of ground water discharge to the Williamson River Basin.

Near Collier State Park and Spring Creek, wells up to 638 feet deep penetrate pumice and sediments without encountering consolidated volcanic rocks. Flowing wells are common in this area and many wells show rising water levels as wells are deepened, demonstrating that this is a ground water discharge area. In general, ground water in the Williamson River Basin moves upward toward low lying areas such as Klamath Marsh and the Williamson River, where it discharges to maintain baseflow for the surface waters. The ground water and surface water both flow south toward Chiloquin and ultimately to Upper Klamath Lake.

## Hydrogeology of the Sprague River Basin

The principal features of the Sprague River basin are the volcanic highlands along the north and east boundary of the drainage such as Yamsay and Gearhart Mountains, and the drainages of Sycan Marsh, Sycan River, and the Sprague River. The Sycan River flows south to its confluence with the Sprague River, while the Sprague River flows west to its confluence with the Williamson River near Chiloquin. Precipitation is the only source of water to this sub-basin. Regional ground water mounds occur in the recharge areas along the highlands beneath Yamsay Mountain, Winter Rim, Quartz Mountain, and similar elevated areas. Recharge for the intermediate ground water system occurs under elevated areas of Yainax Butte, Swan Lake Rim, and similar plateau regions that separate the topographic divide between the Sprague River drainage and Lost River drainage basins.

Well log coverage in the Sprague River drainage is abundant in the areas developed by agriculture. The aquifer units are well defined near the communities of Beatty, Bly, and Sprague River. Near the town of Sprague River, most wells less then 450 feet deep penetrate the sedimentary aquifer. Well yields are generally less then 25 gpm unless relatively high permeable sedimentary zones are encountered. The basalt aquifer is usually found at depths greater then 550 feet in the center of the valley and at shallower depths along the margins of the valley. Yields from the basalt aquifer are generally more than 100 gpm and in some cases up to 1350 gpm.

Near Beatty and Bly similar conditions exist. Wells 950 feet deep have encountered artesian pressures. Flows in excess of 1000 gpm have been reported. Large producing wells have also been reported along the flanks of the valley at shallower depths. In the vicinity of Bly, shallow wells penetrate the lower basalt aquifer with production rates in excess of 2000 gpm.

The ground water discharge areas for the Sprague River basin are Sycan Marsh, the Sycan River and the Sprague River. The direction of ground water flow is toward Sycan Marsh, then south toward the Sprague River, then west through the central portions of the valley. Illian stated that 77% of the water discharged from the basin leaves by evaporation, transpiration, extraction from wells, or exits as baseflow in the Sprague River. The remaining 23% exits the basin as ground water flow. The direction of flow for the regional ground water flow system is either a southerly movement toward the Lost River basin, or a westward movement toward Upper Klamath Lake. He estimated that 150,000 acre feet of ground water underflow left the basin but could not partition the amounts that escaped to each adjacent basin.

## Hydrogeology of the Upper Klamath Lake Basin

The Upper Klamath Lake sub-basin is bounded by the Cascades on the west, Sand Ridge between Crater Lake and Chiloquin on the north, Chiloquin Ridge and the fault block mountains adjacent to Upper Klamath Lake to the east, and on the south the faulted ridges from Klamath Falls toward the Mountain Lakes Wilderness area. The principal drainage that enters the sub-basin is the Williamson River. The primary stream that originates within the sub-basin is the Wood River. This stream flows from springs discharging at the base of the eastern basin bounding fault scarp and flows into Agency Lake. Sources of ground water for the Upper Klamath Lake sub-basin are infiltration of precipitation and surface water infiltration in recharge areas. Illian also indicated that ground water underflow occurs from the Williamson and Sprague River sub-basins. Ground water leaves the sub-basin via evaporation, transpiration, and seepage to surface water in discharge areas. Also, precipitation that falls on discharge areas cannot enter the ground water system because water is moving toward the land surface. Illian calculated that 17% of the ground water in the basin moves through the southern boundary into the Lost River Basin.

Ground water recharge areas in the Upper Klamath Lake sub-basin occur in the elevated uplands regions that contain permeable soils, such as: the Cascade Mountains, the Mountain Lakes Wilderness area, the elevated fault block ridges of Chiloquin Ridge, Modoc Ridge, and similar areas. Ground water recharged in the highland areas, as well as portions of the ground water underflow from the Williamson River sub-basin, moves down gradient toward the low lying ground water discharge areas such as Aspen, Agency, and Upper Klamath Lake. Annie Creek, Sevenmile Creek, Crooked Creek, the Wood River, and many smaller springs discharge the ground water to Agency and Upper Klamath Lake. Ground water in this sub-basin moves toward Upper Klamath Lake and then south toward Lower Klamath Lake.

The majority of wells in the Upper Klamath Lake sub-basin are in the irrigated areas around and north of Agency Lake. Wells are typically less than 50 feet to 363 feet in depth. The aquifer units penetrated by these wells are sedimentary deposits of pumice, sand, clay, gravel and cinders.

Static water levels range from 35 feet below land surface in the north to artesian pressures equivalent to 22 feet above land surface in the areas near Agency Lake. Water temperatures are low ranging from 40° F to 51° F indicating that the water is derived from the local ground water flow system.

## Hydrogeology of the Lost River Basin

The Lost River sub-basin covers 3,016 square miles in the southern portion of the Klamath Basin, 1,315 square miles are in Oregon and the remaining 1,704 square miles in California. Ground water boundaries of the sub-basin lie beneath topographic divides. The eastern regional boundaries extend from the drainage divide of Quartz Mountain near the Lake County line, and extend southward into California. The southern regional divide occurs along the volcanic highlands between the Lost River – Klamath River drainage and the Pitt River drainage in California. The western divide extends from Mount Shasta in the south, reenters Oregon near Hamaker Mountain, and extends north to Aspen Butte on the east slope of the Cascades. The northern boundary separates the Lost River – Klamath River drainages from the Upper Klamath Lake Basin. It extends from Aspen Butte through the city of Klamath Falls then northeastward from Naylox Mountain, Bly Mountain, Yainax Butte, and east to Quartz Mountain. The principal features in the Lost River Basin are the Langell, Poe, Yonna, and Swan Lake Valleys, plus Tule Lake and Lower Klamath Lake. The primary drainages are the Lost River, which discharges to Tule Lake, and the Klamath River, which is the only surface water outflow from the Klamath Basin.

Illian (1970) estimated the total average quantity of ground water moving through the Lost River sub-basin is 900,000 acre-feet per year. 550,000 acre-feet (61%) of the water infiltrates into the ground water system from precipitation within the recharge areas of the Lost River sub-basin. In addition, 200,000 acre-feet (22%) enters the sub-basin as ground water flow from the Upper Klamath Lake sub-basin, and 150,000 acre-feet (17%) from underflow from the Sprague River sub-basin per year. The primary recharge areas for the regional flow system are the east slope of the Cascade Mountains on the western side of the sub-basin, the Quartz Mountain area to the east, and the volcanic highlands to the south. Also, ground water mounds that supply water to the intermediate flow system can be found beneath high elevation areas with permeable soils such as Naylox Mountain, Edgewood Mountain, Yainax Butte, and similar upland areas on the northern margin, and within the sub-basin such as Bryant Mountain and Stukel Mountain.

The ground water recharged in the upper elevation areas of the Lost River sub-basin along with portions of the ground water underflow from adjacent basins, moves toward low lying ground water discharge areas such as Tule Lake, Lower Klamath Lake, the Lost River, and the Klamath River. The direction of ground water movement is generally north and west toward the Lost River, then south and west toward Lower Klamath Lake and the Klamath River. Of the 900,000 acre-feet per year flowing through the Lost River sub-basin, 800,000 acre-feet (89%) per year appears to resurface within the boundaries of the sub-basin. This water: 1) is used by plants (transpired) in Lower Klamath Lake and Tule Lake, 2) is evaporated, 3) exits the sub-basin as baseflow to the Klamath River, or 4) is extracted by wells. The remaining 100,000 acre-feet per year leaves the Lost River sub-basin as ground water underflow beneath the southwestern boundary on its way to discharge points in the Klamath River canyon.

## Previous Hydrologic Study of the Bonanza Area

Gorman (1994) investigated the ground water and surface water conditions in the Bonanza area and adjacent Yonna, Poe, and Langell Valleys. The primary purpose of this investigation was to address the ground water-surface water connection in local wells and Bonanza Springs versus surface water conditions in the Lost River. Two primary issues initiated the need for this study: 1) ground water levels in the Bonanza area were observed to be declining in the early 1990's and, 2) during this time the Oregon Water Resources Department received a large number of applications for the appropriation of ground water for irrigation.

Several events occurred from mid to late 1991 that exacerbated the need to examine the hydraulic connection between the ground water and surface water resources of the Bonanza Springs area.

1) The State Health Division (Nelson, 1991) concluded that the outbreak of bacterial contamination in wells in Bonanza was caused in part by the direct hydraulic connection between the Lost River and the shallow permeable zone in which the wells were developed.
2) The Bonanza Springs were flowing at a reduced rate, as were many springs in the region, probably as a result of the drought of the late 1980's and early 1990's.
3) Between 1991 and June 1992, OWRD received 25 applications for the appropriation of ground water in Yonna, Poe, and Langell Valleys for the purpose of primary and supplemental irrigation (total applied appropriation equaled 97.11 cfs). In addition to those applications, OWRD received 13 emergency drought applications for the appropriation of ground water in the Langell Valley seeking an additional 39.5 cfs. Including the Yonna and Poe Valleys areas, a combined total of 143.33 cfs was requested for appropriation. This amount of potential ground water withdrawal exceeds the normal discharge of Bonanza Springs. Also, at this time the Water Resources Commission denied OWRD's request to withdraw the Bonanza area from further allocation, citing lack of data to distinguish drought versus ground water pumping influences.

Additional background information from previous hydrogeologic investigations also supported the need to characterize the hydraulic connection in the Bonanza area. Data analysis from previous studies (Newcomb and Hart, 1958; Leonard and Harris, 1974) indicated that ground water provides significant baseflow for the Lost River. In the Bonanza area the ground water elevation is nearly at the same level as the surface level of the Lost River with Bonanza Spring functioning as the primary discharge conduit for the baseflow contribution. Aquifers in the Bonanza area provide ground water to domestic wells and contribute to the spring flow. Bonanza Springs occur at the intersection of the regional water table with the highly permeable basalt aquifer, further suggesting the potential for hydrologic connection between the ground water and surface water bodies.

Gorman used static water level measurements from both irrigation and domestic wells as the primary source of data for analysis. In addition he used long term precipitation records and surface water discharge measurements to characterize the changes in flows observed in the Lost River and Bonanza Springs. He also used pump test data (from both aquifer tests and well log data) to define the transmissivity and specific capacity of the basalt and continental sedimentary units in his study area. These data were used to characterize the hydrogeologic properties of both the basalt and continental sedimentary units. The transmissivity reported by Leonard and Harris (1974) for the basalt aquifer in the central Yonna Valley was $2.0 \times 10^6$ gpd/ft. CH2M Hill (1992) also reported a high transmissivity of $1.4 \times 10^5$ to $1.8 \times 10^5$ gpd/ft at the Babson well in northern Langell Valley. These high transmissivity values demonstrate that water moves easily through the basalt aquifer. Previous studies had also recorded high specific capacities for the basalt aquifer.

Newcomb and Hart (1958) reported that the basalt aquifer could produce 3,000 gpm with one or two feet of drawdown from this aquifer. Newcomb and Hart (1958) noted that the water moves primarily through fractures and scoriaceous interflow zones within the basalt flows, and that water moves vertically through fault fracture zones. They also stated that the porous interflow zones overlap and interfinger sufficiently to allow free movement of water vertically across layers. In contrast, the wells completed in the Tertiary continental sediment unit (Tcs) show much lower specific capacities. Gorman reported the average capacity for 15 wells completed only in the Tcs unit is 1.6 gpm/ft. This variance in hydrologic character shows the contrast in the ability of these two different units to transmit water.

Gorman noted from water level measurements of seven State Observation wells that ground water levels had dropped to the lowest levels since measurements were initiated. Water level measurements from wells penetrating the basalt strata showed similar water surface elevations to wells that penetrated the continental sedimentary strata. In the Bonanza area these ground water elevations were nearly coincident with the elevation of Bonanza Springs. In late August and September of 1991 the State of Oregon Health Department observed that the local ground water table in Bonanza was actually lower then the River level. This created a reverse hydraulic gradient and Bonanza Springs were functioning as a drain or conduit for surface water to enter the ground water system. Gorman noted that ground water elevations were the same across geologic structures and/or lithologic contacts. These observations led Gorman to deduce that despite the contrasting hydrogeologic characteristics of the basalt and sedimentary strata, the two water bearing units behaved as a single aquifer.

Gorman used precipitation and pumping data to determine whether the reverse hydraulic gradient produced during periods of low ground water levels was from reduced recharge or from pumping effects. The Bonanza area experienced a dramatic increase in ground water pumping during the spring and summer of 1992. During this time, discharge measurements of Bonanza Springs indicated that spring flows had been reduced to well below the 85 cfs to 100 cfs range reported by previous investigators. The measured flow of 15.4 cfs in November of 1992 was the lowest discharge ever reported. After a series of years of below normal precipitation, in 1993 a large winter precipitation surplus (150% of normal) resulted in a sharp rise in ground water levels and an increase in the discharge of Bonanza Springs. The rising water levels in wells lasted until the irrigation season started and pumping began. These observations led Gorman to conclude that aquifer in the area is affected by both natural climate conditions and ground water pumping.

The primary conclusions from the Bonanza ground water study were as follows:

1) Spring discharge and ground water levels are strongly linked;
2) The Basin and Range basalts and the Tertiary continental sedimentary units are sufficiently interconnected to allow ground water exchange between the two water bearing units, and despite their contrasting hydrologic characteristics, they function as a single aquifer.
3) The drop in static water levels in wells and discharge of Bonanza Springs was the result of both the long term climate conditions (seven years of drought) and from pumping of ground water in the area.

## Geothermal Resources

The geothermal resources of the basin were explored by Peterson and McIntyre (1970). They noted that the Klamath basin has the proper hydrogeologic characteristics for the occurrence of geothermal potential. They identified areas of high heat flow anomalies indicated by the occurrence of hot springs and hot water wells. The basalt flows contain porous and permeable zones of fractured and scoriacious rock for thermal water reservoirs. The lacustrine sediment strata can function as cap rocks to confine the steam in underlying basalt reservoirs. The extensive normal faulting can provide additional zones of porosity and structure to localize the reservoirs. The presence of volcanic eruptive centers of Pliocene and Pleistocene age makes it likely that intrusive bodies are present at depth and are the source of the indicated heat.

Geothermal ground water occurs at several localities within the Klamath basin but are confined principally to three locations. First is an area along the northeast edge of the city of Klamath Falls, second, a stream cut gap at Olene Gap and, third, the southwest flank of the Klamath Hills.

Sammel and Peterson (1976) further explored the hydraulic and thermal characteristics of the geothermal reservoir. Geophysical evidence and geochemical sampling were used to construct a model of the geothermal system. The geophysical evidence relating to the nature of the geothermal resource was obtained from gravity and aeromagnetic surveys. In general, the gravity and aeromagnetic trends were coincident with the northwest-southeast fault trends throughout the area. The more significant gravity anomalies related to structural features and thickness of basin sediments. All of the major thermal zones occurred either in areas not covered by thick valley fill deposits or immediately adjacent to outcrops of faulted basement rocks.

## Geothermal Water Geochemistry

Sammel and Peterson (1976) used ground water samples and temperature gradient profiles from hot water wells to analyze the geochemical nature of the thermal ground water. Ratios of dissolved chemical constituents show that the hot waters have very similar chemical composition whether they came from the Klamath Falls area, Olene Gap, or the Klamath Hills area. Hot waters from each of the three geothermal areas have nearly identical chemical compositions that distinctly distinguish them from the local meteoric water. The dominant ions in the hot water were Na and $SO_4$. The dominant ions in the cold meteoric waters were Ca and $HCO_3$. The similarity in chemical characteristics indicates the hot water is derived from similar geothermal environment and history of water/rock interaction. Sammel noted that on the basis of the chemical data, the geothermal reservoir appears to be predominantly a hot water system of moderate temperature. The water is heated by conduction and not by condensation of steam from a vapor phase dominated system.

## Geothermal System Model

Sammel and Peterson (1976) concluded that the hydrogeologic model of the geothermal system of the Klamath Falls area represents a combination of convection transport of heat and fluid from depth in a cyclical system. The hot water reservoir can be obtained by circulating meteoric water to depths between 10,600 feet and 14,200 feet if normal temperature gradient is present in the crustal rocks. The flow system is formed by meteoric water percolating downward along the extensive network of intersecting fracture zones that characterize the regional structure. The depth of fluid penetration is sufficient to raise its temperature to at least the estimated $266^{o}$ F ($130^{o}$ C) of the hot water reservoir. The water then rises along conduits of the major fault zones in the three principal geothermal discharge areas. The sediments (Tertiary continental sediments and/or Pleistocene lacustrine fill) that occupy the valley bottoms act as effective hydraulic seals as well as thermal insulators.

Based on temperature gradients, chemical evidence, and geophysical evidence, the observed heat fluxes of the geothermal water do not provide information directly related to the source of thermal activity at depth. Sammel and Peterson (1976) concluded that the occurrence of geothermal water in the Klamath Falls area is the result of deep circulation of water at conditions of normal heat flow, and that no magmatic heat is involved in the geothermal system.

GROUND WATER RESOURCES OF THE SHASTA VIEW IRRIGATION DISTRICT

## Purpose of Project

The Shasta View Irrigation District (SVID) was a natural choice to explore the availability of using ground water as an alternative to surface water supply for the following reasons:

1) The district receives its irrigation water from the United States Bureau of Reclamation's (USBR) D canal. Any additional supply of water from ground water would allow for less water to be extracted from surface water supplies, consequently leaving more water in stream.
2) The district already has in place a pressurized piping system, thus providing a delivery system for any groundwater pumped from within the district.
3) The sealed piping system assures efficient delivery and use of any additional water supplied to the district.
4) The presence of irrigation wells in the area allows for data collection and determination of the hydrogeologic characteristics of the aquifer system.
5) The district water demands are large enough to allow a substantial test of the capacity of the ground water resource.

## Shasta View District Setting

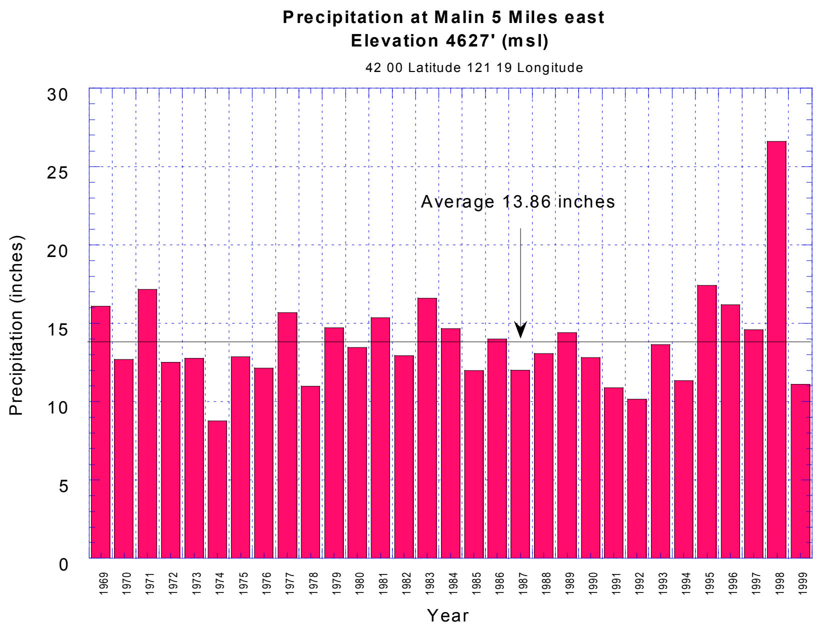
The Shasta View Irrigation District is an agricultural area in the northern portion of the Tule Lake Valley. The district (Plate 1) is north of the town of Malin, and south of the upland slopes of Buck Butte and the topographic divide that separates the Poe Valley and the Lost River drainage basin from the Tule Lake Basin.

The district supplies irrigation water for about 4140 acres of mostly potatoes, sugarbeets, alfalfa, and pasture grass. The district receives water from the USBR's D canal and uses about 12,000 acre feet of water annually. The district supplies water to its users through a pressurized pipe system that normally operates at about 75 psi. The piped distribution system links the D canal to the district's reservoir located on the upland slopes immediately north of the district.

## Physical Geography

The topography of the irrigated areas in the Shasta View district is gently sloped in the north and nearly level in the south district. The elevation ranges from a low of 4070 feet next to the D Canal, up to 4240 feet along the northern border of the district. An exception is Turkey Hill, which reaches 4460 feet elevation. Elevations of the steep slopes surrounding the district show much greater variance, reaching 5391 feet on top of Buck Butte. Higher peaks and ridges occur to the west along Modoc ridge and to the east on Bryant Mountain. Historically, any surface water drainage from the Shasta View area flowed into Tule Lake. Prior to the reclamation process, the Tule Lake Basin was a naturally closed drainage system with the shore line of Tule Lake occurring at the present elevation and position of the USBR's D Canal.

The climate for Shasta View is semiarid, with warm dry summers and cool wet winters. Generally, precipitation amounts increase in proportion to increased altitude. Therefore, the upland hills south and west of the district probably have proportionately higher precipitation amounts. A precipitation data collection site is located 5 miles southeast of Malin at an elevation of 4627 feet. A plot (Figure 4) of precipitation for the period of 1969 through 1999 shows an average of 13.86 inches of precipitation annually.



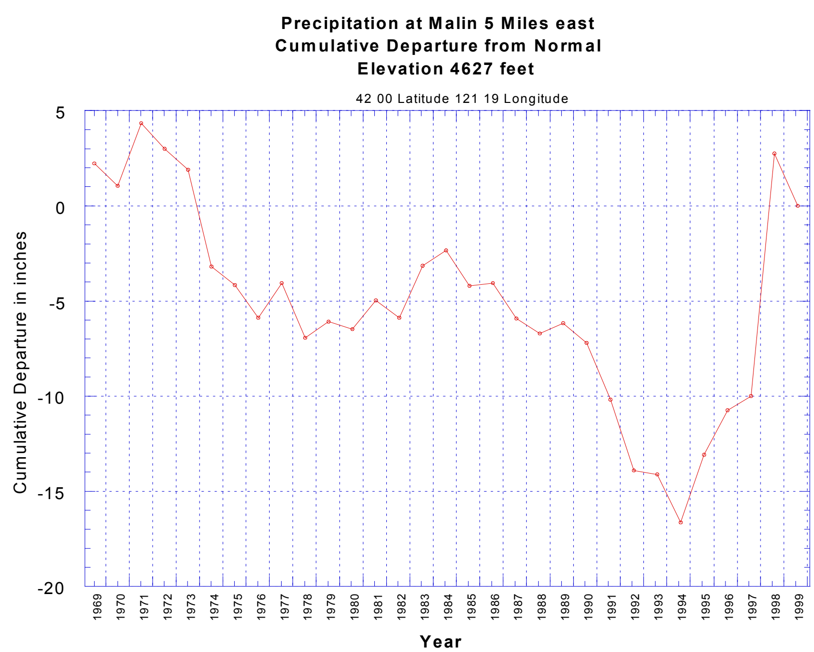




Figure 4. Annual precipitation at Malin 5 miles east from 1969 through 1999. Cumulative departure from normal for 1961 through 1999.

The plot of cumulative departure from normal precipitation over the same time frame shows periods of deficit and surplus in the water supply. The cumulative departure curve clearly displays a deficit in precipitation during the dry years of the mid 1970's and again during the late 1980's and early 1990's, followed by a large increase during the years of surplus precipitation from 1995 through 1998.

## Previous Work in the Shasta View Area

Previous work on the water resource potential of the Shasta View district area is limited. Newcomb and Hart (1958) measured water levels in eight wells in the area. They were also the first investigators to geologically map the area. They also identified sedimentary strata of the Tertiary Yonna Formation, present within the trough of a synclinal fold. In the lower valley floor area they mapped sedimentary deposits of Quaternary alluvium. These sediments were deposited in Lake Modoc during Pleistocene time during higher lake stands and from the remnant Tule Lake in Holocene time, until the lake was lowered by the reclamation process.

Peterson and McIntyre (1970) mapped older Tertiary lava flows overlain by the Yonna Formation sediments, overlain by younger, well fractured Quaternary lavas. They stated that the overall thickness of the mid to late Tertiary and Quaternary volcanic flows and sediments of the Basin and Range province exceeded 10,000 feet. They mapped normal faults bounding both sides of Buck Butte and also along the steep slopes of the unnamed upland hills west of Harpold road. These faults appear to structurally control the upland topographic divide between the Poe Valley to the north and the Shasta View area near the southeastern terminus of the Modoc Ridge trend. They mapped the lithology of these buttes as Quaternary-Tertiary basalt.

Veen (1981) studied gravity anomalies and their structural implications. She noted a positive gravity anomaly in the Shasta View area. This anomaly occurred over areas mapped as QTb (basalt flows and pyroclastics) on the geologic map of Peterson and McIntyre (1970). She stated that the QTb unit was not associated with any known volcanic vents, and the source and stratigraphic relationship of this unit is considered by Peterson and McIntyre to be an unknown mapping problem. She also stated that these basalt flows are associated with sections up to hundreds of meters in thickness. Veen (1981) did not extend her gravity study south of the Oregon – California border, consequently she did not address the thickness of sediments and basin geometry of the Tule Lake basin.

The geochemical study by Mallin and Hart (1991) sampled basalt from near the Shasta View area. Their sample from a site east of Malin near Bryant Mountain yielded an age of 4.98 +/- 0.22 million years. This analysis allowed for more accurate age association with the basalts of the bedrock uplands in the Shasta View area. Current geologic mapping of the Bryant Mountain and Malin Quadrangles by the Oregon Department of Geology and Mineral Industries (DOGAMI) will further refine the age and stratigraphy of rock units in the area.

## Geology

Geology can influence the regional ground water system. The geometry of the deep aquifer and its connection with recharge zones may control ground water flow in the area. Faulting can juxtapose low permeable rock against the aquifer or function as the primary conduit for fluid flow. Faulting can effect the position and distribution of zones of variable permeability produced by secondary mineralization. Understanding the structural geology of the area is essential for understanding the hydraulic characteristics of the basalt aquifer in the Shasta View area.

Well logs were used to create two geologic cross sections. The well locations and cross section alignments are shown on Figure 5. Cross section A-A' (Figure 6) is constructed from wells that occur along a north-south alignment in the western portion of the SVID. The cross section extends three miles from the elevated upland slopes north of the district, south toward the valley floor in the central western part of the district. Six wells were used for stratigraphic control. The profile shows the trough shaped deposits of the continental sedimentary rocks overlying the Tertiary basalts rocks that are the primary aquifer in the area. A buried fault is shown offsetting the basalt rocks. This fault accounts for the greater than 270 feet of vertical offset in 400 feet distance between wells KLAM 14766 and KLAM 14829. The continental sedimentary rocks are not displaced by the underlying fault because no faults have been mapped displacing the surface rocks at this location. Buried faults such as this may be a common occurrence in the Shasta View area as evident from the numerous faults that are exposed at the surface along the elevated slopes to the north and west of this geologic profile.

Cross section B-B' (Figure 7) is constructed from wells that align from west to east, then southeast nearly parallel to the northern district boundary. Ten wells were used as stratigraphic control. The cross section is nearly six miles in length with over 1000 feet of vertical control at two well sites. The profile was extended 4000 feet west of well KLAM 14755 to show the steep faulted slope of the elevated unnamed ridge to the west of the district area. Nine of the ten wells penetrate the basalt strata at depth. The continental sediments overlay the basalts throughout the length of the geologic profile. The depth to basalt ranges from as shallow as 57 feet in KLAM 14838 to greater than 575 depth at KLAM 14829. The cross section shows three faults with each successive block down-dropped to the east. In this profile the faults are shown displacing the continental sedimentary rocks at the surface. This interpretation is consistent with the mapping of Peterson and McIntyre (1970). As much as 900 feet of offset is shown on the eastern fault between well KLAM 14838 and well KLAM 14843 (based on the stratigraphic position of the lower basalt lithology of Illian). It also assumes that paleotopography was nearly level. The sloped contact of between the basalt with the overlying continental sedimentary rocks between wells KLAM 14819 and KLAM 14838 is assumed to be paleotopography, but could be produced by a buried fault with minor displacement.

Both cross sections show the complex faulted structural and stratigraphic characteristics between the continental sediments and the underlying volcanic rocks. These complex relationships suggest that the aquifer characteristics may be highly variable in the Shasta View area.

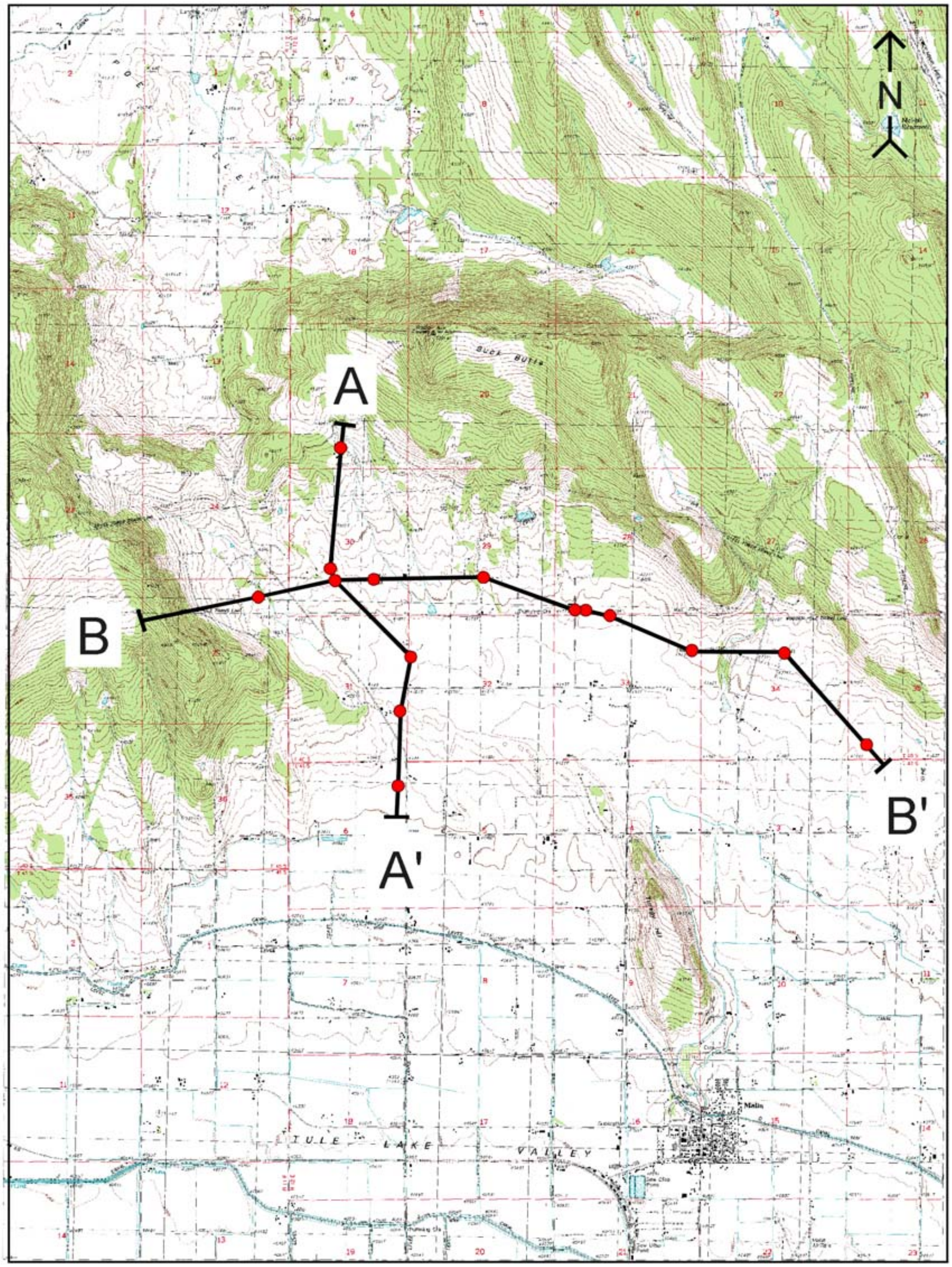



Figure 5. Malin quadrangle with alignment of cross sections A – A' and B – B'.

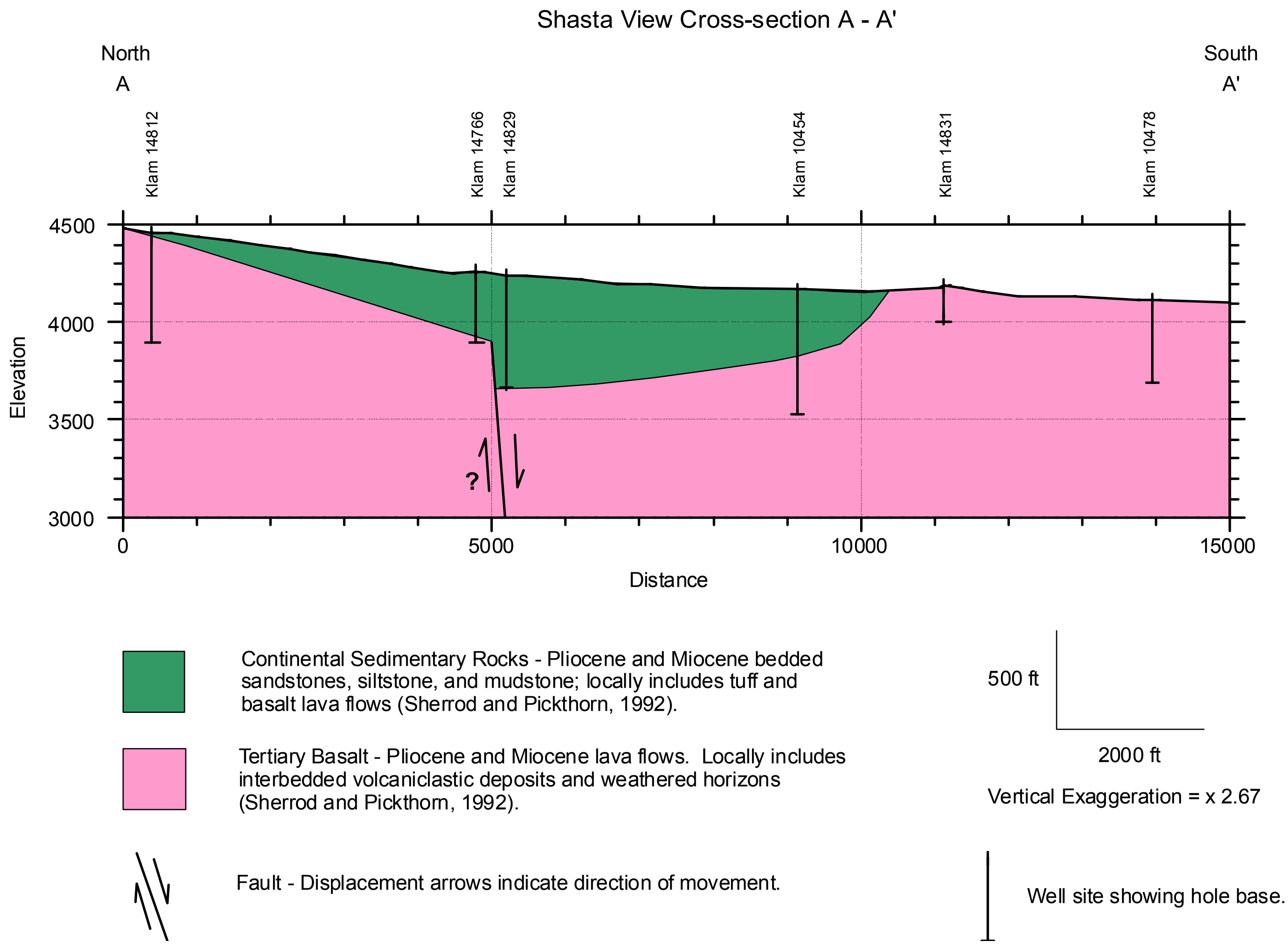



Figure 5. Cross-section A – A'.

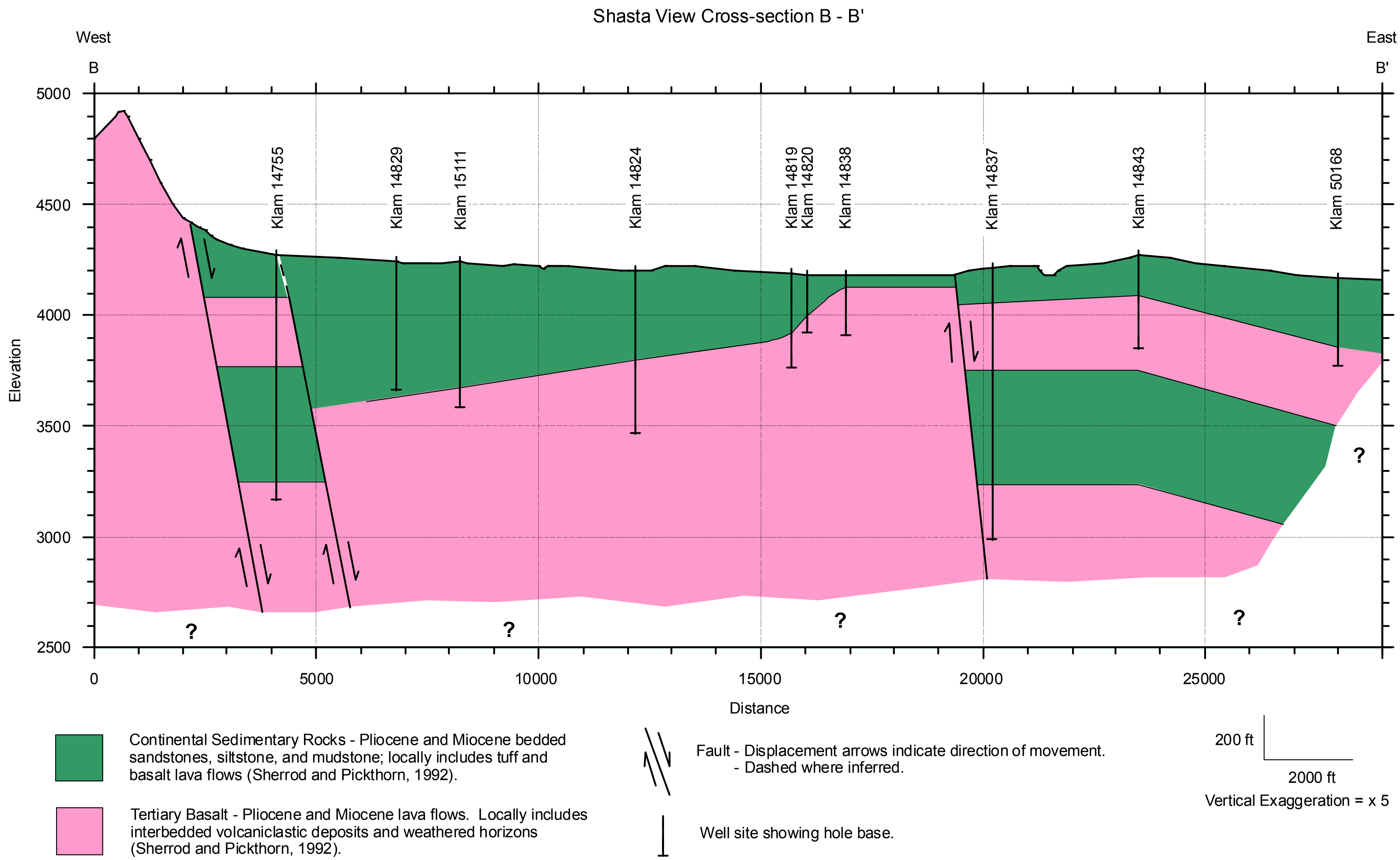



Figure 6. Cross-section B – B'.

## Groundwater Occurrence in the Shasta View Area

The widespread occurrence of Basin and Range faulting in the Klamath Basin has partitioned the basin into many smaller subbasins. Peterson and McIntyre (1970) mapped a system of faults that extend between the southeast Poe Valley and the Shasta View area. Leonard and Harris (1974) and Gorman (1994) indicated that these geologic structures generally impact ground water flow more locally than regionally. They noted that ground water moves freely across fault zones in most areas, but some exceptions do occur.

During this study, it was apparent that certain data were needed in adjacent areas in order to better understand ground water conditions in the Shasta View area. In the southeast corner of Poe Valley, Leonard and Harris reported water level elevations that had dropped significantly due to aquifer compartmentalization. Specifically, they reported that two irrigation wells (KLAM 14746 and KLAM 14742) penetrate the lower basalt aquifer. A nearby domestic well that penetrated basalt was used for quarterly water level measurements from 1963 through 1978. Depth to water measurements fluctuated between a seasonal high of 40 to 60 feet, and a low of 110 to 150 feet (Figure 8). During the same period, springtime water levels in this well were similar to the nearby irrigation wells. Since 1968, annual high water levels in this domestic well have generally been below a depth of 120 feet and annual lows ranging from 140 to more then 150 feet. The large seasonal fluctuation was much greater than the 4 to 6 feet of seasonal decline observed in other Poe Valley wells by Leonard and Harris. They attributed the water level decline in this area to be a localized effect. The result of faults forming a narrow compartment corresponding to the boundaries for that segment of the southeast corner of Poe Valley.

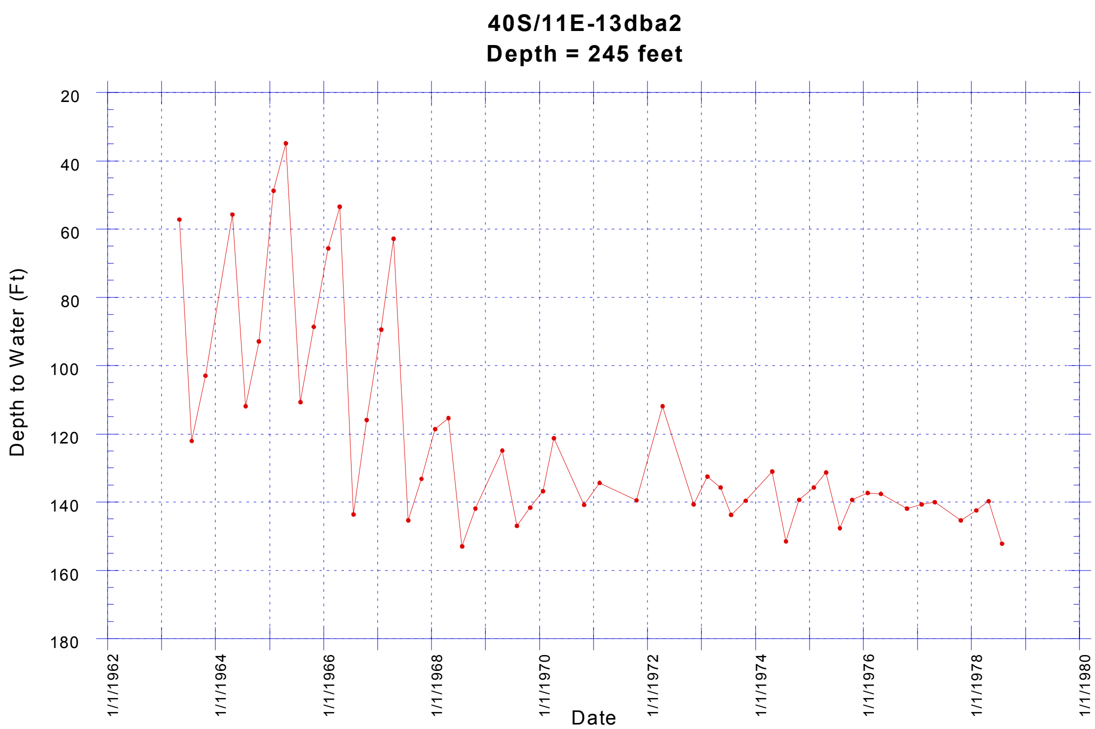



Figure 8. Water level fluctuations in southeast Poe Valley from 1963 to 1978.

Ground water level elevations of the basalt aquifer in the southeast Poe Valley are generally about 90 feet lower than in basalt wells 1.5 miles to the northeast and northwest toward the central Poe Valley. The water level elevation is similar to measured levels of the basalt aquifer in Shasta View area. Therefore, these southeast Poe Valley wells are included as part of the SVID study to evaluate potential aquifer boundaries, ground water flow direction and gradient. Illian (1970) noted the potential for ground water exchange between adjacent valleys in the intermediate flow system. These lower basalt aquifer water level elevations suggest that a ground water divide occurs between these wells. The ground water divide appears to be related to the prominent east-west fault that forms the steep northern slope of Buck Butte and the elevated ridge along the southern margin of the Poe Valley. Also, this feature suggests the potential for ground water flow beneath the topographic divide that separates the Poe Valley from the Shasta View area.

## Shasta View Hydrogeologic Units

The primary aquifer in Shasta View area is the Tertiary basalt unit. Nearly all of the irrigation wells in the area penetrate these basalt strata. The continental sedimentary deposits yield water to wells in the Shasta View area but are not a good water producer. Locally, the continental sediments act as a confining layer for the Tertiary basalt aquifer at depth. The surface sediments consist of sands, silts, and clays. The sediments are a poor water producing unit, but yield sufficient quantities of ground water for domestic wells in the area. The upland areas of Tertiary basalt should readily receive recharge from precipitation provided fracture permeability exists. Hydrographs from wells near the upland areas north of the district distinctly show this seasonal recharge.

## Local Ground Water Observations

Forty-one wells, including five wells in southeast Poe Valley, were field located and used for data collection and hydrogeologic analysis of the aquifer characteristics of the Shasta View area. Plate 1 shows the locations of these wells. Appendices A and B include data collected for these wells. Of the 41 wells measured for static water levels, 33 penetrated Tertiary basalt. Many of these 33 wells penetrated multiple rock types, but if basalt (or lava) was identified in the well log at or below the measured static level, that was designated as the primary aquifer. Plate 2 displays the static water levels for May 1999. The elevation ranges from 4021 to 4037 feet for wells that penetrate the basalt aquifer. The average elevation of the potentiometric surface for the basalt aquifer is about 4028 feet.

The potentiometric surface appears relatively level over most of the area. It is not possible to determine the gradient locally unless well head elevations are more precisely determined. Also, additional data collected from a larger area may allow for a more accurate determination of the local ground water gradient.

Water level elevations for wells KLAM 14742 and KLAM 14746 are of particular interest. These two irrigation wells are in the southeast corner of Poe Valley where Leonard and Harris (1974) identified an aquifer zone isolated from the main Poe Valley basalt aquifer, or "compartmentalized" by local faulting in the area. In May 1999 the water levels were 4025 feet and 4036 feet, respectively. These two water level elevations are essentially the same as observed for the basalt aquifer in the Shasta View area. Therefore, the basalt aquifer in the southeast corner of Poe Valley may be hydraulically connected to the basalt aquifer in Shasta View. This observation also suggests that the northern ground water divide for the regional basalt aquifer occurs along an east-west boundary between two prominent topographic offsets.

Faults with normal displacement are mapped in this area, and the ground water divide is likely controlled by these faults.

Four of the 41 measured wells in the Shasta View area penetrated the Tertiary continental sedimentary deposits aquifer. These wells show variable water level elevations. One of these, well KLAM 14829, is an irrigation well on the northern boundary of the district. Water levels in this well coincide with the static water elevations found in the Tertiary basalt aquifer. Therefore, the continental sedimentary deposit aquifer may be connected to the Tertiary basalt aquifer in the northern and western portions of the district. This hydraulic connection is consistent with the hydrogeologic conditions Gorman (1994) observed in the Bonanza area. The hydraulic connection is probably the result of well fractured strata at depth and/or sufficiently permeable sandstones and cinders as indicated on the well log. The two other wells (KLAM 15045 and KLAM 15047) in the eastern portion of the district that penetrate continental sedimentary strata have water level elevations almost 100 feet above that of the Tertiary basalt aquifer. This suggests that the continental sedimentary unit can also act as a confining layer.

Well KLAM 10462 in the southern part of the district demonstrates the characteristics of the continental sediments as a confining layer. As reported by the driller, this well penetrated a shallow water bearing zone in the continental sedimentary strata, with a static water level of 41 feet below land surface (elevation 4065). The static level then dropped to 77 feet below land surface when the well penetrated the basalt aquifer below 162 feet. The static water level of 77 feet (4028 feet elevation) is consistent with other measurements from the regional basalt aquifer.

Four of the 41 measured wells penetrate alluvial deposits associated with the Quaternary sediments. The water level elevations measured in these wells are extremely variable. All of the wells that penetrate the Quaternary alluvium have water levels elevated above that of the Tertiary basalt aquifer. The thickness of this alluvial aquifer is uncertain. In the study area, well KLAM 15067 penetrated 315 feet of clays without intercepting any basalt or coarse-grained sediments. About six miles south of the Shasta View District, the Tule Lake city well in California (T48N/R04E-35cd2) penetrates 800 feet of alluvium before reaching the basalt aquifer (California Dept. of Water Resources).

Water levels from the city of Tule Lake well can be used to estimate the hydraulic gradient of the basalt aquifer between the SVID and Tule Lake area. Water level elevations at this well in March and October of 1999 were 4015.9 feet and 4023.4 feet, respectively. In the southern SVID area, KLAM 10462 (T41S/R12E-4cbc) is a 471 foot deep well that penetrates basalt below 158 feet. The water level elevations for March and October of 1999 were 4027.9 feet and 4030.4 feet, respectively. The Tule Lake well is 6.3 miles south of KLAM 10462. This corresponds to a gradient of 1.9 feet per mile (March 1999) and 1.1 feet per mile (October 1999). Further water level elevation data from wells that penetrate the basalt aquifer in the Tule Lake Basin are needed to confirm this gradient estimate of 1 to 2 feet per mile.

## Hydrographs

The hydrographs for wells in the Shasta View area show how water levels have fluctuated through time. Well KLAM 14838 is State observation well # 335 (T40S/R12E-33bab). The well is 248 feet deep and produces water from basalt and interbedded cinders. Water levels were measured quarterly from April 1965 through October 1977 when it was dropped from the observation program. Figure 9 shows the hydrograph of this well. During this time water levels ranged from a high of 149.9 feet below land surface to a low of 161.03 feet below land surface. Water level measurements at this well were reinitiated in association with this demonstration project. The recent measurements indicate water levels several feet lower than those from the earlier period of record. Water levels in this well may still be recovering from the drought period of the late 1980’s and early 1990’s.

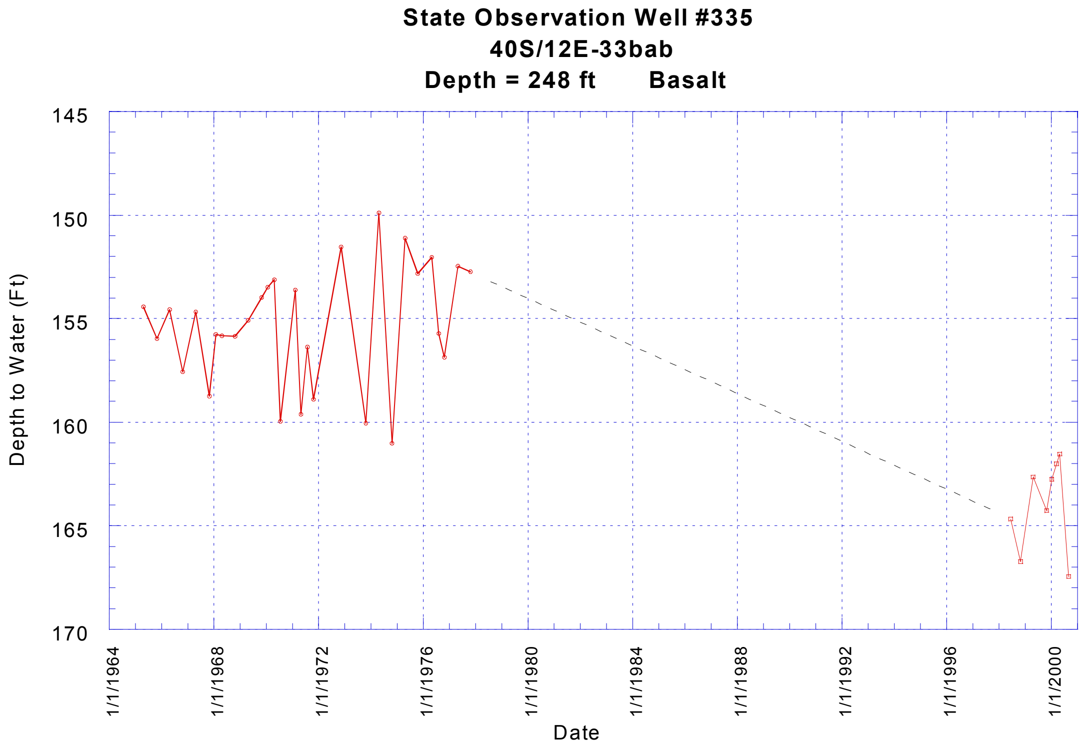



Figure 9. State Observation Well # 335. Water levels from 1965 through 2000.

Well KLAM 14829 is State observation well #1162 (T40S/R12E-30cda), which was added to the observation network in August 1994. This well has been on a quarterly measurement schedule since 1994. The well penetrates only continental sediments but appears to be hydraulically connected to the basalt aquifer either through permeable strata or fractured rock at depth.

The well is located along the SVID northern boundary. The hydrograph (Figure 10) shows that water levels fluctuate seasonally, with the high levels occurring in the spring (Plates 2 and 4) and the low water levels occurring in the late summer or fall (Plate 3). This seasonal trend is normal for a well located in close proximity to the recharge zone. The consistent high spring water levels demonstrate that recharge water readily penetrates the upland slopes north of the district. On an annual basis, water levels have been rising steadily since measurements were initiated in 1994. This water level rise is likely due to the increase in aquifer recharge as a result of the greater than normal amount of precipitation over the past few years (see Figure 4).

Also, comparing spring versus fall water levels for the wells that penetrate the basalt aquifer show distinct trends. Generally water levels in the northern portion of the district show a rising trend in the spring. Many of the wells in the southern portion of the district have their highest water levels in the fall. This trend is likely due to the recharge pulse moving south with time.

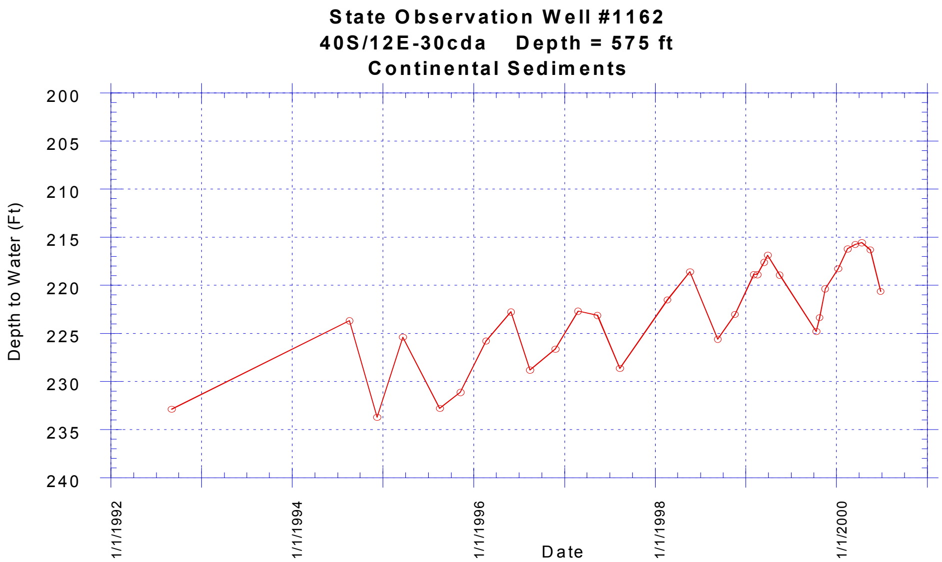



Figure 10. State Observation Well # 1162. Water levels from 1994 through 2000.

State observation well #294 (KLAM 15052, T41S/R12E-3cba) was measured from August 1954 through March 1993 and then again from 1998 through 2000. This well is located in the eastern part of the district. Both Newcomb and Hart (1958) and Illian (1970) used data from this well as part of their studies. This well is 76 feet deep and penetrates only Quaternary sediments. Water levels are very shallow ranging from generally 2 to 4 feet below land surface. Figure 11 shows that water levels appear stable over the past 45 years. The elevation of the water surface in this aquifer is about 4112 feet, or 84 feet above the water level of the basalt aquifer. The distinct difference in water surface elevation between the Quaternary sedimentary deposits and the basalt aquifer demonstrates that these two water bearing units are separate aquifers in the Shasta view area.

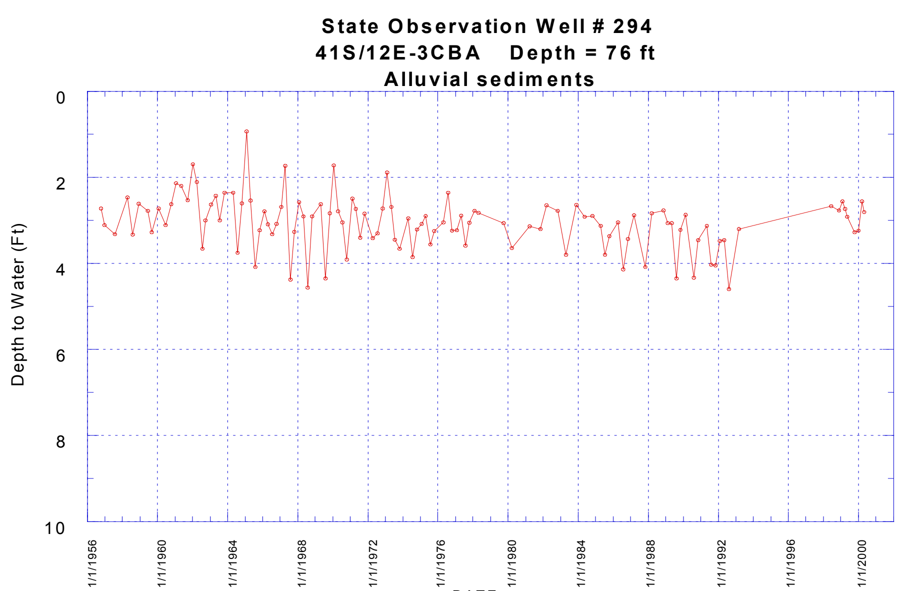



Figure 11. State Observation Well # 294. Water levels from 1956 through 2000.

Other wells in the Shasta View district with past measurement data show stable water levels through time. A water level measurement from well KLAM 14844 (T40S/R12E-34cda) was included in the basin wide hydrogeologic study of Newcomb and Hart (1958). This irrigation well is 625 feet deep and produces water from the Tertiary basalt aquifer. In 1954, the U.S. Geological Survey measured the water level at 142 feet below land surface. The hydrograph (Figure 12) shows that water levels measured for this study are essentially the same as the 1954 measurement. The recent data indicate that no significant long-term change has occurred in the water level of the basalt aquifer between 1954 and the present. The hydrograph also shows a consistent seasonal response with the highest water levels occurring in the spring and the lowest levels in the fall.

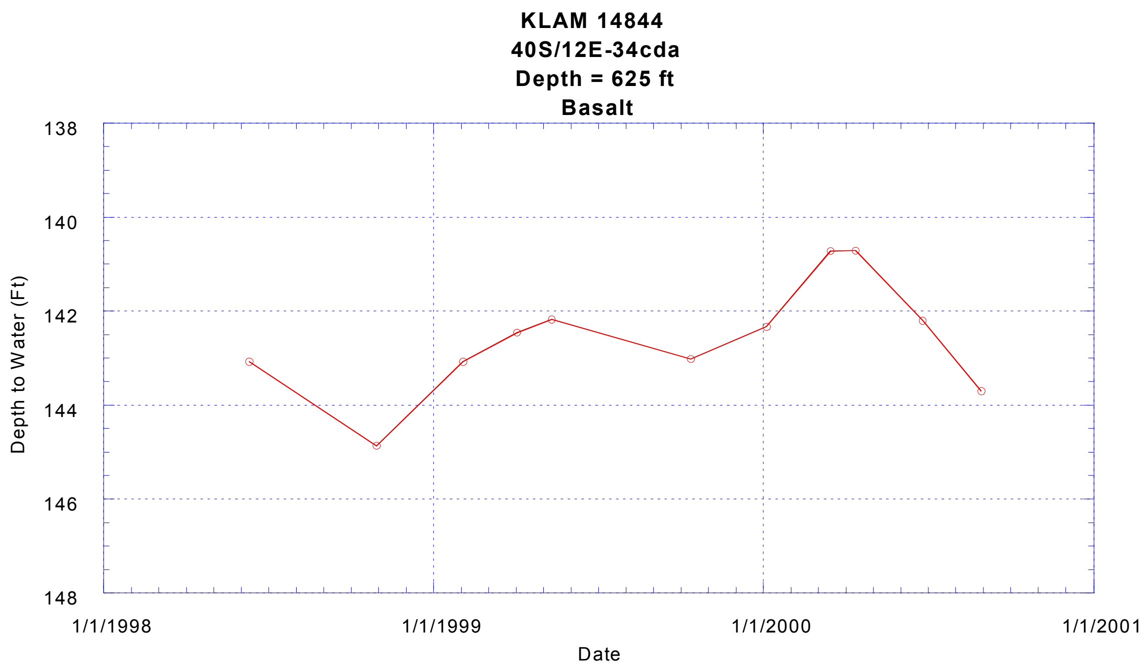



Figure 12 Well KLAM 14844. Water levels from 1998 through 2000.

Wells KLAM 15082 (T41S/R12E-1dcc) and KLAM 15114 (T41S/R13E-7cbd) were also included in the hydrologic study of Newcomb and Hart (1958). These irrigation wells produce water from the Tertiary basalt aquifer. The wells are 302 and 300 feet deep, respectively. In October 1954, well KLAM 15082 had a static water level of 184.3 feet below land surface. In the spring of 2000 (Plate 4), the static water level was measured at 181.9 feet below land surface, a difference of 2.4 feet. Similarly, in 1954 well KLAM 15114 had a static water level of 167.9 feet below land surface. In the spring of 2000, this well had a static water level of 166.97 feet below land surface, a difference of less than one foot. These data support the observation that the basalt aquifer in the Shasta View area is stable through time, and suggest that it may be possible to make additional withdrawals from the basalt aquifer.

## Aquifer Tests in the Shasta View Area

Aquifer tests are one of the best methods of investigation for determining the hydraulic characteristics of ground water movement. These studies involve analyzing the change, with time, of water levels in an aquifer caused by withdrawals through wells. These tests include pumping a well at a constant rate for a period of time and measuring the change in water level in observation wells located at different distances from the pumped well (Heath, 1987).

An important aquifer parameter determined from these tests is transmissivity (T). Transmissivity is the rate at which water is transmitted through an aquifer under a unit hydraulic gradient (Heath, 1987). Transmissivity is expressed in units of volume per unit time (such as gallons per day) per unit aquifer width (such as feet), or simply expressed as gallons per day per foot (gpd/ft). Transmissivity is often calculated by using graphical plots of either the drawdown or recovery portions of aquifer test data.

Aquifer tests also give information of the storage characteristics of an aquifer called the storage coefficient. The storage coefficient (S) is defined as the volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head (Heath, 1987). The volume of water has units of length cubed (such as cubic feet), the area has units of length squared (such as square feet), and the head change has units of length (such as feet). Thus, the storage coefficient is a dimensionless number. Storage coefficients typically span several orders of magnitude from $10^{-5}$ for confined aquifers, to 0.2 for unconfined aquifers.

## Tenaska Aquifer Test

CH2M Hill consulting firm performed a short-term aquifer test near the SVID northern boundary. The purpose of the test was to assess the potential of ground water development for a proposed Tenaska Incorporated natural gas fired electricity-generating facility. The proposed facility required 1,300 gpm of water for cooling (CH2M Hill, 1992).

The pumping well used for the aquifer test was KLAM 14821 (T40S/R12E-28db). This irrigation well is 647 feet deep and penetrates both Tertiary continental sedimentary rocks and Tertiary basalt. No water bearing zone was identified on the well log, but CH2M Hill indicated that the 54 foot thick basalt strata penetrated at the bottom of the drill hole is likely the most productive water bearing zone. These lowest basalt layers were identified as the upper portion of the lower basalt unit identified by Peterson and McIntyre.

The aquifer test was performed in April of 1992. The well was pumped at an average discharge rate of 975 gpm for 12 hours, with a total of 13.3 feet drawdown. The specific capacity derived from the test was 73 gpm/ft. This value was used to estimate an aquifer transmissivity of 190,000 gpd/ft. This transmissivity was used to estimate that pumping at the target yield of 1,300 gpm would result in 22 feet of drawdown in the well. This estimate did not account for well inefficiency or any effects produced by interference from nearby wells. No nearby wells were reported to be pumping during the test period (CH2M Hill, 1992).

KLAM 14837 (T40S/R12E-33ada) was the only observation well monitored during the test. This 1198 foot deep irrigation well is 3,300 feet southeast of the pumping well. This well is located east of a major normal fault (cross section B-B') that occurs between the pumping well and the observation well. No drawdown was observed in the observation well, but since water levels were measured with an airline, drawdown of less than 1.0 to 1.5 feet could not likely be measured.

There are several faults near the pumping well. No hydraulic barriers or conduits were apparent in the data collected from the pumping well, but it is possible that hydraulic barriers could be observed if the well was pumped for a longer time period.

## Water Quality of the Basalt Aquifer

Water samples were collected during the Tenaska aquifer test to assessing the water quality of the basalt aquifer. The laboratory results reported by CH2M Hill are listed in Table 1.

TABLE 1. Results of laboratory analyses for water samples collected at well KLAM 14821.

| Parameter | Result | Reporting Limit |
|---|---|---|
| Alkalinity* | 112 mg/L | 1 mg/L |
| Iron | 23 μg/L | 19 μg/L |
| Hardness | 89.3 mg/L | 1 mg/L |
| Manganese | <2 μg/L | 2 μg/L |
| Laboratory pH | 8.25 | --- |
| Field pH | 8.26 | --- |
| Temperature | 19.5°C | --- |
| Conductivity | 195 μmhos/cm | --- |
| Total dissolved solids | 185 mg/L | 3 mg/L |

*Reported as $CaCo_3$

These analyses show that the sampled water has low concentrations for the chemical constituents listed. In general, the water produced from the basalt aquifer in the Shasta View area has good quality.

The primary conclusion from the aquifer test at the proposed Tenaska site is that the basalt aquifer will produce the target 1,300 gpm without the need for installing additional wells. The report did recommend that a detailed water balance analysis be performed to estimate the long-term sustainable yield of the aquifer.

## Aquifer Test at the Silbernagel/Dark Irrigation Well

During the early spring of 1999, OWRD department staff conducted an aquifer test at a well owned by Tom Silbernagel and John Dark (KLAM 10454). This well was pumped at an average rate of 1416 gallons per minute for 70.5 hours and, following pump shut off, water-level recovery was monitored for an additional 46 hours. The water level drew down a little more than 16 feet at the end of the pumping period. Water levels were also monitored at six observation wells, which ranged from 522 feet to about 4,800 feet from the pumped well. Changes in barometric pressure were also recorded during the test.

The results of the test analysis indicate that the transmissivity calculated from data collected at the pumping well and two of the observation wells (KLAM 14830 and KLAM 14834) ranges from about 120,000 to 205,000 gpd/ft. These values are moderately high, indicating that there is good potential for high production wells in the area.

The results using data from two of the other observation wells (KLAM 15111 and KLAM 14829) have a range in T of 785,000 to 1,300,000 gpd/ft. These are significantly higher values and may be due to actual areal variations in transmissivity, recharge to the aquifer within the zone of influence of the pumping well, or possibly to the existence of one or more low permeability zones which would attenuate the drawdown response at wells located on the opposite side of such zones. However, the analyses do not consistently indicate a typical response to either aquifer recharge or to low permeability zones.

Transmissivity was not determined with the data from the other two observation wells (KLAM 14754 and KLAM 10478), due to a lack of response to the pumping. This may indicate the existence of a relatively efficient barrier to ground water movement between these wells and the pumping well. The coefficient of storage calculated at the four observation wells that responded to pumping ranges from 0.0003 to 0.01, which is expected of a confined to semiconfined aquifer.

# GROUND WATER RESOURCES OF THE ADY DISTRICT

## Purpose of Project

The Ady District Improvement Company (Ady District) was suggested as a candidate to explore the availability of using ground water as an alternative to surface water supply for the following reasons:

1) The lack of irrigation wells in the area suggests that ground water is an underutilized resource in the area. By drilling a well (or wells) this additional water supply could be accessed, and much new information about local ground water conditions could be collected.
2) Ady currently receives all of its irrigation supply from the Klamath River. If the district were to use ground water, more surface water would be left in stream.
3) The current delivery system is an unlined canal that is reported to be leaky and, consequently inefficient. Because use of strategically placed wells would decrease the need for surface water, canal leakage would be reduced and water saved. The wells would deliver the water directly to the area of application.

## Local Setting

The Ady District is west of the Lower Klamath Lake Basin, about 2 miles north northwest of Worden, Oregon. Figure 13 shows the district and well locations in the area. The Ady District irrigates 240 acres along an unnamed valley adjacent to Keno–Worden road. This Valley is an elongate lowland area between two unnamed steeply sloped fault block hills to the northeast and southwest. The District also contains 178 irrigated acres immediately south of the Klamath Straight drain and Wild Horse Butte, a steeply sided faulted butte.

This lower acreage along the Klamath Straight Drain is at a surface elevation of the Lower Klamath Lake basin (approximately 4076 feet). The Klamath Straight Drain connects the Lower Lake drainage to the Klamath River. Prior to the reclamation process, this lower area was periodically flooded during times of high water and/or spring runoff.

The primary crop raised in the district is alfalfa. Neighboring ranches in the area raise livestock. The acreage adjacent to Keno-Worden Road is occupied by single family residences within and adjacent to the area.

The Ady District water supply is derived via pumping water from the Klamath River into small surface canals. According to Bob Flowers, the district owner/operator, the canal is very inefficient and experiences water loss through leakage.

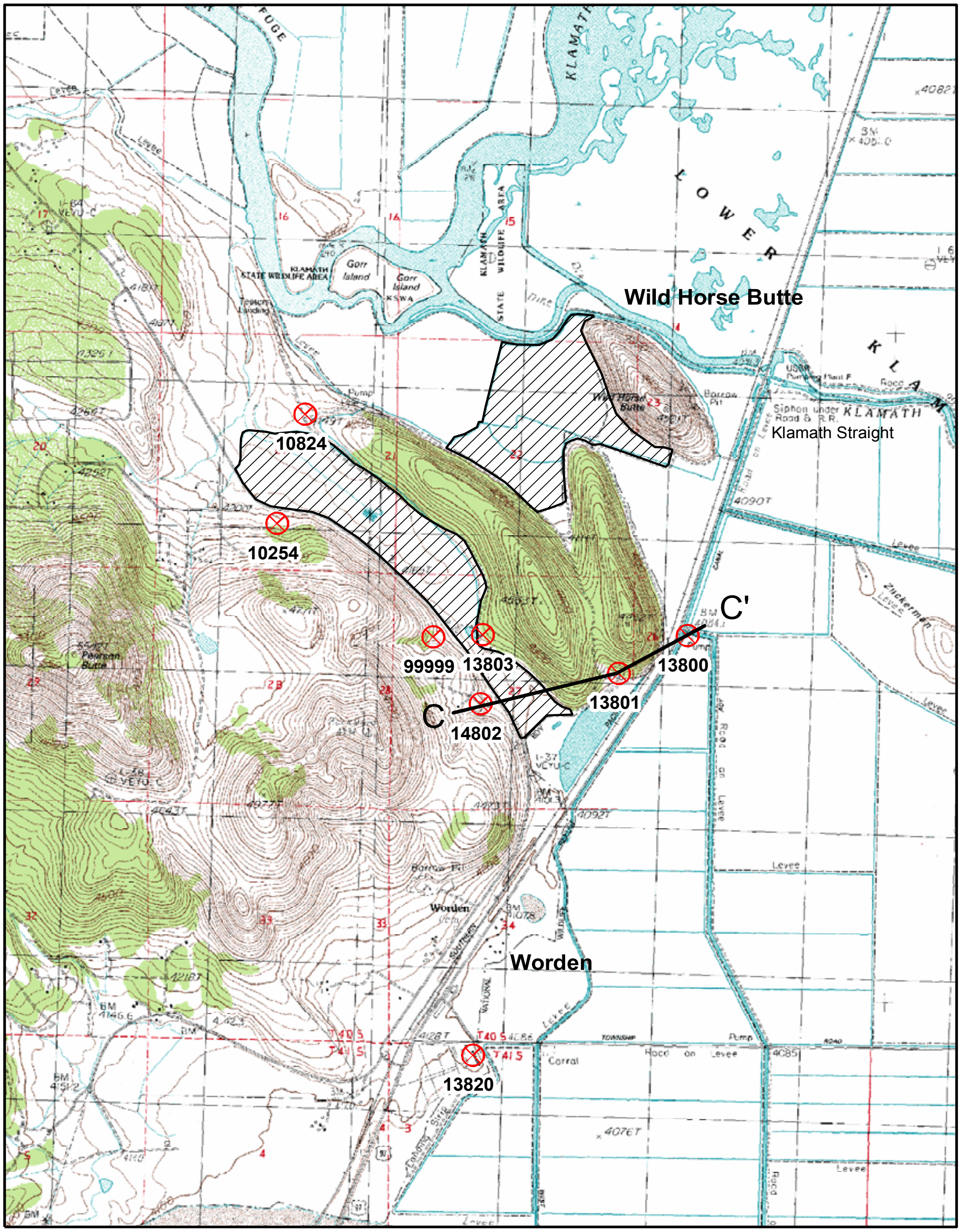



Figure 13. Portion of the Worden Quadrangle showing the Ady District area, the wells used for study, and alignment of Cross-section C – C'.

## Physical Geography

The topography of the irrigated areas in the district is fairly level. The elevation ranges from a low of 4076 feet in the Lower Klamath Lake area, up to 4150 feet in the upper valley region. Elevations of the steep slopes surrounding the district show much greater variance. The unnamed faulted hills and Wild Horse Butte are both essentially within the district area and both exceed 4500 feet. Pearson Butte, about 1.2 miles southwest of the district, reaches 5542 feet. Higher peaks and ridges occur to the west.

There are no streams that directly run off from the Ady District. The only surface water outflow near Ady occurs immediately north of the district at the Klamath Straight Drain. The drain flows between the Lower Klamath Lake basin and the Klamath River. Both the Klamath Straight Drain and the Klamath River flow along the northern margin of the district.

## Previous Work

Sherrod and Pickthorn (1992) identified the lavas associated with the upland hills around the Ady District as Pliocene to Miocene basalt lava flows. They mapped Wild Horse Butte as a Tertiary volcanic vent. They noted the only occurrence of the continental sedimentary rocks in the area is exposed at Zuckerman Island, a small stratigraphic exposure of older rocks, in the Lower Klamath Lake basin about a mile east of the Ady District. In the Lower Klamath Lake Basin and along the Klamath River they mapped the surface sediments as Quaternary sedimentary deposits. They also mapped three faults in the area all trending southeast to northwest and downthrown to the northeast. These faults occur along the axis of the small valley in the upper part of the district, along the topographic offset associated with the faulted hills between the upper and lower areas of the district and at Wild Horse Butte.

Sherrod and Pickthorn did not indicate that any of the faults in the vicinity of Ady were active during Holocene time. Based on the recent 5.9 and 6.0 earthquakes in September of 1993, and the extremely youthful, relatively uneroded exposed fault scarp on Wild Horse Butte, it is suggested that seismic activity could be rejuvenated in the Ady area. The 1993 seismic events occurred along the same structural trend of the faulted buttes along the northern margin of the Ady District.

A cross section was constructed to show the subsurface geology of the Ady area (Figures 13 and 14). The section extends from the upland hills on the southwest across the upper district valley and the faulted unnamed hills to the northeast Lower Klamath Lake Basin. The cross section alignment runs through three wells, used for hydrogeologic control (KLAM 14802, KLAM 13801, and KLAM 13800). The cross section shows that the Tertiary basalt bedrock composes the upland hills and extends beneath the sediments of Lower Klamath Lake. Three normal faults are shown, all displacing the basalt bedrock down to the northeast. The Quaternary sediments are 89 feet thick in well KLAM 13800. The sedimentary basin geometry probably deepens considerably to the northeast (beyond the extent of the cross section). This interpretation is based on the occurrence of mapped faults and the steep basin gravity contours mapped by Veen (1981).

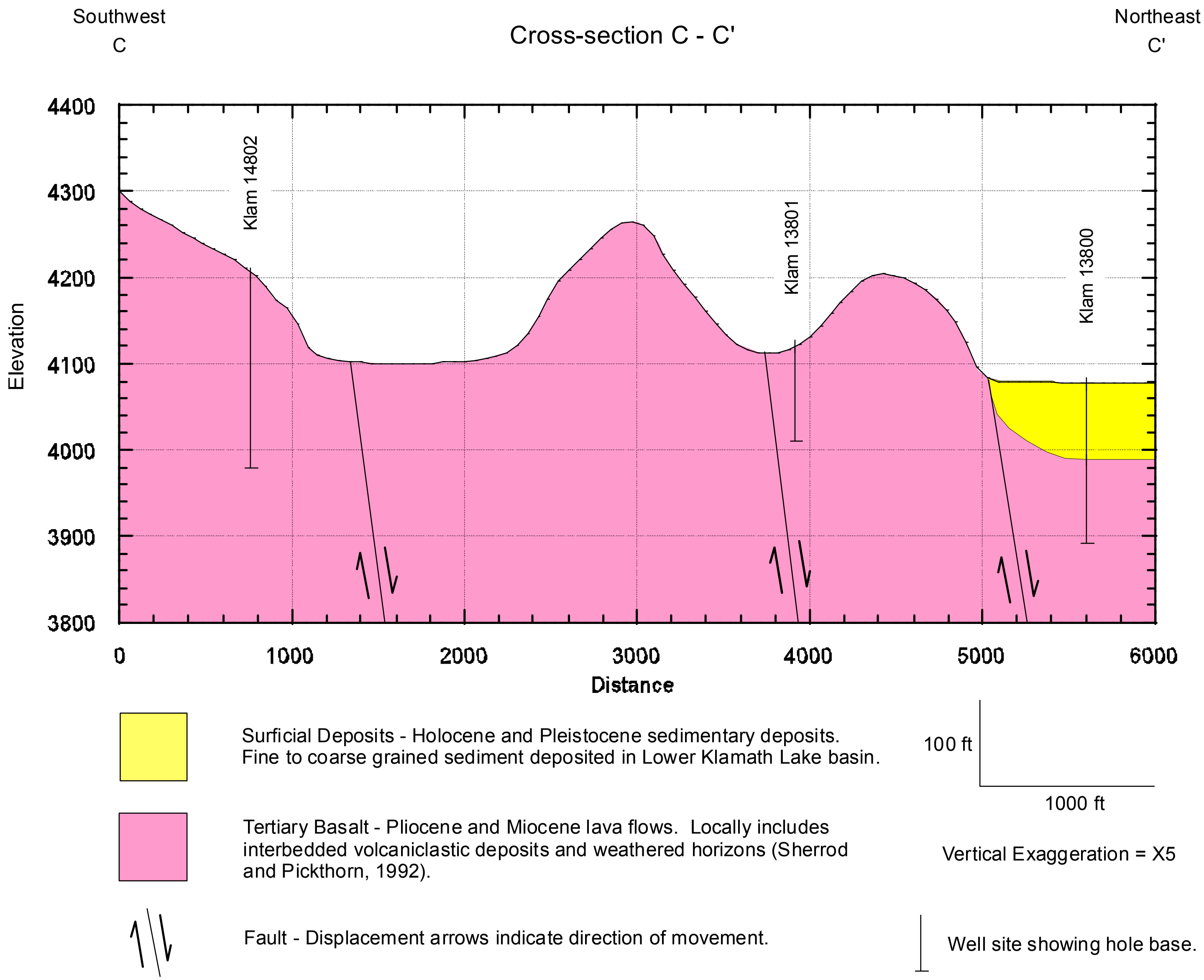



Figure 14. Cross-section C – C'.

## Ground Water

Geology is one of the important factors controlling the occurrence and movement of ground water. In the Ady District, the only aquifer that can provide significant quantities of water is the Tertiary basalt unit. The surface sediments generally yield water poorly and probably act as a confining unit overlying the basalts. Since the upland areas are free of any sedimentary deposits, they should readily receive recharge from precipitation if sufficiently permeable.

Eight wells were field located in the Ady area. Water level data collected at these wells were used to evaluate ground water conditions in the district and surrounding areas. Appendix D lists the data collected for these eight wells. Two surface water sites are also listed in Appendix D to provide data on the corresponding surface water elevations in the area. The surface water data provide information about the potential connection between the surface water and ground water bodies.

All wells used for static water level measurements penetrate the basalt aquifer. Water level measurements indicate that the water table elevation in this area is at an elevation of about 4082 feet (using May 1999 data). This elevation is nearly coincident with the land surface elevation of the drained Lower Klamath Lakebed. While some variance of water level elevation occurs between the different wells, there is insufficient data to determine a gradient and direction of ground water movement without more precise well head elevations.

Water level changes show little fluctuation over both a short-term and long-term time frame. Few reliable water level measurements exist from past ground water investigations for the Worden area. Newcomb and Hart (1958) measured two wells in the area for their basin wide hydrologic study. One of the wells (40S/8E-34C1) could not be located for this study, and it may no longer exist according to the local people. Well 40S/8E-34F1 of Newcomb and Hart (1958), was located for this study and corresponds to well KLAM 13820. The water level for this well was 28 feet below land surface on July 25, 1941. The measurement on May 14, 1999 was 25.79 feet below land surface. A variation of only 2.21 feet over 58 years indicates that water levels appear to be stable over a time frame of many decades. However, these data are insufficient to draw conclusions about aquifer response to variations in climate, pumping, and passage of the seasons.

The other seven wells measured all have water levels that are similar to, and in most cases, higher than at the time of well construction. Water level measurements indicate that the potentiometric surface is at an elevation of about 4082 feet (May 1999 data). This suggests that all of the wells penetrating the basalt aquifer are hydraulically connected. Water levels are similar at wells on opposite sides of faults, suggesting that the faults are not barriers to ground water flow in the Ady District area.

## Hydrographs

Hydrographs for three wells and a surface water site in the Ady District are shown in Figure 15. All three well hydrographs display the same trend. Since the initial water level measurements in May and June of 1998, all of these wells display a slight decline of about 2 feet or less during the summer months to their annual low in the fall (September 1998 measurement), and then showed a rise in water level throughout the winter and spring (May 1999 measurement). The occurrence of high water levels in the spring and low water levels in the fall or early winter is normal for an aquifer that receives most of its recharge during the winter and spring months. This suggests that recharge readily infiltrates to the basalt aquifer in the Ady District area.

A hydrograph of the Klamath River at Lake Ewauna is included in Figure 15 to compare fluctuations in the river level with ground water level changes. The Tertiary basalt is in contact with the Klamath River for a short reach in the Ady District area. The Lake Ewauna pool elevation is controlled by Keno Dam at Keno, Oregon. Comparison of surface water elevation changes with ground water elevation changes allows for a view of the potential for seasonal water level fluctuation as a result of hydraulic connection between the two water bodies. The seasonal rise and fall of ground water levels is not in phase with the rise and fall of the pool elevation of Lake Ewauna.

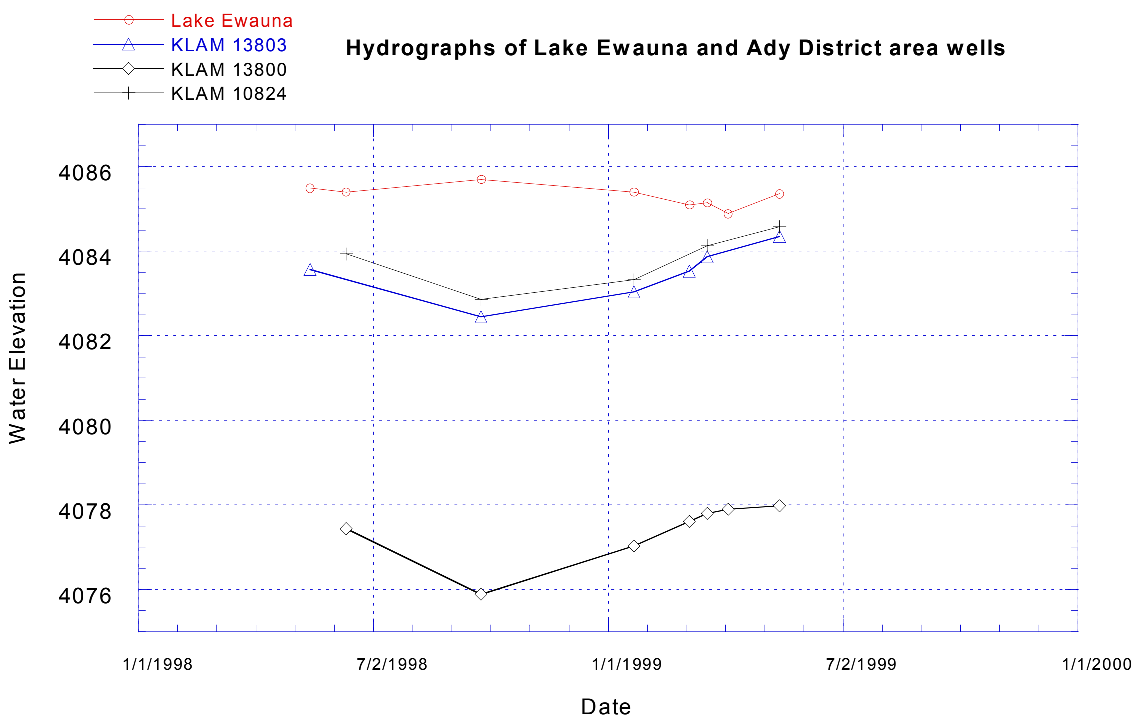



Figure 15. Hydrographs for the Klamath River at Lake Ewauna and Ady District wells KLAM 13800, KLAM 13803, and 10824.

## Summary

Tertiary basalts are the primary aquifer in the area. The upland hills are the principal recharge area for the local aquifer. The discharge area for local ground water has not been defined, but the presence of a flowing well in the Lower Klamath Lake area (KLAM 13800) adjacent to the Ady District suggests that the lake sediments may receive seepage from the underlying basalt aquifer. Whether ground water discharges from either the sediments or the Tertiary basalt aquifer to the Klamath River has not yet been determined.

Static water level measurements from eight wells in the area show that the ground water gradient cannot be determined without further investigation. Hydrographs of water level changes show that all of the wells in the area fluctuate in concert with each other, suggesting they all penetrate the same aquifer. Also, similar water level fluctuations at wells on opposite sides of faults indicate that faults are not locally hydrologic barriers to ground water flow. The hydrograph from Lake Ewauna (Klamath River) shows that no obvious connection exists between surface water and ground water in the area.

The elevation of the potentiometric surface is essentially the same as it was in the mid 1950's, based on measurements from one well (KLAM 13820). Further study needs to be done to substantiate this observation. Further work is also necessary to establish well head elevations and ground water gradients. The apparent long-term water level stability suggests that ground water is a potential source of additional water supply, and may be an underutilized resource in the Ady District area.

# GROUND WATER RESOURCES OF THE FORT KLAMATH AREA

## Purpose of Investigation

The Fort Klamath area was considered as an area for using ground water as a source of irrigation water to supplement surface water supply. The proposed site for a large production irrigation well was the Nicholson property about two miles west of the town of Fort Klamath. The primary land use in the area is cattle ranching. The Nicholson ranch has a permit to drill wells in the Wood River Basin in section 20. The permit is for supplemental irrigation of 758.6 acres with a maximum rate of pumping of 9.48 cfs from the regional aquifer, which is defined as an aquifer below 400 to 600 feet of sedimentary deposits. The ranch presently is irrigated from surface water diversions along the Wood River.

The Nicholson proposal was for a cooperative exchange, such that if the U.S. Bureau of Reclamation (USBR) drills the well(s), the USBR would receive the surface water right to the diverted Wood River water.

If a regional ground water supply ("new water") which is not discharging directly into Klamath Lake from subflow, is identified, the proposal would augment Klamath project water in two ways:

1) Reduction in the diversion of surface water from the Wood River.
2) Return flow from irrigation would flow back into the Wood River drainage or recharge the near surface ground water system.

## Geologic Structure and Basin Geometry

The Fort Klamath area occurs in the northern region of the Upper Klamath Lake graben. The area is in the down dropped broad flat plain between two prominent normal faults. The basin bounding faults are very steep and relatively uneroded. The main graben structure continues northward toward Crater Lake (Sherrod and Pickthorn, 1992). A gravity study by Veen (1981) indicates that low density sediments fill the Klamath graben. Veen's gravity model suggests that the sedimentary fill ranges from 400 to 1200 meters (1,300 to 3900 feet) before high density rock is encountered at depth.

## Characteristics of Hydrogeologic Units

The primary hydrogeologic feature of the Fort Klamath area is the occurrence of unconsolidated to poorly consolidated Pleistocene sediments overlain by recent Holocene deposits from Mount Mazama. The lacustrine sediments are primarily fine grained clays, silts, sands, and organic deposits (Snyder and Morace, 1997). The lacustrine sediments were deposited during high stands of pluvial Lake Modoc. Dicken (1980) noted that at maximum level pluvial Lake Modoc reached an elevation of 4240 feet. This lake level would correspond to a 55 foot water depth at the present site of Fort Klamath and the pluvial shoreline would have reached within a few miles of the present southern boundary of the National Park.

Stratified within the old lake deposits are sands and silts from prior eruptions of Mount Mazama along with organic layers from buried soil horizons. Many of the well logs from the Fort Klamath area display pumice and ash of probable air fall and/or reworked fluvial origin. The fluvial sediments were probably transported in from volcanic materials moved down from the southern flanks of Mount Mazama.

The Klamath graben is still accumulating Mazama sediment, evident from the modern surficial deposits of Mazama ash from the climactic eruption 7,600 years ago. The thickness of air-fall pumice is presently one meter on the upland slopes just east of Fort Klamath (Sherrod and Pickthorn, 1992).

## Surface Water Occurrence

The major drainages in the Fort Klamath area are the Wood River, Crooked Creek, and Annie Creek. Annie Creek flows from the southern slopes of Crater Lake National Park and receives water from elevated springs near the National Park Headquarters and from snowmelt.

The Wood River, Crooked Creek and many other smaller creeks originate from springs. The springs discharge ground water from the basalt aquifer exposed along the main graben bounding faults. These spring fed creeks maintain uniform discharge. Although not located within the Fort Klamath area drainage basin, Spring Creek also flows entirely from ground water discharge. Similar to the Wood River and other spring fed creeks, Spring Creek maintains uniform discharge. The average discharge of both Wood River and Spring Creek is about 300 cfs each.

Snyder and Morace (1997) reported that many of the prominent wetlands and marshes around Upper Klamath Lake and Agency Lake receive water from the upward seepage of ground water. They noted that strong upward flow gradients are evident from the many artesian wells adjacent to the lakes and wetland areas, especially in the lower Wood River Valley.

## Ground Water Recharge and Discharge

Previous investigators (Newcomb and Hart, 1958; Phillips, 1968; Illian, 1970) have discussed the source of ground water recharge and subsequent discharge from the large springs along the graben bounding faults. Newcomb and Hart (1958) identified the high infiltration capacity of the pumice plain on the north, east, and south slopes of the Crater Lake area. They estimated that 10 to 12 inches of precipitation directly infiltrates to the ground water system in areas covered by the pumiceous soils. They also noted substantial seepage losses from surface streams that flow across the pumice plain, specifically Sand Creek, Scott Creek and Miller Creek. In September and October of 1954, flow measurements show the combined discharge of these three creeks was 40 cfs. In dry years it is common for the entire flow Scott and Miller Creeks to be lost to infiltration into the ground water system. Newcomb and Hart also identified Annie Creek as a stream that loses water in its lower reaches to the local ground water system.

Phillips (1968) studied the water budget for Crater Lake. He utilized available hydrologic data from precipitation records, surface inflow from the caldera walls, evaporation, and changes in lake stage to determine annual seepage loss from the lake. He calculated that Crater Lake averages 89 cfs of continuous outflow from deep percolation to the ground water flow system around the lake. The destination for the 89 cfs of ground water outflow from Crater Lake is unknown. The discharge location where the seepage water from Crater Lake reappears has been a subject of debate for many years. Large springs emerge at elevations lower than the lake in the basins of the Rogue and Umpqua Rivers, and in the Upper Klamath Lake tributaries (such as the Wood River, and Spring Creek). All of the spring fed creeks have very steady flow rates, discharge cold clear water, and each stream is very low in dissolved solids, similar to the water of Crater Lake. The potential hydraulic gradient between Crater Lake and the large springs in the area is steep. The difference in elevation between the lake and both Wood River springs and Spring Creek springs is about 2000 feet in 13 miles and 20 miles, respectively. The total flow from each of these spring fed creeks is greater than three times the amount lost from Crater Lake. No direct evidence of hydraulic connection between Crater Lake and the above mentioned springs has ever been identified. Phillips (1968) concluded that some of the seepage loss from Crater Lake may discharge into the Rogue River, but it is more probable that it mingles with the underground waters that discharge from the large springs in the Upper Klamath Lake basin.

## Water Quality

Newcomb and Hart (1958) reported on the water quality for a well in the town of Fort Klamath. Well KLAM 735 (T33S/R7.5E-16dd) is 220 feet deep and produces water from a 24 foot thick section of sand below 196 feet depth. This is a flowing well with a reported discharge rate of 20 gpm. The sampled water temperature was 43 $^{o}$F with a pH of 7.1. The chemical analysis showed very low concentrations of dissolved solids. This well had the lowest concentration of all seven anions and most cations (except Mg) for all 19 of the wells and springs they sampled throughout the Klamath Basin.

## Well log Analysis

Analyses of well logs in the Fort Klamath area all show unconsolidated stratified volcanic sediments. The maximum penetrated depth of any well was 410 feet with no indication of consolidated strata. Well KLAM 743 (Appendix F) referred to “heaving” or “quick” sands suggesting these sediments are poorly consolidated to depths of 320 feet. Locally, many well logs show fine grained clays and silts penetrated. These finer grained units act as confining layers. Two wells penetrated an organic horizon. Well KLAM 743 penetrated 15 feet of pine needles and wood at a depth of 320 to 335 feet below land surface. The other well (KLAM 735) about 0.5 miles northeast of KLAM 743, encountered wood at 186 feet depth with no thickness given. This organic horizon is probably the ‘buried forest’ that some local residents have alluded to in discussions.

All 36 of the well logs reviewed noted static water levels within 22 feet of land surface. Twenty-seven wells were flowing wells or had static levels reported at land surface. The other wells occur at topographically higher elevations to the north of Fort Klamath and along a pumice terrace on the eastern margin of the graben near the Crooked Creek and Klamath Agency area.

## Ground Water Observations

Four domestic wells had static water levels measured in July of 1998 prior to termination of the proposed project. Table 2 lists the data collected for these wells. All of the wells had water levels near or above land surface. The only well with past measurement data is KLAM 738. This well is 2.5 miles east of Fort Klamath. The well is 280 feet deep and produces water from sand at 279 feet. Newcomb and Hart (1958) reported that in 1954 this well was flowing at a rate of 20 gpm. When this well was visited in July of 1998 it was flowing. The static water level measured was 5.27 feet above land surface.

Well KLAM 700 is 0.25 miles further east and measured a static level of 8.36 feet above land surface. This well reported a static level of 2 psi (equal to 4.6 feet) when it was drilled in 1980. The water level measurements from these two wells east of Fort Klamath show similar values for the sedimentary aquifer in this area. These measurements also demonstrate that aquifer conditions have been stable since these wells were last measured.

Table 2. July 1998, water level elevation data for four wells near Fort Klamath, Oregon.

| OWRD Log ID Number | Well Location | Well Depth | Elevation In Feet (± 5ft) | Static Level (ft) (+ if above land surface) | Water Level Elevation (rounded) |
|---|---|---|---|---|---|
| KLAM 10361 | 32S/7.5E-31cdb | 99 | 4310 | - 13.32 | 4297 |
| KLAM 700 | 33S/7.5E-18cdd | 270 | 4193 | + 8.36 | 4201 |
| KLAM 738 | 33S/7.5E-18dcd | 280 | 4195 | + 5.27 | 4200 |
| KLAM 10760 | 34S/7.5E-01cbd | 166 | 4165 | - 7.80 | 4158 |

## Well Production Potential

Reliable well production information is poorly constrained. Thirty-four of the 36 well logs reviewed were domestic wells. The average production rate for the domestic wells was 50.4 gpm. Only 2 of the 36 well logs investigated were large capacity irrigation wells. Well KLAM 1004 (T34S/R7.5E sec. 30) about 8 miles south of the Nicholson site, produced 1200 gpm with 92 feet of drawdown, a specific capacity of 13 gpm/ft drawdown. Well KLAM 1003 (T34S R7.5E sec. 24) about 7 miles southeast of the Nicholson site, produced 400 gpm with no drawdown information given.

## Conclusions

Despite the cancellation of the Nicholson proposal, the Fort Klamath area could still be considered a viable area for a ground water demonstration project. The area has an abundance of excellent quality ground water. The ground water supply from the sedimentary aquifer does not appear to be in overdraft. The occurrence of only two irrigation wells in the Fort Klamath area is not due to limited production potential, but rather to the low demand caused by historically sufficient surface water supplies.

Further exploration of the sedimentary strata below 420 feet needs to be performed to generate a better understanding of the hydrogeologic characteristics of the sedimentary aquifer(s) in the Fort Klamath area.

# INCREASING SURFACE WATER FLOWS IN THE LANGELL VALLEY

## Problem Statement

Multiple factors have become apparent in the recent past that indicate the need for additional water supply in the Lost River sub-basin. These factors include the economic growth of the region, the listing of native aquatic species to endangered status, other in-stream uses, and poor water quality in the Lost River.

The primary source of irrigation water for the Langell Valley is direct pumping from the Lost River and from irrigation canals diverted at Malone Dam in southern Langell Valley. The Lost River originates from the outflows of Clear Lake in northern Modoc County California. In 1992, the listing of endangered suckers in Upper Klamath Lake and Clear Lake, forced the implementation of minimum lake levels. In 1996, concerns about threatened and endangered anadromous fish resulted in a policy change that further reduced the amount of water available to agricultural interests. The current priority for use of stored water is first for lake level maintenance, then for downstream flows and agricultural diversions. At present the operating criteria for Clear Lake states that the lake must maintain a minimum elevation of 4519 feet, and it must store a one-year supply (including 3 feet for evaporation). Therefore, changes in water management practices for Clear Lake combined with the demotion of agricultural diversions to lower priority, has resulted in a need for additional water supplies to support agriculture.

In 1992, the Oregon Department of Environmental Quality (DEQ) identified the Lost River as water quality limited under the U.S. Clean Water Act. The river has exceeded total maximum daily loads for bacteria, chlorophyll A, dissolved oxygen, and temperature. Understanding the local geology and its control on ground water-surface water interaction will be needed to resolve problems of water quality in the Lost River.

Historically, sufficient water has been available during normal years to satisfy irrigation demands. Required adjustments in surface water management practices to protect endangered species and to satisfy in-stream needs has resulted in a reduction of the amount of surface water available to meet irrigation demands. To satisfy irrigation demands, an additional supply of water needs to be acquired. Developing the ground water resource is a possible solution to surface water diversions that degrade water quality and fish habitat. Therefore, ground water has the potential to alleviate surface water demands in the Langell Valley. This section summarizes current knowledge of ground water resources in the Langell Valley in anticipation of its use as a supplemental supply for irrigation.

## Previous Work

The drainage area of the Lost River upstream of Bonanza is 1,300 square miles, including 500 square miles in California. The source of ground water in the Langell Valley is precipitation on the surrounding uplands. The major recharge contributions originate from upland areas to the northeast, east, and southeast. Leonard and Harris (1974) noted that recharge is less for the Langell Valley than the other areas of the Klamath Basin they studied, primarily because precipitation is lower for the Langell Valley area. Also, recharge in, and flow from, Bryant Mountain to the west is lesser in amount, because the rocks comprising Bryant Mountain are of low permeability.

The main aquifer for the Langell Valley is the Tertiary basalt flows of the basin and range. Irrigation and stock wells are generally drilled through the alluvial deposits and continental sediments to the underlying Tertiary basalts. Domestic wells tap the sediments as an aquifer but normally the continental sediments function as a confining layer for the underlying basalt aquifer.

Along the valley floor ground water is discharged by seepage to streams and springs, and lost by evapotranspiration. Seepage measurements of the Lost River between Malone Dam and Bonanza indicated that the river gained 22 cubic feet per second (cfs). Six cfs (27% of the gain) was attributed to direct ground water seepage (Leonard and Harris, 1974). Currently, additional seepage information is being gathered by OWRD to substantiate ground water contributions for this reach of the Lost River (G. Grondin, personal communication, 2000).

Leonard and Harris (1974) reported local geologic controls near Lorella that produced anomalies in the general ground water position and movement. They noted two areas with ground water levels higher than the ground water level in the central valley. One anomalous area, about 5 miles west of Lorella (T39S/R11E-sec. 26) had water levels 100 feet above the regional water table. The other area, about 2.5 miles east of Lorella (T39S/R13E-sec. 29 & 31) had water levels 65 feet above wells in the central valley. They attributed both of these anomalous occurrences to compartmentalization of the confined aquifer in fault blocks.

Gorman (1994) used data from state observation well #291 located just east of Lorella (T39S/R12E-sec 35aad) to characterize the ground water conditions in the Lorella area. This domestic well is 360 feet deep and develops water from the upper basalt aquifer. The hydrograph of this well (Figure 16) shows consistent water levels until 1988. Then the effects of the drought conditions that occurred in the area during the late 1980's and early 1990's show up as a general decline in static water levels. From February 1990 through February 1993, this well showed a total decline of 8.15 feet (Gorman, 1994). Static levels have recently risen to levels measured prior to 1988, suggesting that the ground water resource in the area has recovered to pre-drought conditions.

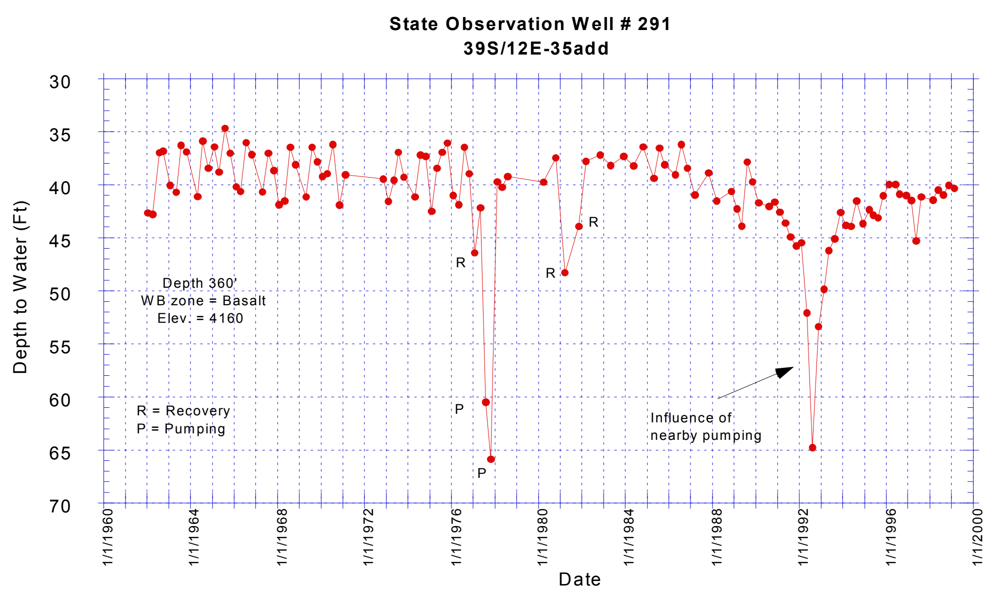



Figure 16. Hydrograph of State Observation Well #291 (updated from Gorman, 1994).

## Additional Study of Langell Valley Hydrogeologic Characteristics

Additional work is needed in the Langell Valley. Surface and subsurface geology controls the occurrence and movement of ground water. The surface water-ground water connection needs to be fully explored. Also, the hydrogeologic characteristics of both the shallow and deep aquifers need to be determined. For potential development of the water resources of Langell Valley additional study needs to include the following:

1) Map the distribution of rock types that influence ground water storage and movement.
2) Define the lithologic characteristics both vertically and laterally to determine hydrologic connection between aquifers and hydraulic boundaries.
3) Determine the permeability of different aquifer units and their storage capacity.
4) Identify and map faults that influence ground water movement. Determine whether the faults act as either conduits or barriers to ground water flow. Identify specific faults that act as zones of surface water-ground water exchange, or inter-aquifer exchange.
5) Identify areas of recharge and discharge for the different aquifer units.
6) Quantify the amount of recharge available for different aquifers.
7) Determine the direction and rate of ground water flow from areas of recharge to areas of discharge.
8) Calculate the impacts of pumping withdrawals from the ground water resource.
9) Sample the ground water from different aquifer units to determine its geochemical character. Determine if the temperature and concentration of dissolved solids are suitable for irrigation application or surface water flow augmentation.

Addressing the hydrogeologic characteristics listed above will allow for future development of ground water projects in Langell Valley. Developing the ground water resources of Langell Valley is essential for alleviating the effects of water shortages during periods of drought, to aid in flow restoration for endangered aquatic species, and to reduce the dependence on surface water diversions for irrigation.

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# Appendix A

## Shasta View District Project Well Data

# Shasta View District Project Well Data

Well Location: Township, range and section with quarter, quarter-quarter designation.
OWRD Log ID #: Oregon Water Resources assigned Identification number of the well log.
Site Name: Well owner reported on original well log.
Date Drilled: Date of completion reported on original well log.
Elevation: Elevation of land surface at well, in feet above mean sea level, estimated from topographic maps.
Topo Error: Potential error of elevation estimate, generally 1/2 of the contour interval, unless spot check elevation data is available.
Well Depth: Depth of completed well, in feet below land surface.
Casing Diam: Diameter of well casing at land surface.
Cased Depth: Depth of casing reported on well log. Unk = Unknown.
Water Bearing strata: Water bearing strata penetrated by the well. Basalt; Tcs = Tertiary continental sediments; QS = Quaternary sediments.
Use: Primary use of water; I = Irrigation, D = Domestic (& stock), O = Observation, Un = Unused, M = Municipal.
Capacity gpm/ft dd: Specific capacity of well in gallons per minute divided by feet of drawdown.

| Well Location | OWRD Log ID # | Site Name | Date Drilled | Elevation | Topo Error | Well Depth | Casing Diam | Cased Depth | Water Bearing strata | Use | Capacity gpm/ft |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | |
| 40S/11E-25aab | 51795 | Dan Rajnus | 1974? | 4275 | 10 | 1148 | 12 | 20 | Basalt | I | |
| 40S/11E-25add | 14754 | Don Rajnus | 5/23/83 | 4225 | 10 | 320 | 12 | 19.5 | Basalt | I | 33.9 |
| 40S/12E-19dca | 14812 | Andy Gaskin | 2/10/77 | 4460 | 10 | 562 | 10 | 41 | Basalt | D&I | |
| 40S/12E-28ccc | 14819 | Weyerhauser | 9/22/72 | 4190 | 10 | 397 | 10.75 | 71 | Basalt | D&I | 20.6 |
| 40S/12E-28ccd | 14820 | Alice Pereira | 5/1/56 | 4185 | 10 | 230 | 14 | 40 | Basalt | I | 35.5 |
| 40S/12E-30cad | 14766 | Albert Ross | 12/1/78 | 4260 | 10 | 364 | 8 | 40 | Basalt | D&I | |
| 40S/12E-30cda | 14829 | Carl Rajnus | 11/15/80 | 4245 | 10 | 575 | 12 | 20 | Tcs | I | 16.3 |
| 40S/12E-30dbd | 15111 | Warren Haught | 3/24/80 | 4243 | 1 | 613 | 12 | 20 | Basalt | I | 110 |
| 40S/12E-31aad | 14830 | Steve Rajnus | 9/26/76 | 4185 | 10 | 238 | 6 | 20 | Tcs | D | |
| 40S/12E-31dad | 14831 | Robert Gallup | 9/29/78 | 4190 | 10 | 181 | 6 | 19 | Basalt | D | |
| 40S/12E-32acc | 14834 | Cliff McKeon | 6/27/74 | 4165 | 10 | 258 | 6 | 21 | Basalt | D | |
| 40S/12E-32bcb | 10454 | John Dark | 4/23/92 | 4170 | 10 | 629 | 16 | 41 | Basalt | I | 110 |
| 40S/12E-32cdb | 52194 | OWRD Obs well | 3/15/00 | 4180 | 10 | 447 | 6 | 59 | Basalt | O | |
| 40S/12E-32dcb | 51602 | Ron McVay | 7/23/92 | 4170 | 10 | 455 | 14 | 19 | Basalt | I | 136 |
| 40S/12E-33bab | 14838 | John Madden | 4/2/57 | 4184 | 1 | 248 | 16 | 61.5 | Basalt | I | 25.3 |
| 40S/12E-34cda | 14844 | C.G. Gross | pre 1954 | 4170 | 10 | 625 | 16 | Unk | Basalt | I | |
| 41S/12E-01dcc | 15082 | Jerry V. Rajnus | 1931 | 4206 | 1 | 302 | 14 | 14 | Basalt | I | 1200 |
| 41S/12E-02cbd | 15047 | E-Z Feed Co. | 5/16/80 | 4160 | 10 | 170 | 6 | 59 | Tcs | D | |
| 41S/12E-02cdc | 15045 | EZD Farms | 1/13/81 | 4140 | 10 | 248 | 8 | 94 | Tcs | I | |
| 41S/12E-02dba | 15050 | Jerry V. Rajnus | 1/4/57 | 4170 | 10 | 650 | 16 | 107 | Basalt | I | |
| 41S/12E-03cba | 15052 | George Rajnus | pre 1962 | 4115 | 5 | 76 | 4 | Unk | Qs | D | |
| 41S/12E-04bda | 15059 | Laddie Rajnus&sons | 11/3/62 | 4150 | 10 | 126 | 6 | 27 | Basalt | D | |
| 41S/12E-04cbb | 15060 | Halousek Brothers | 9/14/81 | 4105 | 5 | 160 | 6 | 19 | Basalt | D | |
| 41S/12E-04cbc | 10462 | Halousek Brothers | 5/12/92 | 4105 | 5 | 471 | 18 | 160 | Basalt | I | 58 |
| 41S/12E-05bbb | 99999 | No Well Log | | 4130 | 10 | | 6 | | Basalt? | Un | |
| 41S/12E-06aad | 10478 | Halousek Brothers | 7/22/92 | 4115 | 5 | 425 | 16 | 30.5 | Basalt | I | 100 |
| 41S/12E-06bdd | 15064 | Cartwright | pre 1954 | 4100 | 10 | 120 | 6 | Unk | Basalt? | D | |
| 41S/12E-08dbd | 15067 | James Drazil | 10/15/85 | 4065 | 5 | 315 | 6 | 39 | Qs | D | |
| 41S/12E-09bad | 51611 | Ron McVay | 8/15/92 | 4085 | 10 | 882 | 16 | 19 | Basalt | I | 33.3 |
| 41S/12E-09cad | 15072 | Ron McVay | 8/16/78 | 4065 | 10 | 80 | 6 | 20 | Qs | D | |
| 41S/12E-10acc | 10349 | Matt McVay | 11/2/91 | 4090 | 5 | 85 | 6 | 48 | Qs | D | |
| 41S/12E-10ccc | 11254 | Malin Cemetary | 2/15/95 | 4095 | 10 | 236 | 10 | 20 | Basalt | I | |
| 41S/12E-13adc | 10539 | Edwin Stastny Jr. | 8/6/92 | 4100 | 5 | 550 | 16 | 93 | Basalt | I | |
| 41S/12E-15cbb | 15096 | Malin Municipal well #2 | 1937 | 4066 | 5 | 380 | 10 | 100 | Basalt | M | 53.2 |
| 41S/12E-16aac | 51832 | City of Malin well #4 | 5/14/99 | 4123 | 1 | 625 | 12.75 | 31 | Basalt | M | 3 |
| 41S/13E-07cbd | 15114 | Frye & Barney | 1953 | 4195 | 10 | 300 | 14 | 20 | Basalt | I | 43.5 |
| | | POE VALLEY WELLS | | | | | | | | | |
| 40S/11E-11bad | 14731 | A.W. Schaupp | 1952 | 4147 | 10 | 992 | 8 | Unk | Basalt | I | 0.9 |
| 40S/11E-13bcd | 14746 | Carl&Laddie Rajnus | 4/5/56 | 4230 | 10 | 736 | 16 | Unk | Basalt | I | 5.6 |
| 40S/11E-13bda1 | 14742 | Carl&Laddie Rajnus | 1952 | 4195 | 5 | 500 | 12 | 272 | Basalt | I | 30 |
| 40S/12E- 16cbd | 14808 | William Rajnus Jr. | 3/15/70 | 4370 | 10 | 720 | 14 | Unk | Basalt | I | 29 |
| 40S/12E-18aac | 14809 | William Rajnus | 1947&50 | 4173 | 10 | 550 | 16 | 20 | Basalt | I | 21.7 |

# Appendix B

## Shasta View Water Right and Measurement Data for Selected Wells

## Shasta View District Water Right and Measurement Data for Selected Wells

Well Location: Township, range and section with quarter, quarter-quarter designation.
OWRD Log ID #: Oregon Water Resources assigned Identification number of the well log.
Site Name: Well owner reported on original well log.
Application: Water right application number.
Permit #: Water right permit number.
Certificate #: Water right certificate number.
Elevation: Elevation of land surface at well, in feet above mean sea level, estimated from topographic maps.
Nov 98 SWL: Static water level measured for given month and year.

| Well Location | OWRD Log ID# | Site Name | Application # | Permit # | Certificate # | Elevation | Nov 98 SWL | Feb 99 SWL | May 99 SWL | Oct 99 SWL | Jan 00 SWL | Mar/Apr 00 SWL | June 00 SWL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40S/11E-25aab | 51795 | Dan Rajnus | G-10637 | G-9774 | 75328 | 4275 | 251.45 | 249.36 | 246.52 | 249.87 | 247.76 | 245.86 | 246.13 |
| 40S/11E-25add | 14754 | Don Rajnus | G-12810 | G-11664 | 74458 | 4225 | | 200.25 | 198.95 | 198.08 | 198.23 | 198.2 | 204.11 |
| 40S/12E-19dca | 14812 | Andy Gaskin | G-9207 | G-8529 | | 4460 | 439.34 | 435.21 | 430.99 | 439.63 | 434.95 | 431.93 | 434.45 |
| 40S/12E-28ccc | 14819 | Weyerhauser | G-6106<br>G-12860 | G-6345<br>G-12228<br>G-12450 | | 4190 | 172.06 | 168.82 | 169.03 | 170.72 | 167.49 | 166.72 | 171.57 |
| 40S/12E-28ccd | 14820 | Alice Pereira | G-379<br>G-12860 | G-255<br>G-12228<br>G-12450 | 27103 | 4185 | 166.16 | 163.00 | 163.06 | 164.81 | 161.53 | 160.79 | 165.77 |
| 40S/12E-30cad | 14766 | Albert Ross | G-9616 | G-9029 | 65768 | 4260 | 241.56 | 236.73 | 233.23 | 241.03 | 235.92 | 233.17 | |
| 40S/12E-30cda | 14829 | Carl Rajnus | G-12335 | G-11248 | | 4245 | 223.07 | 218.90 | 218.92 | 224.81 | 218.28 | 215.78 | 220.64 |
| 40S/12E-30dbd | 15111 | Warren Haught | G-9659<br>G-12978<br>G-13219<br>G-13749 | G-8990<br>G-11545<br>G-12590<br>G-12862 | 67890 | 4243 | | 215.78 | | 221.14 | 214.90 | 212.46 | 217.22 |
| 40S/12E-31aad | 14830 | Steve Rajnus | | | | 4185 | | 150.33 | 147.20 | 151.64 | 151.58 | 149.63 | 152.63 |
| 40S/12E-31dad | 14831 | Robert Gallup | | | | 4190 | | 161.85 | 160.98 | 160.00 | 160.75 | 160.52 | 160.59 |
| 40S/12E-32acc | 14834 | Cliff McKeon | | | | 4165 | 144.89 | 139.66 | 136.81 | 142.88 | 138.86 | 137.21 | 141.59 |
| 40S/12E-32bcb | 10454 | John Dark | G-12935<br>G-12918 | G-11506<br>G-12248<br>G-12432 | 76381 | 4170 | 141.53 | 137.90 | 134.68 | 141.51 | 137.18 | 134.86 | 139.44 |
| 40S/12E-32cdb | 52194 | OWRD Obs well | | | | 4180 | | | | | | 151.85 | 152.00 |
| 40S/12E-32dcb | 51602 | Ron McVay | G-13023<br>G-14266 | G-11571<br>G-13181 | | 4170 | 142.60 | 142.70 | 141.70 | 140.05 | 141.95 | 141.98 | 142.82 |
| 40S/12E-33bab | 14838 | John Madden | G-387<br>G-12824<br>G-12979 | G-365<br>G-11515<br>G-12246<br>G-12433 | 27317 | 4184 | 166.72 | | 162.65 | 164.27 | 162.76 | 162.01 | |
| 40S/12E-34cda | 14844 | C.G. Gross | U-393 | U-361 | 27304<br>30279 | 4170 | 144.87 | 143.07 | 142.17 | 143.02 | 142.33 | 140.72 | 142.20 |

| Well Location | OWRD Log ID# | Site Name | Application # | Permit # | Certificate # | Elevation | Nov 98 SWL | Feb 99 SWL | May 99 SWL | Oct 99 SWL | Jan 00 SWL | Mar/Apr 00 SWL | June 00 SWL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 41S/12E-01dcc | 15082 | Jerry V. Rajnus-well #1 | U-483 | U-468 | 27308 | 4206 | | | | | | 181.91 | |
| 41S/12E-02cbd | 15047 | E-Z Feed Co. | | | | 4160 | | | 40.48 | 40.18 | 40.36 | 40.4 | 48.08 |
| 41S/12E-02cdc | 15045 | EZD Farms | | | | 4140 | | | 24.05 | 25.08 | 23.79 | 23.56 | |
| 41S/12E-02dba | 15050 | Jerry V. Rajnus-well #2 | G-221 | G-138 | 27312 | 4170 | | | | | | 140.8 | |
| 41S/12E-03cba | 15052 | George Rajnus | | | | 4115 | 2.77 | 2.56 | 2.92 | 3.27 | 3.24 | 2.56 | 3.26 |
| 41S/12E-04bda | 15059 | Laddie Rajnus&sons | | | | 4150 | 117.93 | 118.04 | 116.58 | 115.99 | 117.14 | 117.12 | |
| 41S/12E-04cbb | 15060 | Halousek Brothers | | | | 4105 | | | 75.90 | 74.15 | 76.17 | 76.26 | 76.89 |
| 41S/12E-04cbc | 10462 | Halousek Brothers | G-11823<br>G-12777<br>G-12942 | G-11516<br>G-11585<br>G-11822<br>G-12253<br>G-12429 | | 4105 | 77.11 | 77.16 | 76.21 | 74.56 | 76.51 | 76.67 | 76.89 |
| 41S/12E-05bbb | 99999 | No Well Log | | | | 4130 | 107.99 | 108.14 | 106.87 | 103.44 | 106.77 | 106.68 | 105.41 |
| 41S/12E-06aad | 10478 | Halousek Brothers | G-12808<br>G-14421 | G-12254<br>G-12430<br>G-13267 | | 4115 | 91.80 | 91.52 | 90.67 | 89.66 | 90.41 | 90.17 | 90.12 |
| 41S/12E-06bdd | 15064 | Cartwright | | | | 4100 | 67.65 | 71.24 | 70.42 | 69.45 | 70.45 | 70.66 | 70.01 |
| 41S/12E-08bdb | 15067 | James Drazil | | | | 4065 | | 10.24 | 10.06 | 12.53 | 11.24 | 10.77 | 15.12 |
| 41S/12E-09bad | 51611 | Ron McVay | G-13023<br>G-14265 | G-11571<br>G-13180<br>G-11506 | | 4085 | 54.91 | 56.00 | 55.02 | 52.46 | 55.45 | 56.03 | 54.76 |
| 41S/12E-09cad | 15072 | Ron McVay | | | | 4065 | | 12.01 | 10.99 | 9.15 | 12.26 | 11.87 | 11.64 |
| 41S/12E-10acc | 10349 | Matt McVay | | | | 4090 | | 2.95 | 3.51 | 3.65 | 3.97 | 3.72 | 3.65 |
| 41S/12E-10ccc | 11254 | Malin Cemetary | G-14074 | G-12985 | | 4095 | 56.56 | 61.49 | 58.06 | 50.92 | 60.70 | 62.5 | 51.80 |
| 41S/12E-13adc | 10539 | Edwin Stastny Jr. | G-13096<br>G-13214 | G-12243<br>G-12464 | | 4100 | | | | | | 73.88 | 75.14 |
| 41S/12E-15cbb | 15096 | Malin Municipal Well #2 | G-1167 | G-1107 | 37291 | 4066 | | | 29.26 | 22.78 | 30.24 | 31.18 | 24.27 |
| 41S/12E-16aac | 51832 | City of Malin Well #4 | | | | 4123.2 | | | | 86.91 | 92.39 | 95.3 | |
| 41S/13E-07cbd | 15114 | Frye & Barney | U-551 | U-503 | 27010 | 4195 | | | | | | 166.97 | 167.61 |
| | | POE VALLEY WELLS | | | | | | | | | | | |
| 40S/11E-11bad | 14731 | A.W. Schaupp | G-2397 | G-2210 | 34896 | 4147 | 31.41 | | 27.92 | 37.26 | 32.68 | 30.14 | 37.35 |
| 40S/11E-13bcd | 14746 | Carl&Laddie Rajnus | U-502<br>G-1404<br>G-10637 | U-457<br>G-1296<br>G-9774 | 27016<br>33060<br>33258<br>67725 | 4230 | | | 193.54 | 203.30 | | 184.27 | |
| 40S/11E-13bda1 | 14742<br>14743 | Carl&Laddie Rajnus | U-502<br>G-1404<br>G-10637 | U-457<br>G-1296<br>G-9774 | 27016<br>33060<br>33258<br>67725 | 4195 | | | 169.51 | 173.08 | | 157.65 | |
| 40S/12E- 16cbd | 14808 | William Rajnus Jr. | G-6236 | G-5882 | 48453 | 4370 | | | 227.76 | 238.71 | | | |
| 40S/12E-18aac | 14809 | William Rajnus | U-326<br>U-534 | U-301<br>U-650 | 26808<br>26809 | 4173 | 41.71 | | 36.20 | 43.91 | | | |

# Appendix C

## Well Logs for the Shasta View District Area and Selected Wells from Southeast Poe Valley

# Appendix D

## Ady District Area Well Data and Measurements

# ADY District Well Data and Measurements

Well Location: Township, range and section with quarter, quarter-quarter designation.

OWRD LogID#: Oregon Water Resources assigned Identification number of the well log.

Site Name: Well owner reported on original well log.

Date Drilled: Date of completion reported on original well log.

Elevation: Elevation of land surface at well, in feet above mean sea level, estimated from topographic maps.

Topo Error: Potential error of elevation estimate, generally 1/2 of the contour interval, unless spot elevation data is available.

Well Depth: Depth of completed well, in feet below land surface.

Cased Depth: Depth of casing reported on well log.

Mar-99 SWL - Static water level measured for a given month and year.

Mar-99 Elev - Water level elevation for a given month and year.

Aquifer: Water bearing strata penetrated by the well.

Use: Primary use of water; D = domestic, S = stock.

| Well | OWRD | Site Name | Date | Elevation | Topo | Well | Cased | May/June-98 | May/June-98 | Sep-98 | Sep-98 | Jan-99 | Jan-99 | Mar-99 | Mar-99 | May-99 | May-99 | Aquifer | use |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Log ID# | | Drilled | | Error | Depth | Depth | SWL | Elev | SWL | Elev | SWL | Elev | SWL | Elev | SWL | Elev | | |
| | | | | | | | | | | | | | | | | | | | |
| 40S/8E-21ACA | 10824 | Sandy Tucker | 9/16/93 | 4150 | 10 | 179 | 19 | 65.06 | 4085 | 66.15 | 4084 | 65.67 | 4084 | 64.86 | 4085 | 64.42 | 4086 | Basalt | D |
| 40S/8E-21CDA | 10254 | Mike Clifford | 7/27/91 | 4220 | 10 | 282 | 19 | 142.22 | 4078 | 143.37 | 4077 | 142.86 | 4077 | 142.26 | 4078 | 141.56 | 4078 | Basalt | D |
| 40S/8E-26BBD | 13800 | Klam Experiment Sta. | 4/19/74 | 4077 | 5 | 186 | 100 | -0.94 | 4078 | 0.62 | 4076 | -0.52 | 4078 | -1.39 | 4078 | -1.48 | 4078 | Basalt | S |
| 40S/8E-27ADD | 13801 | Mel Stewart | 6/29/84 | 4120 | 10 | 109 | 38.4 | 30.76 | 4089 | 32.05 | 4088 | 31.61 | 4088 | 30.68 | 4089 | 30.53 | 4089 | Basalt | D |
| 40S/8E-27BCA | 99999 | No Well Log | | 4220 | 10 | 180 | ? | 137.39 | 4083 | 138.45 | 4082 | 138.08 | 4082 | 137.16 | 4083 | 136.57 | 4083 | | D |
| 40S/8E-27BDA | 13803 | Francis Flowers | 11/29/59 | 4170 | 10 | 91 | 31 | 86.43 | 4084 | 87.55 | 4082 | 86.96 | 4083 | 86.13 | 4084 | 85.65 | 4084 | Tuff ? | D |
| 40S/8E-27CAB | 13802 | James Flowers | 5/13/77 | 4205 | 10 | 225 | 44 | 119.40 | 4086 | 122.67 | 4082 | 125.04 | 4080 | 124.13 | 4081 | 123.62 | 4081 | Basalt | D |
| 41S/8E-03BAB | 13820 | Hanzel Brothers | pre1941 | 4105 | 10 | 127 | 72 | | | | | | | 25.86 | 4079 | 25.79 | 4079 | Basalt | D |
| | | | | | | | | | | | | | | | | | | | |
| Surface water Sites | | Lake Ewauna | | 4085.5 | | | | | | | 4086 | | 4085 | | 4085 | | 4085 | | |
| | | Ady Canal | | 4083.7 | | | | | | | 4084 | | 4084 | | 4084 | | 4084 | | |

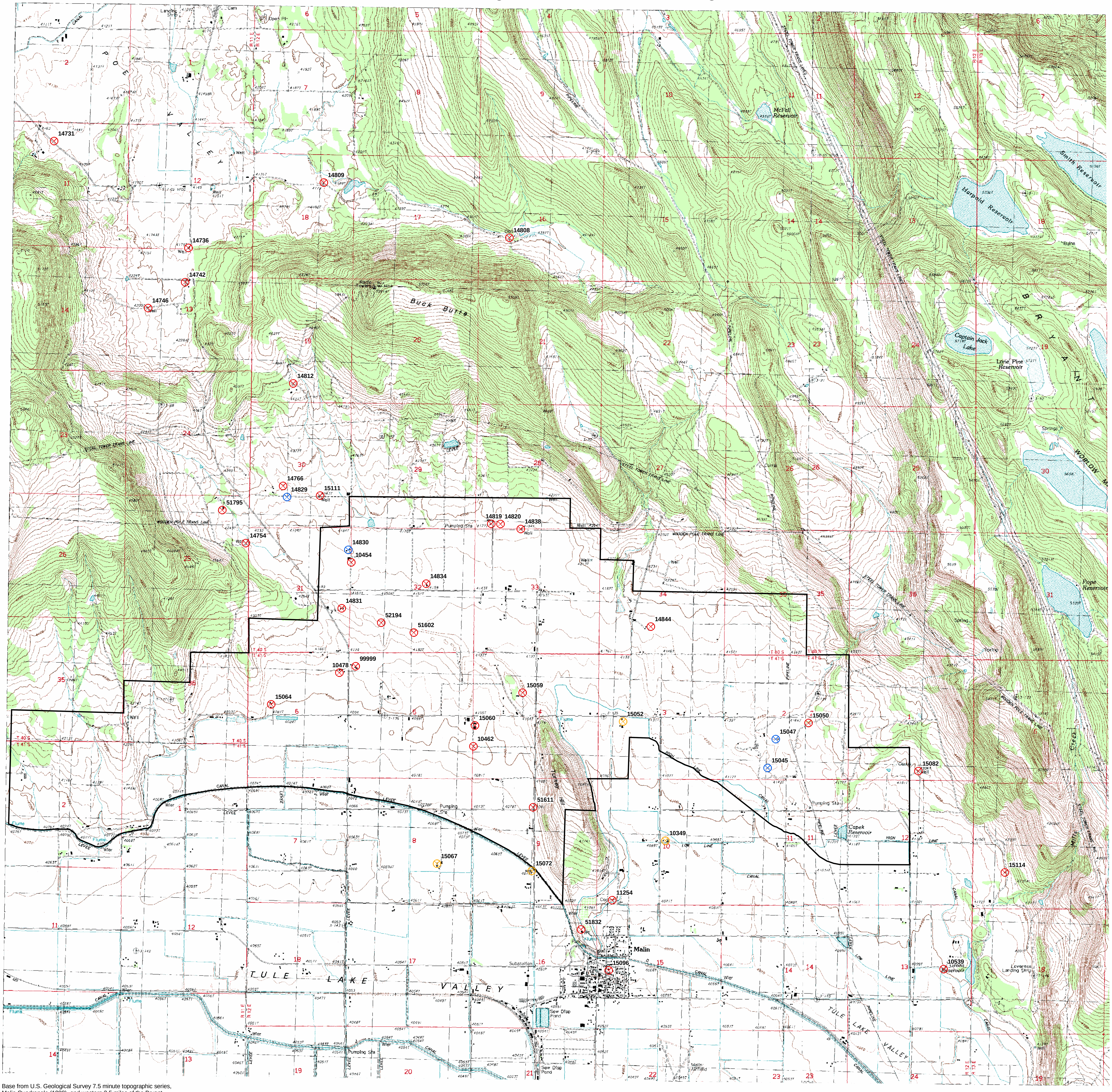
# Appendix E

## Well Logs for the Ady District Area

# Appendix F

## Well Logs for Selected Wells in the Fort Klamath Area

# Plate 1 Shasta View Irrigation District and Well Log ID Numbers




Base from U.S. Geological Survey 7.5 minute topographic series, Malin Quadrangle (1988), and western 2.5 miles of the Bryant Mountain Quadrangle (1988), Klamath County, Oregon.

1 0.5 0 1 Miles

1,000 0 1,000 2,000 3,000 4,000 5,000 6,000 7,000 Feet

1 0.5 0 1 Kilometers

OREGON LAMBERT PROJECTION
Standard parallels 33 and 45 30'
1983 North American Datum

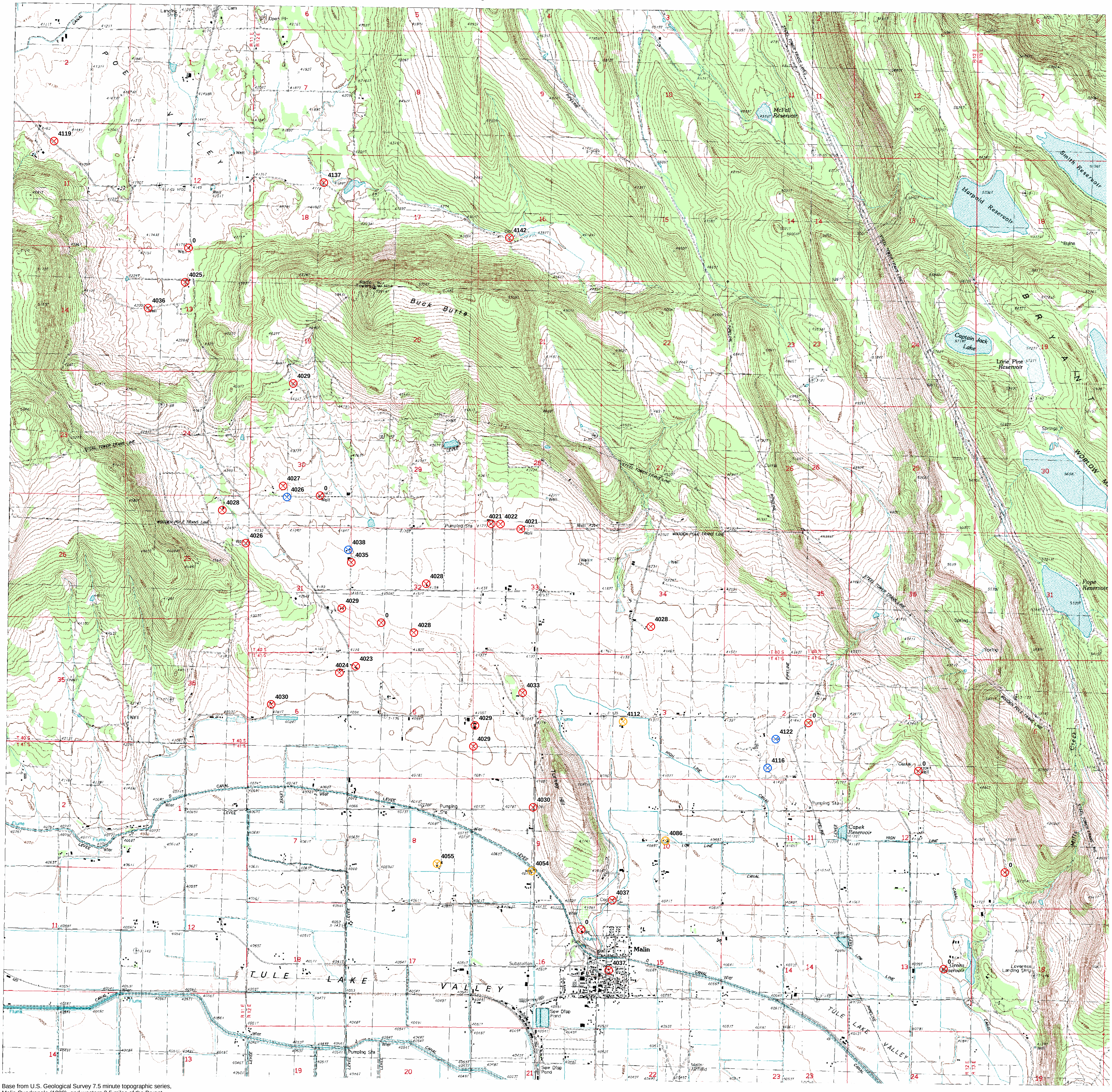
**Legend**

- Well Penetrates Basalt Aquifer
- Well Penetrates Continental Sediment Aquifer
- Well Penetrates Quaternary Sediment Aquifer
- Shasta Irrigation District Boundary

State of Oregon Water Resources Department

Map prepared by J. Eklund

# Plate 2 May 1999 Static Water Elevations




Base from U.S. Geological Survey 7.5 minute topographic series, Malin Quadrangle (1988), and western 2.5 miles of the Bryant Mountain Quadrangle (1988), Klamath County, Oregon.

1 0.5 0 1 Miles

1,000 0 1,000 2,000 3,000 4,000 5,000 6,000 7,000 Feet

1 0.5 0 1 Kilometers

OREGON LAMBERT PROJECTION
Standard parallels 33 and 45 30'
1983 North American Datum

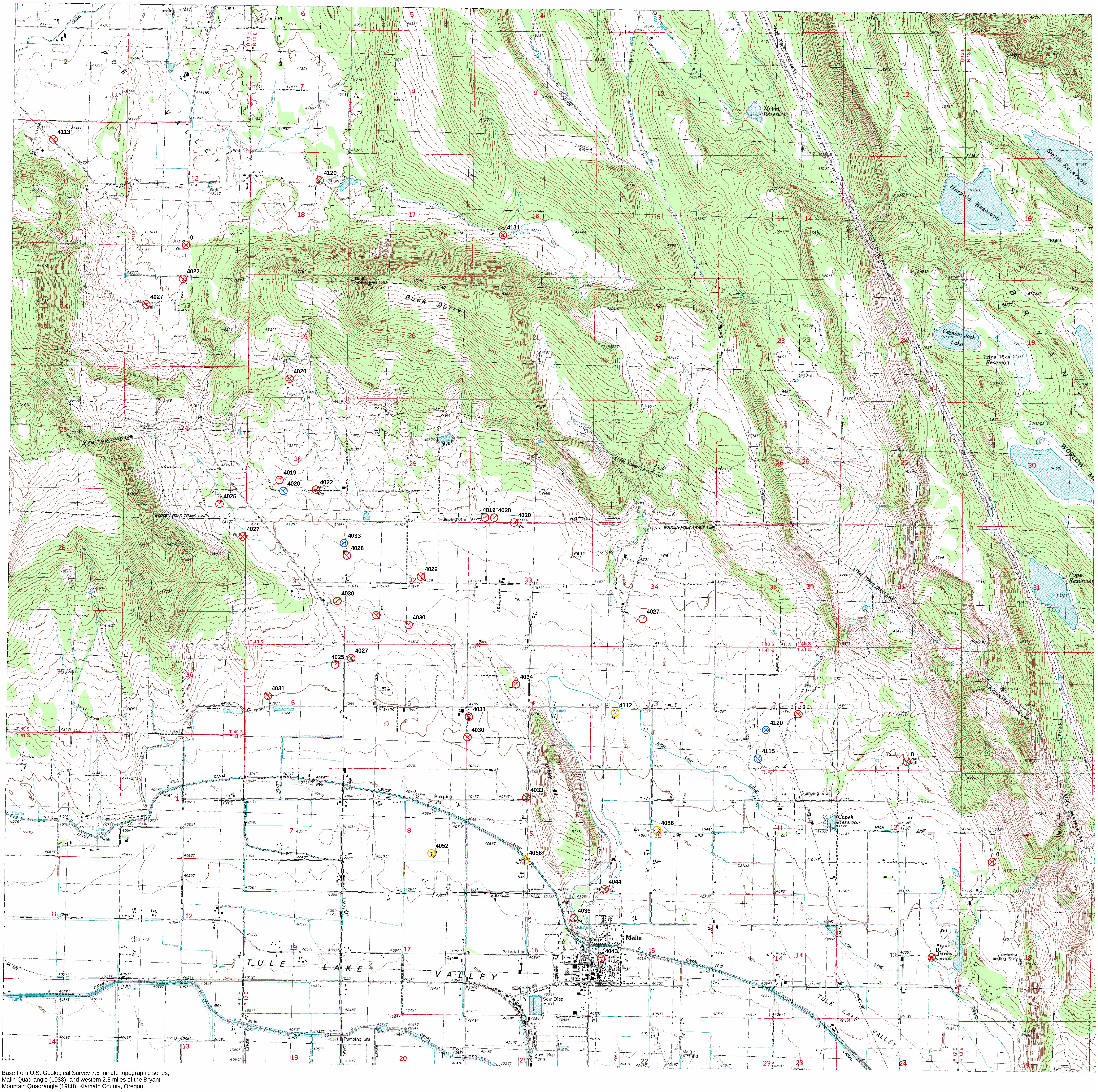
**Legend**

- Well Penetrates Basalt Aquifer
- Well Penetrates Continental Sediment Aquifer
- Well Penetrates Quarternary Sediment Aquifer

Map prepared by J. Eklund

State of Oregon Water Resources Department

# Plate 3 October 1999 Static Water Elevations




Base from U.S. Geological Survey 7.5 minute topographic series, Malin Quadrangle (1988), and western 2.5 miles of the Bryant Mountain Quadrangle (1988), Klamath County, Oregon.

1 0.5 0 1 Miles

1,000 0 1,000 2,000 3,000 4,000 5,000 6,000 7,000 Feet

1 0.5 0 1 Kilometers

OREGON LAMBERT PROJECTION
Standard parallels 33 and 45 30'
1983 North American Datum

N

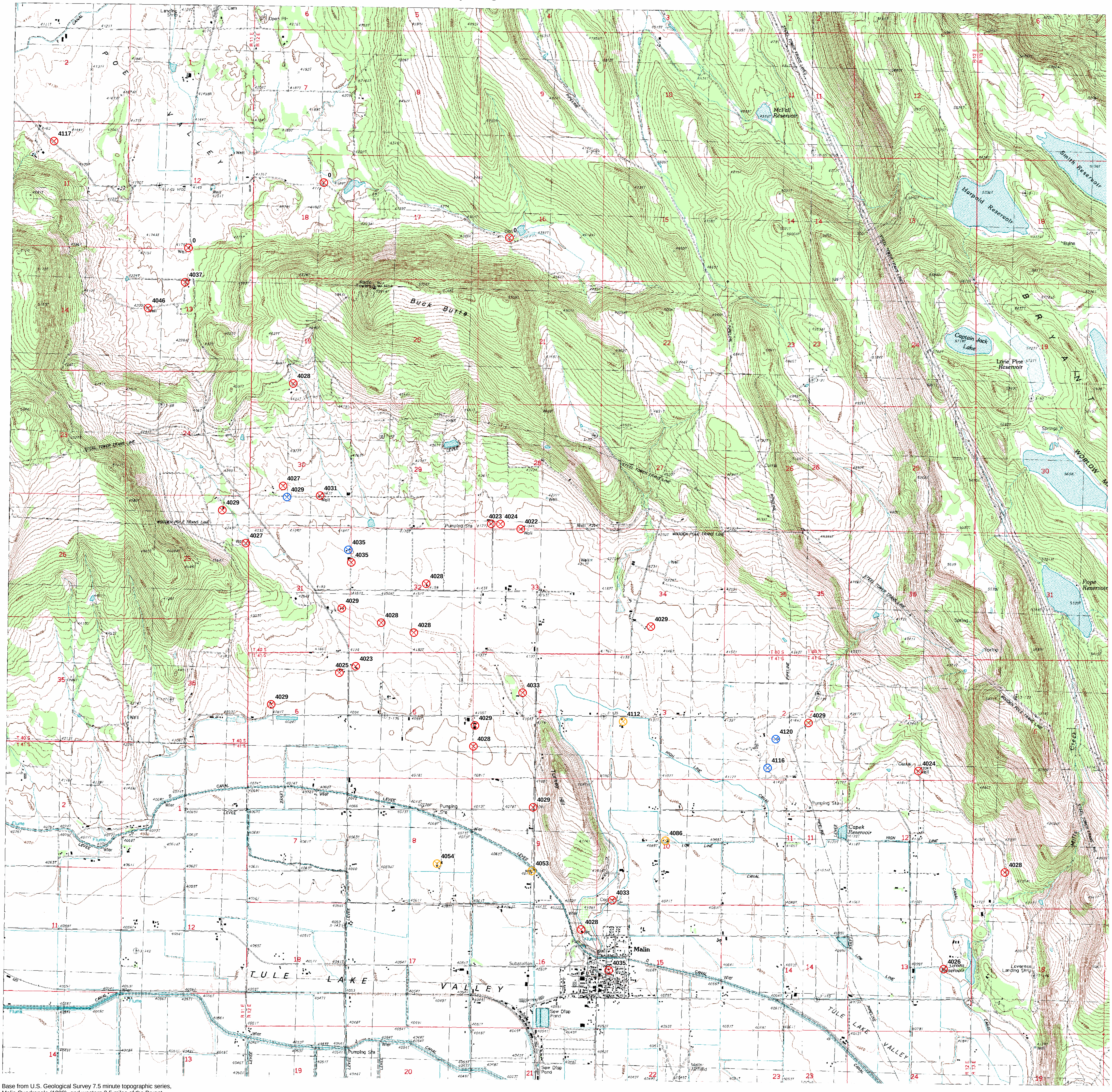
State of Oregon Water Resources Department

**Legend**

- Well Penetrates Basalt Aquifer
- Well Penetrates Continental Sediment Aquifer
- Well Penetrates Quarternary Sediment Aquifer

Map prepared by J. Eklund

# Plate 4 Spring 2000 Static Water Elevations




Base from U.S. Geological Survey 7.5 minute topographic series, Malin Quadrangle (1988), and western 2.5 miles of the Bryant Mountain Quadrangle (1988), Klamath County, Oregon.

1 0.5 0 1 Miles

1,000 0 1,000 2,000 3,000 4,000 5,000 6,000 7,000 Feet

1 0.5 0 1 Kilometers

OREGON LAMBERT PROJECTION
Standard parallels 33 and 45 30'
1983 North American Datum

State of Oregon Water Resources Department

**Legend**

- Well Penetrates Basalt Aquifer
- Well Penetrates Continental Sediment Aquifer
- Well Penetrates Quarternary Sediment Aquifer

Map prepared by J. Eklund