Geology and Geomorphology
Diamond Lake Project Planning Area

In support of the

Diamond Lake Restoration Project

PREPARED BY ________________________________ DATE ____________________
Larry Broeker, Geologist
Umpqua National Forest

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CHARACTERIZATION

Geologic Setting

As portrayed by **Peck and others (1964)**, the Diamond Lake project planning area straddles the crest of the High Cascades *physiographic sub-province* and is underlain by a crudely layered sequence of young lava flows and lesser eruptive breccia that lie atop an older succession of deeply weathered and variably altered Western Cascades volcanic deposits. **Sherrod (1986, 1991)** reports that the initial pulse of High Cascade volcanism in the Diamond lake region began around the onset of the *Quaternary* period some 1.8 million years before present, and is evidenced by outpourings of highly fluid lavas of chiefly *basaltic andesite* composition that emanated from a series of small- to medium-sized *shield* volcanoes. Overlapping lava flows eventually buried the older Western Cascade volcanic strata thereby constructing a broad smooth plateau (elevated plain). During the later part of the *Pleistocene* epoch (past 300,000 years) a more explosive phase of volcanic activity in the southern Oregon Cascades began forming the majestic, steep-sided *stratovolcanoes* that punctuate the landscape today. These volcanic peaks are mostly composed of more viscous *andesite* and *dacite* lavas that contain intervening layers of poorly consolidated volcanic ash and cinders. The glacially sculpted, snow-capped peaks of Mt. Theilsen, Crater Lake caldera (ancestral Mt. Mazama) and Mt. Bailey that encircle Diamond Lake are vestiges to this pulse of explosive volcanism. The climatic eruption of ancestral Mt. Mazama that occurred some 7,500 calendar years before present drastically altered the physical appearance of the landscape. As a consequence of this cataclysmic event, a voluminous plume of air-fall ash blanketed much of the Northwest region and massive *pyroclastic* ash-flows swept down all major drainage systems around ancestral Mt. Mazama (**Bacon, 1983**). Throughout the later part of the Pleistocene epoch (Ice Ages), alpine glaciers scoured the higher elevation terrain of the High Cascades during prolonged cycles of cool wet climatic conditions and deposited eroded materials into surrounding lowland valleys as till and outwash (**Sherrod, 1986**).

Sherrod (1986, 1991) describes the geology of the High Cascades volcanic terrain in west-central Oregon, including Diamond Lake, situated at the extreme south end of his mapping area. As shown in **Figure 1,** isolated exposures of Pleistocene age basaltic andesite (Qoba) crop out along the lake's northern shoreline, mainly east of the Lake Creek outlet (**Plate 1**). Both Pleistocene and *Holocene* age surficial deposits extensively veneer bedrock substrate on the west, east, and south shorelines of Diamond Lake, as well as blanket the lower adjacent hill slopes. The unconsolidated deposits consist of variably compacted glacial *drift* and glacio-fluvial *outwash* (Qgd) (**Plates 2** and **3**), weakly consolidated *pyroclastic ash-flow* (Qaf) (**Plate 4**), and well bedded lacustrine (lake) sand accumulations (Ql) (**Plates 5**). The *pyroclastic* ash-flow deposits followed immediately after the air-fall (tephra) during the cataclysmic eruption of Mt. Mazama. The bedrock and surficial geologic map units are described in greater detail in **Table 1**.

In comparison to the older and deeply eroded western flank of the Cascade Range where volcanism ended millions of years ago, the High Cascades is a geologically youthful landscape that is chiefly characterized by a very low-density drainage network and minimal amount of landscape dissection. The barely incised topography observed throughout the Diamond Lake area reflects the effects of episodic constructional volcanism that has occurred over the last two million years. The relative recentness of volcanism in the Diamond Lake area has not allowed enough time to transgress for significant landscape dissection to take place **(Grant, 2002).**

The hydrology of the Diamond Lake area is strongly influenced by the underlying bedrock substrate as well as the local cover of Mazama air-fall and ash-flow deposits. A pervasive network of fractures (joints) in the young and relatively unaltered High Cascade lava flows allows for the storage of vast volumes of groundwater. Furthermore, these interconnecting fractures provide for the slow and steady passage of groundwater through the rock mass. Snowmelt is the primary source of groundwater recharge into the underlying bedrock aquifer **(Ingebritsen and others, 1994; James and Manga, 2000)**. The upper horizon (top three feet) of the Mazama ash-flow is highly porous with substantial infiltration capacity. Below this zone the Mazama ash-flow appears to be much denser and less permeable with a considerably lower infiltration capacity. This differential in infiltration capacity may be explained by physical processes that include tree root penetration and freeze-thaw mechanisms that loosen the particles in the upper horizon of the ash-flow. The upper horizon of the Mazama ash-flow therefore functions as highly porous sponge that dampens the effects of runoff during sizable storm (rain-on-snow) events **(Sherrod, 1995; Ingebritsen and others, 1994)**. The immense bedrock aquifer underlying the Diamond Lake area thus contributes greatly to the outstanding water quality characteristics of the North Umpqua River, such as sustained summer base flows, coldness, and clarity due to low levels of dissolved solids (**Ingebritsen, and others, 1994; Grant, 2000**).

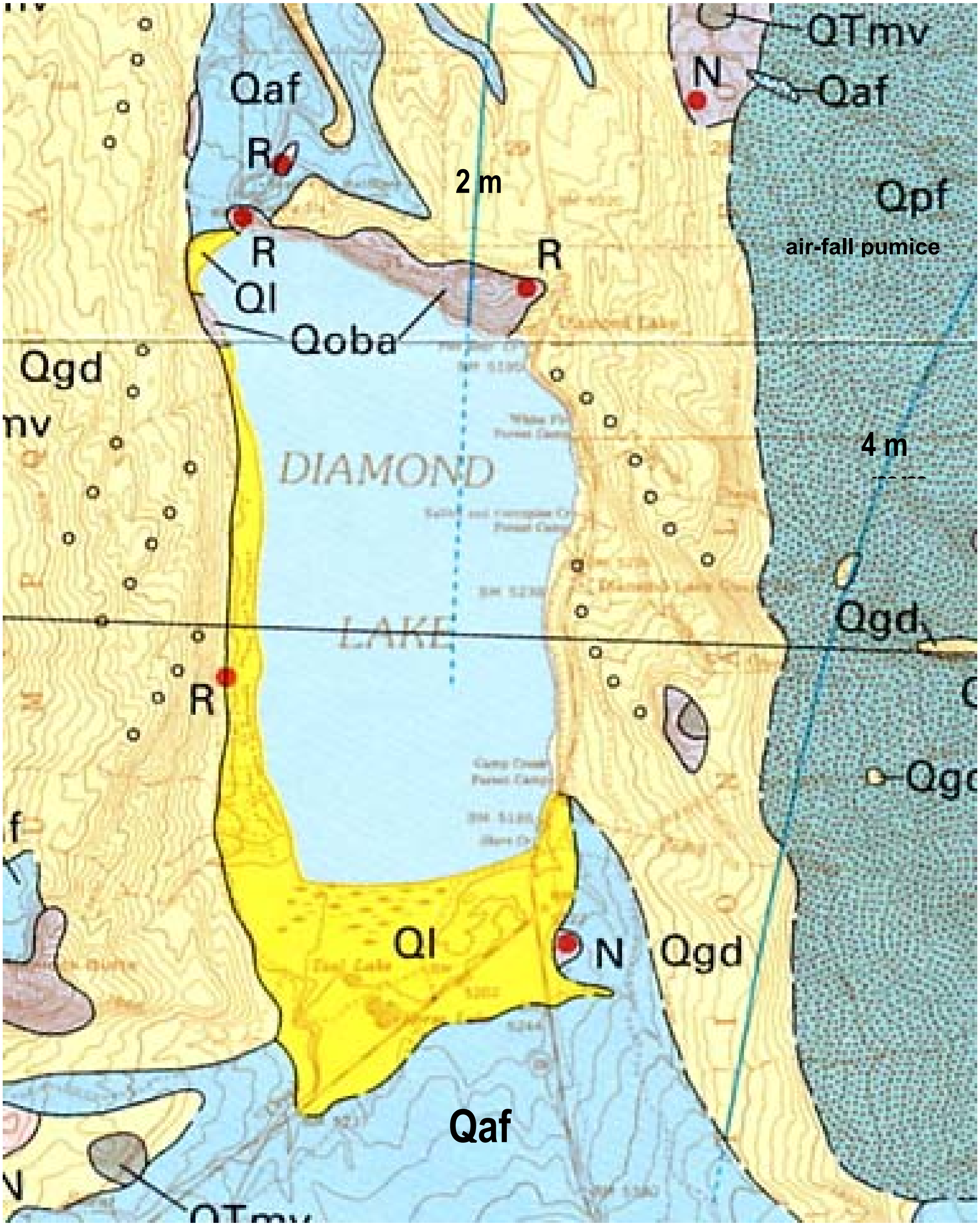

Figure 1. Geologic map of Diamond Lake (from Sherrod, 1991)

Bedrock Units

Qoba **older basaltic andesite** (Pleistocene age) – Lava flows consisting of light- to medium-gray, hard, dense, platy fracturing basaltic andesite and intervening layers and zones of soft (weathered), massive-appearing (non-fractured) reddish-gray flow-breccia and eruptive tuff-breccia that are spatially associated with moderately eroded volcanic vents mostly younger than 0.73 million years in age.

Surficial Deposits

Ql **lacustrine (lake) deposits** (Holocene age) - Unconsolidated deposits of very pale gray, highly porous and permeable, well-bedded, well-sorted, medium- to coarse-grained, pumice-rich sand particles (lapilli) that contains thin layers (zones) of intermixed gravel (rock granules) forming the western and southeastern shoreline of Diamond Lake, as well as the marshy inlet of Silent Creek. The lacustrine deposits stratigraphically overlie the Mazama pumiceous ash-flow (Qaf) and air-fall (Qpf) deposits and are derived from them by fluvial reworking by wave action during a prehistoric high-water level within Diamond Lake.

Qaf **ash-flow deposits** (Holocene age) – Light grayish-white (grayish-pink where oxidized), unsorted, non-welded, unconsolidated to poorly consolidated mixture of pumice fragments (lapilli) embedded in an ash matrix of variable porosity and permeability that erupted from ancestral Mt. Mazama, now the site of the Crater Lake caldera. The Mazama *pyroclastic* ash-flow deposit is the youngest volcanic unit in the Diamond Lake area having been erupted about 6,845 $^{+}/{-}$ 50 ^{14}C-yr. or 7,500 calendar years before present.

Qgd **glacial drift** (Pleistocene age) – Light olive-gray to light brownish-gray, unstratified, poorly sorted mixtures of boulders, cobbles, gravel, sand, silt, and clay (till) that is slightly indurated (partially hardened and compacted) forming ground, lateral, and terminal moraines. Where locally reworked by streams, this unit contains minor outwash deposits consisting of well-laminated (stratified) clay and silt (rock flour) and matrix-supported gravel and cobbles. The glacial drift and outwash have low porosity and poor permeability. The glacial drift grades upslope into gravity-transported talus and gravity-transported detritus (colluvium). Much of the glacial drift exposed in the Diamond Lake area was deposited during the Wisconsin Glaciation that occurred between 75,000 and 12,000 years before present

oooooooo **Morainal crests in glacial drift**

2m **Isopach of Mazama ash-fall deposits** measured in meters (m). Figure 2 provides a broader view of the extent and thickness of Mazama ash-fall deposits in the Diamond Lake-Lemolo Area

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Table 1. Description of geologic units adjacent to Diamond Lake

Sherrod (1991) speculates that Diamond Lake came into existence during the climatic eruption of ancestral Mt. Mazama when a massive pyroclastic ash-flow swept down its flanks burying and extensively altering existing stream networks within surrounding lowland valleys of the Rogue River, North Umpqua River, and Klamath basin **(Figure 2)**. According to this hypothesis, a lobe of the ash-flow choked and blocked a section of stream channel that had once previously flowed through a broad valley now occupied by Diamond Lake. As the newly formed lake began to fill, a bedrock-controlled spillway, now known as Lake Creek outlet, became established several hundred yards to the east of the ancestral stream channel. If this inference is correct, the ancestral (pre-Mazama) stream channel is projected to lie beneath the thickly timbered flat situated in the extreme northwest corner of Diamond Lake directly west of the present day Lake Creek outlet. Mazama ash-flow extensively blankets this locality and wave action along the northwest shoreline of the lake has cut a 9-foot high terrace into this deposit (**Plate 4**).

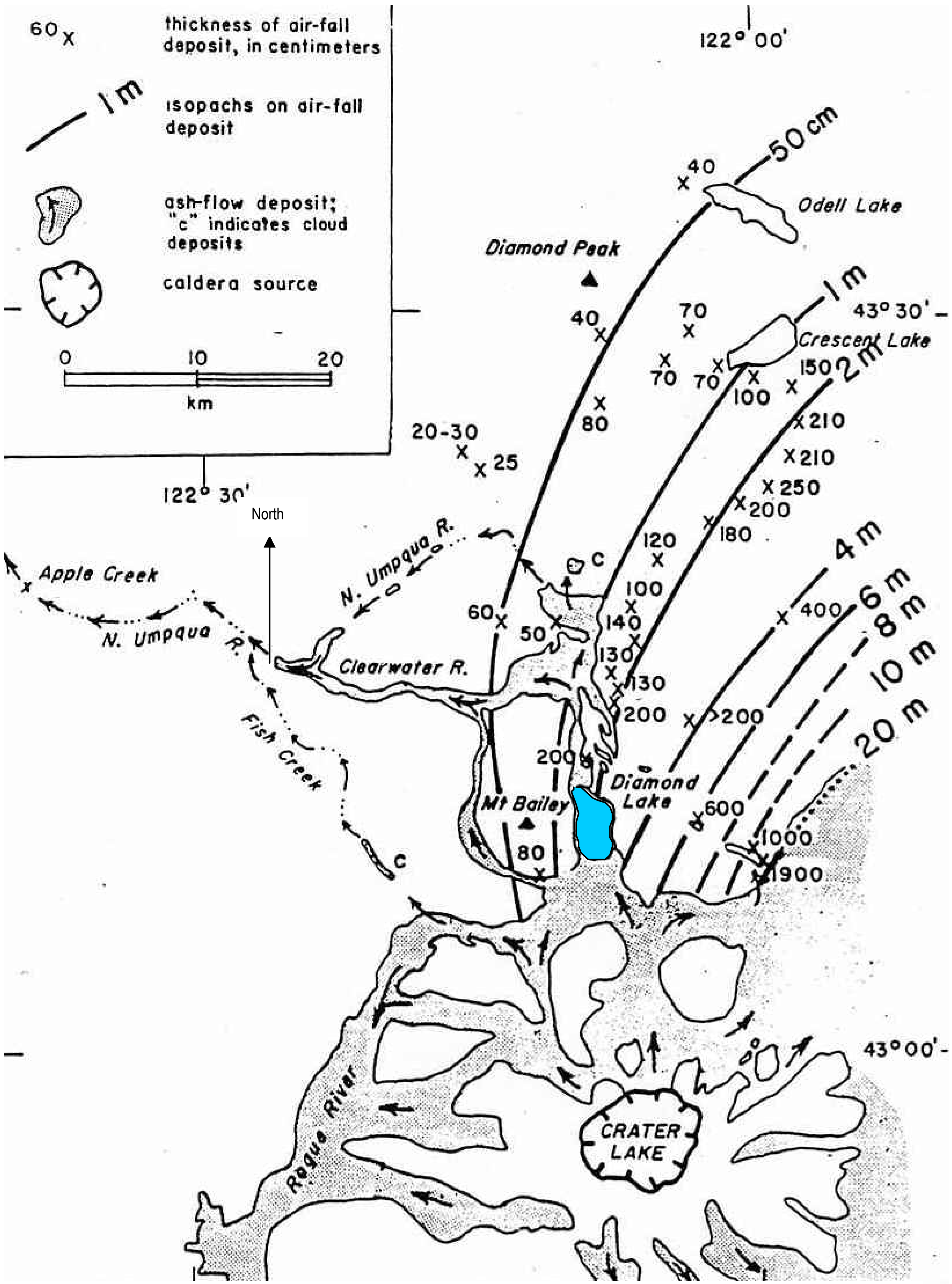

Figure 2. Aerial distribution of Mazama air-fall and ash-flow deposits (from Sherrod, 1986)

AFFECTED ENVIRONMENT

Lake Creek, a perennial fish-bearing stream that extends 11.6 miles from its source at Diamond Lake to its outlet at Lemolo Lake, forms the extended boundary of the Diamond Lake project planning area. Both Alternative 2 (Proposed Action) and Alternative 3 (Put and Take Fishery) in the Diamond Lake environmental impact statement (EIS) involve an 8-foot draw-down of the lake from the current level.

Draw-down of Diamond Lake will entail a sustained period of higher than normal stream flows projected to be at bankfull[1] stage (roughly 110 cfs) for a period estimated to be about six to seven months. The anticipated timeframe for draw-down of Diamond Lake takes into account the likelihood of substantial runoff caused from a severe storm (rain-on-snow) event as well as seasonal snow melt. A sustained flow level at bankfull stage for six to seven months is well outside the range of natural variability (duration) and the potential effects associated with this action are generally perceived as having a potential to affect physical characteristics of Lake Creek. Physical effects to Lake Creek cited in the Wetland Ecology issue statement in Chapter 1 of the Diamond Lake EIS pertain to: (1) accelerating bank erosion, (2) increasing the mobility of in-stream woody debris, and (3) affecting physical changes in the shape, form, and function of the stream channel.

The Aquatic Conservation Strategy (ACS), as outlined under the Northwest Forest Plan, is intended to restore and maintain the ecological health of watersheds and aquatic ecosystems on Federal land (**U.S. Dept. Agriculture, Forest Service; U.S. Dept. Interior, Bureau Land Management, 1994**). The conservation strategy employs several tactics to approach the goal of maintaining the 'natural' disturbance regime. The distribution of land use activities, such as programmable timber harvest or road management activities (including their construction, reconstruction, repair, or improvement) must be designed and implemented in such a manner as to minimize increases in stream peak flows. Headwater riparian areas need to be protected so that when landslides occur and deposit sediment into a stream channel that they also contain coarse wood, a structural element vital for creating riparian habitat further downstream. Lastly, riparian areas along main stem stream channels need protection to limit bank erosion (attributed to fluvial and mass wasting processes), ensure an adequate supply of coarse wood, and provide sufficient shade to maintain properly functioning microhabitat conditions. The following ACS objectives apply to Alternatives 2 and 3 since both alternatives involve draw-down of Diamond Lake and bankful stage flow-levels within Lake Creek to occur for a sustained period of six to seven months.

> No. 3 – Maintain and restore the physical integrity of the aquatic system, including shorelines, banks, and bottom configurations

> No. 5 - Maintain and restore the sediment regime under which aquatic ecosystems evolved. Elements of the sediment regime include the timing, volume, rate, and character of sediment input, storage, and transport.

Woody debris swept down Lake Creek during the draw-down period (or at higher flows) could potentially collect in sufficient quantities at restricted passage points such as narrow culvert inlets so as to impede water flow. Plugging of woody debris at a culvert inlet could conceivably result in the stream channel overtopping the road prism and initiating extensive gully erosion. A Culvert Fish Passage Study conducted on the Umpqua National Forest in 2002 provides detailed descriptions and photographs of four road-stream crossing sites spanning Lake Creek. Review of this data suggests that two of the inventoried road – stream crossing sites that are constructed with pairs of round corrugated metal culverts may possibly be 'at risk' of plugging by woody debris.

Round pipes as opposed to wider spanning squash pipes or open-bottom arches tend to constrict (bottleneck) flow on wider unconfined stream channels and thus may be more prone to trapping mobile woody debris. The two 'at risk' sites include Forest Road 4700-710 located immediately east of the ODOT sand shed (stockpile area) and the Highway 138 stream crossing. Pipes at both sites have high rust lines[2] suggestive that they may be hydraulically undersized at a Q_{100} event (**Hanek and Jones, 1997**). Should these culverts become blocked by woody debris a site failure could potentially result from Lake Creek overtopping road fill.

Prenosil, Haring, and McDermott (1996) conducted a Level II (fisheries condition) stream survey along Lake Creek in 1996 using a modified version of the Hankin and Reeves data collection protocol. Quantitative data was collected. Lake Creek was delineated into eight channel reaches (**Table 2**) based on changes in gross channel morphology using the Rosgen stream channel classification protocol (**Rosgen, 1996**). Findings of the 1996 stream survey indicate that channel reaches 1, 4, 6, 7, and 8 (**Figures 3a-3b-3c**) are characterized by widespread bank erosion (undercutting) mainly along outcurves. Sites of active erosion due to bank undercutting and sloughing at flows higher than bankfull stage were observed within Reaches 1, 2, 4, 5, 6, and 7. Sediment delivery resulting from active mass wasting is said to be fine-textured. Except for the inner gorge section of Lake Creek (Reach 7) that is classified as a "B" channel, the other reaches were classified as "C" or "E" channel types.

Rosgen (1996) recognizes that "C" channel types, generally, are dependent upon the natural stability of their banks, the existing upstream watershed condition, and the flow and sediment regime. Likewise "E" channel types are said to be sensitive to management-related and natural disturbance and can be rapidly adjusted and converted to other stream types in relatively short time periods. According to Rosgen's classification, both "C" and "E" channel types lack resistant armoring from bedrock or abundant large size alluvial materials (cobbles and boulders) and therefore must rely upon ample amounts of large in-stream wood to provide and maintain the stability of their banks.

None of the stream surveys or site investigations conducted within Lake Creek support a conclusion that Lake Creek (in its entirety) is in a degraded condition or outside its range of natural variability with respect to sediment transport, available supply of large wood, or channel shape, form and function. The apparent stability of Lake Creek is due, in part, to the abundance of large wood and a low energy stream flow regime that rises and falls gradually in response to both snowmelt and rainfall events – the later factor being strongly influenced by hydrologic conditions associated with High Cascades geology.

Stream Channel Reach	**Reach Length** (miles)	**Gradient** (%)	**Large Woody Debris** (per mile)	**Width to Depth** (ratio)	**Entrenchment Ratio**	**Sinuosity**	**Substrate** (dominant)	**Rosgen Channel Type**
1	1.79	2	24	7.5	5.2	1.1	gravel	E4b
2	1.25	2	21	13.9	3.7	1.3	gravel	C4b
3	0.35	1	23	9.2	>2.2	est. 1.4	gravel	E4
4	2.72	2	40	14.7	2.4	1.2	cobble	C3
5	2.31	1	62	13.7	3.1	1.4	gravel	C4
6	0.63	4	147	14.1	4.3	1.2	cobble	C3b
7	1.25	3	59	22.1	1.4	1.2	cobble	B3
8	1.29	2	33	12.9	2.6	1.1	sand	C5

Table 2. Lake Creek stream channel characteristics by reach

Since the cataclysmic eruption of ancestral Mt. Mazama some 7,500 years ago Lake Creek has carved through a 40-meter thick layer of highly erodible Mazama ash-flow exposing the underlying glacial deposits that have been, in places, reworked by stream processes. Between Elbow Butte and Highway 138 Lake Creek is characterized as a broad alluvial valley floor bounded by a series of stepped-terraces. Lower-level terraces situated adjacent to the floodplain on the broad valley floor are developed in fluvially reworked glacial deposits, whereas a distinctive mid-level terrace and laterally extensive higher-level plain representing the original depositional surface of the ash-flow deposit, known as Pumice Flat, are formed entirely of weakly consolidated ash and pumice fragments. The ash-flow deposit on the mid-level terrace has been locally reworked by ancestral streams forming horizontal stratified layers of sand.

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[1] Bankfull stage refers to stream flow that just fills the channel to the top of its banks and at a point where water just begins to flow onto a floodplain. Due to their relative frequency (return interval) of roughly 3 events per two-year period, bankfull flows do most of the work in building channels and floodplains.

[2] A high rust line is defined by the condition when the height of the water column (H_w) entering a culvert inlet during periods of rust line flow (average of about 10% of a 100-year [Q_{100}] peak flow event based on both regression of localized stream staff gage data and Q_{100} flows predicted by the Campbell method) is greater than one-quarter the diameter of the pipe, and expressed by the equation (Hw/D>0.25)

Lake Creek flows entirely through glacial deposits that transition from poorly sorted boulder-rich glacial drift with frequent ledges of bedrock nearer to Diamond Lake to finer-textured cobble-gravel-rich glacio-fluvial outwash deposit beginning at a point just south of Highway 138. From Highway 138 to Lemolo Lake, Lake Creek meanders through a wide alluvial valley floor that is punctuated with extensive meadows. Floodplains are generally wider and channel banks are less confined between Lomolo Lake and Highway 138. Between Highway 138 and Diamond Lake floodplains generally narrow and channel banks become more restrictive.

A 1.25-mile long segment of Lake Creek beginning at a point roughly one mile below the Lake Creek outlet is highly entrenched into the surrounding gently sloping terrain and is characterized by a narrow floodplain, confining valley walls, and steeper channel gradient making it distinctive from all the other reaches of Lake Creek. Geologic substrate in this area consists of glacial deposits that are, in part, locally veneered by Mazama ash-flow. These unconsolidated (surficial) deposits appear to be underlain by a sequence of northwest-trending and gently eastward dipping High Cascade lava flows that locally protrude through the bed and banks of the stream channel as bedrock ribs and ledges. This interpretation is supported by a pronounced northwest-trending grain in the topography and corresponding alignment in sections of Lake Creek from Diamond Lake to Highway 138 (**Figure 3b**). The inner gorge section of Lake Creek has been slowly down cutting through a broad north-northwest trending ridge formed of highly resistant lavas. This ridge is interpreted to exert a strong structural control that has influenced geomorphic development of Lake Creek. Furthermore, winnowing of the glacial deposits over geologic time has left a residuum of large erratic boulders (drift) that provide armoring of channel banks.

Lake Creek is currently eroding the toe of the mid-level terrace at three closely spaced sites situated about one-half mile distance north of the Pit Lake No. 2 borrow source. Two of the three sites are landslides, the third site is an incipient mass wasting feature (**Figure 3a, Plate 6**). All three sites occur along outcurve reaches. Fine sediment (sand) is being delivered into Lake Creek during low base level flow conditions at both landslide sites. The larger landslide feature is depicted in **Plate 7**.

A total of eight streamside slope failures (landslides) were identified from examination of the 1997 1:4,000-scale color aerial photos that span the length of Lake Creek. Foot traverses made by Steve Hofford and myself affirmed the existence of four photo-interpreted landslide features located within Reaches 1 and 2. Due to time constraints no attempt was made to visit sites within Reaches 6 or 7 to confirm the existence of the other four photo-interpreted mass wasting features.

The largest landslide feature observed in the field occurs along a section of Reach 2 where Lake Creek encroaches into and undermines the toe of a steep west-facing slope (mid-level terrace) formed of poorly consolidated Mazama ash-flow (**Plates 6, 7**). Based upon its approximate lateral and vertical extent, this landslide feature is estimated to have delivered roughly 2,000 cubic yards of pumice-rich sand into the stream channel over an undetermined period of time. Slope failure is interpreted as being incremental (not a single failure) that likely resulted from many peak flow storm events occurring over the past couple centuries.

A brief description of all eight verified and unverified landslide features is provided in **Table 3**. Neither the 1946 (1:20,000-scale) B&W or 1957 (1:12,000-scale) B&W aerial photos provide coverage of Lake Creek and thus cannot be used to bracket timeframes for landsliding events prior to the 1954 draw down of Diamond Lake or discern the effects from increased stream levels attributed to sustained flows from that draw down event. Three of the eight identified landslide features can be expected to deliver some sediment flux into the channel during bankfull stage flow. The volume of deliverable sediment attributed to further activity of these landslides cannot be quantified.

The 1954 draw-down of Diamond Lake is briefly cited in a 1963 U.S. Geological Survey Water-Supply publication. This publication cites the release of about 20,000 acre-feet[3] of water or 29% of the volume of Diamond Lake from July 15 through September 21 (a period of 69 days) for the purpose of killing undesirable fish (**U.S. Geological Survey, 1963**). Stream flow in Lake Creek during the time of the 1954 draw-down is not recorded however a mean daily flow of approximately 180 cfs is calculated based upon this information, as well as other measurements regarding both surface and groundwater inflow into Diamond Lake (**U.S. Forest Service, 1998**). It is very likely that stream flows in Lake Creek were considerably higher than bankfull stage during the initial period (first couple weeks) of draw down, then began to slowly decline to base level flow conditions when the target depth of draw down in Diamond Lake was attained. It is likely that initial flows may have reached 250 cfs. By comparison, an instantaneous peak flow of 180 cfs within Lake Creek is roughly comparable to a peak flow (flood) event having a six-year return (recurrence) interval, however a peak flow event lasting 69 days has a recurrence interval of less than 1 percent - an event that occurs less frequently than once in a hundred years.

EFFECTS DETERMINATION

Environmental consequences associated with alternatives developed in the Diamond Lake EIS include direct, indirect, and cumulative effects. Direct effects are those that occur at the same time and place as that of the triggering action. Indirect effects are those that occur at a later time or at a distance from the triggering action. Cumulative effects include those stemming from past, present and reasonably foreseeable future actions.

The Wetland Ecology issue cited in chapter 1 of the Diamond Lake EIS addresses the potential for triggering widespread changes to the physical character of Lake Creek resulting from intensified erosion (sedimentation) and extensive movement of woody debris during prolonged bankfull stage flow conditions. Preferred sites of in-stream (fluvial) and mass wasting (landslides) erosion occur along stream channel out curves where bank undercutting is prevalent. Sediment delivery into Lake Creek from erosional processes is anticipated to be mostly fine-textured. The most significant source of large volume sediment flux would come from hill slope failures, including bank sloughs and larger landslides triggered from high stream flow undermining steep confining side slopes. A large-volume delivery of sediment (e.g., > 1,000 cubic yards) into Lake Creek resulting from a landslide could conceivably cause significant localized changes to stream channel shape, form, and function depending on its relative sensitivity (channel type).

Alternative No. 2 (Proposed Action) and Alternative No. 3 (Put and Take Fishery) comprise the only action alternatives in the EIS that entail a draw-down of Diamond Lake. There is no difference in the timing, volume, or duration of daily mean flows that would pass down Lake Creek with implementation of either of these alternatives. As a consequence, the direct, indirect, and cumulative effects associated with these alternatives are the same. Alternative 1 (No Action) and Alternative 5 (Mechanical/Biological) do not involve draw-down of Diamond Lake and therefore seasonal flows would remain within their range of natural variability.

Direct Effects

The direct effects associated with sustained bankfull stage flows in Lake Creek during the draw-down period is likely to result in the delivery of relatively small volumes of fine-textured sediment flux into Lake Creek due to bank undercutting. Much of the fine sediment flux will come from three existing landslide sites located within Reaches 2 and 7 as summarized in **Table 3**. Bankfull stage flow is not anticipated to undercut the banks of the other five recognized in-stream bank failures (landslides) or trigger new slope mass-movements in localities where the stream channel presently impinges on adjacent steep valley walls. The small volume of sediment flux predicted to be delivered into Lake Creek during sustained bankful stage flow is not considered to be of sufficient volume to cause widespread adjustments to stream channel shape, form, and function. Bankful stage flows within Lake Creek lack the energy to transport significant amounts of large woody debris a considerable distance. Woody debris is more likely to be transported short distances and reorganized into numerous debris dams. Smaller size woody debris may possibly become mobilized and accumulate in existing debris dams or at other points of constriction along Lake Creek such as culvert inlets.

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[3] An acre-foot is equivalent to a volume of water one-foot in depth over an acre of land.

Site No.	Aerial Photo ID	Description of Mass Wasting Features
1	9705-287	Mass wasting feature is located in Reach 1 about 100 hundred feet south of the 3401-440 stream crossing on east bank of Lake Creek (**Fig. 3a**). A verified small landslide (~50 feet in width along base) formed on the outside curve of an overflow side channel. There is a very low probability that stream flows at bankfull flow stage would further undermine the base of the hill slope resulting in sediment delivery. Feature developed from stream channel undermining bank at flows greater than bankfull stage.
2	9705-287	Mass wasting feature is located in Reach 1 about 250 hundred feet south of the 3401-440 stream crossing on east bank of Lake Creek (**Fig. 3a**). A verified small landslide (~40 feet in width along base, ~75 feet in width across crown, and 40 feet in height) formed on the outside curve of an overflow side channel. There is a very low probability that stream flows at bankfull flow stage would further undermine the base of the hill slope resulting in sediment delivery. Feature developed from stream channel undermining bank at flows greater than bankfull stage.
3	9705-273	Mass wasting feature is located in Reach 2 roughly 700 feet north of Thielsen Creek confluence on the east bank of Lake Creek (**Fig. 3a**). A verified small landslide (~20 feet in length along base) formed on the outside curve of the stream channel. **There is a very high probability that sustained stream flows at bankfull stage could further undermine the base of the hill slope resulting in limited sediment delivery. Feature is delivering minor amounts of sediment at low base flow.**
4	9705-273	Mass wasting feature is located in Reach 2 roughly 500 feet north of Thielsen Creek confluence on the east bank of Lake Creek (**Fig. 3a**). A verified large landslide (~100 feet in width along base) formed on the outside curve of the stream channel. Feature extends ~80 feet (slope) distance from the stream channel to the top of a mid-level terrace. **There is a very high probability that sustained stream flows at bankfull stage would further undermine the base of the hill slope causing appreciable amounts sediment delivery. Feature is actively raveling and delivering sediment at low base flows.**
5	9709-447	Mass wasting feature is located in Reach 6 about 600-800 feet below the gorge on the west bank of Lake Creek opposite the unnamed tributary that drains from the Diamond Lake sewage disposal ponds and immediately below the gorge (**Fig. 3b**). An unverified very large historic landslide (~400 feet in width along base) formed on the outside curve of an abandoned overflow side channel abutting a very steep side slope. There is a very low probability that sustained stream flows at bankfull stage would further undermine the base of the hill slope delivering sediment.
6	9705-239	Mass wasting feature is located in Reach 7 on the west bank of Lake Creek near the end of the gorge section (**Fig. 3b**). An unverified small landslide (~40 feet in width along base) formed on the outside curve of the main channel that abuts a very steep side slope. **There is a high probability that sustained stream flows at bankfull stage would further undermine the base of the hill slope delivering sediment.**
7	9705-238	Mass wasting feature is located in Reach 7 on the west bank of Lake Creek near the middle section of the gorge section (**Fig. 3b**). An unverified small landslide (~40 feet in width at crown) formed on the very steep side slope. There is a very low probability that sustained stream flows at bankfull stage would further undermine the base of the hill slope resulting in sediment delivery.
8	9705-238	Mass wasting feature is located in Reach 7 on the west bank of Lake Creek near the middle section of the gorge section (**Fig. 3b**). An unverified small landslide (~60 feet in width at crown) formed on the very steep side slope (inner gorge). There is a very low probability that sustained stream flows at bankfull stage would further undermine the base of the hill slope resulting in sediment delivery.

Table 3. Description of photo-interpreted landslide features by reach

The 1996 Level II stream survey revealed that frequencies of large woody material are currently with an expected range of normalcy in high-energy Reaches 6 through 8 that are prone to channel scour and woody material transport. Forest resource specialists involved in preparation of the 1998 Diamond Lake – Lemolo Lake watershed analysis did not observe compelling evidence in the field of widespread slope failures (landslides) or channel adjustments within Lake Creek as would be assumed for "C" and "E" channel types in the aftermath of the 1954 draw-down of Diamond Lake when daily mean flow (~180 cfs) for a 69-day period greatly exceeded those of bankfull stage (~110 cfs). Stream flows in Lake Creek may have approached 250 cfs during the first two weeks of draw down. Antidotal comments made by Frank Moor, longtime resident along the North Umpqua River to Brady Dodd, former Hydrologist on the Diamond Lake Ranger District, indicated that Lake Creek appeared to be functioning properly with respect to its flow and sediment transport parameters, and that the stream channel did not display adverse impacts following the 1954 draw-down event (**U.S. Forest Service, 1998**).

Indirect Effects

No indirect effects are anticipated following the draw-down period of Diamond Lake as a consequence of sustained bankfull stage flows.

Cumulative Effects

Past management activities that had potential to influence the sediment regime and stream channel morphology of Lake Creek generally correspond to a period of road construction and logging activities that took place within the Lake Creek watershed beginning in the early 1950's. The initial objectives for road building in the Diamond Lake – Lemolo Lake watershed involved relocation of a segment of Highway 138 up the North Umpqua Canyon to provide a direct route between Copeland Creek and Diamond Lake, development of the North Umpqua Hydroelectric Project (Lemolo 1 Phase), and providing access in support of programmable timber harvest on the Diamond Lake Ranger District. There are a total of 41.64 miles of roads within the Lake Creek watershed. Road density within the Lake Creek watershed is 1.13 miles per square mile; however most of the roads are concentrated along a narrow corridor that extends between Diamond Lake and Lemolo Lake.

Some 949 acres of regenerative timber harvest[4] has taken place within the Lake Creek watershed with most of the harvest being concentrated along a narrow corridor that extends between Diamond Lake and Lemolo Lake. Only 4.0 percent of the total area of the Lake Creek watershed has been impacted by regenerative timber harvest. Most of regenerative sale units are situated on gently sloping to flat terrain that abuts the lower and middle reaches of Lake Creek north of the Mt. Bailey Inventoried Roadless Area, and along the lower and middle reaches of Thielsen Creek (**Figure 4**). Little sediment flux attributable to logging activities or roading within the Lake Creek watershed is thought to have entered Lake Creek due to the gently sloping to flat topography, very low drainage density, and highly porous and permeable soils. The limited amount of regenerative timber harvest that has taken place within areas proximal to Lake Creek (including riparian reserves) is considered to have negligible effect on the volume and timing of peak flows within Lake Creek due to lack of a well developed drainage network.

Nearly all of Lake Creek extending between Diamond Lake and Hwy. 138 is situated within a part of the Mt. Bailey Inventoried Roadless Area that has a management direction allowing road construction or reconstruction (**U.S. Forest Service, 1990**). The northern sector of the Mt. Bailey Inventoried Roadless Area remains relatively intact from the effects of land management activities of roading and timber harvest. Due to fairly low road densities and limited acreage where regenerative timber harvest has taken place, riparian habitat within the upper reaches of Lake Creek does not appear to have been severely degraded. Lake Creek contains an available supply of large woody material that falls within the range of natural variability (**Table 2**). Large wood functions to dissipate stream flow energy and turbulence, store sediment bed load, and maintain channel complexity.

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[4] Regenerative methods of timber harvest are broadly defined as harvest prescriptions where the vast majority of trees are cut and a few widely scattered trees are left standing (seed trees) for natural regeneration.

Other past management activities in the Lake Creek watershed that contribute to cumulative effects include the 69-day draw-down period of Diamond Lake in 1954 for improving water quality and fisheries habitat. The rate of water flow released down Lake Creek during the draw-down event, as averaged for the 69 day period, is roughly equivalent to a 100-year event

There are three Forest designated material sources[5] situated in close proximity to Lake Creek. In 1964, Highway 138 was paved in the Diamond Lake area and crushed rock materials used in formulation of the asphalt mix were excavated from the Pit Lake No. 1 borrow source #311201. The pit Lake No. 2 borrow source #311202 was subsequently excavated in 1990 for use as rock materials when Highway 138 in the Diamond Lake area received an asphalt overlay. Both the Pit Lake Nos. 1 and 2 borrow sources are currently filled with water from groundwater recharge and their water levels are said to fluctuate from 5 to 25 feet below the level of Lake Creek (**Jones, 1990**). The Sheep Creek material source #321301 located at the end of the 4792-100 road was initially developed in 1975 for Federal Highway Administration (FHWA) Diamond Lake By-pass construction project along Hwy. 138.

At present there is no surface connectivity between Lake Creek and either of the water-filled material sources, Pit Lake Nos. 1 and 2 borrow pits. A concern exists in that natural channel movements and migration of Lake Creek have been slowly encroaching towards the earthen berm that forms the eastern limit of Pit Lake No. 1. Sustained bankfull flow conditions may possibly breach the dike and flow into Pit Lake No. 1 borrow source.

Reasonably foreseeable actions (natural disturbance patterns) that may cause impact to Lake Creek are rain-on-snow storms that trigger flood events. Stream flows at flood stage have a much greater potential for triggering streamside slope failures and causing widespread channel adjustments than are bankfull stage conditions. Flood events are not predictable and when they do occur they are within the range of natural variability.

RECOMMENDATIONS

(1) Conduct periodic monitoring of the 4700-710 and Highway 138 stream crossings during the draw down period with frequent monitoring taking place during winter storms (rain-on-snow events). An emergency plan should be developed for having the necessary equipment readily available to remove woody debris from culvert inlets in the event blockage occurs.

(2) Conduct monitoring at landslide sites Nos. 3, 4, and 6 where bankfull flow conditions during draw down are likely to result in sediment delivery from slope mass failure. Sites surveys can be conducted at these three sites prior to and immediately following draw down to determine the approximate volume of sediment delivery into Lake Creek, if mass wasting were to take place.

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[5] A material source is an area established by the Forest under the authority of an approved Site Development Plan for the entry, removal, and use of common-variety mineral materials (rock resources) for Forest projects, including the sale of rock materials to the general public, Federal, State, and County agencies via free use or mineral-material permits, where and when feasible.

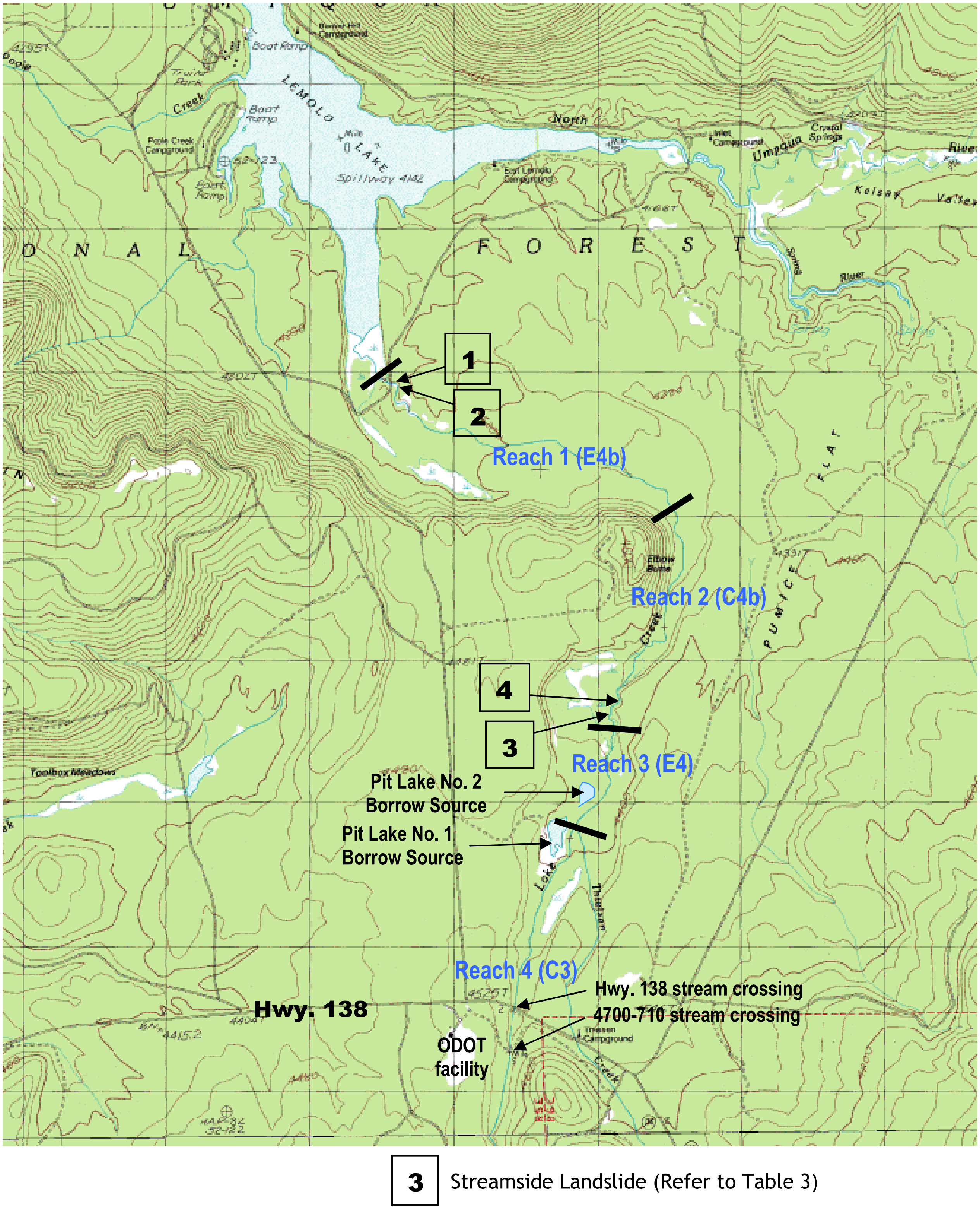
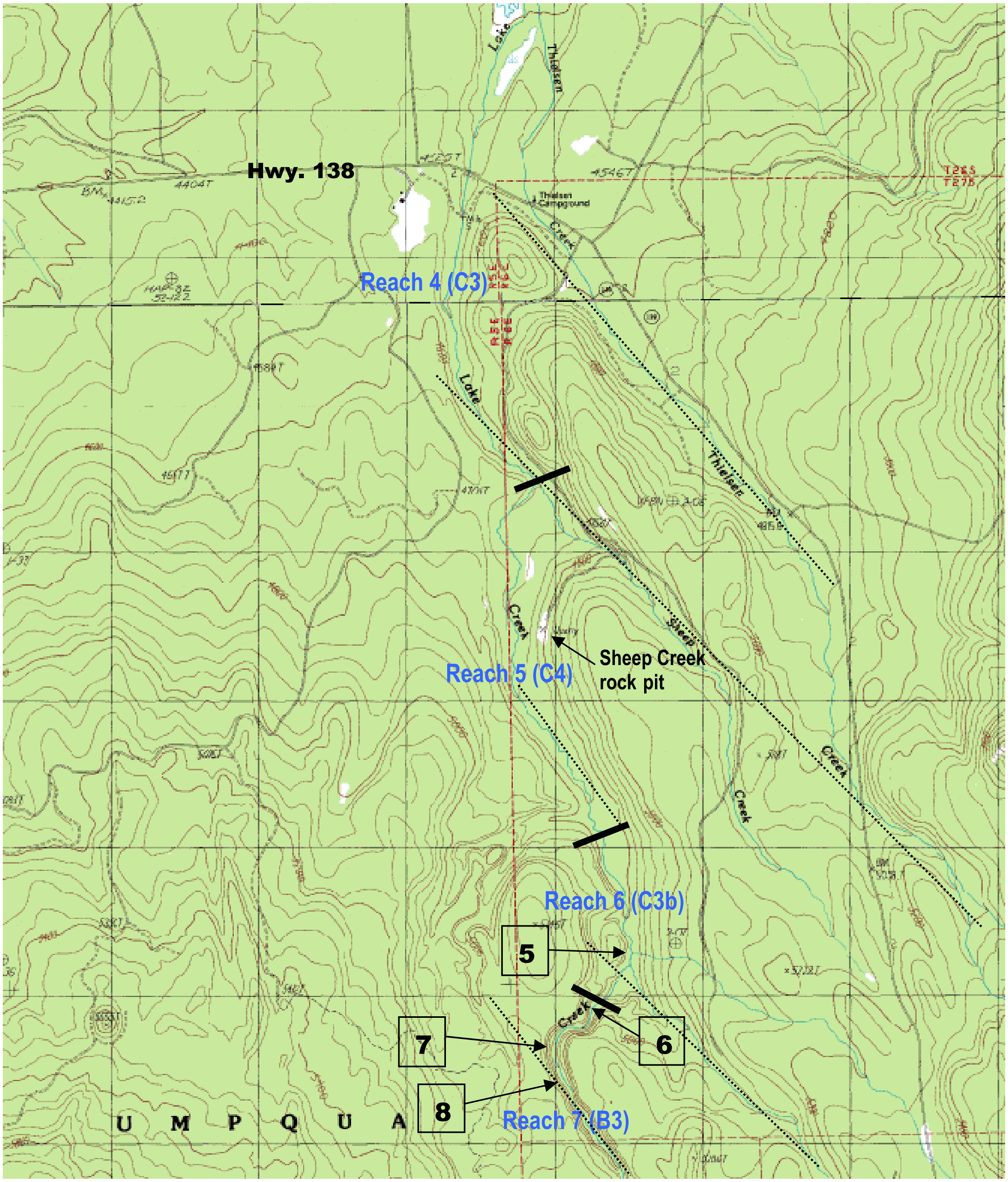


Figure 3a. Section of Lake Creek between Lemolo Lake and State Hwy. 138.



6 Streamside Landslide (Refer to Table 3)

Figure 3b. Section of Lake Creek between State Hwy. 138 and gorge (Reach 7).

Figure 3c. Section of Lake Creek between gorge (Reach 7) and Diamond Lake.

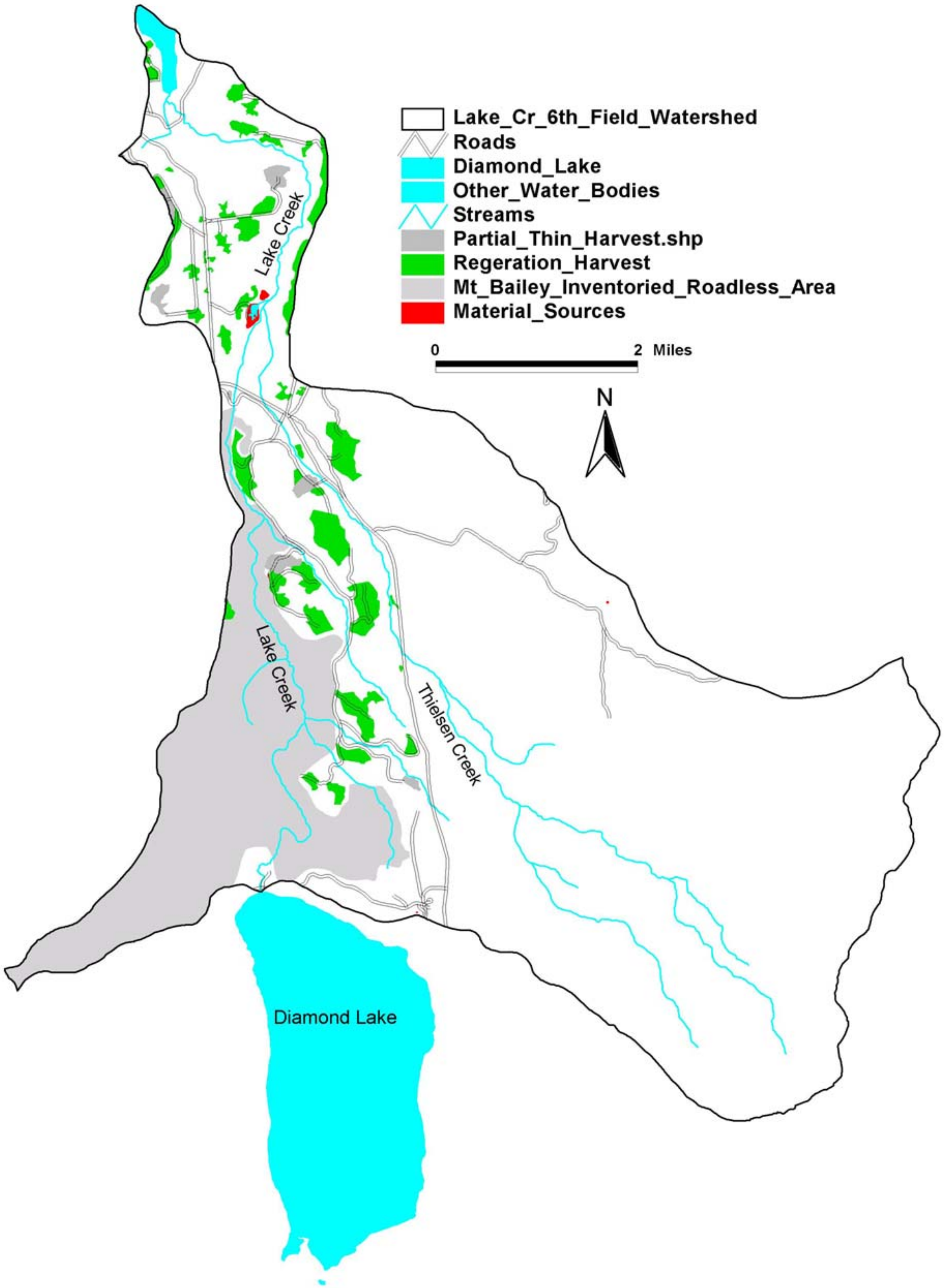


Figure 4. Location of regenerative timber harvest units and roads within Lake Creek watershed

Plate 1. Platy fracturing basaltic andesite (Qoba) exposed on the Dellenback Trail approximately two thirds of a mile east of the Lake Creek outlet on the north shoreline of Diamond Lake. Photograph by Larry Broeker on May 16, 2003.

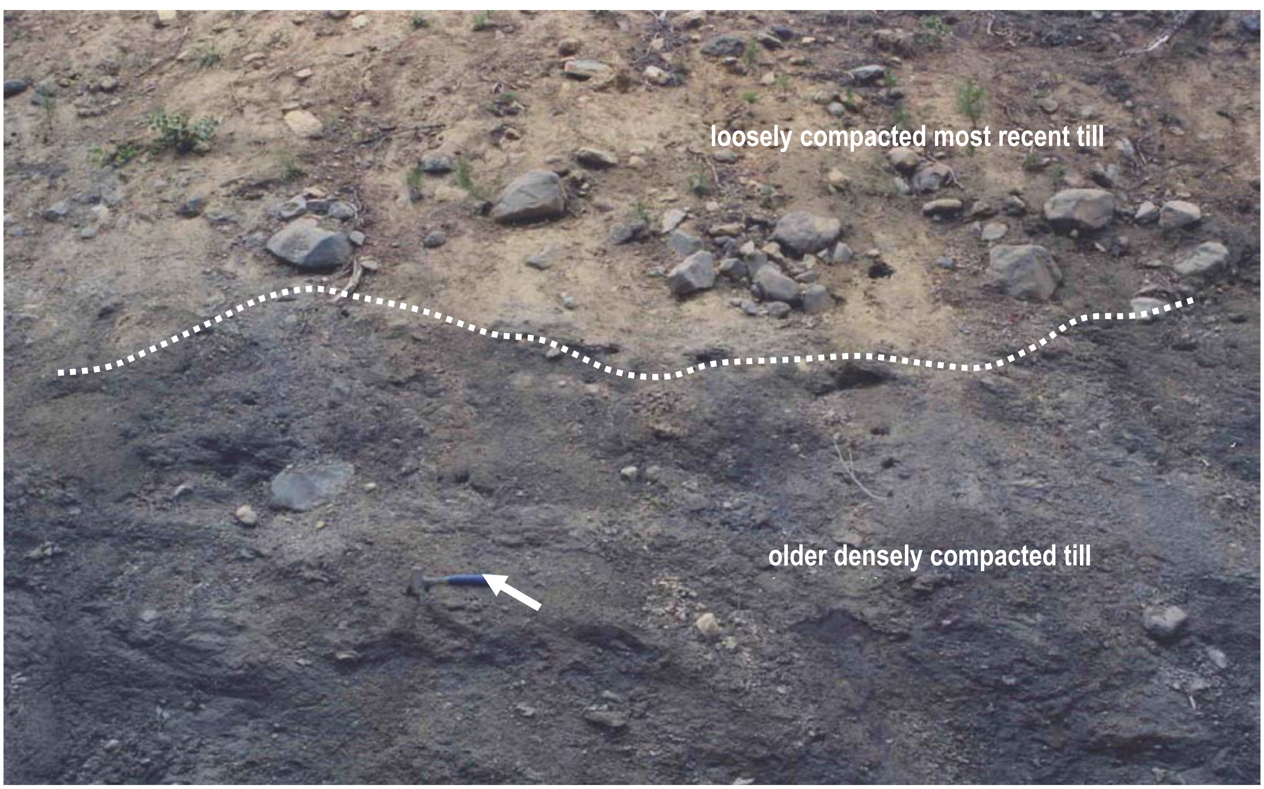


Plate 2. Deposit of loosely compacted cobble-boulder-rich glacial drift lying above older densely compacted glacial outwash (Qgd) exposed in a road cut (Forest 4795) along the west side of Diamond Lake near the access road leading into cabin sites 40,42,47, 48, and 52. A 10-inch diameter rock maul next to white arrow provides scale. Photograph by Larry Broeker on June 19, 2003.

Plate 3. Deposit of loosely compacted cobble-boulder-rich glacial drift (Qgd) exposed in road cut (Forest 4795) several hundred yards to the south of Diamond Lake Resort. Steve Hofford, Forest Hydrologist provides scale. Photograph by Larry Broeker on May 16, 2003.

Plate 4. Mazama pumiceous ash-flow (Qaf) exposed in a nine foot high wave cut terrace along northwest shoreline of Diamond Lake about two hundred yards west of Lake Creek outlet. Photograph by Larry Broeker on May 16, 2003.

Plate 5. View of poorly consolidated and stratified lacustrine sand and gravel deposit (Ql) representing fluvially 'reworked' Mazama ash-flow exposed in road cut (Forest 4795) along the western side of Diamond Lake near the access road leading into cabin sites 40, 42, 47, 48, and 52. Bedding (stratification) in deposit is near horizontal. Photograph by Larry Broeker on October 18, 2003.

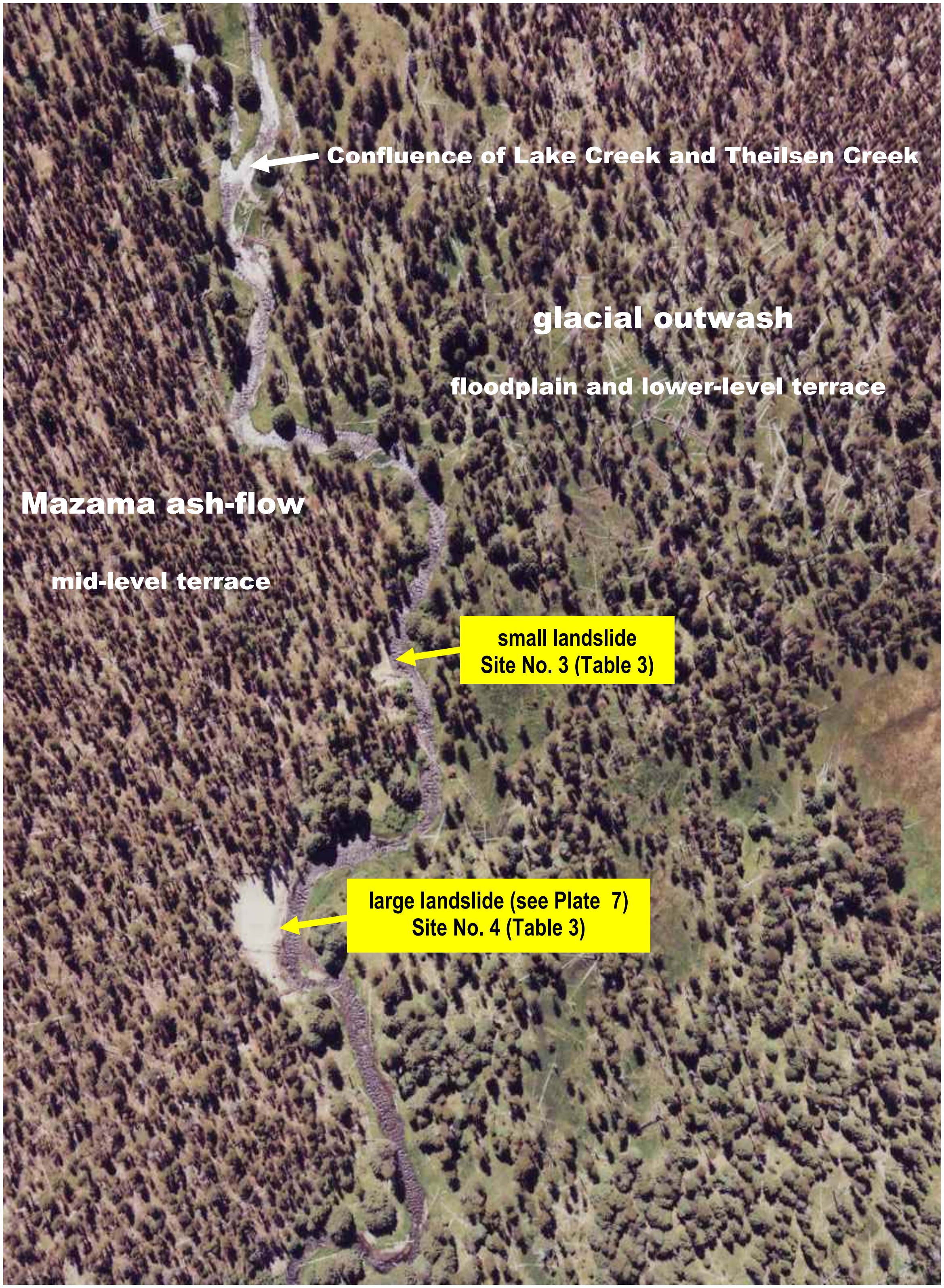


Plate 6. Enlargement of 1997 (1:4,000-scale) aerial photo (9705-273) depicting landslide features where Lake Creek impinges on and undermines the east valley wall (mid-level terrace). Valley floor floodplain and lower-level terrace landforms (to right of Lake Creek) are underlain by glacio-fluvial outwash deposits while the 60 foot high east valley wall (mid-level terrace) is composed of Mazama pumiceous ash-flow locally capped by stratified fluvially 'reworked' ash flow deposits (sand). Scale of aerial photo is 1 inch = approximately 100 feet.

Plate 7. Mass wasting feature (landslide) along Lake Creek that measures roughly 35 yards (length), 30 yards (height), and 2 yards (average depth) deriving a volume of about 2,000 cubic yards of delivered sediment. Age of landslide feature is unknown but appears on B&W 1966 (1:12,000-scale) aerial photo. Valley wall is composed of light colored Mazama pumiceous ash-flow with a darker cap of stratified fluvially reworked Mazama ash (sand). This reach of Lake Creek impinges on and undermines the valley wall. This mass wasting feature corresponds to Site No. 4 in Table 3. Photograph by Larry Broeker on September 23, 2003.

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GLOSSARY

andesite: A fine-grained, moderately dark-colored igneous volcanic rock that has a mineralogic composition composed of roughly equal amounts of calcium-rich and sodium-rich plagioclase feldspar , iron-magnesium rich minerals, mainly biotite and/or amphibole with subordinate quartz (silica) .

ash-flow: A weakly to moderately consolidated, but not necessarily welded (fused) tuff formed from the deposition of a highly heated mixture of volcanic ash and gasses traveling at high velocities down the flanks of a volcano into the surrounding valley lowlands. An ash-flow may also form by deposition from a gaseous (glowing) ash cloud. The ash flow is produced from the explosive disintegration of viscous silica-rich lava in a volcanic crater or by the explosive emission of gas charged ash from a fissure or group of fissures. A pyroclastic ash-flow typically attains speeds of over 60 miles per hour (100 km/hr) and reaches temperatures of more than 800 degrees Fahrenheit (400 degrees Celsius) while cascading down the flank of a volcano.

basaltic andesite: A fine-grained, generally dark-colored igneous volcanic rock that has a mineralogic composition ranging between basalt and andesite, and which is composed primarily of calcium-rich plagioclase feldspar and iron-magnesium rich minerals, mainly pyroxene.

dacite: A fine-grained, generally light-colored igneous volcanic rock that has a mineralogic composition similar to that of andesite; but having a lesser content of calcium-rich plagioclase feldspar, a higher content of sodium-rich feldspar and quartz (silica), and subordinate iron-magnesium rich minerals, mainly biotite and/or amphibole.

drift: A deposit of poorly sorted glacial material transported by either the advance or retreat of a mountain glacier or continental ice sheet that consists of mixtures of clay, silt, sand, gravel, cobbles, and boulders.

Holocene: An epoch (subdivision) of the Tertiary period that spans an interval of geologic time between roughly 0.01 million (10,000) years and present.

outwash: Stratified mixtures of chiefly sand and gravel that have 'washed out' of a mountain glacier by melt-water streams and subsequently re-deposited in the wake of a retreating glacier.

physiographic province: A contiguous region, in which all parts are similar in geologic structure with a unified geologic and geomorphic history, and whose pattern of relief (topography) and landforms differs appreciably from that of adjacent regions. The Cascades range in Oregon is partitioned into two volcanic sub-provinces; the older and deeply eroded Western Cascades, and the present day geologically active High Cascades that forms its hydrologic crest. The chief distinction between these two volcanic terrains is the strong contrast in landscape dissection resulting from different timeframes of constructional volcanism.

Pleistocene: An epoch (subdivision) of the Tertiary period that spans an interval of geologic time between roughly 1.8 and 0.10 million (10,000) years ago. The Pleistocene epoch corresponds to the time of the Ice Ages.

pyroclastic: A term that describes a poorly consolidated fragmental volcanic rock composed of varying proportions of volcanic ash (<2 mm), lapilli (2-64 mm), or bombs and blocks (>64 mm) formed by volcanic explosion from a vent.

pumice: A pale lightweight frothy appearing volcanic (extrusive) rock that contains numerous air voids (cavities) and is often sufficiently buoyant so as to float on water.

Quaternary: A period (subdivision) of the Cenozoic era that spans the previous 1.8 million years of geologic time and encompasses both the Pleistocene and Holocene epochs.

shield volcano: A broad, gently sloping volcanic cone constructed mostly of very fluid lava flows comprising basalt and basaltic andesite.

stratovolcano: A steep-sided volcanic cone constructed of alternating layers of pyroclastic debris, including tuff and volcanic breccia, and lava flows of dacite, andesite, basaltic andesite, or basalt. A stratovolcano is also known as a composite cone.

tuff: A general term for a consolidated (variably solidified) fragmental and explosively expelled (pyroclastic) rock .