<u>General Geohydrology in the Original Cascade-Siskiyou National Monument</u>

June, 2017; Prepared by Jad D'Allura, Ph.D.

The geology and some geohydrology within the year 2000 boundaries of the Original Cascade-Siskiyou National Monument (OCSNM) have been investigated with the intent of determining whether there is a difference between the older Western Cascade (**WC**) volcanic rocks and High Cascade (**HC**) volcanic rocks with respect to not only geology but geohydrology. Data collected during the summer of 2016 were combined with data derived from different sources to develop a short time frame understanding of the surface (and indirectly the groundwater) flow. These data and some chemical data of surface water samples collected during the same time period and analyzed by a Southern Oregon University Chemistry student, Kendra Madaras-Kelly, are also included in this report. Place names referred to in this document can be found on the accompanying **geologic map** in PDF format (courtesy of BLM). The outlines of the year 2000 original boundary of the Cascade –Siskiyou National Monument (**CSNM**) are shown in **figure 1** while 7.5' topographic quadrangle names are shown in **figure 2**. All figures are in the Word document **OWRD figures to accompany text**. Site names mentioned in the text or in figures can be found on topographic base maps.

Thirty rocks were selected for X-Ray Fluorescence (XRF) and ICP-MS (Inductively Coupled Plasma Mass Spectrometer) analysis at Washington State University: seven for XRF only and 22 for ICP-MS analysis. Those rocks were selected to determine the sources of some of the dissolved ions in solution as well as to identify the general characteristics of the source rocks. The results occur in an Excel table entitled **OWRD_geochemical_analysis**. The GPS coordinates are in the horizontal datum **NAD27**, <u>NOT</u> **NAD83**. Elements Ni and above (to the right of Ni) are in parts per million. XRF data for the ICP-MS analyses have been taken from earlier non-OWRD sources and are supplied as a courtesy.

Springs and seeps where found and which aren't on the original 7.5' topographic quadrangles have been identified where discovered in the context of field mapping. Those springs and seeps have been located on a topographic base as a PDF file (**Springs1Fixed**). Seasonal bogs, normally developed during the spring on some HC lava flow units, have been mentioned in the text and related to those units which can be identified on the geologic map. Most of the newly identified springs and seeps also are seasonal and normally run dry or become quite flow-restricted during the months of August and September. Seasonal rains in this Mediterranean climate normally begin in mid- to late October. Maximum stream flow normally occurs in mid to late February into March tapering off through the rest of the year until October.

<u>General geologic setting</u>

A geologic map in GIS format has been developed in conjunction with a BLM grant (contact Joel Brumm at jbrumm@blm.gov). That map forms the base for the geohydrologic study. In that map different geologic units have been identified. In very general terms the geohydrology is overlaid on this map and related to those different units including Quaternary mass wasting features such as landslides.

Western Cascade (WC) Volcanic Rocks

WC rocks belong to the uppermost Eocene to Oligocene Colestin, Oligocene Roxy and Wasson Formations, and the lower Miocene Heppsie Formation. The Colestin Formation was not included in the OWRD project. The WC rocks are poorly dated but range from at least 35.9 +/-0.32 Ma at the base of the Colestin Formation to slightly younger than 22.27 +/- 0.36 Ma (million years old) in the Heppsie Formation although a dike that cuts across the rocks has been dated at 20.92 +/- 0.16 Ma. The top of the WC is not exposed as High Cascade (HC) rocks overlie them with a profound unconformity. Unlike HC rocks, the compositional extent is wide-ranging extending from basalt to rhyolite. Rock types include voluminous lava flow- and heterolithologic- and monolithologic-breccia as well as volcanic sandstone and tuffaceous rocks. All are inclined toward the north and northeast due to tilting of the Klamath Mountains on the west and the down-dropping of the Basin and Range geologic province on the east (such as exemplified by north to northwest-trending ridges formed by faulting in the Klamath Lake area). Flows are common and range from rhyolite or dacite to dominant andesite or basaltic andesitic with minor basalt. Unlike the younger HC volcanoes, no constructional WC volcanic landforms are preserved. Due to deep burial, WC rocks have suffered diagenetic to low grade (zeolitic) metamorphic alteration that decreases from the bottom of the WC pile to the top. That alteration inhibits percolation of ground water due to the growth of secondary alteration minerals (such as zeolites, calcite, celadonite, and smectite clays) and the reduction of pore space due to compaction during burial.

Whereas HC rocks in the mapped area form relatively low profile shield volcanoes comprised mainly of fluid basalt and basaltic andesite (see Parker Mountain, **figure 3**), the wide variety of compositions indicate that most WC rocks formed on composite volcanoes which are steeper and comprised of "stickier" (more viscous higher silica content) lava and pyroclastic products.

Plagioclase is the dominant phenocryst followed by two pyroxenes, hypersthene and augite, as well as ubiquitous titanomagnetite or magnetite. In some flows the percentage of phenocrysts is nearly 35%. Hypersthene is commonly the first pyroxene to form then augite. Augite, plagioclase, and opaques continue to crystallize in the groundmass. Early-crystalllizing olivine phenocrysts are common in some flows although most crystals are totally altered to brown, red-brown, or yellow-brown "iddingsite". Vesicles are dominant in most breccias and occur in many lava flows. Tuffaceous rocks are generally associated with breccia or volcanic sandstone. Welded and non-welded lapilli tuff contains accidental rock fragments.

Topographically WC rocks are deeply eroded forming rugged drainages and steep slopes (see **figures 4A** and **4B**). Slopes developed on WC rocks not overlain by HC debris are commonly 10-30° with steeper angles in deeply-incised canyons and where WC rocks are highly lithified. While trees are established on north-facing slopes, breccia and tuff units are sparsely vegetated (favoring dry climate Ponderosa, Juniper, and Rabbit Brush) on south-facing slopes due to longer duration of direct sunlight, the ease of erosion, thinness of soil, and relatively high clay content. Soils are lighter-colored (light brownish gray to pale red) than those developed on HC rocks, have a higher clay content, and range from pebbly to sandy. On north-facing slopes or where porous rocky debris from HC rocks overlies WC rocks, vegetation has a higher probability of becoming established. Due to the high clay content of WC soils (especially those formed on volcanic sandstone and tuff), compactness due to burial, growth of secondary minerals in interstices, and lower content of open fractures, these rocks form steep, highly dissected slopes and contain notably less groundwater than HC rocks. Groundwater in WC is a function of fracturing and lithology with lava flow units retaining more groundwater than volcaniclastic rocks.

As silica content in WC rocks increases concentrations of some harmful elements such as mercury and arsenic increase. Tuffaceous rock which erode more easily than lava flows of the same composition are prone to releasing soluble ions. Of particular concern is the area around the sites southeast of Soda Mountain explored by Peters and Willett (1989) for potential mining development prior to designation of the Monument. Minor red veins in the rocks likely caused by arsenic and mercury sulfides were detected in a past field season. Due to the relative difficulty in accessing this region in the Wilderness Areas of the Monument sampling of stream water wasn't accomplished.

Fractures affect WC rocks forming a prominent northwest-trending fabric in many rock units in most of the Monument (NE-trending faults in the western part) and likely control concomitant or later northwest-trending faults. Some dikes, also affected by diagenesis or low-grade metamorphism, follow the same trend suggesting emplacement during and after formation of the fractures. That relation suggests early formation (during the middle to early Miocene or earlier before the eruption of HC volcanoes) of the area's structural fabric. Aquifers are of the fracture-control type in both HC and WC rocks due to either fracture during cooling and contraction of lava flows or tectonic features such as described above. Groundwater in WC rocks is more likely found where rocks are highly jointed or fractured.

High Cascade Volcanic Rocks

The only parts of the Monument not underlain by rocks of the Western Cascades Volcanic Series are found in its eastern regions. There lavas of the younger and overlying High Cascade volcanoes are exposed. High Cascade lavas range in age from 6.5 +/- 0.2 **Ma** (Late Miocene) on the shield volcano of Grizzly Mountain to 1.2 +/- 0.05 Ma (Quaternary) on Little Chinquapin Mountain. Not all dates obtained by Mertzman (2000; 2008)The lavas create distinct constructional landforms such as Chinquapin, Little Chinquapin, Grizzly, and Parker Mountains (**figure 3**) or gently-sloping lava flows that originated from the east and are either cut by Jenny Creek or form its eastern boundary (see **figure 4B**).

Lava flows are dominant while volcanic breccia or broken lava flows are uncommon. Pyroclastic rocks are absent except within scattered cinder cones. All lava flows are comprised either of porphyritic-aphanitic basalt or basaltic andesite and almost all contain olivine phenocrysts of various sizes. Such olivine may be partially altered to yellow or reddish brown "iddingsite". Plagioclase occurs as elongate minerals in the groundmass of most lava units and forms phenocrysts in some of them. Trachytic texture formed by small flow-aligned plagioclase laths is typical. Augite is a common phase in the groundmass of all lavas and attains phenocryst size in a small number of lava units. Titanomagnetite and magnetite (grouped together as "opaques" due to their inability to transmit light as seen in a petrographic microscope) is ubiquitous in all lavas contributing to notable magnetism of those lavas. Most lava appears to have flowed over relatively subdued terrain eroded atop the older Western Cascade (WC) substrate. Shallow channeling into which lava flowed within and at the base of flows is typical although deep incising occurred through some WC rocks. Rarely exposed are oxidized reddish clay-rich paleosols ("old soils") developed as a result of weathering affecting underlying WC rocks prior to deposition of HC lava flows (**figure 5**).

HC lavas form gentle tree-covered slopes (3-9° with steeper inclinations seen on Parker and Grizzly Mountains and very gentle slopes to the west of those mountains; **figures 3 and 6**) as contrasted to deeply-incised steep slopes underlying Western Cascade volcanic rocks. HC lavas characteristically exhibit large boulders, blocks, slabs, or chips protruding from deep red-orange to brown soil (**figure 7**). Contact between the HC and WC is manifested as steep cliffs from which trains of rock fall, talus, landslide, and slope debris are typical. Such rubble regularly obscures WC rocks beneath them, especially where the canyon walls are particularly steep. Due to columnar and platy jointing cracks (see **figures 8A** and **8B**) formed during cooling and contraction of lava, surface water percolates and collects providing potential water reservoirs throughout the dry Mediterranean summer. That phenomenon and typically gentler slopes result in the high percentage of vegetative cover as contrasted to areas underlain by many WC rocks, especially on south-facing slopes. Due to higher percolation of rainfall and snow melt, drainages are less ramified (more widely spaced) than on WC rocks. Springs or seeps intermittently (although commonly) occur at the contact below HC rocks where they overlie less permeable WC rocks. A number of the low-lying lava flows east of Parker and Grizzly Mountains form bogs that persist through the spring and are locally aquitards (see **figure 9**).

All HC rocks show moderate offset due to northwest-oriented faulting and minor northeast-oriented faulting. Due to fracturing in both HC and WC rocks and water retained in those fractures as contrasted to outside the fractures, vegetation is generally more vigorous, clearly outlining the fracture systems where logging hasn't obliterated such evidence. Although most faults show minor offset, this area must be considered moderately active.

<u>Landslides, colluvium, and alluvium</u>:

Landslides are of both rotational and debris-flow types (**figure 10**). Rotational landslides commonly exhibit step-like appearances where cohesive segments have rotated back along curved step-like failure surfaces while debris flow landslides are non-cohesive. The latter break into unconsolidated blocks and smaller broken fragments embedded haphazardly in a finer matrix. All landslides have steep to muted arcuate head wall scarps and some have subtle side wall scarps. The mid and lower parts of these slope failures contain gentler hummocky ("bumpy") topography and downward-bowed topographic lines. Springs may occur at the head walls, within the body, and at the toes of recent slides forming boggy ground rich in water-loving vegetation with fewer trees. Rotational landslides, such as those on the slopes on the east side of Jenny Creek northeast of the Box D Ranch or east of Fredenburg Spring (**figure 11**) are commonly back-rotated leaving depressions in which water may accumulate. Directions of landslide movement are shown on the geologic map by arrows.

Landslides are common both within HC and WC units but many are localized, as are other slope failures, at the contact between the HC and WC units (**figure 11**). Causes are linked to the relative permeability of the HC units (due to pervasive columnar and platy jointing formed as HC lava flows cooled and contracted; see **figure 8A** and **8B**) and the less permeable WC units (especially where tuffaceous rocks occur) that tend to pond groundwater at their interfaces. These factors lead to an increase in hydrologic pore pressure at the top of the WC.

That combined with the steepness of most HC rock faces where the HC contacts the WC contribute to the relative ease of slope failures.

Landslides, like massive rock avalanches, affect drainages. Such effects include change in direction of stream flow and ponding of sediment due to formation of rock and debris dams. Ponding of sediment contributes to change in vegetation to water-loving plants behind the impounded areas distinct from the normal forested terrain. Although landslides have affected the Jenny Creek drainage in numerous areas, the most obvious place is northeast and southeast of the Box D Ranch (see **figure 12**).

Rock avalanches, talus, debris flows, and colluvium (Qc):

Rock avalanches and talus (scree) form at the interface between HC and WC units, many extending all the way from steep cliffs down slope and to drainage channels (**figure 11**). Other talus slopes form in the WC where resistant lava is undermined by less resistant volcaniclastic rocks. Most rock avalanches haven't been separated from talus and slope debris yet recent rock avalanches are clearly visible on aerial photographs and are seen as areas where vegetation has been either removed or hasn't become established due to rugged boulder terrain. Older rock avalanches show enhanced growth of vegetation.

Slope failures contributing to rock avalanches are common in the WC such as in the steep walls of Jenny Creek and other steep outcrops such as southeast of Rosebud Mountain where very resistant dike rocks crop out but are underlain by weak volcaniclastic rock. The Wasson Formation which is comprised of resistant lava flows and easily-eroded volcaniclastic rock is especially prone to such failures that strew slopes with large boulders often obscuring the character of the underlying rock.

Debris flows include all slope failure features that aren't landslides, talus, or rock avalanches. Colluvium (**figure 6**, debris raveling from edge of cliff; seeps are also in this area but most are covered by blocks) represents rock fall and tumble debris that is older or distinct from rock falls but which has not been worked by water; alluvium is water-worked or stream material. Most debris flow and colluvium occur at the contact between HC and WC rock units but are common within such units.

In some places where the slopes are gentle and tree-covered, ancient slope failures are were likely active during wetter times, such as during the Pleistocene. Water-saturated failures commonly flow farther and form gentler slopes than less water-rich failures. On the gentler slopes as seen on aerial photographs fracture control of the overlain substrate continues to control vigorous vegetation allowing identification of dominant fractures or faults even beneath shallow landslide debris.

Controls on surface water availability and topographic expression of stream drainages:

Availability of water is controlled by lithology (including soils developed from specific rock types) and fractures/faults. As an example of the former see **figure 4A**. The relatively bare slope in the left foreground is underlain by less permeable clay-rich breccias and coarse volcanic sandstone while the strips of vegetation occur in broken and coarser-grained breccia that traps water. The same relation is seen in WC lava flows where cooling joints and fractures impound water allowing deep rooted vegetation to survive. Secondary fractures and faults also can provide linear reservoirs for water that allows vegetation to grow in otherwise low permeable lithologies (see **figure 14**).

Stream drainages in the Monument are partially controlled by fault and fracture patterns, general radial drainage patterns from HC volcanic centers (such as from the crests of Parker, Grizzly, Chinquapin, and Little Chinquapin Mountains) and formed between volcanic flows issued from adjacent High Cascade volcanoes (such as from volcanic centers on either side of Jenny Creek in the Little Chinquapin topographic quadrangle).

The path of Jenny Creek is strongly influenced by faults and fractures, not all of which are shown on the geologic map. The abrupt and straight trend of the creek toward the southeast of the Box D Ranch (**figure 13**) is fault controlled as are some of the jogs in the south-trending portion of that creek toward the Box O Ranch. Near the Oregon-California border the NNE trend of the creek along a fault is offset by later small NW-trending faults. It is strongly suspected that the NNE trend of the creek south of the Pinehurst Inn is affected by a similar fault offset by later NW-trending faults. The same relations are seen in the Jenny Creek drainage east of Little Chinquapin Mountain.

Resistant rock units control the constriction of Jenny Creek forming linear but broad meadows and habitat. Resistant dacite flows and especially an ENE-trending dike south of the Box O ranch (see geologic map and **figure 12**) form an impediment to stream flow that caused Jenny Creek to deposit sediment in the north-trending valley. Another dike ~0.4 km downstream caused another impoundment forming a small meadow north of that dike. Colluvium eroded from the HC rocks that were undercut by erosion of the softer rocks constricted the flow of the creek to its SW trend. Hard dacite intrusive and flow rocks south of Taylor Ranch formed another impediment to stream erosion causing the formation of the NW-trending meadow currently used to graze cattle.

It is postulated that the formation of the broad lowland known as Agate Flat near the Oregon-California border in the SE part of the Soda Mountain quadrangle was also caused by hard bedrock impediments. In this case the impediments were caused by resistant flows of the Torscl, most of which are covered by colluvium, cascaded from the steep cliffs underlying HC lava flows. Jenny Creek Falls south of the border (now in the extended Monument as designated by President Obama in 2017) is formed by a series of nearly vertical dikes (intrusive into the Torscl). As an interesting aside the only place we've found pillow lava and yellow palagonite tuff at the base of the HC (both evidence of flow into water) is at the top of the WC dike complex as lava flowed into water herein speculated as being water of ancestral Jenny Creek. An age date of the HC flow would give us a reliable estimate of the down-cutting rate of Jenny Creek.

The subdued topography of Agate Flat existed at the time the Tpbsm lava was erupted (~3.4 Ma, the age of the Tpbpi). The Tpbpi lava extends across what is now Jenny Creek to pond in the Agate Flat area. If the 3.4 Ma date of the flow is correct then Agate Flat originally existed prior to that age. Subsequently the creek was able to cut through the impediment that existed and established the current channel.

The formation of Agate Flat not only was facilitated by the backing up of Jenny Creek but the relative ease of erosion of the Torsc volcaniclastic rocks. No evidence of a shallow lake was found during this study although here to there are dark carbon-rich soils that formed either in wet areas or meadows. Most of the soils in the area are thin and rubbly.

It isn't known whether Jenny Creek existed prior to eruption of HC volcanism or, if it did exist, where it flowed. In the Little Chinquapin and Parker Mountain quadrangles most of Jenny Creek flows at the western edge of HC lava units. There are exceptions where the creek cut its way through some HC flows likely along faults or fractures as zones of weakness. No known lavas from Grizzly Mountain (~6 to 6.5 Ma) are cut by Jenny Creek although 3.4 Ma rocks (Tpbpi), most of which form the eastern edge of Jenny Creek, were cut by the creek.

Assuming that Jenny Creek established its current course along zones of weakness immediately after the Tpbpi lava cooled, the down-cutting rate of the creek could be ~59'/my (where my=million years) near Agate Flat to ~118'/my about two km SE of the Box D ranch. Estimates from calculations along Jenny Creek north of Pinehurst Inn assumed that the creeks flowed around and between lava flows. Those calculations suggest down-cutting rates ranging from 75'/my to 110'/my along Jenny Creek depending on which High Cascade lava flows are used. These are average rates which undoubtedly were affected by periodic landslides (recent landslides are evident on the geologic map) and by faulting which uplifted or down-dropped areas along the creeks throughout the eruptive history of HC lavas.

Summary of general geomorphic, hydrologic, and vegetation relations to underlying rocks and soils:

Control of where major and minor creeks occur has been addressed above however additional observations are in order. Such observations are differences between HC and WC groundwater storage and location of springs.

The hydrologic character of the Western and High Cascade rocks is remarkably different, especially with respect to groundwater. Due to compaction and the devitrification (change of volcanic glass to clays and other minerals such as zeolites) of tuffaceous rocks and growth of secondary minerals during diagenesis or low grade metamorphism, some lavas and most volcaniclastic materials have low to very low permeability (see **figure 14**). Hence they aren't conducive to percolation and storage of groundwater unless fractured (see Gannett and others, 2010). On the other hand most High Cascade lavas have a much higher permeability. The higher permeability is due to the joints and fractures induced mostly during cooling and contraction of the lava as well as rubbly material at the tops and bottoms of some lava flows that allows for storage and transmission of groundwater. Lavas are the major water producing units in the Klamath Basin (Gannett and others, 2010) and in the HC rocks of the Big Butte Springs area on the western flank of Mt. McLoughlin, a major water supply for the Bear Creek Valley (Medford Water Commission, 1990).

In their 2010 study Gannett and others (2010) used Jenny Creek as measured from the headwaters to its mouth (Klamath River) and Fall Creek (Parker Mountain7.5' quadrangle; headwaters to Jenny Creek in California) to assess surface and groundwater flow. Fall Creek flows dominantly through HC rocks while Jenny Creek flows mostly through WC rocks although tributary streams commonly head in HC especially to the east and north of Jenny Creek. The average flow for Jenny Creek was 9 cubic feet per second while Fall Creek (with a much smaller drainage basin) was 36 ft^3/sec. It must be pointed out that Fall Creek, where measured, contains water not only from Fall Creek (the upper parts of which mostly dries to isolated puddles in the late summer) contains water diverted from Spring Creek along irrigation ditches to Fall Creek Ranch then to join water from Fall Creek below the Ranch. The Spring Creek water where tapped by irrigation ditch to Fall Creek Ranch flows only over HC rocks. Nonetheless, collectively water flow in Fall Creek is typical of flow in areas underlain by HC lava.

The disparity in groundwater/surface water flow (especially during summer months) between HC and WC terrain is a direct function of the lower permeability of WC rocks. Succinctly said, the WC rocks acts as a barrier to regional groundwater flow (Gannett and others, 2010). Low permeability of WC rocks also contributes to more rapid run-off during high rain events assisting in producing the highly ramified drainage pattern in areas underlain by WC rocks. Low permeability of WC rocks is conducive to persistence of “Great Basin” type flora (such as Juniper, Rabbit Brush, Mountain Mahogany, etc.), in the Agate Flat region and especially on south-facing slopes, which retain less moisture during the summer months of southern Oregon’s Mediterranean climate.

The occurrence of springs is directly related to the underlying geology. Mapped and unmapped springs (mapped as new springs in the PDF) can be seen at the contacts of unlike lithologies due to differences in transmissivity of those dissimilar lithologies. Fault or fracture control produces secondary porosity and permeability in otherwise solid rocks such as seen in Shoat Springs issuing from a fault near the junction of two different HC lava flows (**figure 15**). A similar relation is seen in the Oregon Gulch area. Faults also can generate impediments to groundwater flow by producing “fault gouge” (finely pulverized rock that acts like low permeability clay) or by juxtaposing permeable rocks against low permeable rocks that causes groundwater to rise to the surface interface. Fault or fracture springs in the WC normally run dry in late summer.

Steeply-dipping fault or fractures localize springs due to localized intense fracturing along small segments of a given fault or fracture. Numerous examples can be seen on the map (see location of mapped and unmapped topographic springs on the PDF), especially in WC rocks (see areas near Soda Mountain).

Not all lava flows equally transmit or pond groundwater as is clearly seen in the Big Butte Springs watershed that derives its water draining from Mt. McLoughlin (Medford Water Commission, 1990). Some lava flows are aquifers while others are aquicludes. Where groundwater encounters lava flows acting as aquicludes water increases stream flow; the opposite relation occurs along streams where lava flows are more permeable: the streams lose surface water to groundwater flow.

Springs can also occur at the interface below permeable HC rocks and less permeable WC rocks. Springs, but more likely seeps (which are active in the spring but are rare and insipid during late summer), occur along the Keene and Jenny Creek canyons at that contact especially where volcaniclastic rocks occur. Clay weathered from volcaniclastic rocks act as a relatively impermeable membrane that tends to restrict water flow causing water percolating through permeable HC lava to escape at cliff faces. In the Agate Flat region springs on the topographic map of the Soda Mountain quadrangle occur at the contact of the Tpbpi and the clay-rich Torsc unit. That contact is a bit deceptive as alluvium covers an earlier and lower flow. That flow is seen intermittently in drainages and where springs appear. However, because of the thickness of the alluvium exact mapping of that earlier flow is impossible hence has been left off the map. It’s suspected that it underlies the flatter areas in the Agate Flat region.

Bogs and meadows form in areas along Jenny Creek where hard bedrock or landslide impediments cause water to back up. Bogs also appear on top of some low-lying High Cascade lava flows in the Parker Mountain quadrangle east of Jenny Creek. These bogs, developed specifically on Tpbpi (Basalt of Pinehurst Inn) are caused by the lower permeability of Tpbpi and the higher permeability of the overlying Qpbcl (Basalt of County Line). The same relation is seen on top of the low-lying areas of the Tpbfc (Basalt of Fall Creek) which are fed by more permeable lavas of the Tpbpj and the older lavas of Grizzly Mountain to the east. Where the older lavas of Grizzly Mountain overlie the Tpbfc near Leonard Ranch a series of year-round springs are located. Hence not all HC lavas have the same degree of permeability, a relation also seen among the different lava flows of Big Butte Springs (Medford Water Commission, 1990). These boggy areas tend to dry during late summer producing meadows punctuated by blocks of dark very vesicular lava amid grassy areas (**figure 9**). The boggy HC units do transmit water although slowly.

An interesting relation occurs on some creeks such as Lincoln Creek and Camp Creek. Whereas Mount McLoughin lavas provide continuous supplies of water to Big Butte Springs (the major source of drinking water for Medford and other cities in the southern Bear Creek Valley) during the late summer some streams in the Monument go dry in their lower reaches but continue to flow in their upper reaches. That's the reverse relation as is seen in the Big Butte Springs areas and most other streams. There are several possibilities as to why that "reverse" situation occurs however the causes haven't been studied in detail. The causes might be analyzed during the summer of 2017 which will not be part of this report.

Landslides can localize springs such as those unmapped springs at the headwall and toe of the large slump north of the Box D Ranch near the confluence of Keene and Jenny Creeks. Fredenburg Spring north of Jenny Creek occurs in a rotational landslide block. The spring originates in the steeper face of that block in broken HC lava that slipped from the north along a curved fracture surface. South and southeast of the Fredenburg Spring, south of Jenny Creek, numerous small springs and ephemeral ponds in depressions in back of rotated slump blocks can be seen during early spring months.

General relations of hydrogeology to soils:

Soils are generally well-coordinated with basic rock types (see Soil Conservation Service maps, 1993, and descriptions; those descriptions, though very general, are moderately accurate; also see the NRCS Web Soil Survey site: https://websoilsurvey.nrcs.usda.gov/app/). In areas where WC rocks crop out in steep canyons the soils referred to are only those developed on colluvium. Those soils are generally well drained as contrasted to soils underlain by exposures of WC rocks, especially WC rocks containing a high percentage of volcaniclastic material. Soils developed on HC rocks are uniformly described as deep, well drained and are moderately permeable with little danger of water erosion. On steeper slopes of WC rocks, even those covered with colluvium, the soils are poorly drained, show low to moderately slow permeability, and are susceptible to severe water erosion because rain water tends to run off rather than soak into the soil. Where WC rocks crop out most extensively the soils developed on colluvium show moderately slow run-off and moderately slow permeability. High potential for water erosion and slower permeability occurs on steeper slopes.

The shrink-swell potential of soils is directly proportional to the content of clays that swell when wet and shrink when dry and which are particularly well developed as weathered from volcanic rocks. That capacity of the soil contributes to soil instability especially on steep slopes. The shrink-swell potential as reported by the Soil Survey is not only very general but poorly correlated with field observations obtained during this study. Those soils, and many of the WC soils, especially developed on volcaniclastic rocks such as are abundant in the Wasson Formation and volcaniclastic units of the Roxy Formation, have a moderate to high shrink-swell potential. HC soils, in general, exhibit lower shrink-swell potential than WC soils although locally specific rock types and shrink-swell potential varies within the WC. In general the shrink-swell propensity is greater on soils underlain by volcaniclastic rocks (especially tuffaceous rocks) than on soils derived from andesitic or andesitic basalt lava flows. The clay content of WC soils developed on volcaniclastic rocks such as in the drainage on north slopes of Oregon Gulch is always much higher than on WC soils developed on largely volcanic flow rocks such as on Keene Creek Ridge and its northern dip slopes. The clay content significantly reduces permeability to less than 0.6"/hour and in many cases 0.02"/hour. That relation combined with the high shrink/swell capacity of such soils induces gullying during high intensity rainstorms or rapid snow melt runoff as well as contribute to slope instability in steep terrain.

Discharge Data:

Discharge data recovered for this project are derived from stream measurements taken in 2016 (this project), data from Tim Montfort of the BLM (specifically the more continuous measurements taken in 1997), and from Michael Parker, Chair of the Southern Oregon University Biology Department. Only general inferences can be drawn but may serve as a basis for future measurements. Specifically, but not part of this report, would be data collected from an unusually "wet" year (winter of 2016-2017; October through March) as compared to "drier" years. Yearly rainfall data taken from the only continuous monitoring site in the Rogue Valley (Medford airport) is useful but not indicative of overall rainfall in the region as it is located in the driest part of the Valley. Data collected from Parker Mountain just to the east of the southeastern boundary of the original Monument was used to document precipitation during the winter through summer of 1996-1997, a year of early 1997 flooding in southern Oregon. The precipitation amounts were taken from October 1996 through August 1997 (maximum winter through summer precipitation accumulations). Companion rainfall amounts for the same months during 2015 through 2016 (a relatively dry year) were also tabulated to understand stream discharges despite the fact that the data are not nearly as comprehensive as taken during 1996 through 1997 as taken by BLM hydrologist Tim Montfort. Discharge and stream data for some selected streams in the Monument for 2011 as part of a base line study for the Park Service are tabulated in an Excel document **CSNM Stream Discharge_Parker**. The rainfall amounts from the Parker Mountain station appear in the Excel file entitled **PM_Rainfall 9697 1516**. The data are taken from the RAWS stations at Parker Mountain accessible at [WRCC] Western Regional Climate Center, climate summaries online at: http://www.wrcc.dri.edu .

Discharge data obtained from Tim Montfort are mostly continuous but only for 1997 and are sporadic for other years. Hence only the 1997 data was tabulated and analyzed. The BLM locations of the sampled streams and the raw data appear in the Excel file entitled **BLM Site Designations and Locations**. The Excel locations and data for the data collected in the summer of 2016 is entitled **Revised Discharge as of 24AUG16**. A general topographic map with

BLM locations (blue) and 2016 sampling sites (red) as well as the general HC/WC contact for the eastern portion of the Monument appear in a PDF file.

The discharge graph for the BLM's 1997 discharge data is in an Excel file **BLM disch 1997**. No data were collected in September and October which are seasonally months of no to very minor accumulation of rainfall. The expected discharge for that high water year (late winter/early spring floods) follows the expected path of higher flows in winter and spring months and low flow in late summer to early fall. Stream discharge was high in March and May but no data exists for January and some stations in February during which the stream flow was likely much higher.

Stream designations on the **1997 BLM discharge** chart are, from left to right, located based on whether they drain only WC rocks (LINL and MILL), drain both WC and HC (JNYU through BXON), drain mainly HC in upper reaches and WC in lower reaches (CRLL and BVRL) or just HC (JNSX). A useful plan of measurement in future studies to determine the contribution of water to either WC or HC rocks would be to measure discharge where the stream flows only through HC rocks then through WC rocks to determine if there is any loss or gain of water along the stream's trace. Corral Creek or Beaver Creek north of Highway 66 would be reasonable streams to measure to detect such change in WC rocks. Jenny Creek has too many tributaries flowing into it from many sources so that wouldn't be a place to measure potential changes unless done on a very detailed study of all streams flowing into Jenny Creek.

The discharge graph for 2016 data (including only June and August measurements and not including streams that were dry in June) is presented in an Excel file entitled **2016 discharge chart.** Note the general decrease in discharge as summer proceeds *except* for Jadi 1 (Shoat Springs, the headwaters of Spring Creek) which drains only HC rocks. There is an increase in flow likely due to lag time for ground water to make its way through the Tpbjg (Basalt of Juniper Glade) and along the fault and basal contact to the bog-producing HC lavas of Tpbpi (Basalt of Pinehurst Inn). The Tpbpi isn't exposed here as it is covered by colluvium.

Some temperature, conductivity, pH, DO and ORP TDs measurement were taken on a few streams on July 11, 2016 just to test the instrument. Those data appear in a short Excel table: **YSI multiprobe measurements**.

A pilot study for the BLM report looking at **<u>water chemistry</u>** taken from streams in August (low flow time of year where solutes are most likely to obtain the highest concentration) were analyzed using an ICP-OES instrument at Southern Oregon University by an undergraduate Chemistry student, Kendra Madaras-Kelly, under the guidance of Chemistry Professor Steven Petrovic, Ph.D. The results of that report occur in a separate PDF document entitled **Final Results_Kendra**. The methods that were used to process the water samples for analysis on the ICP-OES are in the Word document entitled **Acid Digestion Procedure for ICP Analysis (1)**. A copy of her short PowerPoint presentation to the Friends of the Cascade Siskiyou National Monument Research Symposium is also attached and is entitled **Water Samples(2)**.

Water samples were collected in August 2016 as water flow is lowest during August and subsequently streams carry their highest load of solutes during that time. The analysis of 11 water samples from 10 selected sites (see **figure 16**) utilized the ICP-OES (Inductively Coupled Plasma-Optical Emission) spectrometer was done Southern Oregon University's (SOU) Chemistry Department. The instrument can analyze ppb (parts per billion) of elements dissolved in water samples. The results of the study are presented in ppm (parts per million). A standard was purchased to quantitatively analyze for Pb, As, Cu, Ni, Cr, and Hg. Addition elements, K, Ca, Fe, Na, Mg, and indirectly Si, were semi-quantitatively analyzed using existing standards at SOU. The water samples were prepared using accepted standard procedures.

The process involves vaporizing the sample at temperatures of 10340 F – 13940 F which will emit characteristic spectra for each element. The spectra were detected, compared to the standards, and the amount of element in each sample was recorded. Two examples, one for Pb and another for Ni and Si (the peak for Si which is present in all water samples lies close to that of Ni) are shown in **figure 17**. The green lines represent elements dissolved in the water samples while the red lines represent the standards.

Results of the analyses are represented in **figure 18**. All of the quantitatively analyzed elements (Pb, As, Cu, Ni, Cr, and Hg) lay well below the MCLs (Maximum Contaminant Levels) for drinking water as listed by the EPA. Streams draining the Western Cascade rocks (WC) are WS 9, 10, and 11. Fe is precipitated in all streams accounting for its very low levels in all samples. All show the highest concentrations of Ca but are low in everything else. The only pure HC stream (WS-6) is low in everything but Mg (HC rocks are normally higher in Mg than most WC rock). The remaining results are from streams that drain both HC and WC rocks and are chemically intermediate in solute composition. Solutes in WC and HC streams differ with WC generally higher in dissolved elements than streams flowing through HC rocks. Jenny Creek shows a downstream increase in K, Fe, Na, Mg, and Si (WS-1->4->7) was expected as solute normally increases downstream.

Discharge data shared by Michael Parker (**CSNM Stream Discharge_Parker** Excel table) contains data only for 2011 hence wasn't applicable for making a graph. Nonetheless, it is existing data which might be included in subsequent discharge data in the Monument.

Summary Well Log Data for a portion of the CSNM

The accompanying Excel document entitled **Summary well log data** contains data gleaned from the Oregon Water Resources site in the eastern area of the original Monument:

http://apps.wrd.state.or.us/apps/gw/well_log/Default.aspx

The reason for looking at water well data was to couple, as best as possible, conclusions regarding ground and surface water differences between the older Western Cascade Volcanic Series (WC) and the younger High Cascade (HC) volcanic series. It must be mentioned at the outset that the wells spudded in (drilled into) the HC only penetrated the thin edges of HC lava flows from shield volcanoes. Therefore inferences as to ground water production similar to those for the Big Butte Springs Watershed draining from Mount McLoughlin (Medford Water Commission, 1990) cannot be as comprehensive.

The wells are located in the Township Range Section (TRS) designation and most are situated only as close as the section or, in some cases, refined only to the ¼ section of a ¼ section. Just the eastern portion of the Monument and contiguous areas were sampled. The townships of the Willamette Base and Meridian are, from north to south, T38S, T39S, T40S, and T41S and the companion ranges of R4E, and R3E and R5E where appropriate, as far as the Oregon-California border. Well locations are not equally distributed. The vast majority of wells were spudded on private property, not BLM land. Most were located adjacent to Highway 66 or along the Copco road hence the general applicability of the conclusions below aren't comprehensive yet tentative conclusions regarding ground water may be inferred.

In very general terms the WC rocks are comprised of a wide variety of lava flows and volcaniclastic rocks with compositions ranging from basalt through dacite or andesite. Fresh exposures of volcaniclastic rocks exhibit very compact characteristics of well cemented grains or their interstices filled with secondary minerals, all of which reduces the permeability of these rocks. Lava flows that contain vesicles invariably have those vesicles filled with secondary minerals and a number of them have fractures sealed with secondary minerals (calcite, zeolites, or clays). Water flow, as inferred from exposures in road cuts or cliffs, occurs through secondary fractures in both rock types but most specifically the lava flows where those secondary fractures were likely induced by contraction during initial cooling of those flows. It is quite common to find lava flows separated by brecciated horizons, some resembling scoria. Those horizons are likely referred to as "broken lava" in well logger parlance but some may actually intersect fracture zones. Tuffaceous rocks are compact but weather readily to clays, most of which are likely shrink-swell smectite clays.

High Cascade rocks, except for rare cinder cones, are comprised of lava flows ranging from basalt through basaltic andesite erupted from shield volcanoes or, rarely, fissures. Flows are separated by the usual flow-foot breccia and most flow tops exposed at the earth's surface are comprised of broken fragments or rounded boulders embedded in reddish orange soil. Cooling contraction joints are common. Most of the flows are topped by weathered soil containing boulders with the exception of Tpbpi (Basalt of Pinehurst Inn) and Tpbfc (Basalt of Fall Creek) whose tops are comprised of dark broken vesicular lava which, during the spring months, are characterized by very low gradient grass-rich bogs. The thickness of those lava units varies from less than 60' to 120' (~20m-40m) based on observations at the edges of cliffs bordering Jenny Creek. Lower thicknesses of individual flows in the relatively flat areas west of Parker and Grizzly Mountains are most common. Where more than one HC lava flow exists (such as Tpbjg overlying Tpbpi) the combined thickness is presumed to be greater than thicknesses of any individual lava flow exposed at the rim of Jenny Creek canyon. The tops of many HC flows are vesicular. Most vesicles are free of inclusions but where filled or partially filled contain white easily weathered zeolites.

On the Excel table the *first water* designation indicates when water in the well bore was first detected. *TD* is the total depth of the well. *GPM* assigns the initial Gallons per Minute of the well test. *Static* refers to the static water level of the test. *Rock type* refers to the well logger's designation of their inferred rock encountered during drilling (a general designation at best) and if data was present, how far down the rock type was encountered. Above that rock type was either soil or soil with boulders. *WC/HC* refers to whether I believe the rock type was spudded in Western Cascade (WC) rock or High Cascade (HC) rock. Following the WC or HC designation is the best estimate of the rock unit as it appears on the geologic map.

Many of the water bearing horizons, where the data is good enough to evaluate, occur in "fractured rock". That is true of both WC and HC lava.

Very general inferences can be drawn from the Excel table. Most of the wells spudded into HC rocks penetrate the Tpbpi unit (rarely Qpbcl, the Basalt of County Line, Tpbjg, the Basalt of Juniper Glade, or Qpbc, Basalt of Chinquapin Mountain). Occurrence of the first water detected is from 72'-180' likely within the basalt units while deeper wells likely hit the contact between the HC and WC. That contact, from observations at cliff faces, commonly produces seeps due to the less permeable character of the WC rocks. The wells are normally shallow to moderate (up to 200', a little more for wells that likely penetrate the HC/WC contact). Water yield is moderately low (3-40 GPM averaging around 25 GPM). The lower producing wells are spudded through thinner Tpbpi lava flows (T40S, R4E, S8) and likely penetrated the "tighter" water-producing WC.

Wells spudded in WC rocks dominate in the region bridging Highway 66 between Lincoln and the Pinehurst Inn. They penetrate the breccia and minor lava flow unit Tmhbr (Hyatt Reservoir Breccia unit of the Heppsie Formation). This unit is characterized by a dominance of compacted debris flow breccias, volcanic sandstones, and thin tuffs interspersed with thin dark lava flows and some dikes. Because of lateral discontinuity, stratigraphic continuity within this unit is difficult to demonstrate. In general the wells are deeper than in the HC (100-350', average ~150'), the intersection with the well's first water is variable and the GPM ranges from ~15-40 GPM depending on location. In "claystone" or volcaniclastic material GPM is quite low. The deepness of the wells allows for percolation of water from many fractured horizons that, in themselves, might produce little water. The deepness of the well allows water storage and likely is responsible for the static water levels therein.

The remaining WC is represented by very few wells. Tork (Roxy Formation Keene Creek Ridge unit) is mostly a lava flow unit with deep wells and GPM = 20-30. Torsc (Roxy Scotch Creek volcaniclastic unit) is deep but produces relatively little water. The single well in Towl (lava flows in the Wasson Formation) produces water from a relatively shallow interval while Towt (Wasson tuffaceous rocks) produces less water from a much deeper well. Farther north production from the Tmhsc (Soda Creek unit of the Heppsie Formation) sandstone's deep wells produces a modest amount of water.

The overall conclusion is that ground water can be produced from either the WC or HC where "claystone" and other volcaniclastic rocks are at a minimum. Wells spudded in the WC's Tmhbr unit vary remarkably, likely due to the varying amount of fracture-bearing lava flows and fractured breccia. Wells in the WC are generally deeper which provides a volume for storage of water. Most of the wells of the HC are spudded in the Tpbpi unit likely because of standing water in bogs on this unit combined with the location of most wells in proximity to private land south of Highway 66 and along the Copco Road.

References:

Big Butte Springs Watershed Geohydrologic Report, 1990, Medford Water Commission, Volumes I and II, Note: hard copies are available at the Medford Water Commission; the e-copy referenced herein is incomplete: soda.sou.edu/Data/Library1/020926d1.pdf.

Soil Survey of Jackson County Area, Oregon, 1993, U.S. Department of Agriculture, Soil Conservation Service; 3 books including maps. Also accessible from the NRCS web site: https://websoilsurvey.nrcs.usda.gov/app/

Gannett, Marshall, Kenneth Lite Jr., Jonathon La Marche, Bruce Fisher, and Danial Polette, 2010, Ground-Water Hydrology of the Upper Klamath Basin, Oregon and California: U. S. Geological Survey Scientific Investigations Report 2007-5050, version 1.1, http://pubs.usgs.gov/sir/2007/5050/

Mertzman, S. A., 2000, K-Ar results from the southern Oregon-northern California Cascade Range: Oregon Geology, v. 62, n. 4, p. 99-122.

Mertzman, S. A., S. Crabtree, A. Lunt, and I. Weaver, 2008, Preliminary Geologic Map of the Little Chinquapin Mountain 7.5' Quadrangle, Jackson and Klamath Counties: Oregon, State of Oregon Department of Geology and Mineral Industries Open File Report O-08-04.

Peters, T. and S. Willett, 1989, Mineral Resources of the Soda Mountain Wilderness Study Area, Jackson County, Oregon: US Dept. of the Interior, Bureau of Mines Mineral Land Assessment (MLA) 32-89, 24 pages.