Appendix A.

Detailed Geologic and Hydrogeologic Description

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Geology

Clarno Formation

The Eocene Clarno Formation consists of lavas, mudflows, tuffaceous sediments, ash flows, claystone, siltstone and conglomerate of predominantly andesitic composition (Enlows and Parker, 1972; Noblett, 1981; and Peck, 1964). Individual rock units are laterally discontinuous and stream-reworked material is common. Paleosols and saprolites are dispersed throughout the Clarno Formation (Bestland and Retallack, 1964).

John Day Formation

The Oligocene to late Miocene John Day Formation unconformably overlies the Clarno Formation. The John Day Formation consists predominantly of pervasively altered andesitic ash flows, air-fall tuffs and tuffaceous claystone. The formation also includes rhyolite domes, and andesite and basalt lava flows. The John Day Formation material issued from volcanic vents within its the basin of deposition and volcanoes to west in the ancestral Cascades. The tuffaceous material that comprises the bulk of the formation is altered to clay and zeolite minerals. The uplifting of the area along the axis of the Blue Mountain anticline and subsequent erosion has resulted in occurrence of the John Day Formation around the periphery of the Clarno Formation upland. The John Day Formation occurs just east of Prineville and extends north from Smith Rock to Trout Creek at the north end of the UDB. North of Trout Creek the formation is covered by Grande Ronde basalt of the Columbia River Basalt Group. The John Day Formation extends to the west beneath Quaternary to Miocene lava and ash flows and volcaniclastic deposits in the central portion of the UDB to interfinger with volcanic material of the older Western Cascades (Lite and Gannett, 2002; Sherrod et al, 2004). Recent mapping work done by McClaughry (2007), with the Oregon Department of Geology and Mineral Industries (DOGAMI), has identified a large caldera within the John Day Formation centered near Prineville. The Crooked River caldera is filled with zeolitized pumice-lithic tuff and rhyolite flows that issued from vents that ringed the collapse structure. It is likely that there are other calderas associated with the John Day Formation.

The Miocene Picture Gorge basalt lava flows overlie the John Day Formation in the eastern most portion of the UDB. In the Prineville area the Miocene Prineville basalt lava flows overlie the John Day Formation and are overlain by late Miocene and Pliocene basalts lava flows of the Deschutes Formation. North of the UDB the Prineville basalt lava flows interfinger with the Grande Ronde basalt lava flows of the Columbia River Basalt Group over a wide area extending from the Portland to the John Day River (Hooper, et al, 1993). The thickest section (690 feet) is located south of Prineville near Bowman Dam and it is suspected that the basalt erupted from Basin and Range type extensional fractures in this area (McClaughry, 2007).

Deschutes Formation

The late Miocene to Pliocene Deschutes Formation occurs in the area north of Bend and primarily west of the Deschutes River. To the south, north and northeast of Madras the Deschutes Formation laps onto uplands consisting of the John Day Formation. The Deschutes Formation is a complex assemblage of volcaniclastic sedimentary and volcanic rocks consisting of; mudflows, debris flows, sandstone, conglomerate, basalt, basaltic-andesite and andesite lava flows, ash-flow tuff and air-fall ash (Sherrod, et al, 2004). The formation also includes the Cline Buttes rhyolite dome complex, the rhyodacite lava flows near Steelhead Falls and scattered cinder cones marking vents that were sources for lava flows. The volcaniclastic sediments, ash-flows and lava flows primarily derived from the High Cascades were deposited in a basin aligned along the east flank of the High Cascades through which the ancestral Deschutes River flowed. East of the Deschutes River and south of Bend the Deschutes Formation is buried beneath lava flows of the Newberry Volcano. The basin was defined on the east by uplands consisting of the John Day Formation. The western part of the Deschutes Formation is dominated by andesite and basaltic-andesite lava flows deposited on the flanks of the early High Cascades (Smith, 1991). The more fluid basaltic lavas flowed far into the central basin which was being inundated with coarse grained volcaniclastic sediments and ash-flows. The channel of the ancestral Deschutes River and the shallow braided channels of its tributaries were regularly rapidly filled and buried by debris flows related to eruptive events thus forcing streams to establish new channels and profiles and rework earlier deposits. Lava and ash flows that flowed into the central portion of the basin filled shallow sinuous channels.

In the late Miocene to early Pliocene of the High Cascade Mountains subsided into a graben bounded on the east by the Green Ridge fault and by the Horse Creek fault zone on the west. Thus the central portion of the UDB was robbed of its source of volcaniclastic sediments that had inundated the basin (Sherrod, et al, 2004; Smith, 1991). Today the deeply incised canyons of the Deschutes River, Crooked River and tributaries provide excellent exposures of the Deschutes Formation.

Pliocene Volcanic and Sedimentary Rocks

Pliocene volcanics within UDB include basaltic-andesite lava flows that form the shield volcanoes of Little Squaw Back and Squaw Back Ridge; two low buttes north of Sisters. These two small shield volcanoes cap basalt lava flows of the Deschutes Formation. The basalt of Redmond and Dry River are lava flows in the Redmond area and to the east and southeast of Redmond (Sherrod, et al, 2004). These lavas likely erupted from fissure vents southeast of the basin in the High Lava Plains province. Pleistocene to Pliocene sediments include alluvial fan deposits derived from uplands composed of the John Day Formation and Prineville basalt on the lower flanks Powell Butte and to the north of Prineville (Sherrod, et al, 2004).

Quaternary Volcanics

During the Pleistocene a number of pyroclastic eruptions occurred in an area that has been referred to as the Tumalo volcanic center, an area between Bend and Broken Top mountain (Hill and Taylor, 1990). Ash-flow tuffs and pumice air-fall deposits occur west and north of Bend. These deposits overlie Deschutes Formation material and are overlain by Newberry volcano basalt lava flows and andesite and basaltic-andesite lava flows of the High Cascades. Faults of the Sisters fault zone cut the pyroclastic deposits and the overlying lava flows.

The Quaternary volcanic field of the High Cascades and Newberry shield volcano cover large areas in the western and southwestern portions of the UDB. The High Cascades includes the Mount Bachelor volcanic chain consisting of a chain of basaltic-andesite shield volcanoes extending south from Mount Bachelor to the southwest corner of the UDB. The major High Cascade volcanoes include: Broken Top, The Three Sisters, Mount Washington, Three Fingered Jack and Mount Jefferson. There are many smaller vents. Rock types include; basaltic-andesite lava flows and pyroclastics, basalt lava flows and cinder cones, and dacite, rhyodacite and rhyolite lava flows and domes. The vesicular basalt lava flows of the Newberry volcano cover a large area to the east of Bend, extending from the summit crater to just north of Redmond.

Hydrogeology

The properties of earth materials that influence the movement of groundwater are of primary concern. The porosity and the degree to which pores are connected (permeability) in rocks and unconsolidated material are dependant on many factors. Two examples of factors that determine a rocks initial porosity and permeability are the energy of the depositional environment for sediments and the volatile content of erupted magmas. The initial porosity and permeability may be reduce or increased by weathering, hydrothermal alteration and deformational fracturing.

The basement of the UDB groundwater flow system is largely defined by older less permeable rocks that underlie the Miocene to Quaternary volcanics and volcaniclastic sedimentary rocks of the basin. These include the altered upper Eocene to lower Miocene volcanics and volcaniclastic sedimentary rocks of the John Day Formation that extend from the east to interfinger with Miocene to Pliocene volcanics of the ancestral Cascade Range (Fig. 5-1). The John Day Formation also defines much of the eastern and northern lateral boundaries of the groundwater flow system The John Day Formation has very low permeability due to diagenetic and hydrothermal alteration of the original volcanic material, largely ash, to clay and zeolite minerals. The andesite and basaltic-andesite lava flows and intrusives of the ancestral Cascades are pervasively hydrothermally altered resulting in low permeability. The basement of the flow system beneath the Newberry volcano area is also defined at depth by pervasive hydrothermal alteration that has greatly reduce permeability (Lite and Gannett, 2002).

Quaternary volcanic deposits of the High Cascades and the Newberry Volcano are very permeable. The great majority of groundwater recharge occurs in the very permeable Quaternary deposits of the High Cascades and Newberry volcano. The greatest recharge occurs along the Cascade crest where the annual precipitation can locally exceed 100 inches annually. Precipitation and snowmelt rapidly percolate into the fractured lava flows and tephra deposits. To the south of Bend and west of the Green Ridge and Sisters Fault zones the High Cascade and Newberry volcanic deposits are saturated and discharge to spring-creeks. Fall River and the upper Metolius River are classic examples of this discharge.

The leaky network of unlined irrigation canals to the northwest, north and east of Bend which are cut into High Cascade and Newberry volcanics are an important source of recharge. Approximately 46% of the water diverted, primarily from the Deschutes River, into the canals leaks out of the bottoms of the canals (Gannett, et al, 2001). The great majority of the water leaked from the canals returns as groundwater discharges to the Deschutes River and Crooked River in the northern portion of the UDB. A portion of the water leaked from the canals recharges perched aquifers that supply shallower water wells.

The Deschutes Formation is the principal aquifer and the great majority of groundwater in the UDB flows in a northerly direction through it to discharge to the Deschutes River, Metolius River and the lower Crooked River. At the northern end of the UDB the impermeable rising basement rock of the John Day Formation, against which the Deschutes Formation terminates, forces essentially all of the groundwater in the Deschutes Formation to discharge to streams in the three rivers confluence area, at and upstream of Lake Billy Chinook. The groundwater discharge in the confluence area totals approximately 2,300 cubic feet per second (cfs) (Gannett and Lite, 2004).

A generalized model for the deposition of the Deschutes Formation provides insight into the permeability distribution within the Deschutes Formation. The model was initially proposed by Smith (1986) and is referred to in water resource studies of the UDB published by the USGS (Lite and Gannett, 2002; Gannett and Lite, 2004). The model recognizes three depositional environments to the east of the ancestral High Cascade volcanic arc, the primary source area: an arc-adjacent alluvial plane, the ancestral Deschutes River, and the inactive-basin margin (Fig. 5-3). In the arc-adjacent alluvial plain facies the volume of lava flows decrease and the volume of volcaniclastic sediments increase from west to east. The arc-adjacent alluvial plain facies composes the bulk of the Deschutes Formation and it is chiefly composed of volcaniclastic sediments. Generally the grain size of the sediments and therefore, permeability decreases to the east and north in the basin.

The ancestral Deschutes River facies is characterized by channel deposits of the ancient river. These channel deposits consist of very permeable coarse sandstones and conglomerates, and intra-canyon basalt lava flows. The inactive-basin margin facies consists of generally fine grain less permeable sediments deposited along the eastern margin of the basin by streams draining uplands composed principally of the John Day Formation. The inactive-basin margin facies also includes volcaniclastic sediments and air-fall ash of the of the High Cascade volcanic arc province.

A fourth proximal facies constitutes the bulk of the Deschutes Formation along the western and southern margins of the depositional basin consisting primarily of lava flows, flow breccias and coarser tephra (Lite and Gannett, 2002). This permeable facies is composed of material deposited in near proximity to volcanic vents of the High Cascades and Newberry Volcano.