2 GEOLOGIC AND HYDROLOGIC SETTING AND GEOMORPHIC PROCESSES

2.1 INTRODUCTION

Understanding the geologic and hydrologic setting of the focal study area in combination with the underlying geomorphic processes is critical to understanding the current form and function of the creeks and wetlands. This knowledge helps define restoration opportunities. The following sections are intended to develop this understanding, which is used in Chapter 7 to relate existing problems facing the focal study area to the governing hydrologic and geomorphic processes and to restoration options.

2.2 RECONNAISSANCE SURVEY ASSESSMENTS

Geomorphic reconnaissance of the Taylor, Tallac, and Spring Creek watershed was performed by PWA between October 14 and November 15, 2003. The reconnaissance was used to develop an understanding of the existing form and function of the creeks and wetlands with respect to observed natural and anthropogenic processes.

2.2.1 EXTENT OF SURVEY ASSESSMENTS

The assessments focused most intensively on the lower portions of both Taylor and Tallac Creeks between State Route (SR) 89 and their outlets into the lake. The upstream investigation concentrated on the main channels and major tributaries of Taylor, Tallac, and Spring Creeks. In the Taylor Creek watershed the upstream study concentrated on Taylor Creek up to its outlet from Fallen Leaf Lake. In the Tallac and Spring Creek watershed, the upstream focus was on the reach in the portion of the watershed accessible by road. Exhibit 2.2-1 shows the locations where observations were made and a generalized assessment of creek conditions. In addition to creek sites, representative portions of the surrounding watershed were also assessed for their general condition and likely impact on the creeks by sediment and water contributions.

2.2.2 METHODS

The creeks, major tributaries, swales, and surrounding watershed areas were visited on foot. PWA made observations at frequent intervals (e.g. typically every 100 feet or when conditions changed). At each observation point PWA logged the location using a handheld GPS unit and took digital images. Digital images are shown in Appendices A and B with the location of the images shown by Exhibit 2.2-2. Channel conditions (i.e. approximate dimensions, bed material size, dominant geomorphic processes, channel type) and any obvious restoration opportunities or constraints, or causes for concern were noted. The GPS coordinates, notes and images were transcribed into ExpertGPS, a software system that organizes spatial data.

2.2.3 GENERAL GEOMORPHIC SETTING AND ORIGIN OF THE TAYLOR/TALLAC WETLAND

The geomorphic background to the watershed will be described more fully in Section 2.4, but an overview is provided here. Taylor and Tallac Creeks are both steep, confined creeks upstream of their respective SR 89 crossings. Just downstream of SR 89 both creeks show a pronounced break in slope separating the upper erosion and transport zones from the lower depositional fans or deltas. A ridge of slightly higher ground, occupied by the Baldwin Beach access road, separates the alluvial fans of each creek. There is a subtle but definite break of slope marking the boundary between this ridge and the respective alluvial fans. The lower edge of the fans is marked by several transverse ridges and depressions, running parallel with the lake shoreline. These topographic features dominate the movement of water between and in the two wetlands, and control the extent to which the wetlands interact hydrologically. During high lake stands, water flows through ephemeral swales between the ridges in some locations, but is prevented from flowing between Taylor and Tallac wetlands by the ridge of higher ground between the two wetlands in lower lake stands. It appears that the ridge is a natural barrier to movement, but that it has also been exacerbated in some places by filling associated with the Baldwin Beach access road.

An interpretation of these features needs to be set in the context of fluctuating lake levels and the glacial history of the area. Since the 1870s, the upper 6 feet of the lake have been controlled by a dam at the head of the Lower Truckee River in Tahoe City operated to conserve water for Reno and Sparks, NV. During this period, lake levels have fluctuated in a range from 2 feet below the natural outlet (6,221.86 feet NGVD 29) to 8 feet above it in response to climatic changes (Lindstrom 1999). However, in a geomorphic timescale, lake levels have fluctuated greatly. During some glacial periods lake levels have fallen by more than 590 feet below current lake level, while at other times ice is believed to have blocked the outlet to the Lower Truckee River, raising lake levels 1,280 feet above their current position (Gardner et. al. 2000).

From studies of submerged tree stumps, it is known that the lake had lower lake levels (tens of feet) for sustained periods of time between 4,800 and 6,300 years before present (BP), and previously had much lower levels (more than 500 feet below present levels). It is likely that during these periods the two creeks or their glaciers cut down to the lower base level, creating a depression where the wetlands are currently located and forming two discrete valleys separated by a low divide. As lake level rose after the glaciers melted, the channels would have aggraded in response, filling in the depression with fine sediment to create the present alluvial fan surface. At lake levels slightly higher than present the sediment was organized into ridge beaches by one or more of several possible mechanisms. Large storm events can create beach ridges along the current shoreline. Storm beaches formed during periods of higher than present lake level (for example when Lake Tahoe's outlet was blocked) would form raised beaches when the lake fell to its present level. An alternate theory is that a tsunami, triggered either by faulting every 1,500 to 3,000 years (Ichinose et al. 2000) or massive landslides from earthquakes, would evolve into a seiche and create raised beaches as the waves hit the shore.

The ridge of higher ground occupied by the Baldwin Beach access road is likely a remnant of the divide (probably a medial moraine that formed between the two glaciers or a lateral moraine from the most recent Taylor glacier) between the two former depressions, now almost buried by sediment deposited at higher lake levels.

2.2.4 UPPER TAYLOR CREEK

Taylor Creek drains Fallen Leaf Lake, and has a length of approximately 0.6 miles between Fallen Leaf Lake and SR 89, and 1.4 miles from SR 89 to Lake Tahoe. The upper watershed is dominated by the 1,400-acre Fallen Leaf Lake, which occupies the majority of the watershed and which acts as a sediment trap disconnecting the eroding upper watershed from the lower reaches. Fallen Leaf Lake is a natural lake that has been dammed and slightly raised, and is now regulated (see Appendix A20). The dam structure and its operation do not appear to be detrimentally affecting the creek; there is no evidence of accelerated erosion downstream of the dam or of vegetation encroachment into the channel, two common impacts of dams on channel morphology. The upper creek channel is typically 30–50 feet wide with a bankfull depth of approximately 1.0–1.5 feet deep. The gradient is moderately steep (6% between Fallen Leaf Lake and SR 89) and the channel is mostly characterized by step-pool morphology in the steeper reaches (see Appendix A18) and riffle-pool morphology in the less steep reaches (see Appendix A20). The bed material is typically gravel or sand in pools and coarse gravel, cobbles and boulders in riffles and runs. In general the creek appears to be relatively undisturbed and in good condition; its morphology is what would be expected in this setting and does not appear to have been extensively impacted by the surrounding landuse. There are numerous high eroding banks on outside bends, typically 5 feet high but with some reaches 13–16 feet high (see Appendix A17). There is one very large eroding bend 300 feet upstream of the SR 89 Bridge where the creek impinges onto a lateral moraine (see Appendix A13). Bank erosion here may be enhanced by the presence of a gabion structure that intrudes into the channel at a pump inlet on the opposite (river right) bank. However, in most cases these erosion hotspots appear to be natural, caused by the channel eroding into lateral or terminal moraines. These sites are a significant source of both fine and coarse sediment that is transported all the way through the lower wetland. The channel is mostly a single sinuous thread, with two sites where the channel bifurcates and rejoins. There are two sites where beaver dams and large woody debris (LWD) have formed blockages that impound water (see Appendix A19). LWD is found in several locations on the channel, often as a result of failing banks. In general, the creek is somewhat naturally incised, and does not have a floodplain. There are several locations where trails run close to the banktop, and where there appears to be some erosion of fine sediment into the creek because of foot, horse or mountain bike traffic. This fine sediment source is most noticeable where trails run by eroding outside bends, and the creek would benefit from erosion control and trail relocation or the installation of barriers to keep the trails away from the banktop.

2.2.5 LOWER TAYLOR CREEK AND WETLAND

Lower Taylor creek below the SR 89 Bridge starts out as a coarse gravel and cobble bed channel with riffle-pool morphology (see Appendix A11 and Appendix A12). The channel is

approximately 30 feet wide below the bridge, with a bankfull channel depth of approximately 1.0–1.5 feet. The channel is sinuous with well-developed gravel bars and eroding outside bends with low banks. The channel gradient between SR 89 and the lake is 0.5%. The channel is unconfined and has a well-developed floodplain below the bridge. Approximately 1,000 feet downstream of the SR 89 Bridge the channel becomes disorganized and splits into multiple threads as a result of several large beaver dams that are a significant trap of fine and coarse sediment (see Appendix A9 and Appendix A8). During low flows these dams have caused flow to spread out and seep through the beaver dams in numerous small, often grass-lined channels that come together again downstream to form two main channels and numerous small secondary channels (see Appendix A7). This area is very wet as a result of the dispersed drainage. There is a single, ephemeral, coarse gravel bedded, high flow channel (probably formed during the 1997 rain on snow event) that appears to function when flow exceeds the capacity of the beaver dams to dissipate energy and disperse flow. Downstream of the beaver dam area the flow combines to two main channels. The west channel is approximately 30 feet wide and 1.5 feet deep, with a predominately coarse gravel bed (see Appendix A6). The banks are composed mostly of sand with some finer sediment. The morphology is sinuous riffle-pool, with cobbles in the riffles and sand in pools. There is a small amount of bank erosion on outside bends and gravel deposition on point bars. In general this channel appears to be functioning naturally, and is in good condition. It has a well-defined floodplain that is dry during low flows but which appears to become inundated frequently (assumed to be on an annual basis).

The east channel is a less coherent channel that flows through a wetland area (see Appendix A4). The channel is smaller (16 feet wide by 1 foot deep) and the bed is much finer than the west channel. This branch appears to be a significant sink of fine sediment from the watershed. It is much more closely coupled to the floodplain, which appears to be inundated or wet most of the time.

Both channels combine approximately 500 feet upstream of the outlet into the lake (see Appendix A2). As the west channel of Taylor Creek approaches the outlet the banks of this branch become higher (approximately 4–5 feet) and there is some evidence that the channel has slightly incised, presumably in response to falls in the level of the lake. Both channels and several of their tributaries have knickpoints, indicating falling base level on the mainstem that is now migrating upstream (see Appendix A3). Downstream of the knickpoints, the channels are significantly deeper and wider than upstream, and riffle habitat is lost. Observations of one knickpoint revealed negligible headward migration in a one year period, because of armoring of the head by a layer of embedded gravel. It is anticipated that these knickpoints could migrate headwards during large events, until lake level rises, causing deposition in the oversized lower portions of the channel due to a decrease in sediment transport capacity.

The outlet of Taylor Creek is controlled by a sand bar that currently deflects the mouth westwards. There is evidence that the sand bar is migrating or growing southwards, deflecting the outlet's left bank onto a raised beach ridge that is Tahoe Yellow Cress habitat and causing accelerated bank erosion (see Appendix A1). There are two potential alternative outlets (discussed below).

Taylor Creek appears to be transporting significant amounts of bedload (ranging from small cobbles and coarse gravel to sand) and wash load (fine sand and silt) from the reach downstream of Fallen Leaf Lake to the wetland, with sand and finer sediment reaching Lake Tahoe. The main source of sediment appears to be bank erosion in the reach between Fallen Leaf Lake and the SR 89 Bridge. While some of this erosion is natural and expected in an alpine setting, there is some accelerated erosion because of trail impacts and potentially the presence of the flow deflection structure upstream of SR 89. It is recommended that these be considered as potential sites for erosion control to reduce sediment loading into the Taylor Creek wetland and Lake Tahoe.

2.2.6 UPPER TALLAC AND SPRING CREEKS

Tallac and Spring Creeks drain the watershed north east of Mt. Tallac. Unlike Taylor Creek, there are no large lakes to act as sediment traps in this watershed. The upper watershed is steeper than the Taylor Creek watershed, and dominated by debris flow erosion and deposition. The main channel of Tallac Creek is typically 12–15 feet wide and 1.5–3.0 feet deep, with a steep gradient and step-pool morphology. The bed material tends to be coarse, dominated by cobbles. The channel is more variable than Taylor Creek, with a range of conditions from a very high quality relatively undisturbed step-pool channel to highly eroding and incised sections and areas where debris flow deposits have obliterated the channel. The headwater tributaries of Tallac Creek are steep boulder and cobble step-pool channels with large amounts of LWD (see Appendix B19). The average channel gradient is 12% between Floating Island Lake and the confluence of the main Tallac Creek tributaries at Spring Creek Road. In many places these channels have avulsed because of debris flows. Further downstream, below the confluence of the main tributaries of Tallac Creek, the next 1,000 feet of channel is deeply incised and actively eroding, possibly as a response to the large 1997 flow event (see Appendix B18). There are eroding outside banks up to 15 feet high, and a great volume of sediment has been eroded from this reach. As an estimate, between 1.5 and 3.0 feet of channel incision appears to have taken place, with up to 10 feet of recent bank widening, giving an eroded volume of approximately 10,000–20,000 cubic feet of sediment. Downstream of this reach the sediment has been deposited, partly in response to an undersized culvert where Tallac Creek is crossed by Spring Creek Road (see Appendix B15). The deposition has partly filled the creek with coarse gravel from 400 feet upstream (near Matole Road) to the culvert and for 200 feet downstream (see Appendix B16 and Appendix B14), at which point the channel has been obliterated and vegetation has occupied it (see Appendix B13). Unless the channel erodes at this point there is a danger that the next debris flow event upstream of this point will cause an avulsion in this area. For the next 200–300 feet, the channel is obliterated, with some small secondary channels taking some of the flow. Below this point the main channel re-emerges and recaptures lost flow. From this point to the confluence with Spring Creek and downstream to the SR 89 culvert, the channel is a high quality step-pool channel with some local bank erosion on outside bends (see Appendix B11 and Appendix B12). The average channel gradient between the main Tallac tributary confluences and the Spring Creek confluence is 6%.

Spring Creek has a very different character than Tallac Creek, with a lower gradient (4% from the headwaters boundary to the confluence with Tallac Creek) and a channel that is dominated by beaver dams in the reach between the Tallac confluence and the loop road (see Appendix B20 and Appendix B21). Above the beaver dams, Spring Creek is typically 3-6 feet wide and 4-12 inches deep, with fine bed material. In many areas it is a wet meadow channel, with a narrow but deep channel cut through a grass-covered floodplain and bordered by willows (see Appendix B22). Towards the headwaters, Spring Creek rises out of a wet meadow to form a boulder step-pool channel with a gradient of 5%.

2.2.7 LOWER TALLAC CREEK AND WETLAND

Tallac Creek passes under SR 89 through a large culvert. During the 1997 flood event sediment and water exceeded the transport capacity of the culvert and caused water to flow across SR 89. The upper 100 feet of lower Tallac Creek is confined, especially on the right bank where the channel cuts into debris flow deposits. At this point the channel has a step-pool and riffle-pool structure (gradient of 12%) and is in good condition (see Appendix B10). Bed material is a mixture of coarse gravel, cobbles and sand. Below this point, the creek emerges onto the gentler alluvial fan area (average gradient between the fan top and lake is 0.4%). The upper part of the alluvial fan is dominated by beaver dams, and flow disperses through numerous small distributary channels (see Appendix B9). The combination of gradient loss, water seepage through the beaver dams and dispersal through undersized channels has created a wetland area that is a significant sediment trap. The secondary channels eventually coalesce into two main channels and several smaller channels, with the two main channels essentially marking the east- and west-most extents of the wetland area. Both channels are highly degraded from horse grazing, with evidence of trampling and bank erosion instability (see Appendix B6). On the higher ground there is evidence of soil compaction and erosion from grazed areas. The channels are typically 4 feet wide by 1 foot deep, with silt beds. All channels are well connected to their floodplains, with no evidence of incision. The channels appear to frequently overflow because of their small size, creating a large area of wetland. Secondary channel systems such as this one tend to create wetter conditions than single thread channels because they are hydraulically less efficient and cause more of a backwater effect during high flows. In addition, at times of lower groundwater seepage out of the channels may contribute moisture to a wider area than would be the case in a single thread system. The two channels rejoin close to the outlet to the lake and form a more distinct sinuous sand bed channel that is approximately 15 feet wide and 1 foot deep (see Appendix B3).

This channel has a sand bedded meandering structure with pools in outside bends, structure until it passes over the concrete-encased sewer line, which acts as a grade control structure (see Appendix B2). This structure appears to have been constructed somewhat below grade, but is now exposed 6 inches above grade, indicating channel incision of at least six inches. Downstream of the structure the channel appears to have incised by at least an additional 6 inches, and goes into a scour pool that is 3-4 feet deep (see Appendix B1). The remaining channel from this point to the outlet is over deepened and is causing bank erosion. According to the JSA report (JSA, 2000) the peat layer that overlays the Tallac wetland and the area of

land near the beach is not greater that 1.5 feet in thickness. The channel below the sewer line crossing has therefore incised through this peat layer and scoured significantly below the sewer crossing (by up to six feet or more). There appears to be a groyne structure (possibly an old bridge crossing) on the left bank that was installed to deflect flows away from the bank. However, it appears to have created a scour pool and bank erosion behind it.

The main source of sediment on Tallac Creek appears to be from debris flows and channel erosion in the upper reaches. Compared with Taylor Creek, the Tallac Creek watershed is currently highly disturbed because of debris flows and associated channel avulsions, though this may be distorted because of the relatively recent large flow event of 1997. Given the lack of lakes or other buffers between the headwaters and the channel, it seems likely that the geomorphic character of Tallac Creek is controlled by episodic 'pulse' disturbances. While these events are natural and part of the make up of steep alpine streams, they are probably exacerbated by the presence of undersized culverts in the watershed.

2.2.8 SWALES AND BACK CHANNELS

There are several swale channels that are parallel to Baldwin Beach and which appear from aerial photos to follow topographic features such as the raised beaches. In addition, there are several swales that are not aligned with the shoreline. These were investigated to assess the degree of connectivity between and in them.

Swale 1 (indicated on Exhibit 2.2-1) runs immediately behind the beach and is the most continuous channel. It originates in Tallac Creek where it joins the second swale. It bifurcates immediately southeast of the western parking lot, rejoins north of the eastern parking lot, and almost connects to Taylor Creek. Its southwest end is separated from Taylor Creek by a narrow but high sand bar and spit. It seems likely that historically this bar opened occasionally, forming an alternative mouth for Tallac Creek. This channel is constricted by three raised road and pathways with undersized culverts that are approximately 4 feet in diameter and partially filled with sediment. By comparison, the channel dimensions are approximately 40 feet wide at base, 100 feet wide at bank top and 6 feet deep. Although water is able to pass through the culverts, there is severe constriction and evidence of 1-3 feet of sediment deposition in the sloughs near the culverts. Erosion is likely to be an important process in maintaining this channel as a viable connection between the two wetlands if such a condition existed historically. There is evidence that this channel has been quite active in the past – the bank top is quite clearly defined and eroded. Re-activating this channel would ideally involve almost completely removing the earth causeways, or at least replacing them with significantly larger dimension multiple culverts.

Swale 2 is not continuous; it forms two separate features in Tallac and Taylor Creeks that appear from aerial photos to occupy the same raised beach level, and to have potentially been connected in the past. Swale 2 shares the same connection to Tallac Creek as Swale 1, but has a different outlet in Taylor Creek. The channels are approximately 20 feet wide at the base, 40 feet at the banktop, and 4 feet deep. They are less eroded than Swale 1, and appear to be back channels rather than active channels. Both arms of the swale die out topographically before

the Baldwin Beach access road, and lodgepole pines have grown at the location between the potential juncture. The distance between the ends of the arms of the swale is approximately 500 feet. Based on the field inspection, these two arms of the swale do not appear to have been actively connected for a considerable period of time, if ever.

Swale 3 lies 100 feet inland from Swale 2. The swale is approximately 10 feet wide at the base, 25 feet at top of bank, and 3 feet deep. These channels come closer to connecting than Swale 2; the Tallac Creek arm dies out 50 feet from the access road while the Taylor Creek arm dies out 150 feet from the road. Though reconnection of Swale 3 would be more viable than Swale 2, it appears that these channels have not been connected recently, if ever.

Swale 4 lies 500 feet inland from Swale 3, at the point where the Baldwin Beach access road drops off the higher fan onto the lower surface. The use of fill to maintain an even road surface has blocked this swale, but in spring and summer of 2004 water reached the road from both sides, indicating that this feature could transmit water if breached or made more hydraulically permeable.

2.2.9 ALTERNATIVE CREEK OUTLETS AND CHANNEL DYNAMISM

Both Tallac and Taylor Creeks appear to have dynamic outlets because of lake current circulation patterns and the barrier-beach nature of the Lake Tahoe shoreline. Aerial photo analysis (see Section 2.6) shows that Taylor Creek periodically opens up an outlet east of the current mouth. Topographic and historic map evidence suggests that Tallac Creek may periodically discharge some or all of its flow through the channel described above as Swale 1, exiting via the sandbar near the current mouth of Taylor Creek. In the case of Tallac Creek the flow diversion appears to occur when high flows are constricted by a sharp meander bend in the outlet that potentially blocks with sediment or debris, and steered by a floodplain terrace towards Slough 1. However, it seems unlikely that flows from Tallac Creek would generate sufficient energy to cause the necessary erosion of the outlet to Taylor Creek on their own, given the circuitous and low gradient route this swale takes. It is possible that the outlet is periodically eroded by Taylor Creek, providing an alternative route for Tallac Creek.

Both creeks appear to have a certain amount of channel dynamism in the wetland areas upstream of their mouths. Alluvial fan or delta systems with distributary channels are naturally dynamic, as periodic pulses of sediment from the watershed easily fill and obliterate undersized channels and force the water to follow new flow lines. For example, in the Taylor wetland there is a LWD jam on the lower mainstem that appears to have blocked one distributary channel, forcing more flow down the mainstem (as shown by Exhibit 2.6-4). This process has been exaggerated by the presence of beaver dams. We would expect to see a certain amount of channel migration and avulsion over time, but there does not appear to be anything in the wetlands that is unnaturally inhibiting that process. Both creeks are slightly vertically unstable (incising) near to their outlets, probably because of low lake levels. This instability is unlikely to migrate up Tallac Creek as long as the concrete sewer line remains in place and acts as a grade control the headcuts on Taylor Creek are currently stable but may migrate upstream into the

wetland, and will cause an oversized channel to develop, but will cease and probably aggrade somewhat once lake levels rise again.

In the upper watershed, Tallac Creek near Spring Creek Road is the most dynamic system, because of the presence of debris flows and resulting channel avulsions. The channel is both vertically and horizontally unstable (adjusting from 1997). Beaver dams cause distributed drainage on Spring Creek, but there is less potential for significant channel avulsion here because of the lower energy stream and topography. Taylor Creek between Fallen Leaf Lake and the SR 89 Bridge appears to be relatively stable. There is evidence of slow lateral migration in the channel on outside bends, but this process appears to be natural and does not threaten significant infrastructure. There is no evidence of vertical instability.

2.3 HYDROLOGIC SETTING

2.3.1 DRAINAGE BASIN CHARACTERISTICS

Taylor and Tallac Creeks are located on the south shore of Lake Tahoe in El Dorado County, 4.5 miles west of the City of South Lake Tahoe (see Exhibit 2.3-1). Taylor Creek, at its outfall to Lake Tahoe, drains approximately 18.4 square miles, including the area draining to Fallen Leaf Lake. The area between Lake Tahoe and Fallen Leaf Lake is bisected by SR 89 and is composed of mixed forest and wetlands and ranges in elevation from 6,222 feet NGVD 29 at Lake Tahoe to 7,170 feet NGVD 29 at the divide with Fallen Leaf Lake. Fallen Leaf Lake drains approximately 16.6 square miles and is located in the Lahontan basin with a sizeable portion of the basin being in the Desolation Wilderness (Forest Service 1981). The Fallen Leaf Lake basin is primarily drained by Glen Alpine Creek to the south end of the lake. The alpine glaciated basin is steep and relatively narrow and rises from 6,380 feet NGVD 29 at Fallen Leaf Lake to 9,980 feet NGVD 29 at Dicks Peak. About 30% of the basin is forested with soils of glacial or residual origin with the remainder supporting thin residual soils or being composed of granodiorite bedrock and talus slopes (Forest Service 1981). Because of this, the basin provides limited soil water storage, and the semi-ephemeral Glen Alpine Creek is dry in the months of August and September in drought years.

Tallac Creek, at its outfall to Lake Tahoe, drains approximately 4.6 square miles, with its tributary Spring Creek draining approximately 0.8 square miles. Tallac Creek ranges in elevation from 6,222 feet NGVD 29 at Lake Tahoe to 9,740 feet NGVD 29 at Mt. Tallac. Between Lake Tahoe and SR 89, Tallac Creek is a series of distributary channels that meander through the wetlands. Above SR 89, the Tallac Creek basin is of similar origin and composition as the Taylor Creek basin. However, groundwater seeps at the base of the mountain and throughout the marsh sustain flows in Tallac and Spring Creeks even in drought years (LTBMU 2000).

2.3.2 PRECIPITATION CHARACTERISTICS

Precipitation in the Lake Tahoe Basin varies strongly with geographic location. This is probably because of a variety of orographic, lake, and atmospheric circulation effects. The

climate is typically Sierra montane with warm daytime and cool nighttime summer temperatures and cold daytime winter temperatures seldom below 20°F (Forest Service 1981). In the Lake Tahoe Basin, precipitation occurring in the months of October through June is usually caused by frontal type events associated with Pacific weather systems, with major rainfall-induced flooding occurring between November and January (Forest Service 1981). Precipitation falling as snow is dense because of the generally mild winter climate. This results in a "warm" snowpack that commonly yields melt throughout the winter (Forest Service 1981). For the months of July through September, precipitation is because of convective type thunderstorm events (Forest Service 1981).

Annual precipitation (AP) data in the vicinity of the project area was available from the nearby Fallen Leaf Lake SNOTEL (SNOw TELemetry) site (NRCS 2004). The 24-year record (1980 through 2003) at the SNOTEL site was lengthened by correlation with the 85-year record (1915 through 2003; incomplete records for 1937, 1941, 1977, and 1978) at Tahoe City (WRCC 2004). Exhibit 2.3-2 shows the high correlation between the two data sets for the period of 1980 to 2003 less the outliers. The outliers indicate that significant differences in annual precipitation occurred between the north and south shores of Lake Tahoe in 1984 and 1986. According to the extended record (see Exhibit 2.3-3), the mean annual precipitation (MAP) at the project site is 31 inches, but may range annually from 13 inches in very dry years to more than 60 inches in very wet years. This cyclical variability in precipitation is very much a driver of the cyclical variation in lake levels (as described further in Section 2.3.4). Based on a preliminary analysis of hourly data for the SNOTEL site for the period of 1998 to 2002, roughly 60% of the precipitation falls as snow (NHC 2003). In the headwaters, the MAP may well exceed 60 inches with 80% of the precipitation falling as snow (Forest Service 1981).

2.3.3 STREAMFLOW CHARACTERISTICS

Streamflow data are only available for Taylor Creek at the gaging station near the outlet of Fallen Leaf Lake. Taylor Creek streamflow is attenuated naturally by Fallen Leaf Lake but also partially by Forest Service operations in accordance with the Memorandum of Understanding between the Forest Service and the Fallen Leaf Lake Protection Association (1972). The USGS operated the gaging station from 1968 through 1992, after which the Forest Service resumed responsibility for operation and maintenance of the gaging station. Exhibit 2.3-4 shows the period of continuous record available for the gaging station. Notice that the rainfall-induced floods occurring in 1970, 1973, 1980, 1981, and 1986 account for the most severe type of flooding in the Taylor Creek basin. Data for 1997 was not available for this study; however this data would likely only modify the estimated the flood frequency analysis for larger events. A flood frequency analysis of annual instantaneous peaks using the USGS program PEAKFQ (Thomas et al. 1998) for USGS gage 10336626 is shown in Exhibit 2.3-5 with tabular results in Table 2.3-1. The flood frequency analysis results were developed using the station skew provided by the USGS, a Weibull plotting position of 0.0, and all peaks to include those designated as regulated. Assuming that the 2-year flood is representative of the bankfull discharge, the bankfull discharge for Taylor Creek downstream of Fallen Leaf Lake was estimated to be 282 cfs, but may reasonably range from 215 cfs to 364 cfs based on the 95% confidence limits.

Streamflow data is not available for Tallac Creek. However, based on discharge estimates performed by for the Forest Service in July 1999 (LTBMU 2000), it was estimated that discharge from Taylor Creek was 4 to 5 times larger than Tallac Creek for low flows. This ratio is consistent with the ratio in basin size between Taylor and Tallac Creeks. Additionally, an estimate of the flood frequency for Tallac Creek was performed based on the regulated flood frequency estimates for Taylor Creek using the methods outlined by Waananen & Crippen (1977). Using Equation 2.3-1 below, it was possible to estimate the flood frequency of Tallac Creek at Lake Tahoe given its proximity to Taylor Creek:

$$Q_u = Q_g \left(A_u / A_g\right)^b$$

where Q_u and Q_g are the discharges at the ungaged and ungaged sites, A_u and A_g are the drainage areas, and b is an exponent (see Table 2.3-1 for details). Results of this analysis for Taylor and Tallac Creeks at Lake Tahoe are shown in Exhibit 2.3-6 and Table 2.3-1. This analysis demonstrates that flood flows on Taylor Creek are approximately 2.9 to 3.4 times larger than those on Tallac Creek for flows ranging from the 100-year event to the 2-year event, respectively. These findings are generally consistent with the findings for low flow conditions. However, the Forest Service suggests that for unregulated conditions in drought years, low flows from Tallac Creek exceed those from Taylor Creek.

Table 2.3-1
Flood frequency estimates for Taylor and Tallac Creeks

Recurrence Interval	Taylor Creek at USGS Gage# 10336626[1]	Drainage Area Exponent, b[2]	Taylor Creek at Lake Tahoe	Tallac Creek at Lake Tahoe	Flow Ratio
(years)	(cfs)	---	(cfs)	(cfs)	---
1.005	64				
1.010	71				
1.053	99				
1.111	121				
1.25	157				
1.5	207				
2	282	0.88	307	91	3.4
2.33	322				
5	564	0.82	610	196	3.1
10	847	0.80	915	302	3.0
25	1,355	0.79	1,463	489	3.0
50	1,872	0.78	2,019	685	2.9
100	2,539	0.77	2,736	941	2.9
200	3,393				
500	4,893				
Drainage Area (mi^2)	16.7[3]		18.4	4.6	4.0

[1] Bulletin 17B (Interagency Advisory Committee on Water Data, 1982) estimate using the USGS program PEAKFQ v4.1 (Thomas et al., 1998)
[2] Exponent in Equation 1 from Table 1 in Waananen & Crippen (1977)
[3] Drainage area defined by the USGS for gage 10336626

2.3.4 LAKE TAHOE WATER LEVELS

The water levels of Lake Tahoe affect the surface and groundwater interactions in the focal study south of SR 89. The natural rim of Lake Tahoe at its outlet to the Lower Truckee River is at an elevation of 6,221.9 feet NGVD 29 (6,223.0 feet lake datum). Before human alteration of the outlet in the 1870s, the maximum lake level would have been limited by the rim elevation and the minimum lake level would have varied with climatic conditions. The Lake Tahoe Dam in Tahoe City was originally constructed in 1874 with its current configuration being constructed in 1913. Construction of the dam modified the natural rim and raised the outlet. The 1935 Truckee River Agreement set the maximum legal lake level to 6,228.0 feet NGVD 29 (6,229.1 ft lake datum) and the 1944 Orr Ditch Decree has since provided for downstream water supply (Horton 2003).

Exhibits 2.3-7 to 2.3-9 show Lake Tahoe water levels since 1888. Exhibit 2.3-7 shows the annual maximum and minimum lake levels from 1888 to 1923 by comparing historic high and low lake elevations (Glass 1990) to end of month lake levels from 1900 to 1923 supplied by the Federal Water Master's Office in Nevada which has compiled USGS data since measurements began in 1900. This exhibit illustrates that the annual high and low lake elevations correlate closely with the USGS data since 1900. Therefore, it is assumed that the lake levels before 1900 have a similar relationship to the data measured by the USGS since 1900. Exhibit 2.3-7 shows low lake levels in the late 1880s followed by high lake levels around 1890 and 1895. Exhibit 2.3-8 and Exhibit 2.3-9 show end of month lake levels since 1900 and demonstrate that there were relatively high lake levels up to the 1920s, which was then followed by a period of relatively low lake levels through the late 1930s. Since the late 1930s, lake levels have cycled between wet and drought years with an average period of 14 years between each drought with the lowest recorded lake level occurring in November during the drought of 1992. The lake level is typically the highest in spring and early summer because of snowmelt runoff, but may peak in winter because of rain-on-snow events. Lake levels then decline during the summer months as streamflow inputs decrease and evaporative losses increase.

Analyses for the period of record post 1944 were undertaken to characterize the statistical nature of recent lake levels. The mean, standard deviation, median, minimum, and maximum water surface elevations were calculated and are summarized in Table 2.3-2. The mean value is about 0.6 feet lower than the median value because of skew in the distribution (Exhibit 2.3-10).

Table 2.3-2
Lake Tahoe Elevation Summary Data

Distribution Descriptor	Elevation (ft NGVD 29)	Date of Occurrence
Mean	6,225.1	-
Standard Deviation	2.0	-
Median	6,225.7	-
Minimum	6,219.1	Dec 1992
Maximum	6,228.0	Feb 1997

The minimum, maximum and mean water surface elevation for each calendar year is shown by Exhibit 2.3-11. The mean annual minimum and mean annual maximum elevations are 6,224.0 feet and 6,226.1 feet, respectively. The mean inter-annual range in lake elevation is 2.2 feet.

Percent exceedance is shown by Exhibit 2.3-12. The mean annual minimum value (6,224.0 feet) is exceeded 71% of the time. An elevation 0.5 feet higher than this (6,224.5 feet) is exceeded 68% of the time, and an elevation 1.0 feet higher than the mean minimum (6,225.0 feet) is exceeded 62% of the time. The mean annual maximum value (6,226.1 feet) is exceeded 42% of the time.

The frequency of occurrence of lake levels ± 0.5 foot are shown by Exhibit 2.3-13. A lake level of 6,226.7 ± 0.5 feet occurred most commonly during the record period (27.4% of the time). This is actually 1.0 foot higher than the mean value of the dataset, and 1.6 feet higher than the median value.

An appreciation of the statistical frequency of lake elevations is useful generally to this assessment. These results form the basis of understanding the frequency at which the swales will likely be inundated under different lake elevations (see Section 2.6).

2.3.5 GROUNDWATER CHARACTERISTICS

In general, watershed-scale groundwater flow paths are from the uplands towards the lake with discharges from seeps to stream channels and springs or with discharges directly to the lake (Thodal 1997). In the vicinity of Baldwin Beach and the wetlands and swales nearest the beach, such as Swales 1 and 2, it appears that lake levels control the local groundwater, but it may also be governed by local topography and soil properties.

Monthly piezometer data from the Forest Service was made available to PWA for the Tallac Creek wetland below SR 89 for the 2003 water year. This period of time was characterized by very low lake levels (6,222.9 feet NGVD 29 on average ± 1 foot) and an annual precipitation of 31 inches (equal to the average annual). Exhibit 2.3-14 shows the piezometer locations and the cut line used to extract longitudinal groundwater profiles. Exhibit 2.3-15 shows groundwater profiles for the 2003 water year in comparison to the existing ground surface. Based on Exhibit 2.3-15, the following can be said regarding groundwater levels in the Tallac Creek wetland adjacent to the lake:

1. If there is minimal error in the photogrametrically derived, ground surface near the beaver dam because of vegetation, the water level in the beaver dam, indicative of local groundwater conditions, decreases in the winter months through seepage and evaporation as available precipitation is stored in the snowpack; increases in the spring with the capture of snowmelt; and decreases in the fall with the decline of snowmelt, seepage from the dam, and an increases in evaporative losses.

2. Assuming there is minimal error in the piezometer data and/or lake level readings in the vicinity of the east parking lot, the water table behind the barrier beach has an average

gradient towards the lake of 0.3%, similar to the ground surface gradient. The localized gradient is likely dependent on lake level and available water stores from upslope.

3. At low lake levels under average climatic conditions, the portion of the water table governed strictly by lake level is restricted to the vicinity of the barrier beach. As the lake level increases, the portion of the water table governed by lake level likely advances well into the wetland.

2.4 GEOMORPHIC ASSESSMENT

2.4.1 GEOLOGICAL SETTING OF THE TAYLOR AND TALLAC CREEK WATERSHEDS

Taylor and Tallac Creeks drain the eastern Sierra Nevada Mountains into the southwestern corner of Lake Tahoe (see Exhibit 2.4-1). Lake Tahoe occupies a graben ('rift valley') that formed between 7.4 and 2.6 million years ago (Ma) (Wahhaftig 1965). The graben is believed to have formed as a subsiding block between two north-south running normal faults that roughly follow the eastern and western shores of Lake Tahoe. The so-called West Tahoe fault runs through the upper end of both watersheds, and is roughly delimited by the sharp transition between lower angle footslopes and steep headwalls rising up to Mt Tallac, Cathedral Peak and Keith's Dome. Though figures are not available for the Western Boundary Fault in this location, studies from Yosemite National Park suggest that land to the west of this fault is rising relative to land to the east at a rate of approximately 3.8 cm (1.5 inches) per 100 years (Huber 1987). Lake Tahoe formed when the northern end of this graben was blocked approximately 1.9 to 0.1 Ma. Though there are several theories for how this happened, the most widely accepted assessment is that volcanism associated with the graben created flows that blocked the northern margin. Lake Tahoe initially filled until flow overtopped the northwest divide, cutting the Lower Truckee River valley.

The two watersheds are composed of Mesozoic volcanic and metasedimentary rock overlain by glacial and lake deposits (see Exhibit 2.4-2). The headwalls are made of Jurassic metavolcanics above Mesozoic granite. The boundary between the two groups is a local expression of what is believed to be the Western Boundary Fault. The lower headwalls and most of both watersheds down to SR 89 are covered with Quaternary glacial deposits. These sediments are poorly sorted mixtures of fine material, sand, gravel and boulders. The lower watershed (below SR 89 on Taylor Creek and from upstream of the Taylor-Spring confluence in the Tallac watershed) is made up of glacial outwash deposits that are mostly gravelly loams and coarse sands. In the central portion of the wetlands the glacial deposits are overlain by Older Lake Sediments, while the current and former beach lines are characterized by sandy beach deposits.

2.4.2 TECTONICS, UPLIFT, AND INFLUENCES ON SEDIMENTATION

The eastern edge of the Sierra Nevada is rising as the block continues to tilt to the west, while the Tahoe Basin is subsiding. This means that there is a large discontinuity across the Taylor and Tallac Creek watersheds, with their headwaters rising relatively rapidly west of the Western Boundary Fault. Watersheds that are experiencing uplift tend to have

correspondingly high rates of erosion. In the Sierra Nevada, erosion rates are generally keeping pace with uplift rates. Thus, the headwaters are eroding relatively rapidly compared with the area east of the fault. Although empirical data are not available, field evidence and experience in other alpine areas such as the European Alps suggests that landslides and debris flows are responsible for most erosion, often triggered by fluvial channel erosion and undercutting of oversteepened slopes. The presence of the fault line can be seen in the stepped profiles of Tallac Creek and its tributaries (Exhibit 2.4-3).

Channel systems that cross active faults generally have relatively high rates of erosion as they seek to reach an equilibrium grade. In the case of the Taylor Creek watershed most of the eroded material from the upper watershed is being deposited in Fallen Leaf Lake and is not reaching the lower watershed. Bank erosion downstream of Fallen Leaf Lake is contributing sediment to the lower watershed. In Tallac and Spring Creeks there are no impediments to sediment transfer beyond the limited capacity of the creeks, so coarse material from landslides and debris flows is able to pass through the upper watershed and be periodically delivered to the break of slope at the upslope limit of the wetland. Because only the headwaters are uplifting and the lower watershed is relatively static, both creeks have a relatively high natural erosion rate in the headwaters but a very low sediment transport capacity in the lower reaches, resulting in large natural sediment accumulation rates.

2.4.3 GLACIAL HISTORY OF THE SITE AND IMPACT ON LAKE TAHOE LEVELS

The Lake Tahoe Basin has undergone numerous glacial periods since its formation. The most recent and best-understood periods occurred ~160 Ka (the Tahoe Glacial) and ~20 Ka (the Tioga Glacial). During the Tahoe Glacial, glaciers occupied both the Taylor and Tallac Creek watersheds, while during the Tioga Glacial Taylor Creek was glaciated while the status of Tallac Creek is less certain. The TRPA geological data (Exhibit 2.4-2) indicates that Taylor Creek's deposits are recent Tioga Till Glacial Moraines while Tallac and Spring Creeks contain Tahoe Till Glacial Moraines. This would indicate that the smaller Tallac watershed was not affected by the less severe Tioga Glaciation. However, other research (LTBMU 2000) suggests that both creeks were glaciated during the Tioga Glaciation, raising questions about the interpretation of these deposits. The extent of the Tahoe Glaciation is unclear in parts of the Tahoe Basin (Molitor and Clark 2002). Evidence from a recent lake basin morphology study (Gardner et al. 2000) suggests that glaciers from these periods extended beyond the current shoreline at lower lake levels, depositing terminal moraines that are now submerged somewhat below current lake level. Work by Dingler et al. (2001) suggests that during the last glaciation lake levels were 40 feet below present. Evidence of hanging valleys now 590 feet below lake level suggests that previous, as yet undated, glaciations were much more severe and occurred during lower lake levels. There is also evidence that glaciers extended from Squaw Valley into the Lower Truckee River valley and dammed Lake Tahoe's outlet during the Donner Lake and Tahoe Glacials, and possible during the Hobart Glacial. Evidence from raised shoreline features suggests that damming the outlet raised Lake Tahoe's level by 490 feet during the Donner Lake Glacial and 66 feet during the Tahoe Glacial.

2.4.4 EVOLUTION OF TAYLOR AND TALLAC CREEKS

The glacial periods and fluctuating lake levels have had many important effects on the geomorphology, hydrology and ecology of Taylor and Tallac Creek watersheds. A conceptual visualization of these effects is shown in Exhibit 2.4-4. During glaciation at lower lake levels, the creeks cut valleys that were deeper than at present (Exhibit 2.4-4, A and B). It is likely that during the last glaciation (~20 Ka) the area currently occupied by the wetlands (below SR 89) would have been two depressions separated by either a low medial moraine between the Taylor and Tallac glaciers or a lateral moraine from the Taylor Creek glacier. This moraine (now occupied by the south-north running portion of the Baldwin Beach access road) is significant because, though low, it partially separates Taylor and Tallac creek wetlands into two distinct hydrological units until close to the current shoreline. Additional channel incision and valley deepening may have occurred between 7,000 and 4,000 BP when a warmer, drier climate lowered lake levels (LTBMU 2000).

As the glaciers receded and the lake level rose the depressions would have become drowned estuaries (Exhibit 2.4-4, C). Over time sediment from the watersheds filled the estuaries from the shoreline outwards, creating emergent wetlands that gradually filled in and dried out on their inland side (Exhibit 2.4-4, D). West (1985, cited in LTBMU 2000) estimated that the lake level rose and a marsh began to form in Taylor Creek between 5,000 and 2,800 BP. A barrier beach system would have formed on the shoreline, as lake currents and storms deposited sand and periodically blocked the mouths of the two creeks. There is a series of raised beaches that run parallel with the current shoreline. Two hypotheses have been put forward to explain these: raised beaches created over time as the lake level persisted at a particular elevation, and tsunamis associated with major seismic events. As more sediment was deposited and the wetland emerged and grew northwards into the lake, these ridge features were left behind as relic raised beaches (Exhibit 2.4-4, E–G).

Sediment delivery to the wetland has most likely varied greatly since the last glacial period. There have been large changes in the temperature and precipitation pattern in the Tahoe Basin during the Holocene period, with associated changes in vegetation cover, snow melt pattern, and erosion and sediment delivery. Superimposed on these natural changes have been human factors, such as logging during the Comstock era. Research on other Tahoe watersheds shows that sediment delivery has varied by an order of magnitude in the last 150 years (Simon et al. 2004.) Overlaid on these changes in sediment delivery have been lake level fluctuations that have caused the resulting alluvial deposits to alternate between a wetland and a dry fan or delta.

During periods of high creek flow or high lake levels, or when the beach barrier system was temporarily closed, water from the creeks have backed up in channels between these raised beaches, breaching the higher ground that forms the divide between the two watersheds in some places (Exhibit 2.4-4, H). In drier periods the two watersheds have functioned independently (Exhibit 2.4-4, I).

2.4.5 HORIZONTAL AND VERTICAL STABILITY OF THE CREEKS, AND IMPLICATIONS FOR WETLAND FUNCTION

The horizontal stability of creeks in the study watersheds is discussed in Section 2.6. Previous studies (LTBMU 2000) and an examination of historic aerial photographs (see Section 2.6) suggest that the main channels have been relatively laterally stable with the exception of their outlets into Lake Tahoe. Photographic evidence shows that Taylor Creek has migrated between two or three outlets over the last fifty years, presumably in response to sand buildup on the barrier beach.

Vertical stability refers to the degree to which creeks downcut or aggrade. The primary control on the vertical stability of the lower reach of Tallac Creek is the level of Lake Tahoe. Lake levels have varied greatly over the last 10,000 years, as discussed above. Since the construction of the dam outlet at Tahoe City in 1870, the lake has fluctuated by up to 10 feet.

There is evidence of incision on both creeks in response to lower lake levels. On Taylor Creek there are distinct headcuts on both main channels and tributaries approximately 700 feet upstream of the lake (see Exhibit 2.4-5). On Tallac Creek, there is a headcut that has been stopped by the concrete structure where the sewer line crosses the channel approximately 300 feet from the lake. The sewer acts as grade control for Tallac Creek, preventing incision from migrating upstream into the wetland. There is a second grade control at the SR 89 culvert crossing on Tallac Creek, and additional grade controls from culverts on both Tallac and Spring Creeks. On Taylor Creek, the dam of Fallen Leaf Lake acts as an upstream grade control structure. Other grade controls were not apparent in either watershed, except for the large boulders in the headwater sections of Tallac and Spring Creeks, which act as partial grade controls.

In addition to the lower portions of both creeks, the upper reach of Tallac Creek (above Spring Creek Road) is incised, potentially from the large 1997 flow event (see Exhibit 2.4-6). Reasons for accelerated "unnatural" channel incision are not evident; the incision encountered appears to be a natural response to disturbance in the watershed.

There is evidence for unnatural aggradation: on Tallac Creek the culvert on Spring Creek Road appeared to have contributed to sediment deposition and the blockage of the channel (see Exhibit 2.4-7). This is a potentially serious problem, because the creek here is sufficiently blocked that a future debris flow or large flood might be expected to leave the channel in an unpredictable manner

It is expected that on Taylor Creek there will be future cycles of incision during low lake periods, with associated channel erosion and bank collapse. This incision creates more lagoonal conditions in the lower area of the wetland, increasing the amount of open water. At the same time it creates locally drier banks by somewhat lowering the water table in the immediate vicinity of the creek. The amount of incision possible because of lake level fluctuations does not significantly affect wetland extent compared to the large-scale fluctuations of the water table. During periods of higher than average lake levels, the oversized channels

could fill up with sediment from the watershed and be stabilized by vegetation, reverting to their original size in a cyclical manner. If the concrete sewer line on Tallac Creek were removed, incision may migrate headwards until it equilibrates, with some associated channel erosion and local bank drying. During high lake levels the oversized channels would be expected to aggrade and narrow as sediment builds up in them and is stabilized by vegetation. In general peak sediment delivery is expected to coincide with highest lake levels (wet years), contributing to channel aggradation. By contrast, minimum sediment delivery will tend to coincide with lower lake levels (dry years), encouraging incision. Because of the Lake Tahoe dam, current and future lake level fluctuations, and associated channel incision, will be on a smaller scale than natural levels. It is expected that future natural disturbances such as floods and debris flows will occur in Taylor Creek as a result of the steep upper watershed. If the current culverts are not upgraded, it is anticipated that there will be future deposition and channel avulsion problems in the area around Spring Creek Road.

2.4.6 EFFECTS OF BEAVER DAMS

Beaver dams dominate Spring Creek, along with the upper wetland portion of Tallac Creek, and to a lesser extent the upper wetland portion of the Taylor Creek. The beaver dams are important controls on hydrology, channel course, and sediment transport. During average flow years they act as effective water and sediment barriers, causing water to disperse laterally into many small distributary channels that eventually coalesce several hundred feet downstream of the dams. They create areas of enhanced groundwater recharge, and increase the area of wetland. They also act as sediment and debris traps, reducing the transport of fine material to the lake during most conditions.

Less is known about the function of beaver dams during high flows, but some inferences can be made from anecdotal and field evidence. On Taylor Creek there is a high flow channel (assumed to have formed during the 1997 rain on snow event) that cuts across the beaver dams. Its appears likely that during high flows many beaver dams fail and "blow out," generating pulses of sediment as they fully or partially evacuate. The dams also increase the likelihood of a lateral channel avulsion in the lower wetland area, as high flows cause the dams to fail in new locations and re-direct flows. There is no evidence that the beaver dams adversely affect the geomorphic function of the watershed (e.g., increase sediment loads or encourage erosion) and they appear to generally reduce sediment loading to the lake by dispersing sediment over the alluvial surface of the wetland.

2.4.7 EROSION SOURCES AND SEDIMENT TRANSPORT

As discussed above, because of their tectonic and topographic setting, the headwaters of both Taylor and Tallac Creeks have relatively high erosion rates compared to other parts of the Tahoe Basin, and are expected to generate large volumes of sediment during episodic disturbances (e.g., landslides and debris flows during especially wet years). Fallen Leaf Lake traps almost all sediment from the upper portion of the Taylor Creek watershed. By contrast the headwaters of Tallac and Spring Creeks are connected, and so able to transport sediment all the way to the wetland area. Despite the fact that the effective watershed area for sediment

production (below Fallen Leaf Lake) is smaller in Taylor Creek than Tallac Creek, more sediment appears to be transported by Taylor Creek. Evidence for this includes the size of the delta (seen in some aerial photos) and the size of bed material (larger mean bed particle size in Taylor Creek channels). There are two potential reasons for this. First, although Taylor Creek's sediment-contributing watershed is smaller, its water-contributing watershed is larger than Tallac Creek. Thus, the sediment transport capacity is higher. In addition, water flowing out of Fallen Leaf Lake is "hungry" water (sediment starved) and, therefore, more erosive than comparable flows in Tallac Creek. This is a natural process in large lakes, and the increase in lake level from the dam probably has a negligible effect. Sediment depleted water in Taylor Creek is likely to pick up sediment in the reach downstream of Fallen Leaf Lake, regaining equilibrium between sediment transport capacity and sediment load. Most of the sediment in Taylor Creek appears to come from erosion on outside bends downstream of Fallen Leaf Lake where the creek flows against moraines. Some fine sediment comes from trails and footpaths adjacent to the creek in the same area. In Tallac and Spring Creeks most of the coarse sediment appears to come from debris flows and channel erosion in the headwaters and immediately upstream of Spring Creek Road. Most fine sediment appears to come from horse grazing and bank trampling in the wetland area of Tallac Creek.

2.4.8 TIME, SPACE, AND CAUSALITY IN TAYLOR AND TALLAC CREEK WETLANDS

In their classic paper "Time, Space and Causality in Geomorphology," Schumm and Lichty (1965) argued that different processes affect landform evolution over different time periods. This framework can be adopted to look at how the Taylor and Tallac Creek wetlands have evolved, and how they continue to evolve as dynamic systems (Exhibit 2.4-8).

Over millions of years the dominant control is the tectonic geology of the Sierra Nevada block and the Tahoe Basin graben, which determines the relationship between Mount Tallac and the lake, causing relief fluctuations between mountain and lake that vary by thousands of feet, and so controlling the gross scale stream gradient. Over thousands of years the dominant control is climate, causing glaciations and lake level fluctuations of hundreds of feet, controlling the scour and filling of the basins currently occupied by the wetlands. Over the scale of years the dominant control is weather pattern and associated fluctuations of ten feet or so in the level of Lake Tahoe, controlling the water table and beach barrier dynamics and so the local drainage and wetness of the wetland area. Human activities have superimposed a layer of new processes in the last one hundred and fifty years, by increasing sediment yield, changing vegetation patterns, introducing beaver, and by modifying drainage in the watershed. These processes may come close to, or equal the magnitude of short term processes such as water table fluctuations due to lake level changes. However, because of the relatively undisturbed state of the watershed, human activities are probably on a scale that is similar to, or smaller than small scale (yearly) processes such as lake level fluctuations and weather fluctuations.

2.5 DOMINANT DISCHARGE

Dominant discharge is the flow that moves the most sediment through a fluvial system over a long period of time (i.e. decades). Smaller, more frequent (annual) flows move sediment more

often but carry less net sediment because of their limited transport capacity. Larger episodic flows carry more sediment per event, but occur so infrequently that they transport less net sediment. The dominant discharge combines relatively large sediment transport capacity with a relatively high recurrence interval, and so moves the most sediment. It is geomorphically significant because it is believed to be the main channel-forming flow (the flow that determines the width and depth of a channel). Knowing the dominant discharge is useful in determining the flows that shape the Taylor and Tallac Creeks and wetlands, and it allows us to assess whether the channels are currently over- or undersized, which sheds light on their history and degree of disturbance.

Where there is both a long-term flow gage record and a sediment-rating curve these two data sources can be combined to calculate the dominant discharge. In their absence, the use of morphological indicators and hydraulic modeling can be used to identify apparent bankfull stage and ultimately, the associated dominant discharge. The following sections summarize the methods used to derive an estimate of the dominant discharge for Taylor and Tallac Creeks:

2.5.1 FLOOD FREQUENCY ANALYSIS

A flood frequency analysis for Taylor Creek was performed as described in Section 2.3.3. The 2-year flood discharge, assumed by many researchers to be representative of bankfull conditions, was estimated to be 307 cfs and 91 cfs for for Taylor and Tallac Creeks, respectively.

2.5.2 HYDRAULIC MODELING

To determine if the 2-year flood frequency estimates are truly indicative of bankfull conditions, uncalibrated hydraulic models were developed for reaches on Taylor and Tallac Creeks. Locations were selected where all flow is contained in a single channel and there were clear indicators of the bankfull stage (evidence of active bank erosion and the edge of vegetation). The Taylor Creek reach is located just downstream of the SR 89 bridge (see Exhibit 2.5-1). The hydraulic model for Taylor Creek is based on a single surveyed cross section (this study; see Appendix C3) and a bed slope of 0.0024 estimated from a surveyed longitudinal profile (this study; see Appendix C1). A photo of the cross section of interest is shown in Exhibit 2.5-2. Using the 2-year flood discharge of 307 cfs and a Manning's n-value of 0.04 for the main channel, Exhibit 2.5-3 demonstrates that the 2-year flood discharge for Taylor Creek at Lake Tahoe is a good predictor of bankfull conditions.

The Tallac Creek reach is located near to Baldwin Beach and extends approximately 1,260 feet upstream from its mouth at Lake Tahoe (see Exhibit 2.5-4). The hydraulic model is based on 11 surveyed cross sections and a surveyed channel alignment (this study; see Appendices D3 to D14). A photo of the cross section of interest is shown in Exhibit 2.5-5 as well as Appendix D5. Using the estimated 2-year flood discharge of 91 cfs, a Manning's n-value of 0.03 for the main channel, and an average bed slope of 0.0018 to represent the normal depth boundary conditions, Exhibit 2.5-6 demonstrates that the estimated 2-year flood discharge is greater than bankfull conditions. Exhibit 2.5-6 shows that a discharge of 50 cfs is contained in the bankfull

indicators. The scour line where vegetation roots and bare earth were exposed was taken as the bankfull indicator. Though use of such indictors is subjective, in the current setting it appears acceptable. The channel is not incised (which can leave a relict bankfull indicator 'hanging' above the current channel). Though grazing may have led the channel to widen, this would not affect the validity of a bankfull indicator, which would be scoured by the flow that does most of the work in the channel.

2.5.3 ASSESSMENT OF DOMINANT DISCHARGE

The results suggest that the dominant discharge in Taylor Creek is approximately a 2-year flood, which is consistent with many other fluvial systems. There is less certainty about the dominant discharge in Tallac Creek. While the flood frequency analysis suggests that the 2-year flow for Tallac Creek is 91 cfs, the flow that exceeds bankfull capacity is only 50 cfs. There are several potential explanations for this. One potential explanation is that the main channel of Taylor Creek was formed during events that occur every two years on average, while the channel at the mouth of Tallac Creek is formed by events that occur approximately annually. It is possible that because of its smaller size and steeper gradient the Tallac Creek watershed generates channel-forming events more frequently than the larger, less hydrologically-connected Taylor Creek watershed. Another potential explanation consistent with field observations is that while the sediment transport capacity of Taylor Creek is in relative equilibrium with sediment inputs from upstream. Tallac Creek is currently aggrading near its mouth, above the grade control structure. This may be in part because of the fact that it has not been able to incise upstream of the grade control structure, resulting in a lower gradient than Taylor Creek. In addition, it is possible that livestock grazing trampling of the creek banks and grazing in the meadows above this reach has resulted in an excess fine sediment delivery, causing the creek to slightly aggrade and create an undersized channel that has not yet been able to adjust.

2.6 AERIAL ASSESSMENT

An assessment was performed by PWA of a sequence of aerial photographs obtained from the Forest Service and approximately rectified by EDAW. The sequence of aerial photographs included photographs flown on 7/13/1940, 8/14/1952, 6/27/1967, 8/24/1976, 9/10/1983 and 8/19/1995. The rectification by EDAW involved rotating and scaling the images to match as closely as possible topographic features identified from a USGS quadrangle for the project area, but the images still contain some distortion as they were not orthorectified. This sequence of aerial photographs was supplemented by the most recent aerial photograph taken for this project on 10/9/2003. The 2003 aerial photograph was projected to real coordinates using ground control. Assessment of stream channel and stream mouth pattern and character was made by interpreting and then digitizing water features from the photographs as well as using a photogrametrically-derived topographic model developed by PWA to identify theoretical inundation areas because of lake level.

2.6.1 TAYLOR CREEK MOUTH DYNAMICS

Exhibit 2.6-1 shows the sequence of photographs for the mouth of Taylor Creek from 1940 to 2003. It appears from this sequence of photographs that littoral drift tends to move the fluvial deposits emerging from Taylor Creek in a westerly direction, because of prevailing currents in Lake Tahoe in combination with delta formation. The features at the mouth of Taylor Creek shown by the sequence of photographs display qualities typical of sand spits often found at coastal estuaries subject to large littoral drift. The evolution of the sand spit at Taylor Creek typically appears to project from east to west approximately parallel to the shoreline. From the sequence of photographs it appears that the mouth of Taylor Creek does not typically close off because of littoral processes. Closure of the sand spit or barrier beach would typically occur at periods of lower flows in Taylor Creek, probably in late summer to early fall. Anecdotal evidence provided by LTMBU suggests that the barrier beach at the mouth of Taylor Creek does, in fact, periodically close off, and in recent memory, this closure has been artificially breached by LTBMU staff to accommodate the Kokanee salmon run from Lake Tahoe into Taylor Creek in the fall. This seasonal closure is similar to the mouth dynamics for the coastal zones of California rivers and streams, which typically close in late summer.

In high flow events, flow from Taylor Creek probably rapidly erodes the sand spit which forms across the mouth of Taylor Creek, resulting in the alignment of the mouth developing in a more northerly direction. To a lesser extent, spring snow melt runoff that typically occurs from April to June may also result in some erosion of the sand spit by flows out of Taylor Creek.

It is clear from the sequence of photographs that the mouth of Taylor Creek is highly dynamic and is influenced by the large variation in flows and the large sediment supply from the Taylor Creek watershed that exists because of the relatively large watershed. It is believed that the main source of this sediment is predominantly from the reach between Fallen Leaf Lake and SR 89 (see Sections 2.2 and 2.4). The regulation of Taylor Creek by Fallen Leaf Lake may also play a role in the evolution of the mouth of Taylor Creek; however, it is impossible to identify the effect of Fallen Leaf Lake from the sequence of photographs, because control existed at Fallen Leaf Lake before the earliest photograph of 1940.

It is likely that the elevation of Lake Tahoe has an influence on the evolution of the mouth of Taylor Creek. The sequence of photographs suggest that a larger deltaic effect is observed after a prolonged period of high lake elevations followed by a period of lower lake elevations, which is dependent upon the bimodal oscillation trend that is apparent in the water level of Lake Tahoe over the last century. The bimodal oscillation appears to have a period of between approximately 10 and 15 years for Lake Tahoe. For example, the mouth of Taylor Creek shown by the aerial photographs taken in 1976 and 2003 appears to have larger deltaic area than the photographs taken at other time intervals. However, it is not clear if this is merely an artifact of the lower lake elevations as the time of the photographs (for example, the lake elevation for the 2003 photograph was 6,222.4 feet NGVD 29). The physical processes by which deltaic features evolve suggests that a larger delta would form during periods of higher lake elevation with erosion of these deltaic features by stream energy at lower lake elevations. In addition, the sediment supply during periods of high lake elevation would likely be higher

during as higher lake elevations are associated with periods of greater mean annual precipitation.

2.6.2 TALLAC CREEK MOUTH DYNAMICS

Exhibit 2.6-2 shows the sequence of photographs for the mouth of Tallac Creek from 1940 to 2003. Over the last 63 years, the mouth of Tallac Creek appears to be a relatively static feature in comparison to the mouth of Taylor Creek. Therefore, it is difficult to characterize the mouth according to lake level or annual precipitation. For example, the 1952 and 1983 photographs show that the mouth of Tallac Creek is closed in 1952 but open in 1983. Both photographs were taken in the late summer during a time with high lake levels following a year of relatively high precipitation. However, close examination of the photographs reveals that in years before construction of the roads and parking structures (i.e., the 1940 photograph) the mouth of Tallac Creek was closed and in years post-construction it was open. While human intervention (i.e., opening the mouth) cannot be ruled out, it is possible that construction of the roads and parking structures modified the connectivity of Tallac Creek surface and groundwater flows to areas north and west of the paved surfaces. In post-construction years, the opening of the mouth in the summer might be caused by increased flows that create enough head to maintain a small opening to the lake.

Additionally, construction of the South Lake Tahoe Public Utilities District (SLTPUD) sewer line in 1972, consisting of a pipe encased in a protective concrete surround, in the vicinity of Tallac Creek and compaction of backfill elsewhere, might also modify the surface and groundwater connectivity in a similar manner. The constriction caused by the sewer line is clear from the sequence of photographs from 1976 to 2003. Currently, the concrete encasement is exposed in the creek bed and is likely acting as a grade control for Tallac Creek. It is possible that if the grade control were not present that the lagoon may have developed further "lobes" into the Tallac wetland upstream of the mouth but the rate and extent of the evolution of these lobes would also have been a function of lake elevation. From characteristics that were observed in the Taylor Creek wetland, it appears that upstream migrating head-cuts are the physical process by which the lobes of the lagoon formed. However, the wetland upstream of the mouth of Tallac Creek may also not have developed to such a great extent had the grade control caused by the sewer line not been present, since an incising channel would have drained the adjacent floodplain. However, the wetland development may have also been restricted by as a function of grazing adjacent to the Tallac Creek wetland.

Clearly, the mouth of Tallac Creek is significantly less dynamic than the mouth of Taylor Creek. This is a function of the smaller watershed area of Tallac Creek and hence the lower magnitude of flow events, the smaller associated sediment supply (also reduced by upstream capture of sediment by beaver dams) and also probably a function to some degree of the grade control caused by the sewer line.

Recent monitoring by PWA through the spring, summer and fall 2004 has identified that Tallac Creek periodically closes off because of the formation of a barrier beach in conjunction with low flows in the late summer months of August and September.

2.6.3 TAYLOR CREEK CHANNEL ALIGNMENT

Exhibit 2.6-3 shows the sequence of photographs for the alignment of Taylor Creek between the confluence with Lake Tahoe and SR 89 from 1940 to 2003. Over the last 63 years, the planform alignment of Taylor Creek appears to have changed very little except just downstream (north) of SR 89. At this location, and as shown by comparison of the 1940, 1952, and 1967 photographs, the channel appears to have somewhat straightened and slightly reduced in sinuosity. This may be a function of the effect of regulation caused by Fallen Leaf Lake. Additionally, Exhibit 2.6-4 demonstrates that the 1997 flood resulted in flows that avulsed from the right bank of Taylor Creek just downstream of SR 89. From the aerial photography, it appears that the flows avulsed just upstream of beaver activity (see 1995 photograph) where some flows were forced out of the main channel. The beaver activity coupled with LWD probably plugged the channel, causing the flows to divert through a previously developed side channel and deposit large amounts of sand and coarse gravels with some cobble in the channel and the easterly floodplain. Exhibit 2.6-4 also suggests that flows from Taylor Creek have gone out of bank in the past because of the persistence of the estuary channel that drains the easterly floodplain. However, even the 1997 flood and subsequent channel blockage was not sufficient to cause the channel to permanently avulse.

2.6.4 TALLAC CREEK CHANNEL ALIGNMENT

Exhibit 2.6-5 shows the sequence of aerial photographs for Tallac Creek between the confluence with Lake Tahoe and SR 89. The aerial photography suggests that Tallac Creek, through this predominantly wetland area, consists of distributary channels that appear to be relatively persistent, interspersed with beaver dams, particularly in the upper extents of the wetland. The occurrence of flow in multiple channels in the summer is presently dependent upon high precipitation combined with the presence of beaver activity. It appears from the aerial photographs that beaver activity on Tallac Creek downstream of SR 89 began sometime in the early 1970s.

2.6.5 ESTUARY AND WETLAND EXTENTS

Exhibits 2.6-6 to 12 show the theoretical inundation of the project area according the 2003 topographic model because of lake level for the 1940, 1952, 1967, 1976, 1983, 1995, and 2003 photographs, respectively. Theoretical inundation areas were developed by mapping the extent of land below a series of lake levels in the range found in the historic record. The theoretical inundation areas were overlaid onto each photograph using the lake level for that year to assist in the interpretation of the water features. Initially, the photographs were examined in an attempt to ascertain the wetland extents. However, it was found that the delineation of wetland area was very subjective, particularly for the black and white photographs and in areas where aquatic vegetation obscures the inundated areas. Where the observed areas of wetland correspond with the theoretical inundation levels this is evidence that wetland extent is controlled by lake level through the intermediary mechanism of the subsurface water table. Where observed wetland areas exceed the theoretical inundation areas this suggests that the wetlands are controlled by surface water inputs from upstream, rather

than the lake level. Overall, the theoretical inundation areas approximately match a visual assessment of the water features in the photographs, suggesting that lake elevation dominates groundwater patterns and wetland extent, at least during the summer months, during low flows from the upstream watershed. The noted exception is Exhibit 2.6-10, where the theoretical inundation area overestimates the extent of the visually assessed inundated areas in the 1983 photograph; the reason for this discrepancy is unknown, but it seems that the most likely explanation is an incorrect date for the aerial photograph.

Exhibit 2.6-13 and Exhibit 2.6-14 further show the theoretical variation in wetland extent with lake elevation overlayed on the 2003 aerial photograph. If lake elevation is assumed to be the predominant factor governing wetland inundation, as is suggested by this aerial assessment, then the relationship between lake elevation and wetland area for Tallac and Taylor Creeks can be assumed to be approximately parabolic as shown by Exhibit 2.6-14.

2.6.6 ADDITIONAL INTERPRETIVE ELEMENTS

Other visual observations were made from the sequence of photographs, which can be summarized as follows:

- Swale 1 just to the west of the mouth of Taylor Creek was open in 1940 and then appeared to close sometime between 1940 and 1952, as shown by Exhibit 2.6-7. The closure persisted through 2003.

- The wetland area to the east of Tallac Creek near the lower extents of the creek appears to be a persistent feature, despite the presence of beaver activity altering the flow distribution in later years, as shown by Exhibit 2.6-5.

- The development of a more recent secondary channel is evident on the west side of Tallac Creek which probably formed sometime between 1952 and 1967, perhaps as a result of an avulsion caused by beaver activity or a high flow event, as shown by Exhibit 2.6-5.

- As shown by Exhibit 2.6-8, there was ponding on the east side of the main access road near Swale 3 in 1967 after construction of the road, suggesting that the road potentially creates a barrier to groundwater flows between the east and west sides of Swale 3.

- Exhibit 2.6-8 demonstrates that in late spring the lake elevation is primarily responsible for ponding in the wetland areas of Tallac and Taylor Creek in a year with high water levels and slightly above normal precipitation.

- Exhibit 2.6-9 shows that in a year with low precipitation, 1976, the mouth of Taylor Creek was nearly closed. With insufficient flow to rework the fluvial deposits near the beach, some additional ponding occurred because of increased water levels behind the beach. Tallac Creek also exhibited similar behavior.

- It appears that the west beach access parking lot closest to Tallac Creek is positioned on relatively high ground that, according to photographs since 1940, is not inundated at high

lake elevations. However, the inundation patterns are based on the 2003 topography and it is unclear if fill material was imported to construct the west beach access parking lot. The access road to this west parking lot appears to disconnect the swale closest to the lake from Tallac Creek wetland.

- Similarly, the east beach access parking lot closest to Taylor Creek is positioned on relatively high ground that according to photographs since 1940, is not inundated at high lake elevations.

- The ponding pattern observed in the sequence of aerial photographs seem to indicate some degree of groundwater disconnection as a result of the main access road to Baldwin Beach, particularly for Swale 3 and Swale 4.

2.7 REFERENCES

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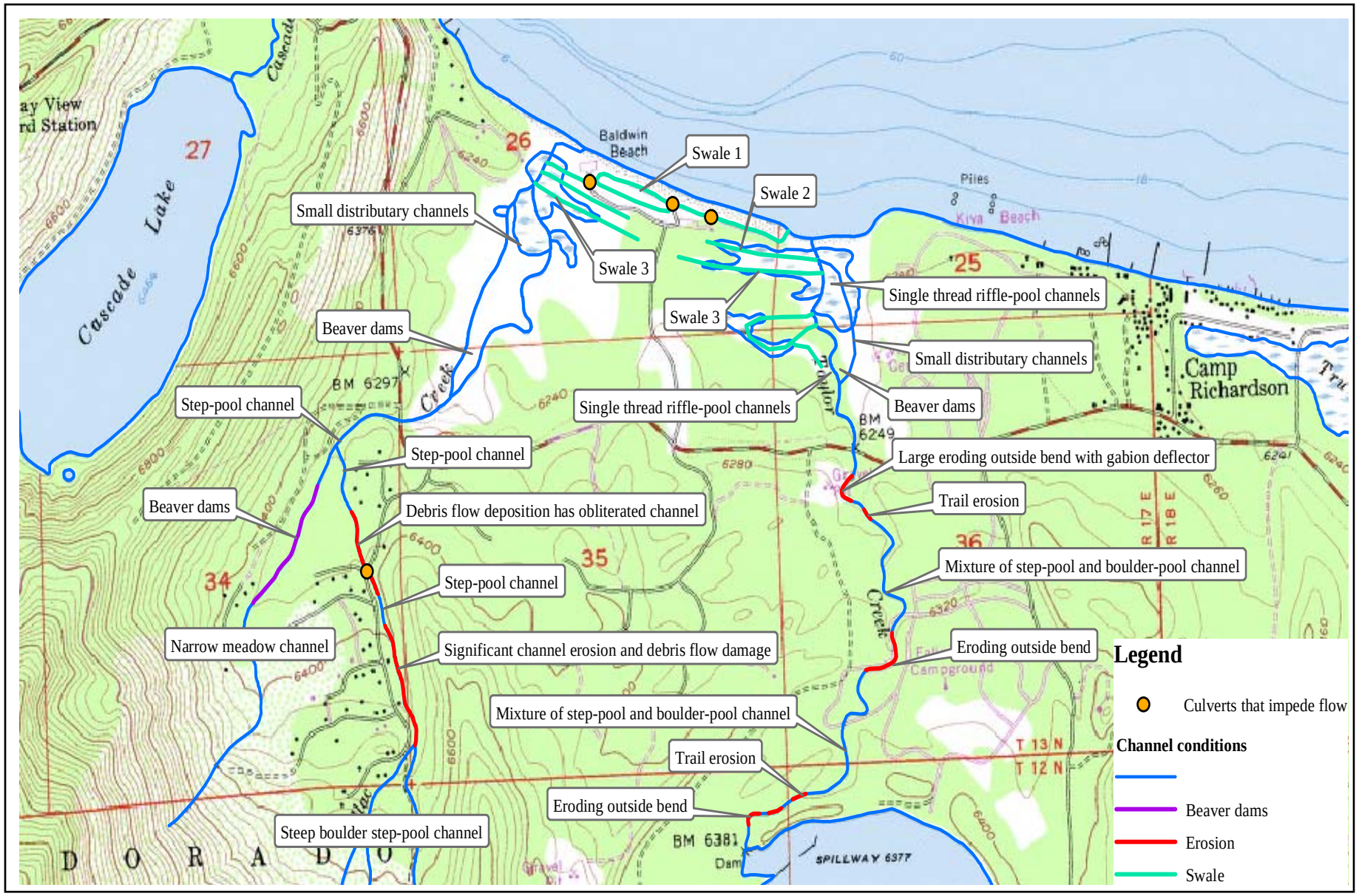
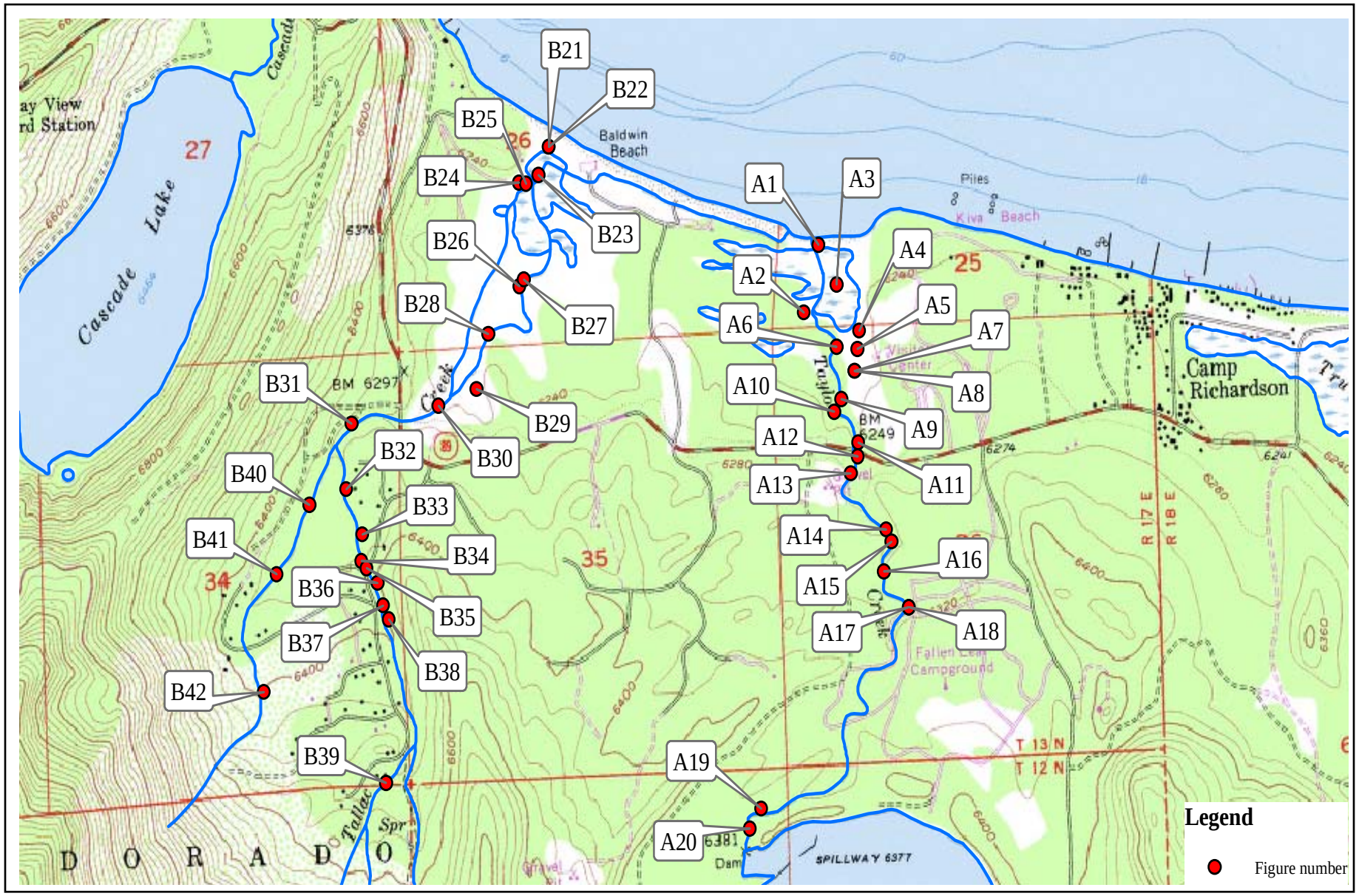


Source: PWA

Generalized Assessment of Channel Conditions

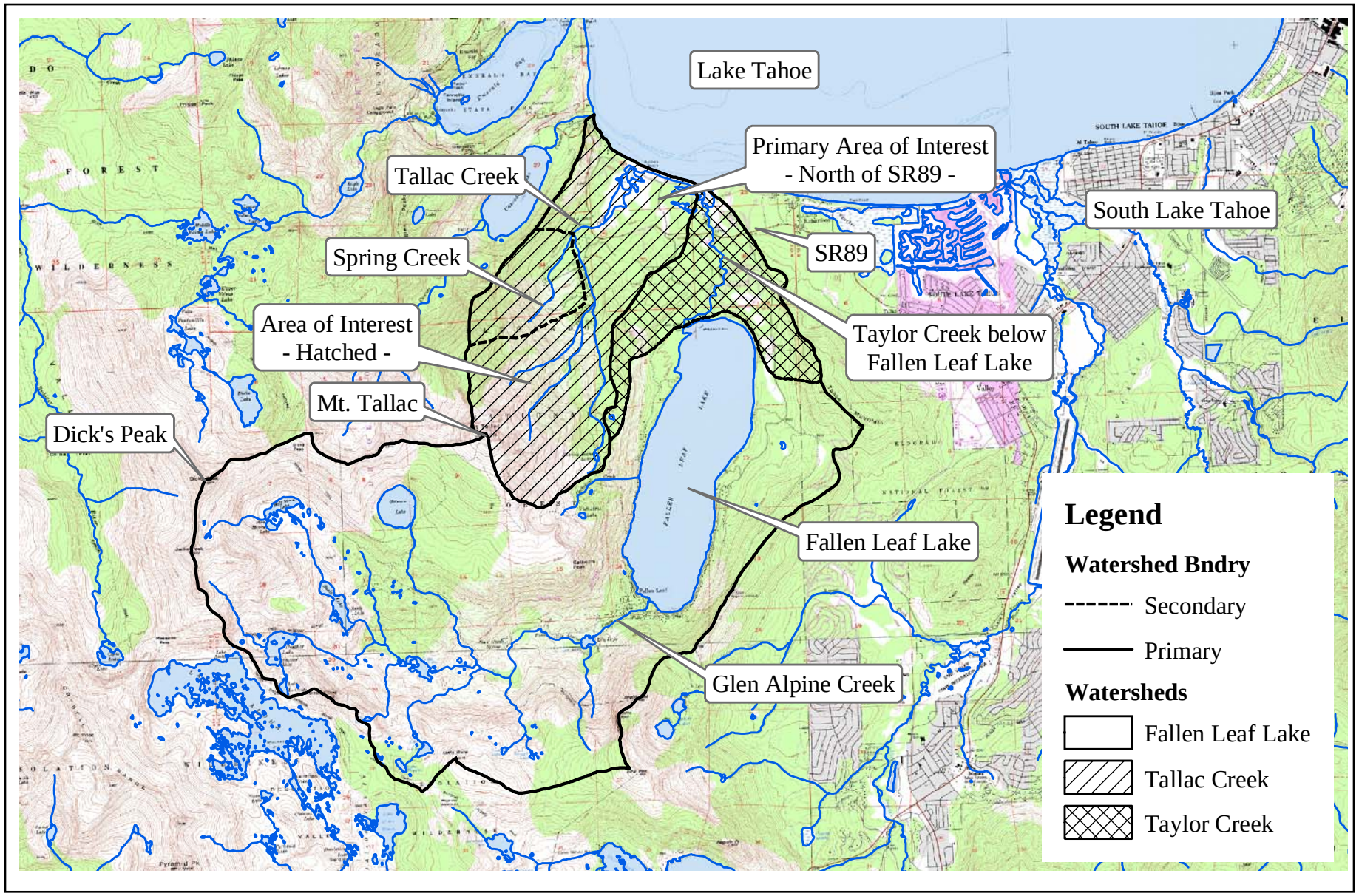
EXHIBIT 2.2-1



Source: PWA

Location of Pictures in Appendices A and B

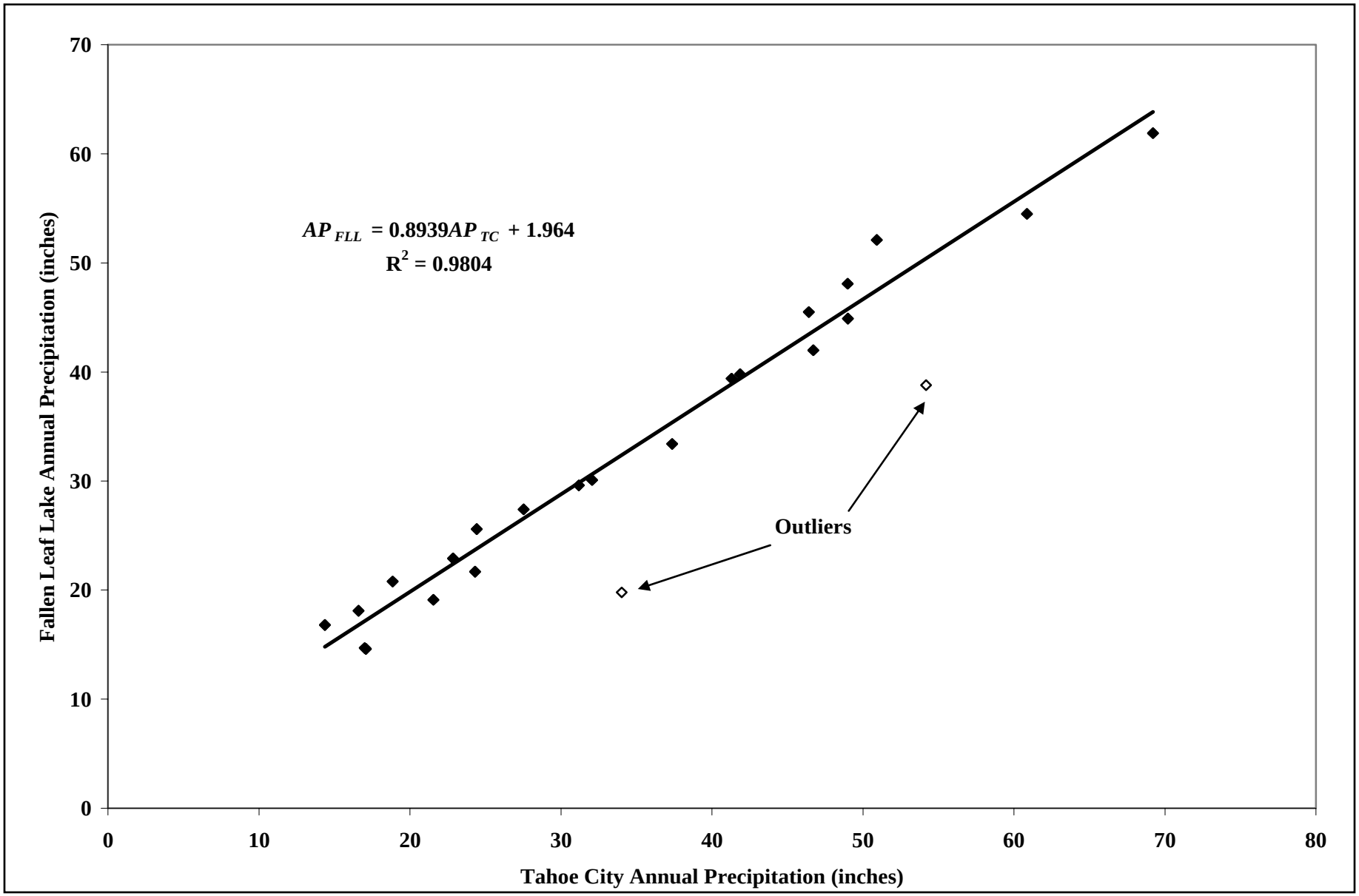
EXHIBIT 2.2-2



The area tributary to Fallen Leaf Lake is not part of this study.

Location Map and Drainage Basins

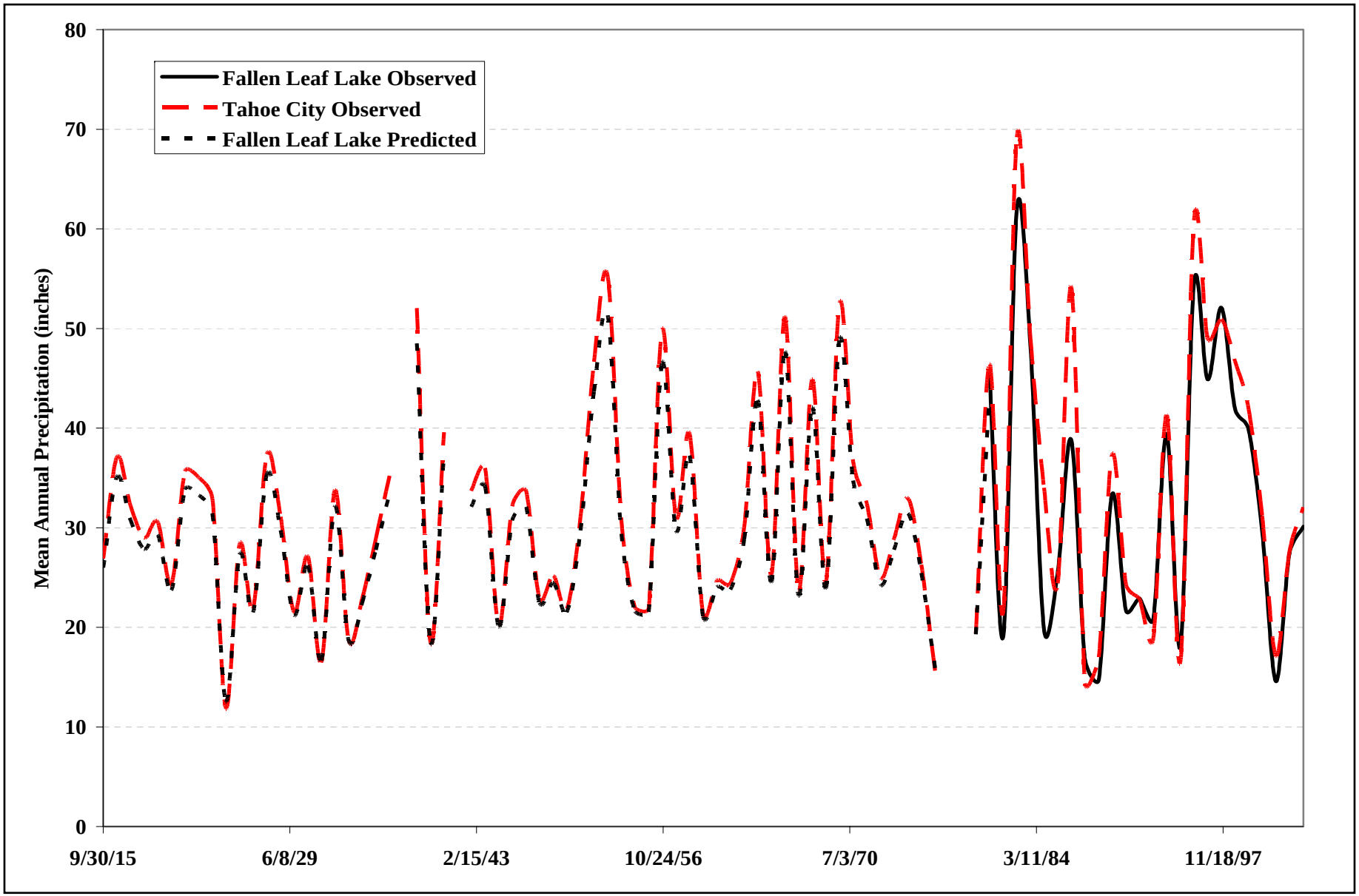
EXHIBIT 2.3-1



Source: PWA; Fallen Leaf Lake annual precipitation (NRCS website, 2004); Tahoe City annual precipitation

Annual Precipitation Correlation

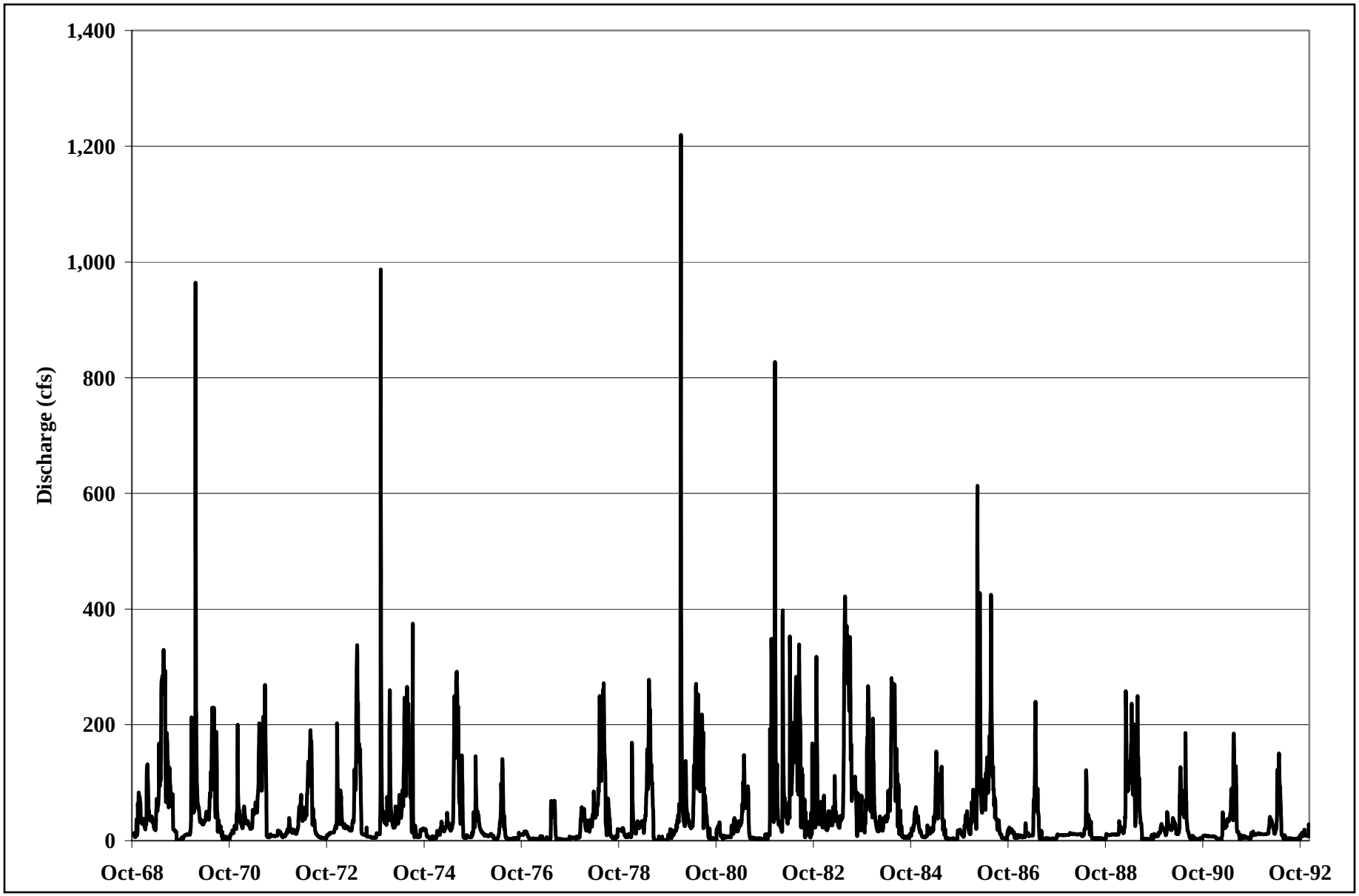
EXHIBIT 2.3-2



Source: PWA; Fallen Leaf Lake annual precipitation (NRCS website, 2004); Tahoe City annual precipitation (WRCC website, 2004)

EXHIBIT 2.3-3

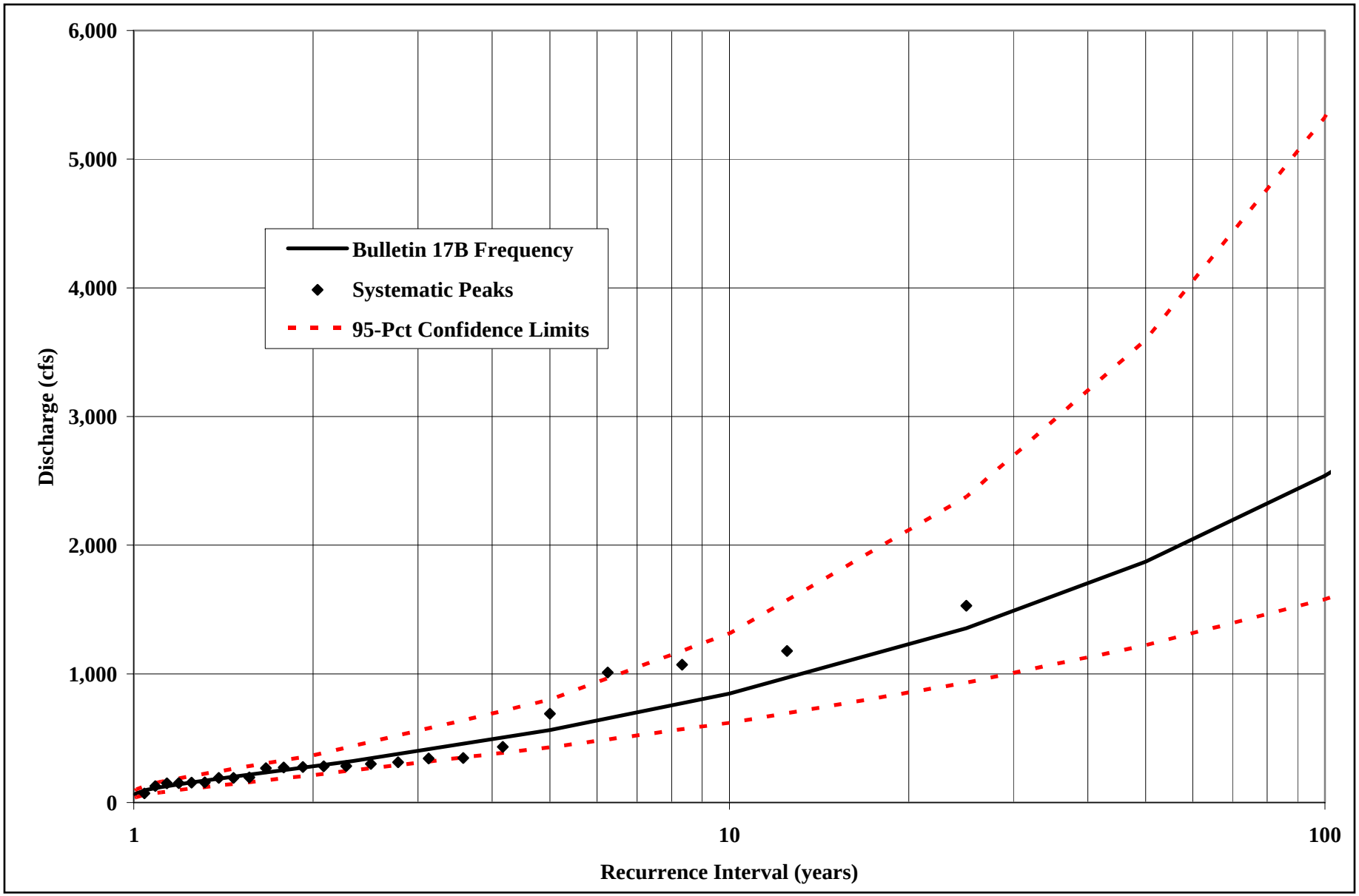
Time Series of Annual Precipitation



Notes: the USGS operated the gaging station between 1968 and 1992 after which the USFS resumed operation of the gaging station
Source: USGS gage 10336626, Taylor C Nr Camp Richardson CA, 10/1/1968 to 12/14/1992

Taylor Creek Daily Discharge (1968 - 1992)

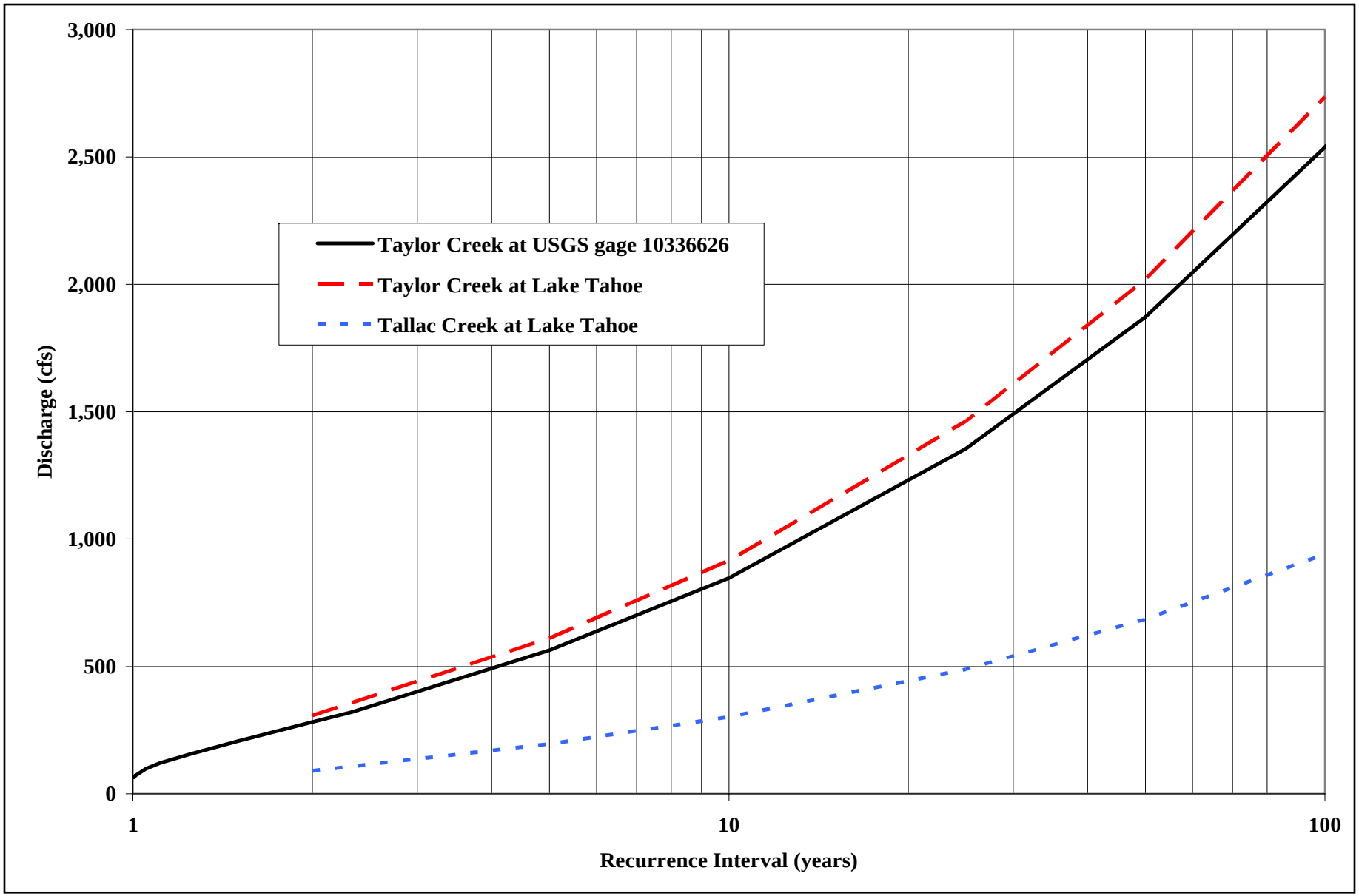
EXHIBIT 2.3-4



Notes: Bulletin 17B (Interagency Advisory Committee on Water Data, 1982) and systematic frequency curves are identical when using the station skew and the Weibull plotting position for 24 years of peaks with regulation

Regulated Flood Frequency for Taylor Creek

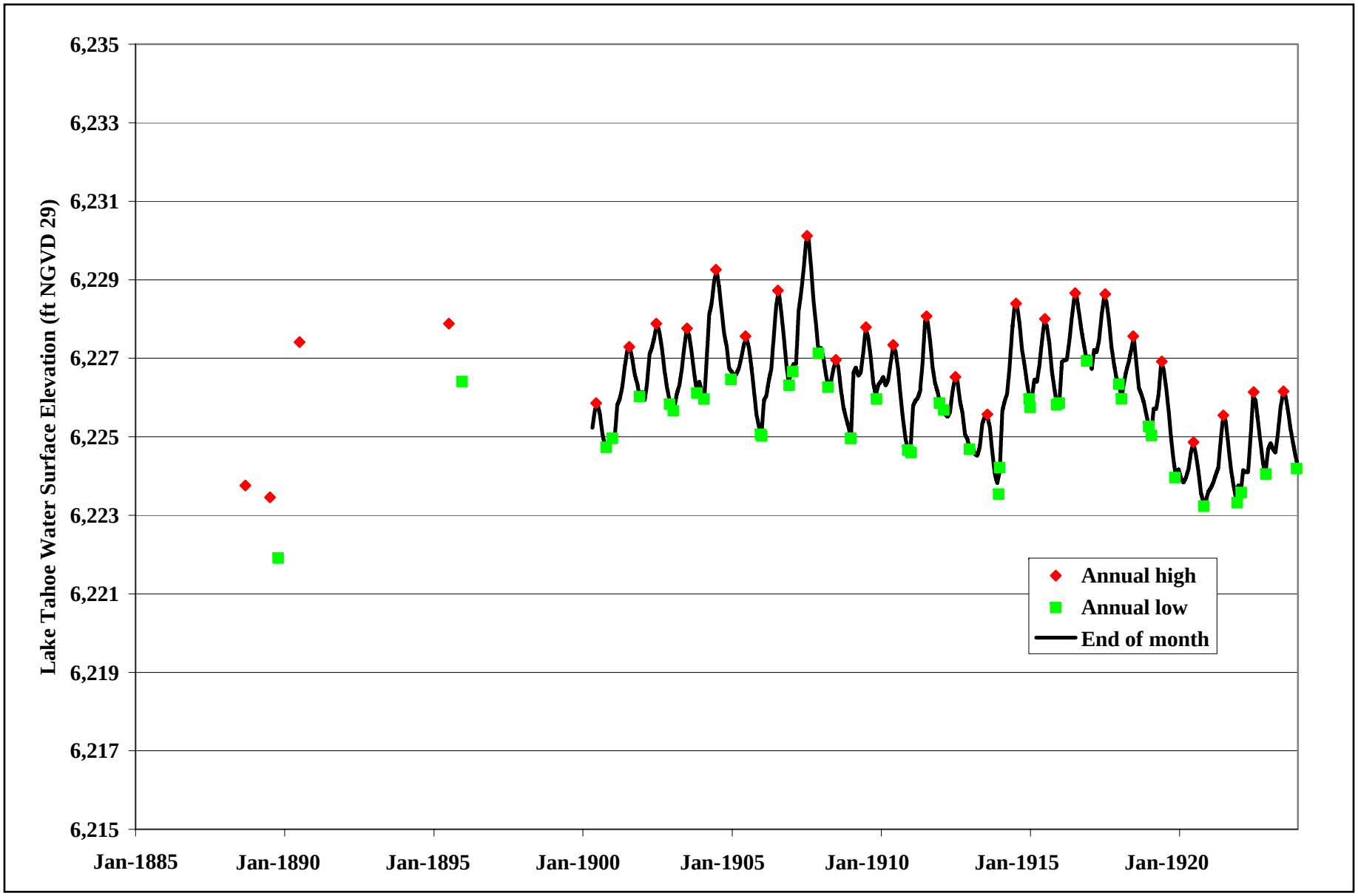
EXHIBIT 2.3-5



Notes: the Taylor Creek regulated flood frequency (this study) at USGS gage 10336626 was used to estimate the flood frequency for Taylor and Tallac Creeks at Lake Tahoe using the methods outlined by Waananen & Crippen (1977). Source: PEAKFQ program and WATSTORE ASCII file for USGS gage 10336626

Flood Frequency for Taylor and Tallac Creeks

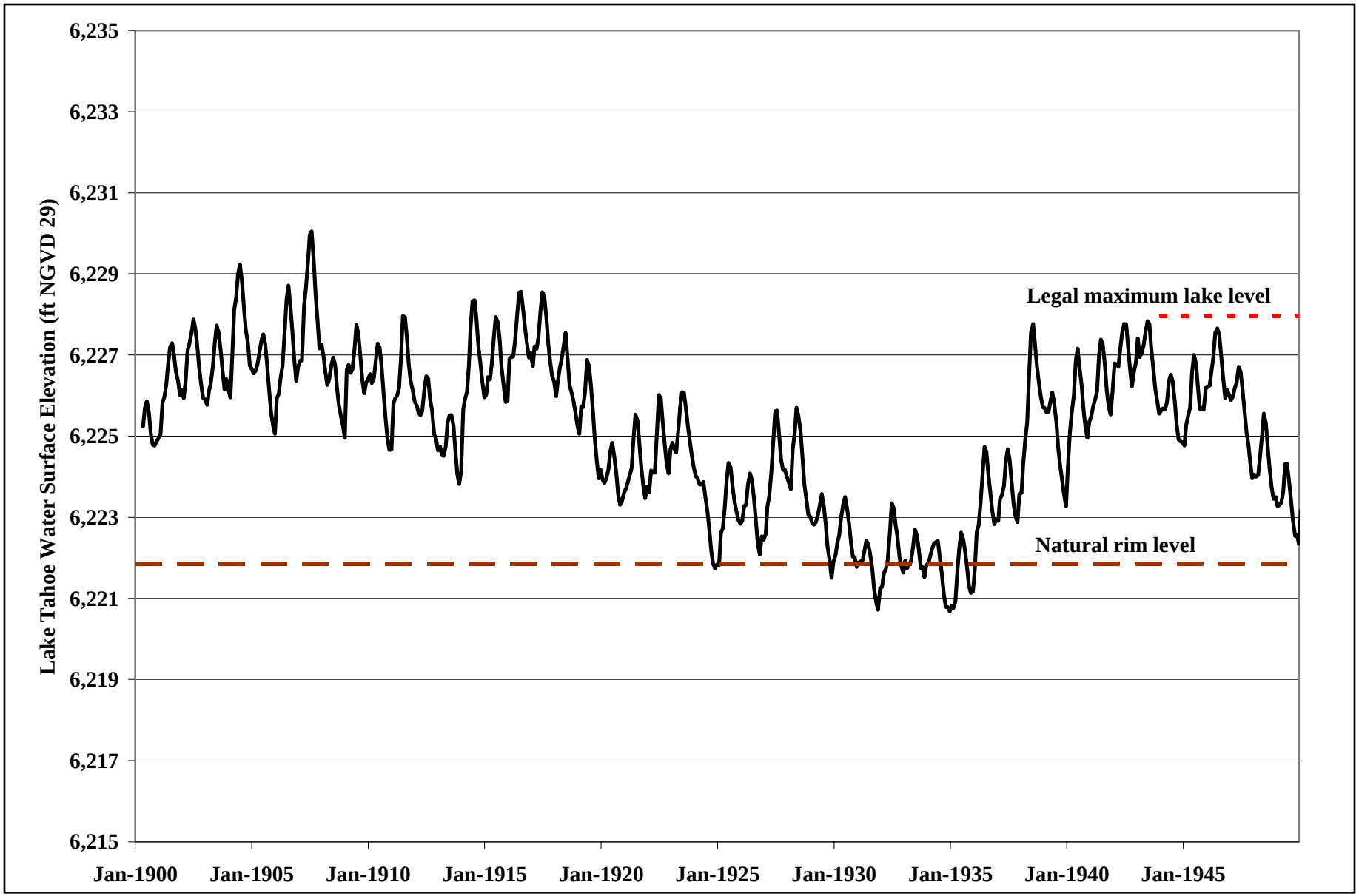
EXHIBIT 2.3-6



Notes: sometimes low water levels were recorded more than once per year; the historic and end of month data was converted to NGVD from Lake datum by subtracting 1.14 feet
Source: historic highs and lows from Glass (1990); end of month data are from Chad Blanchard, Chief Hydrologist, Federal Water Master's Office, 290 S Arlington Ave, Reno, Nevada 89501, (775) 784-5241

Historic Lake Tahoe Water Levels (1885 – 1923)

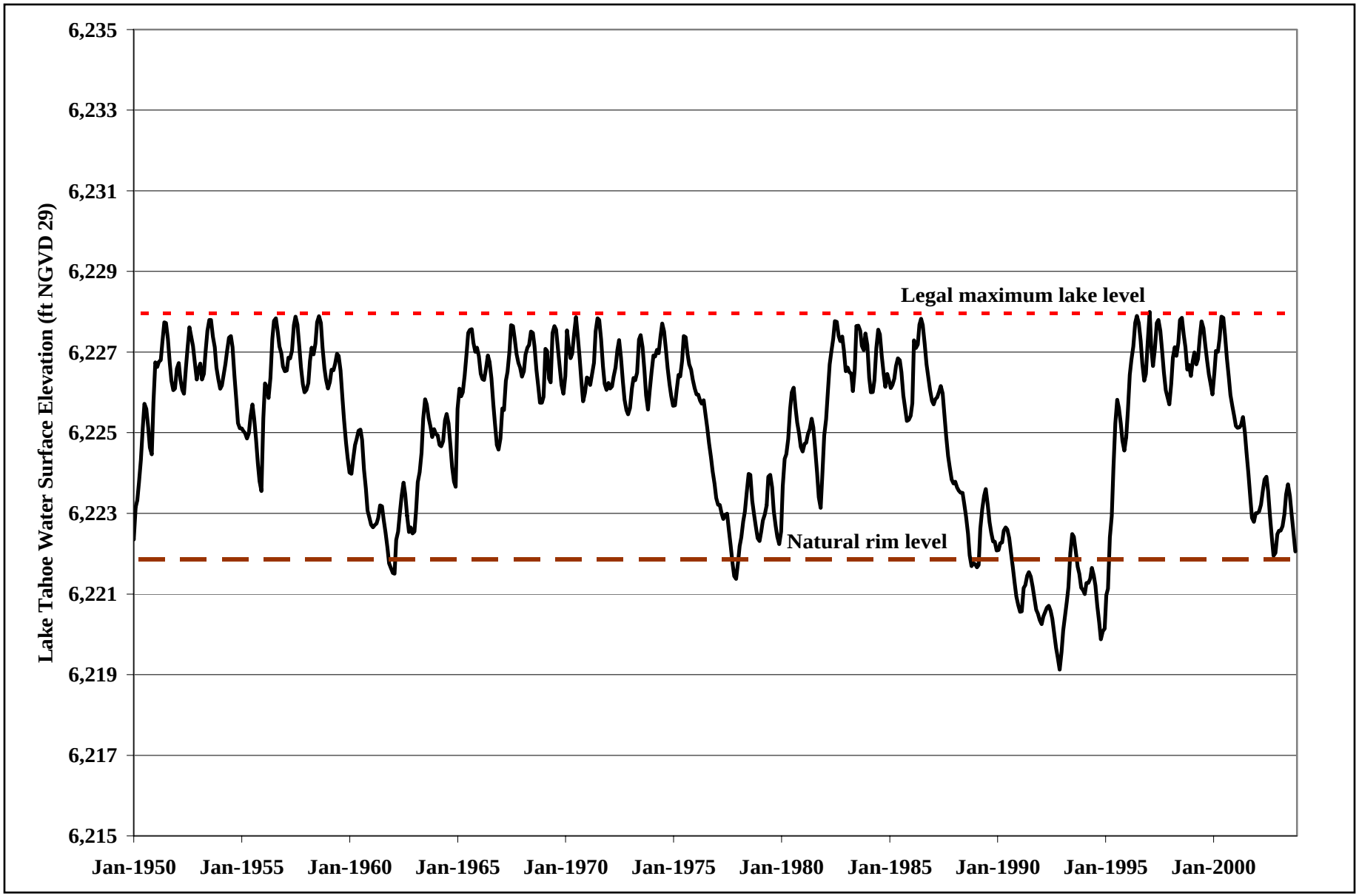
EXHIBIT 2.3-7



Notes: the end of month water levels are from the USGS (i.e. gage# 10337000) except for 7/1912 through 9/1916 which are from the USWM; water levels converted to NGVD from Lake datum by subtracting 1.14 feet. Source: Chad Blanchard, Chief Hydrologist, Federal Water Master's Office, 290 S Arlington Ave, Reno, Nevada 89501, (775) 784-5241

EXHIBIT 2.3-8

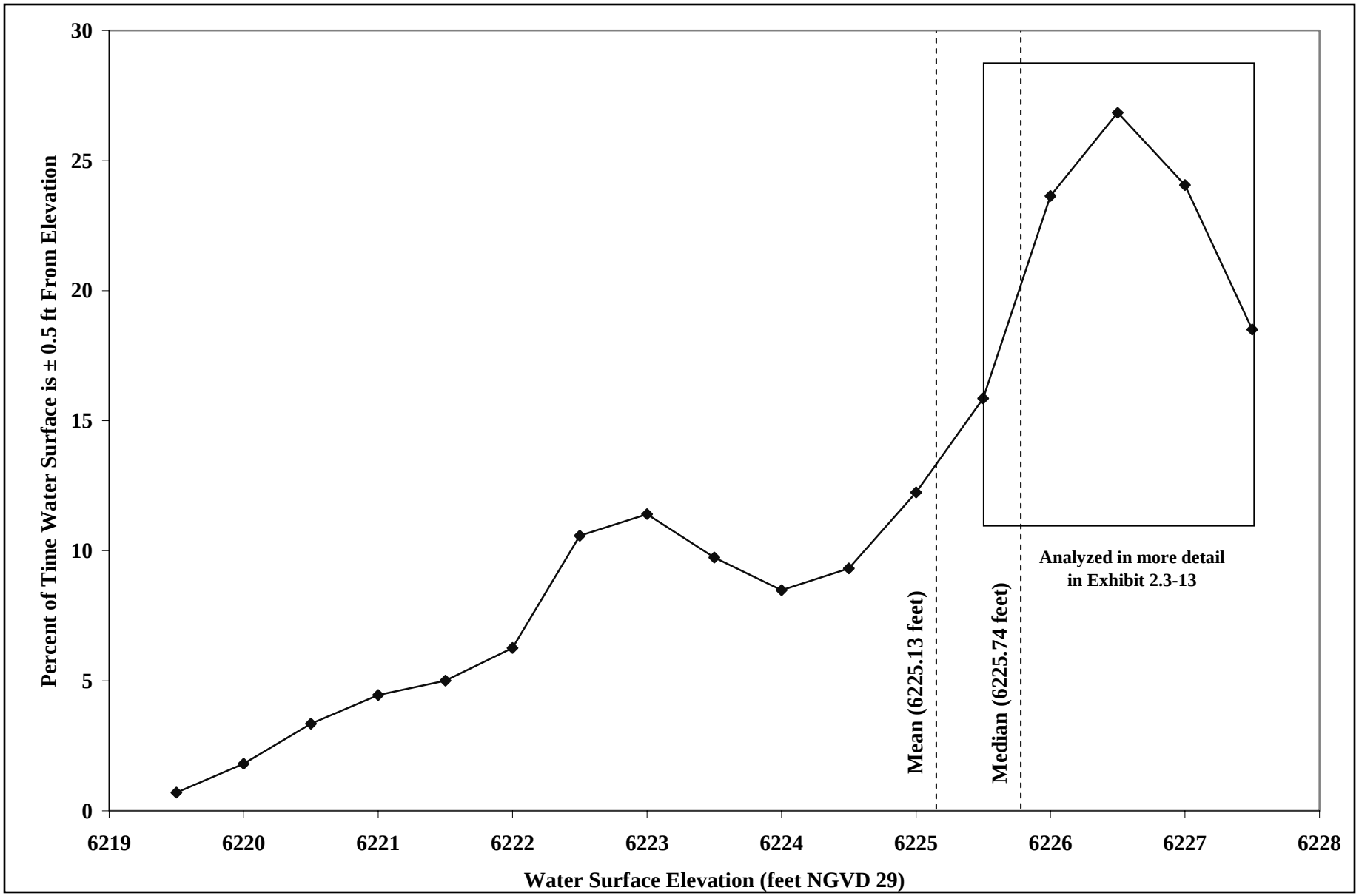
Lake Tahoe End of Month Water Levels (1900 – 1950)



Notes: the end of month water levels are from the USGS (i.e. gage# 10337000) except for 7/1912 through 9/1916 which are from the USWM; water levels converted to NGVD from Lake datum by subtracting 1.14 feet Source: Chad Blanchard, Chief Hydrologist, Federal Water Master's Office, 290 S Arlington Ave, Reno, Nevada 89501, (775) 784-5241

EXHIBIT 2.3-9

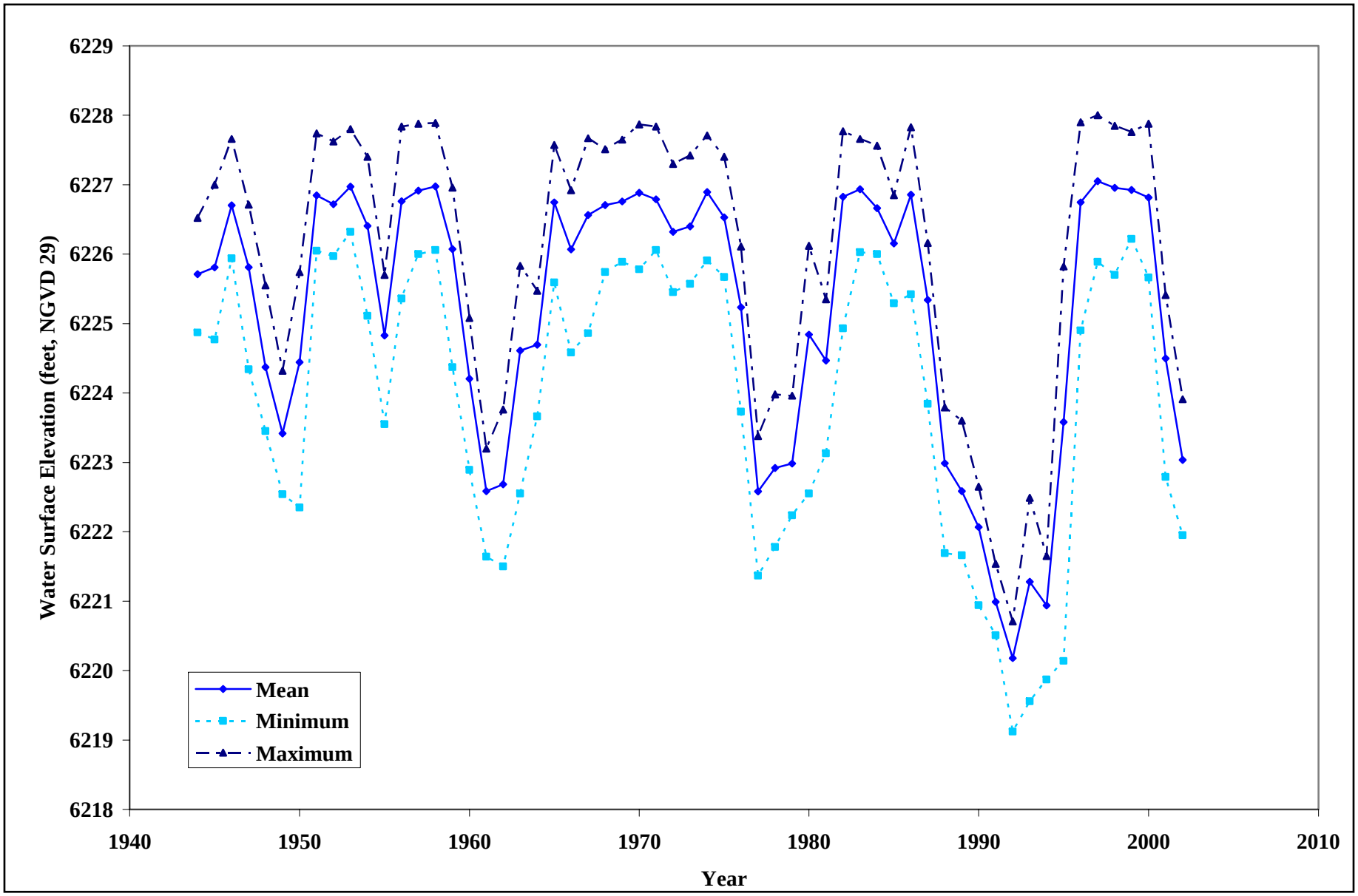
Lake Tahoe End of Month Water Levels (1950 – 2003)



Source: Chad Blanchard, Chief Hydrologist, Federal Water Master's Office, 290 S Arlington Ave, Reno, Nevada 89501, (775) 784-5241

EXHIBIT 2.3-10

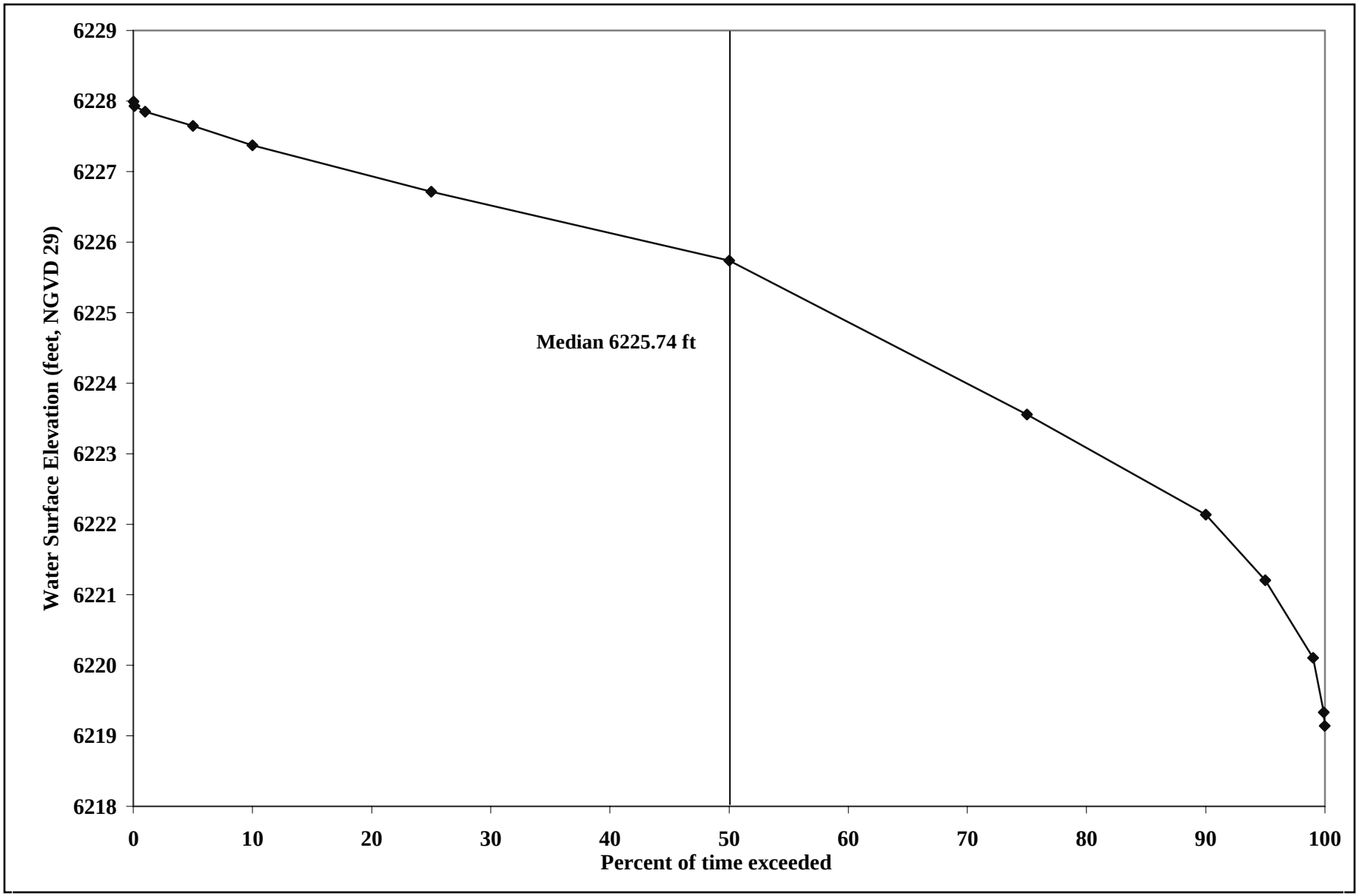
Water surface elevation ± 0.5 ft occurring most frequently: full record



Source: Chad Blanchard, Chief Hydrologist, Federal Water Master's Office, 290 S Arlington Ave, Reno, Nevada 89501, (775) 784-5241

EXHIBIT 2.3-11

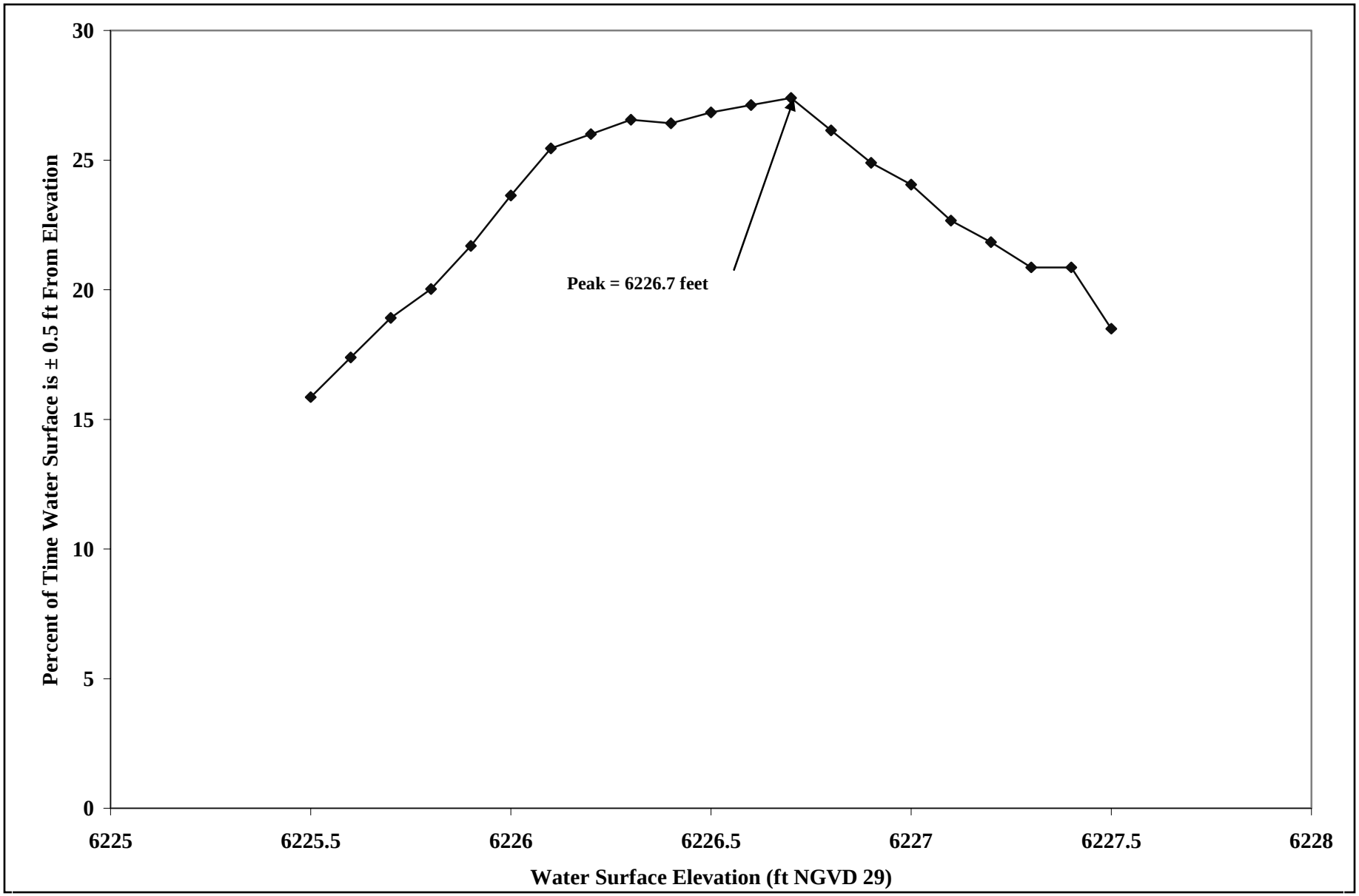
Annual Lake Tahoe Minimum, Maximum and Mean Water Surface Elevation



Source: Chad Blanchard, Chief Hydrologist, Federal Water Master's Office, 290 S Arlington Ave, Reno, Nevada 89501, (775) 784-5241

EXHIBIT 2.3-12

Percentage Exceedence Plot of Lake Tahoe Elevation Data



Source: Chad Blanchard, Chief Hydrologist, Federal Water Master's Office, 290 S Arlington Ave, Reno, Nevada 89501, (775) 784-5241

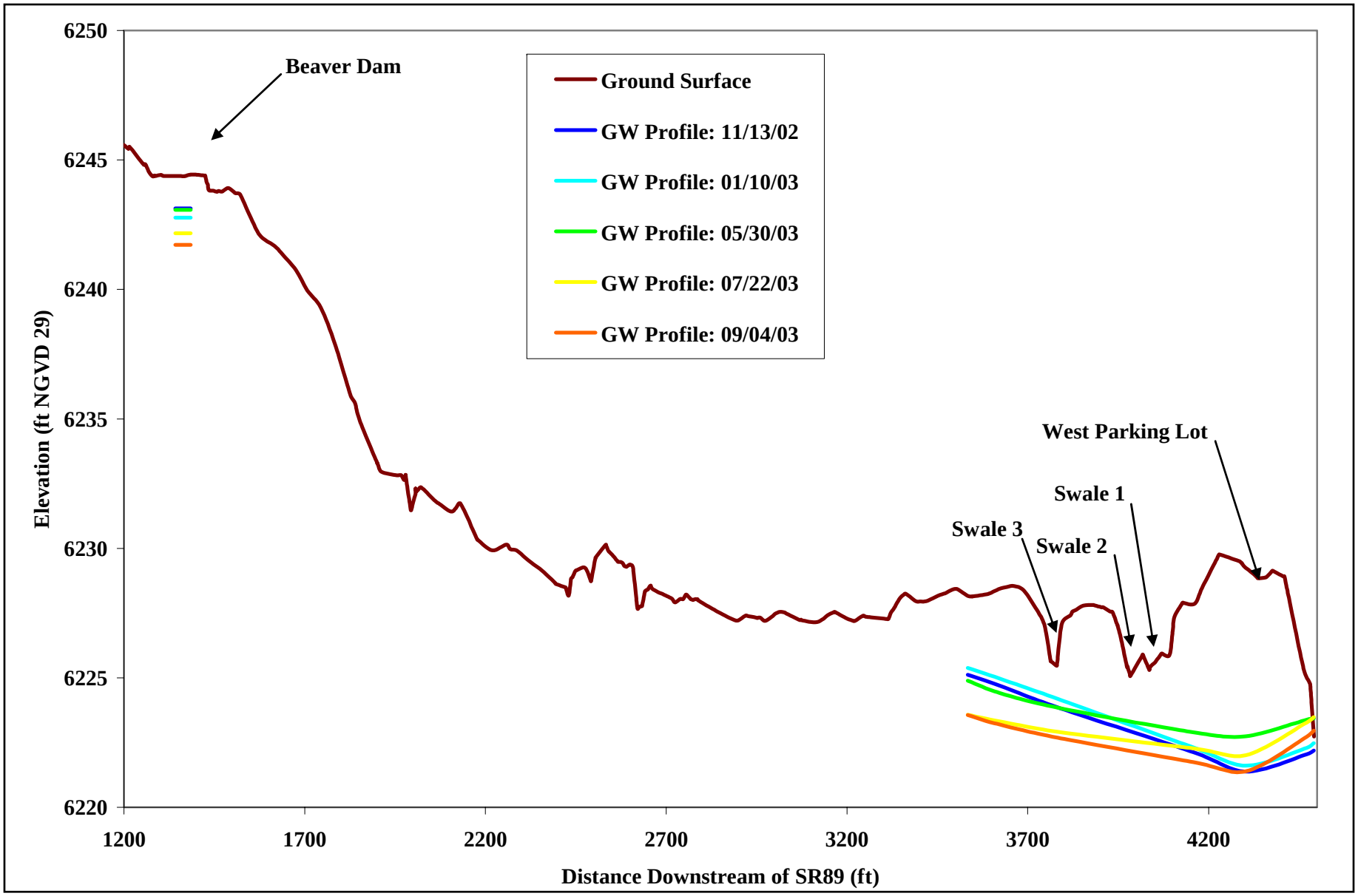
Water surface elevation ± 0.5 ft frequency of occurrence Since 1944

EXHIBIT 2.3-13

Piezometer Locations within Project Area

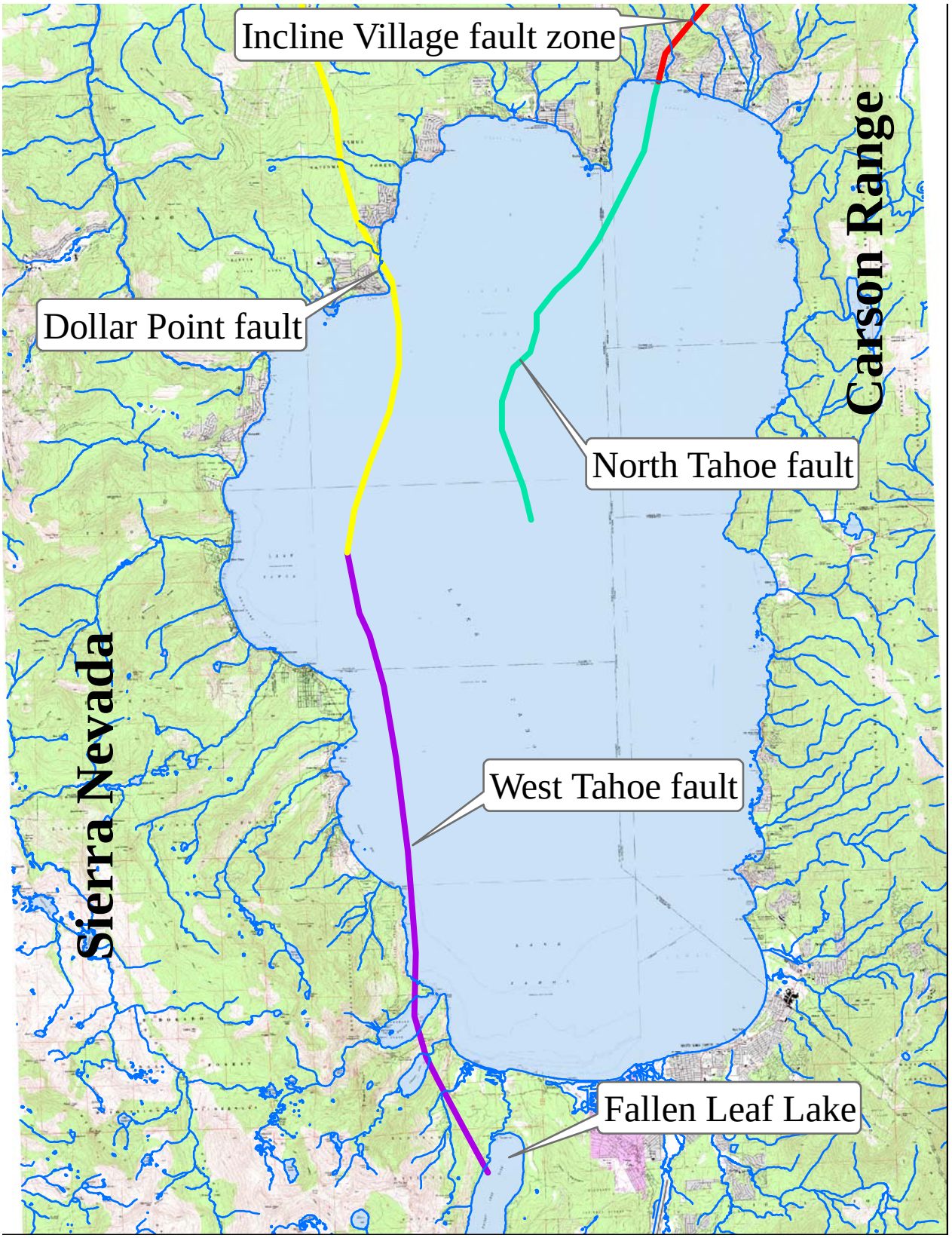
EXHIBIT

2.3-14



Year 2003 Groundwater Profiles

EXHIBIT 2.3-15

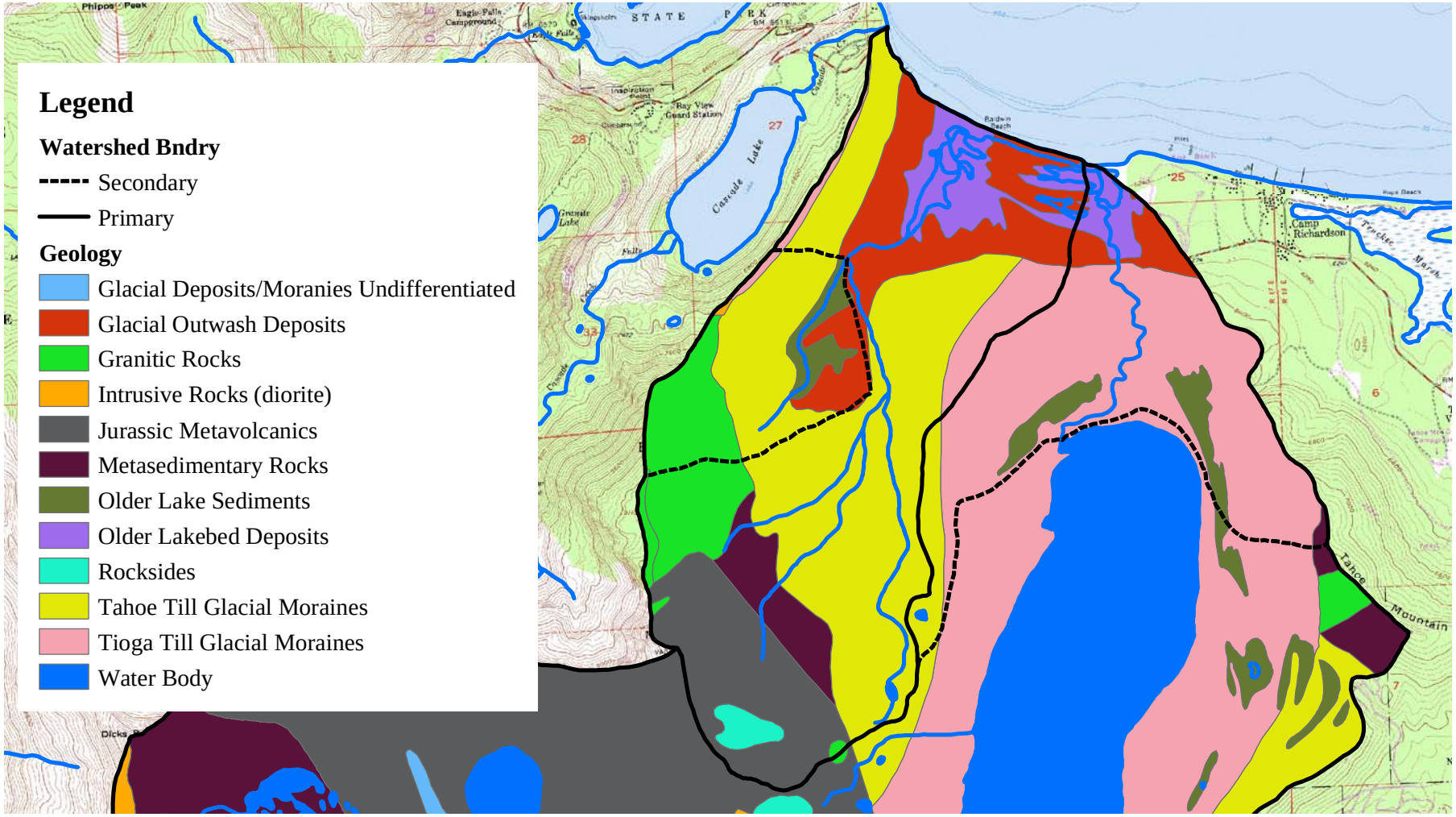


Geologic Setting

EXHIBIT 2.4-1

PWA Philip Williams & Associates Consultants in Hydrology

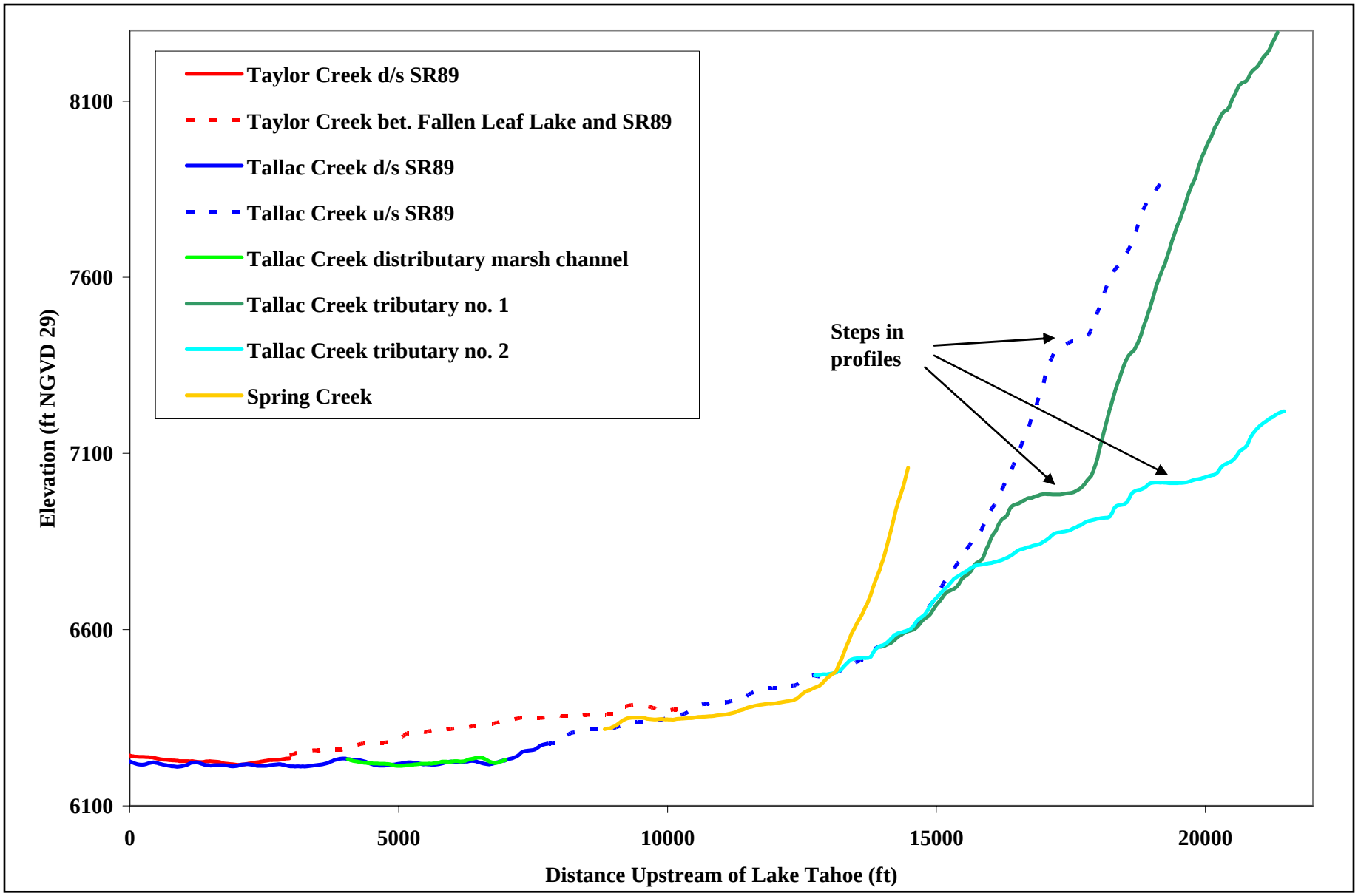
EDAW



Source: TRPA geology shapefile

EXHIBIT 2.4-2

Geology of Project Site

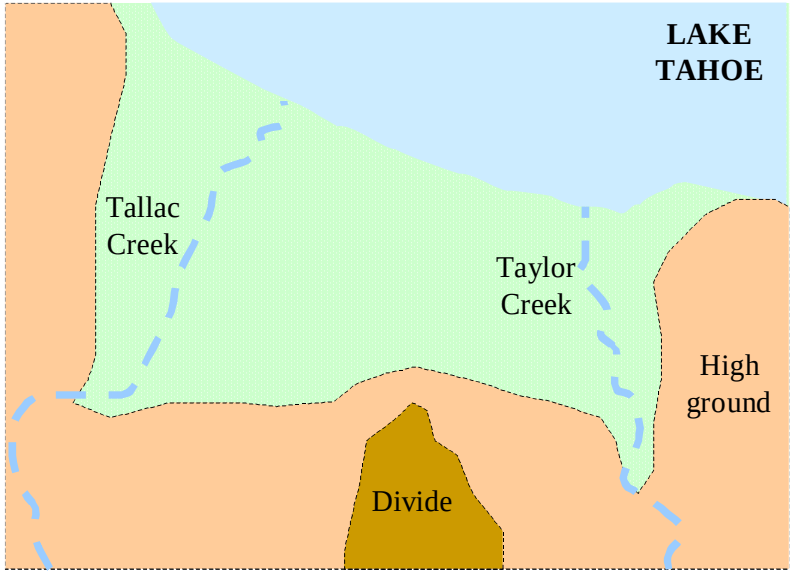


Source: USGS 24K rivers and USGS 10k DEM

EXHIBIT 2.4-3

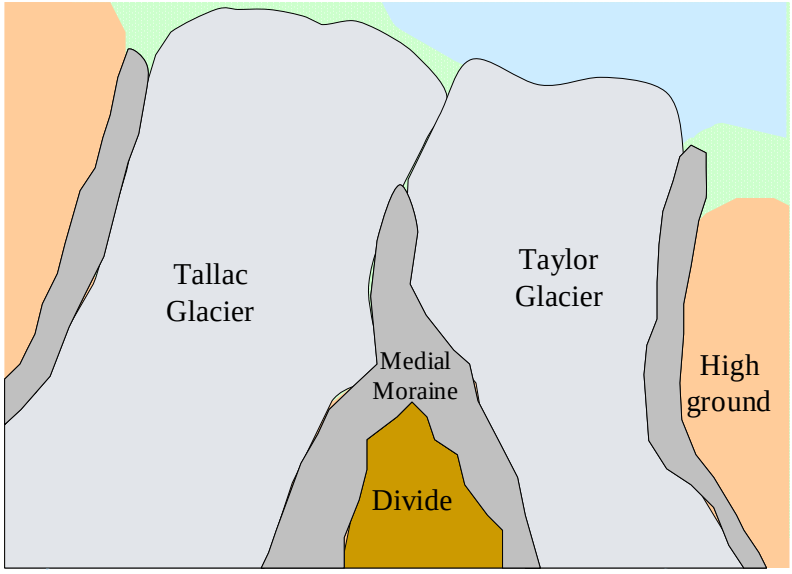
Longitudinal Profile of Creeks

Inter Glacial



4A: Project setting prior to the last glacial period

Glacial Period

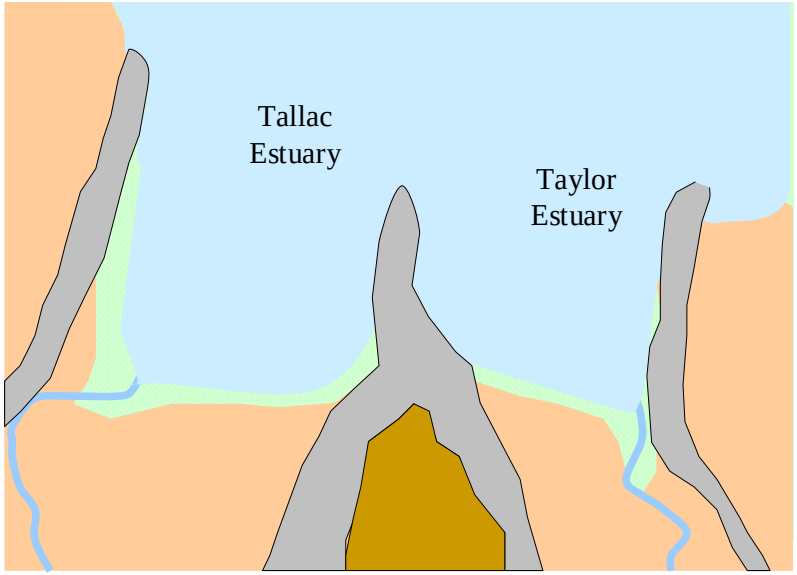


4B: Project setting during the glacial maximum

Geomorphic Evolution

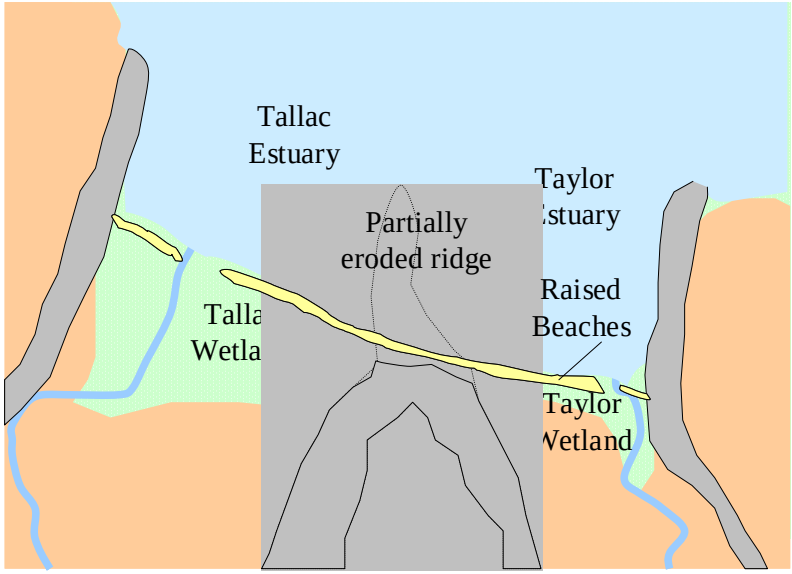
EXHIBIT 2.4-4

Post Glacial Period



4C: Development of an estuary in the deeper Tallac and Taylor valleys during higher lake levels

Sedimentation of Estuaries ~5 Ka

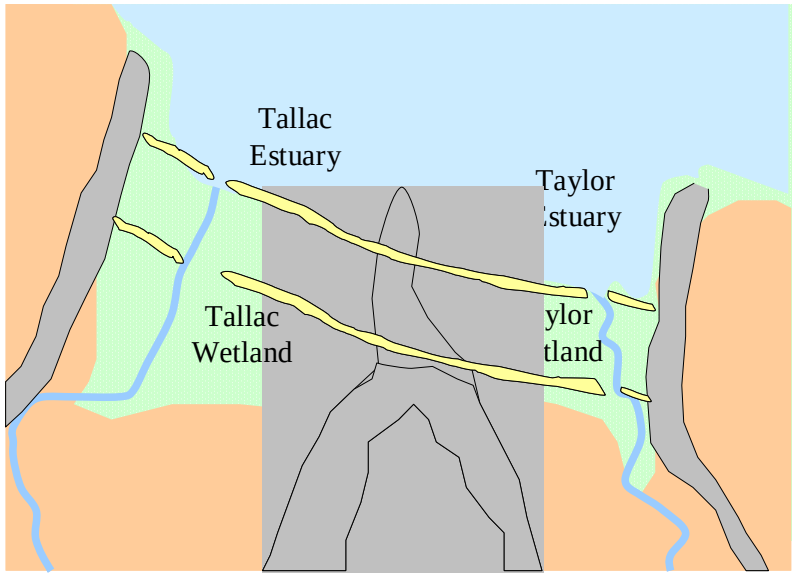


4D: Sediment infilling and the creation of barrier beaches

Geomorphic Evolution

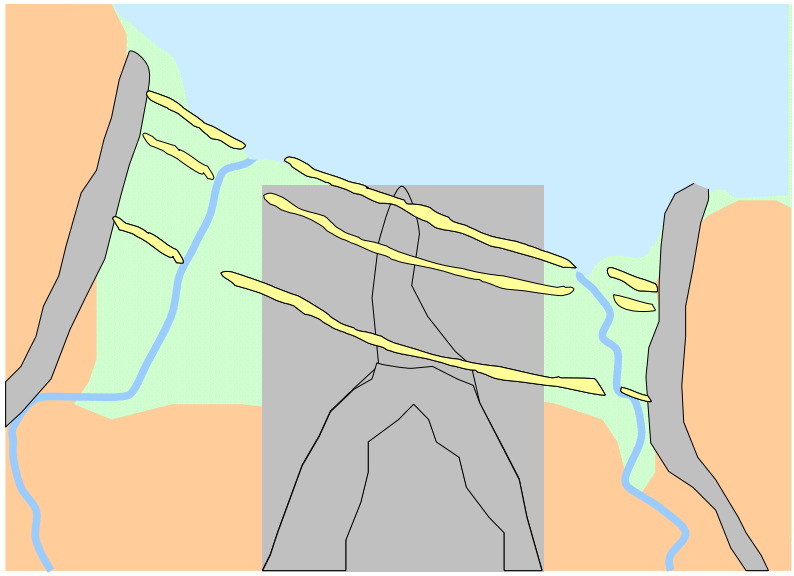
EXHIBIT 2.4-4

Sedimentation of Estuaries ~5 Ka



4E: Further sedimentation and beach line development

Sedimentation of Estuaries ~2.9 Ka

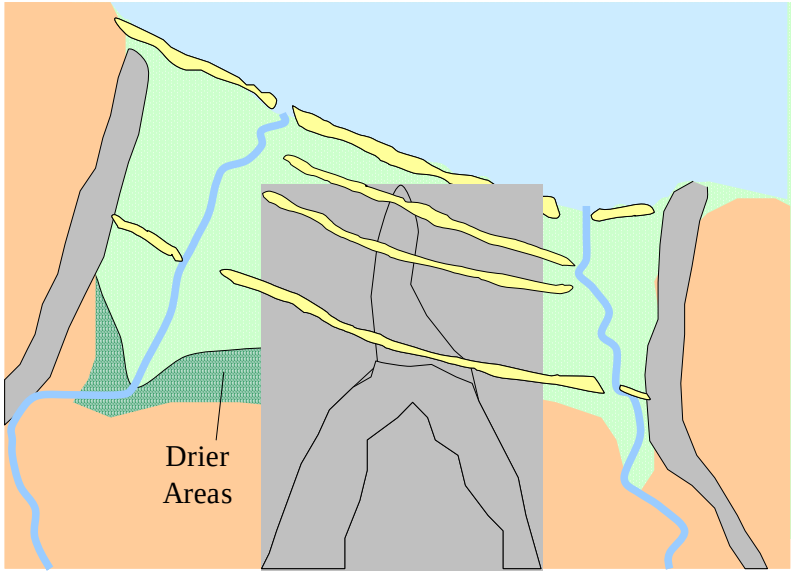


4F: Further sedimentation and beach line development

Geomorphic Evolution

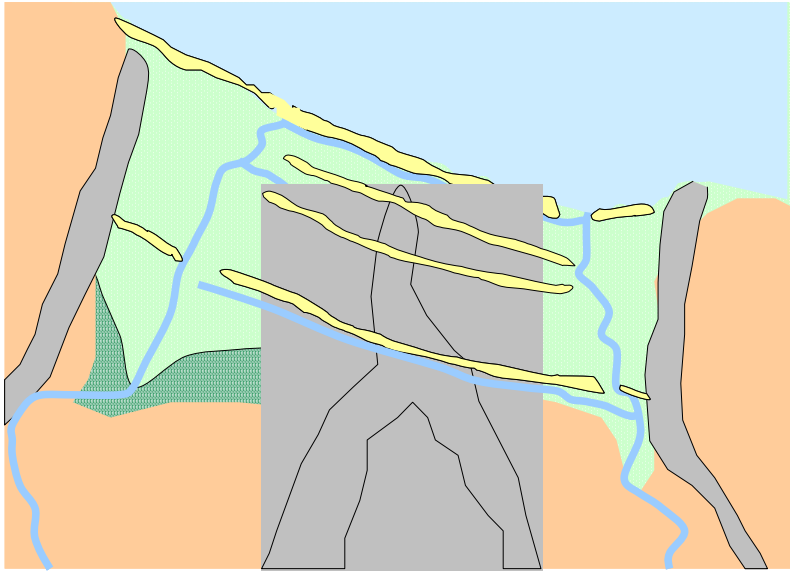
EXHIBIT 2.4-4

Sedimentation of Estuaries ~1800AD



4G: Further sedimentation and beach line development

Hydrologic Function ~1800AD

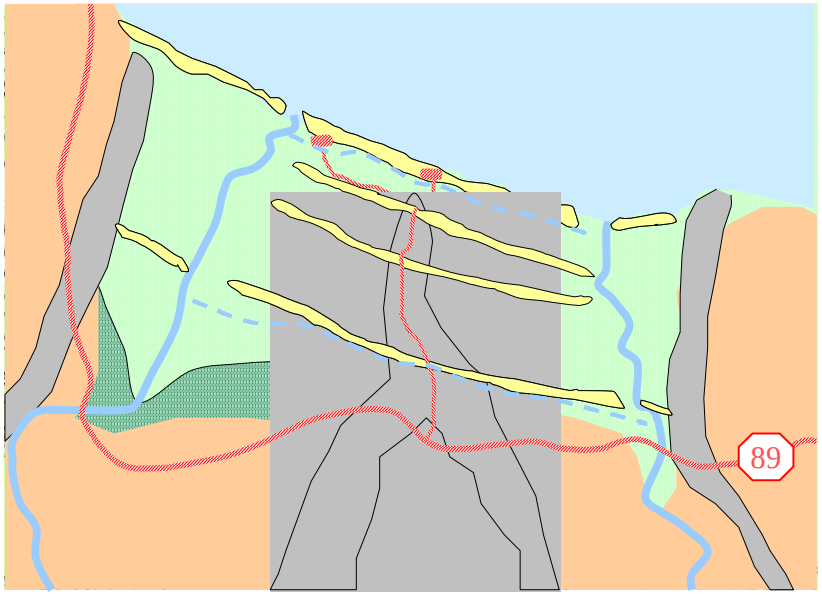


4H: Hydrologic responses to closure of Tallac Creek outlet: flows diverted between the barrier beach and the medial moraine

Geomorphic Evolution

EXHIBIT 2.4-4

Hydrologic Function ~2000AD



4I: Present-day hydrologic function

Geomorphic Evolution

EXHIBIT 2.4-4

Notice bank erosion downstream of headcut

Source: PWA

Headcut on Taylor Creek Near Lake Tahoe

EXHIBIT 2.4-5

Photograph taken upstream of Spring Creek Road on Tallac Creek

Source: PWA

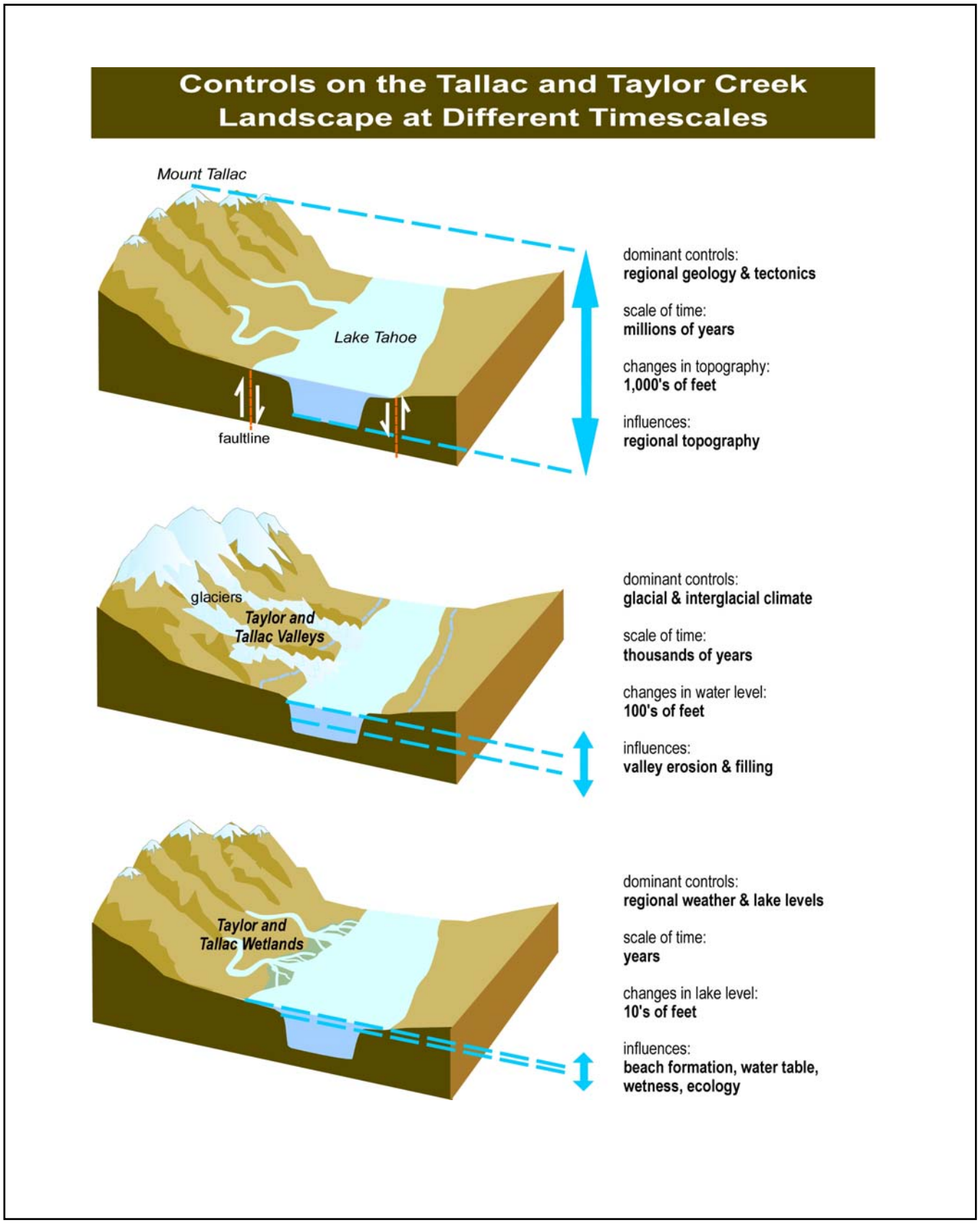
Channel Incision and Bank Erosion on Tallac Creek

EXHIBIT 2.4-6

Source: PWA

Sediment Deposition in Tallac Creek at Spring Creek Road

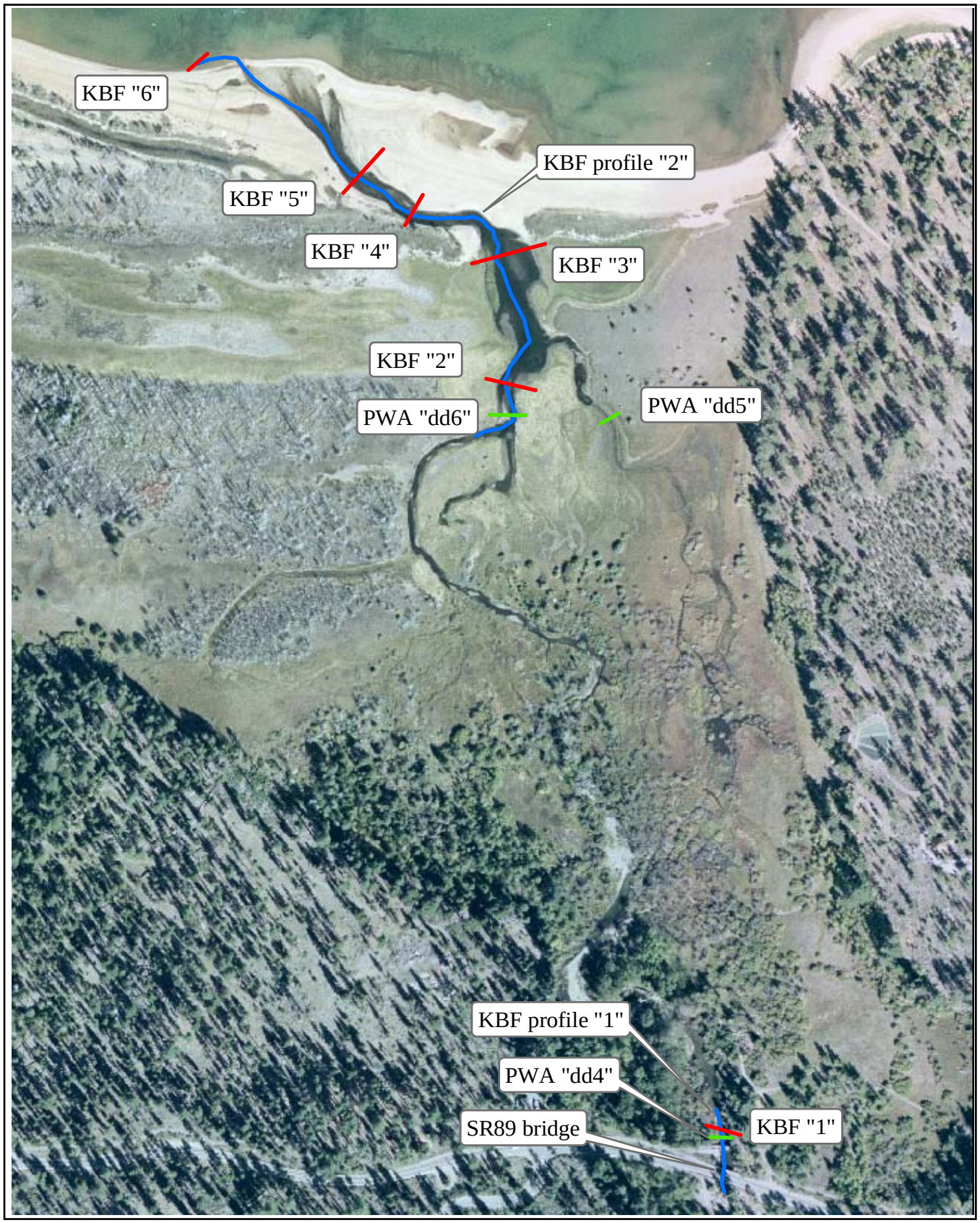
EXHIBIT 2.4-7



Source: PWA

Temporal Evolution of Tallac and Taylor Creek Wetlands

Exhibit 2.4-8



Source: PWA

Taylor Creek Survey Location

Exhibit 2.5-1

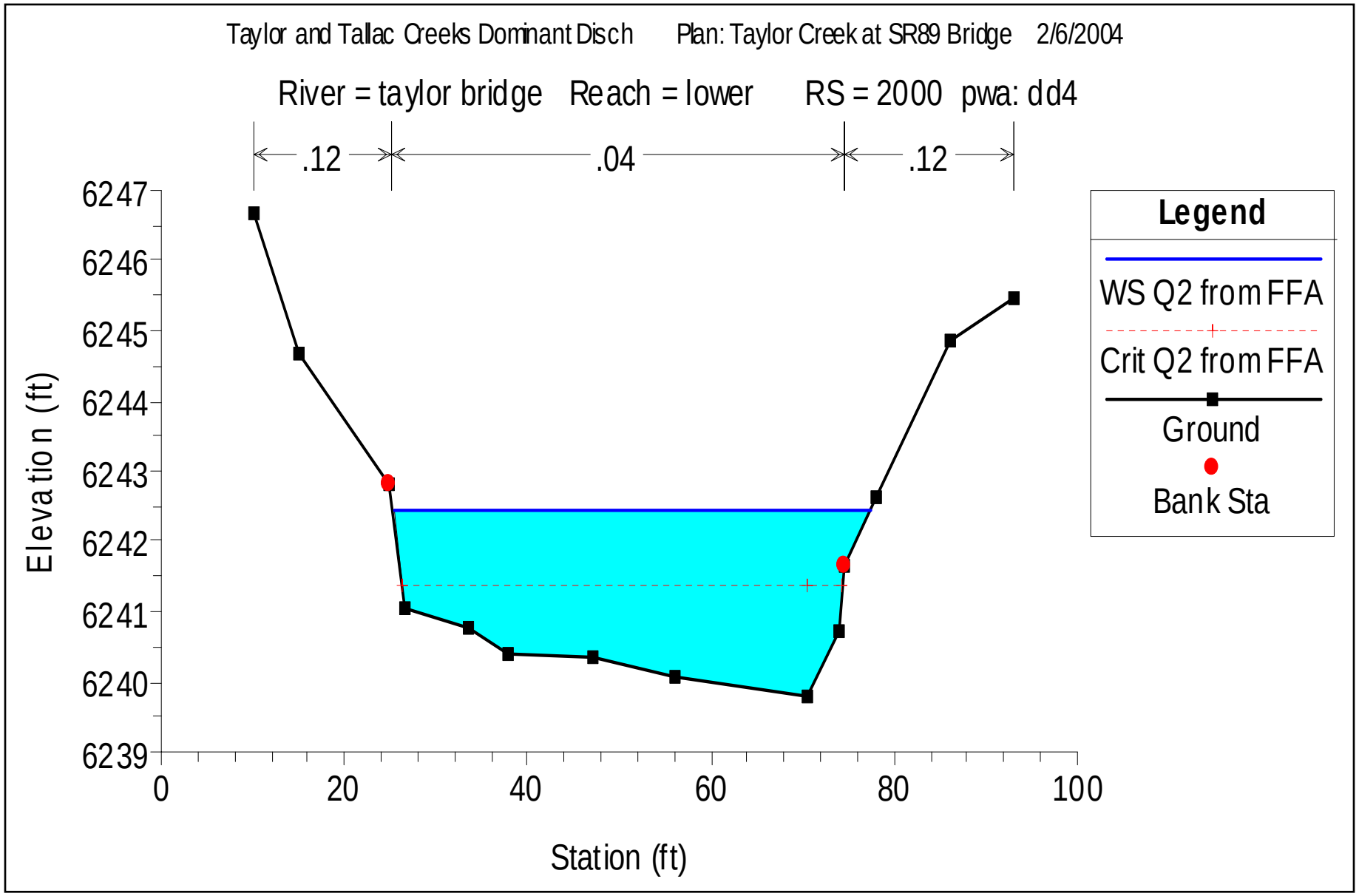
Taylor, Tallac, and Spring Creek Watershed EAR
U.S. Forest Service
P ?T???.01 01/04

PWA cross section “dd4” looking downstream from SR 89 bridge

Source: PWA

Taylor Creek Cross Section for Dominant Discharge

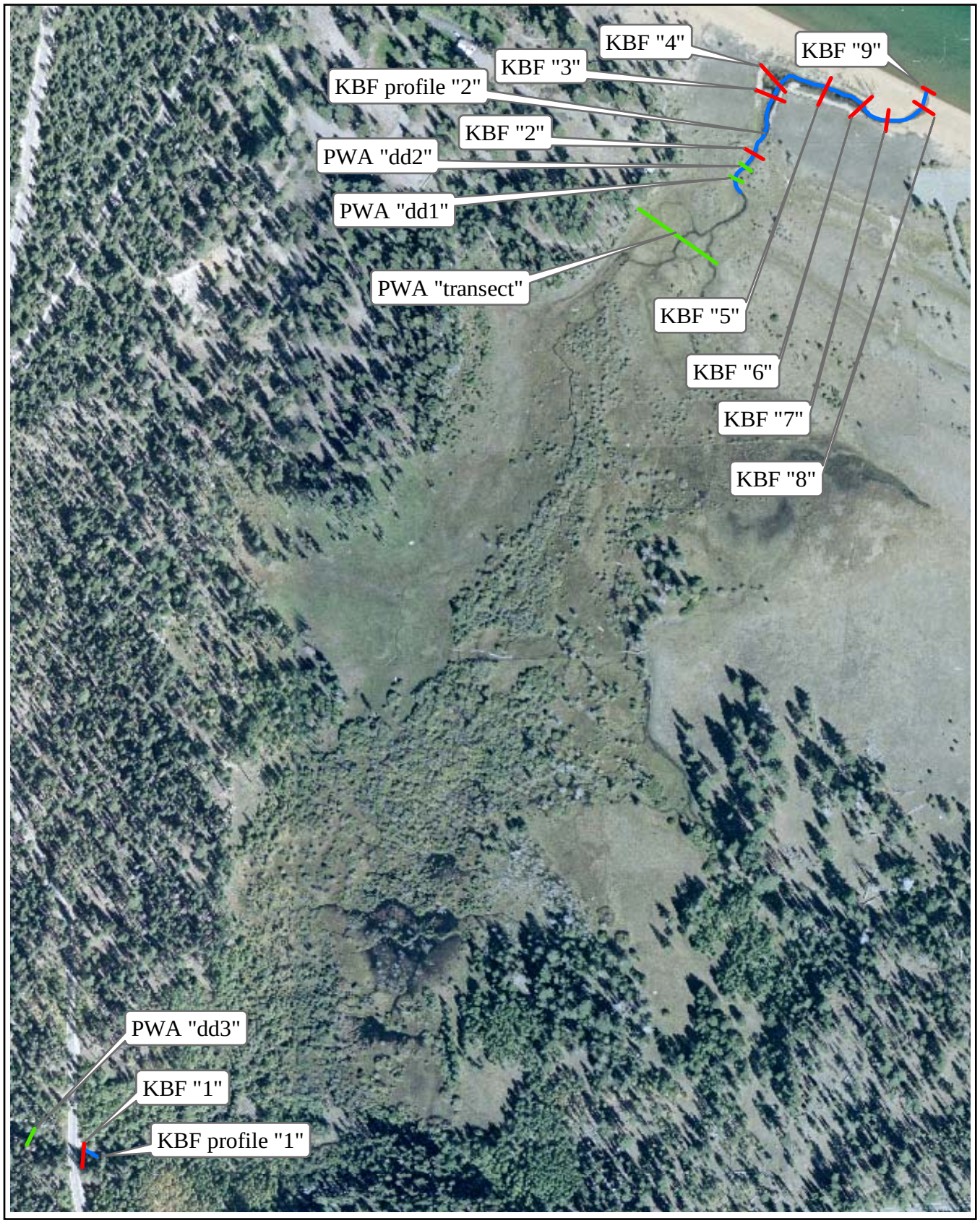
EXHIBIT 2.5-2



Source: PWA HEC-RAS output for Taylor Creek

Estimated Dominant Discharge for Taylor Creek at SR 89 Bridge

EXHIBIT 2.5-3



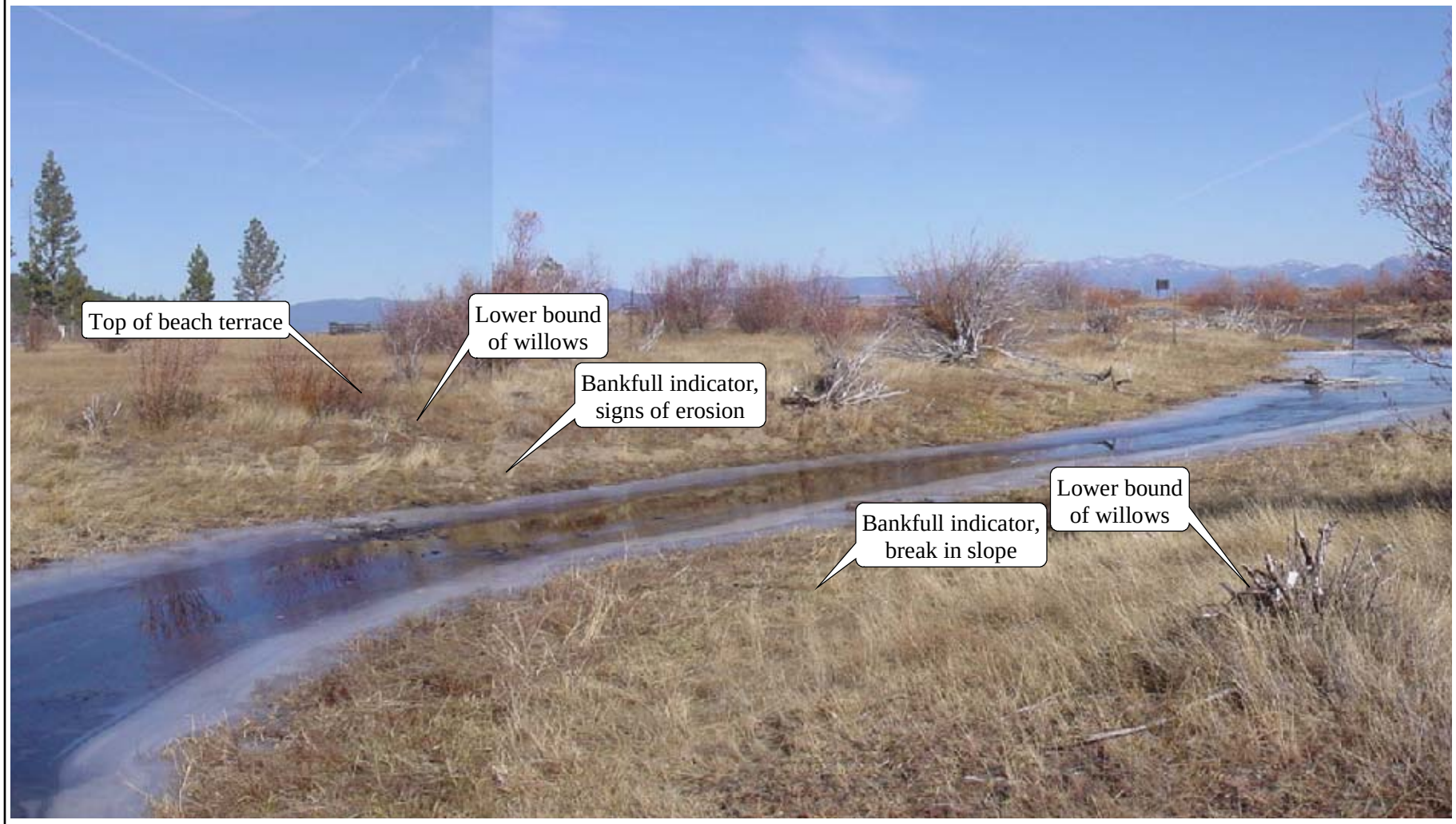
Source: PWA

Tallac Creek Survey Location

Exhibit 2.5-4

Taylor, Tallac, and Spring Creek Watershed EAR
U.S. Forest Service
P ?T???.01 01/04

PWA Philip Williams & Associates Consultants in Hydrology
EDAW

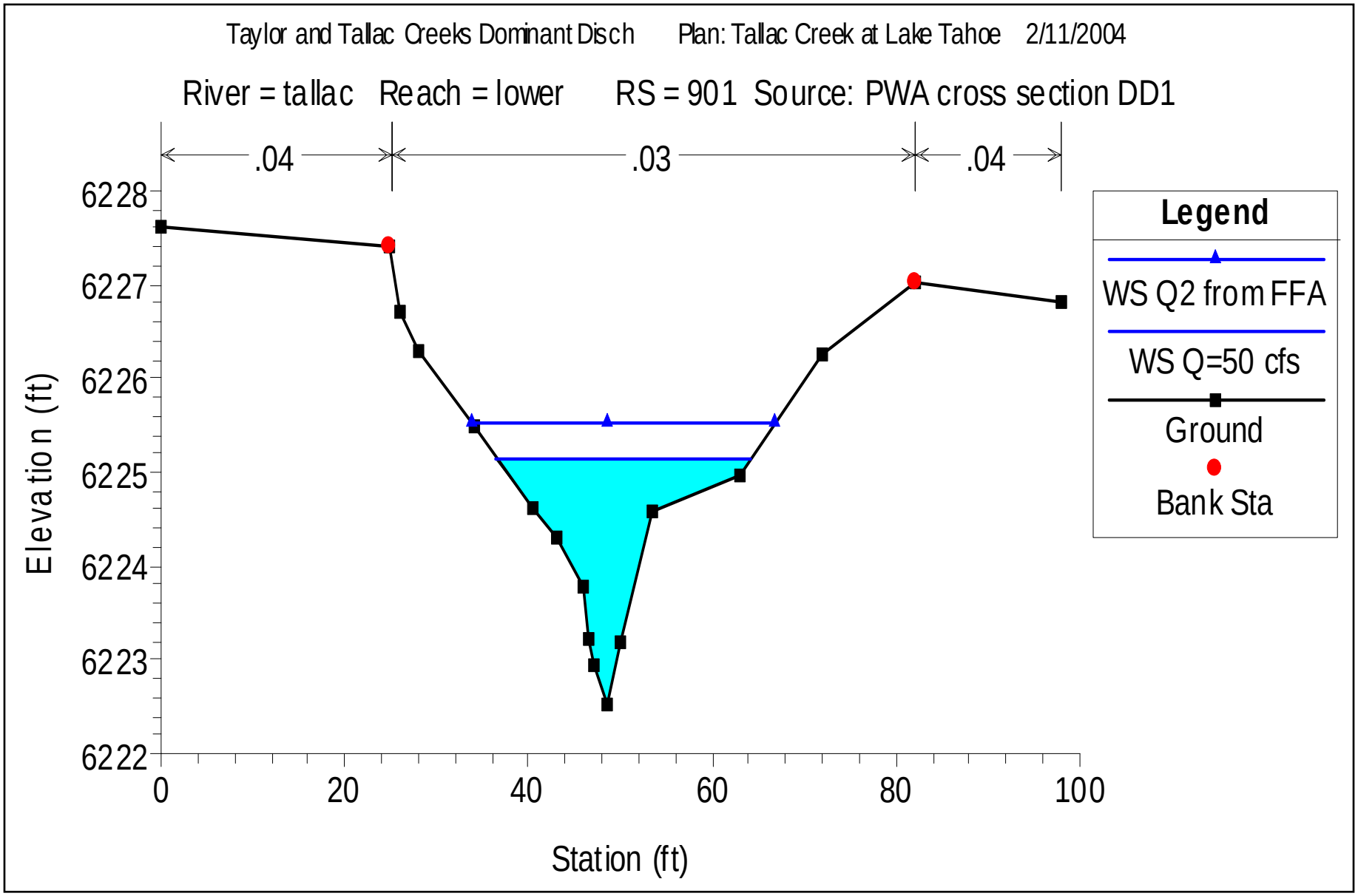


PWA cross section “dd1” looking downstream

Source: PWA

Tallac Creek Cross Section for Dominant Discharge

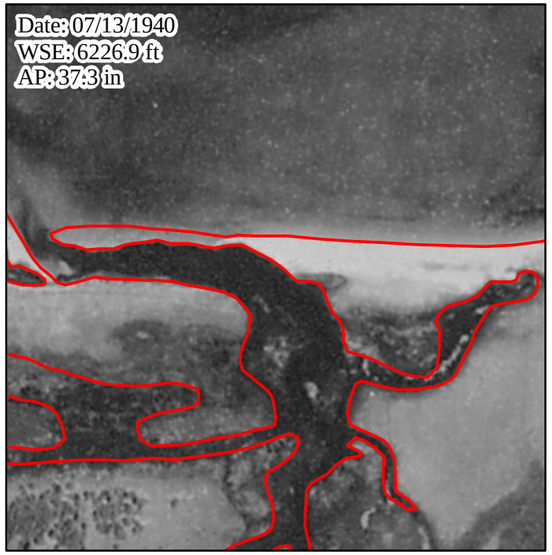
EXHIBIT 2.5-5

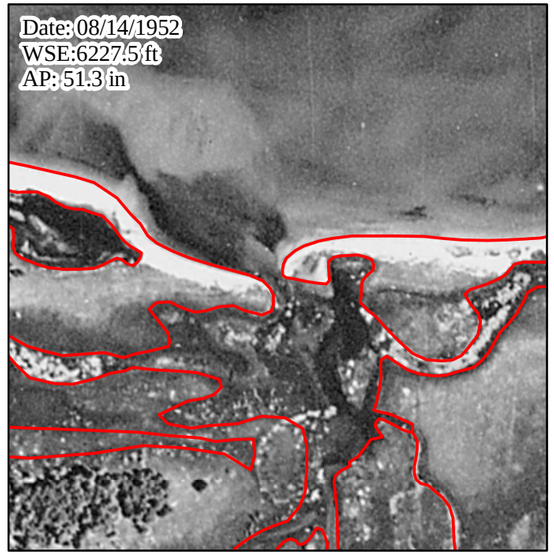


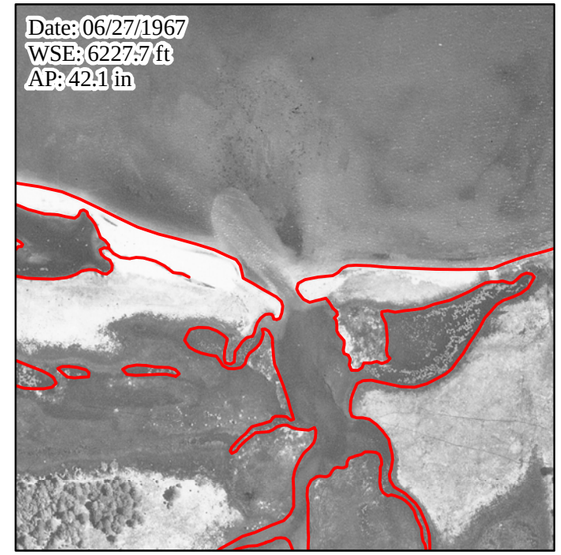
Source: PWA HEC-RAS output for Tallac Creek

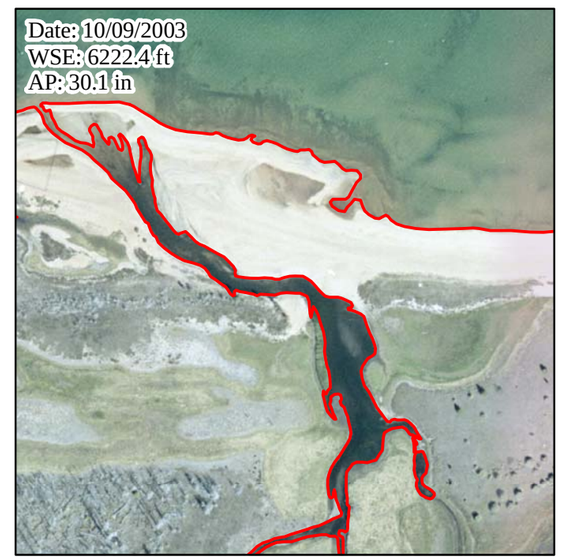
Estimated Dominant Discharge for Tallac Creek at Lake Tahoe

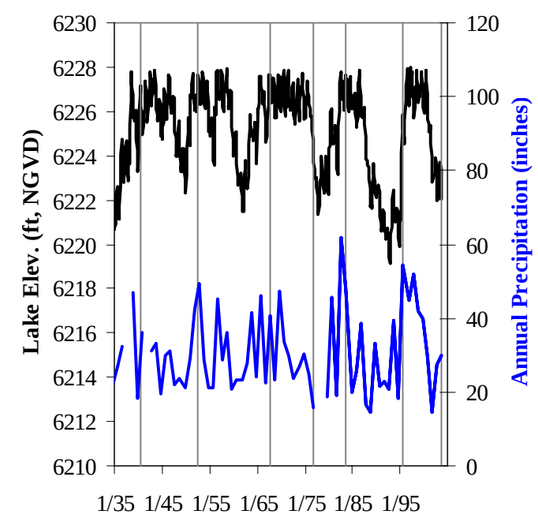
EXHIBIT 2.5-6











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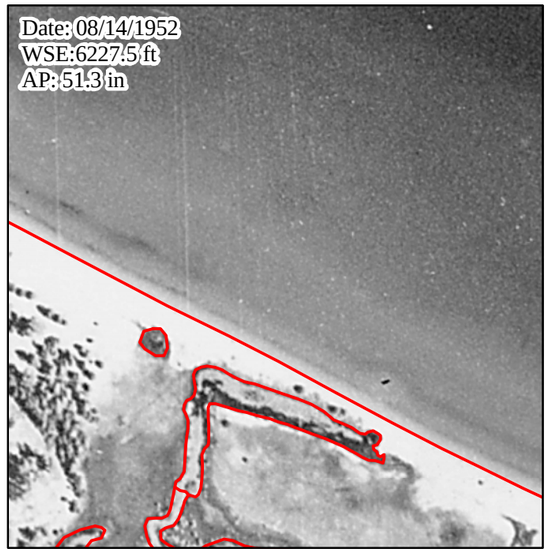
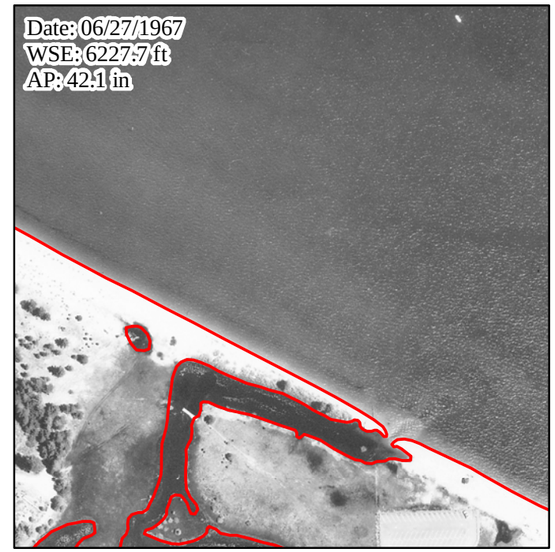
Source: PWA 2005

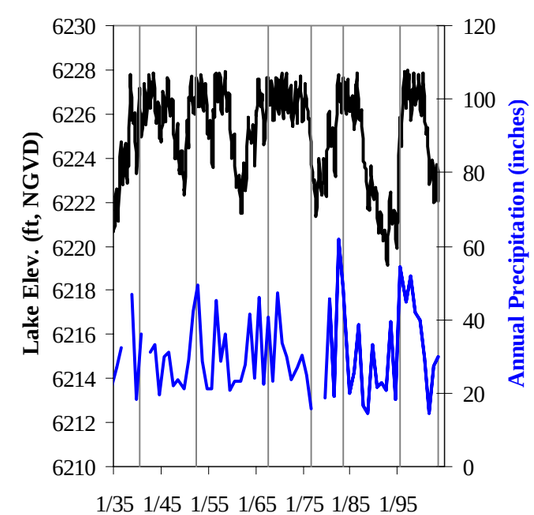
Mouth Dynamics: Taylor Creek

EXHIBIT 2.6-1

PWA EDAW







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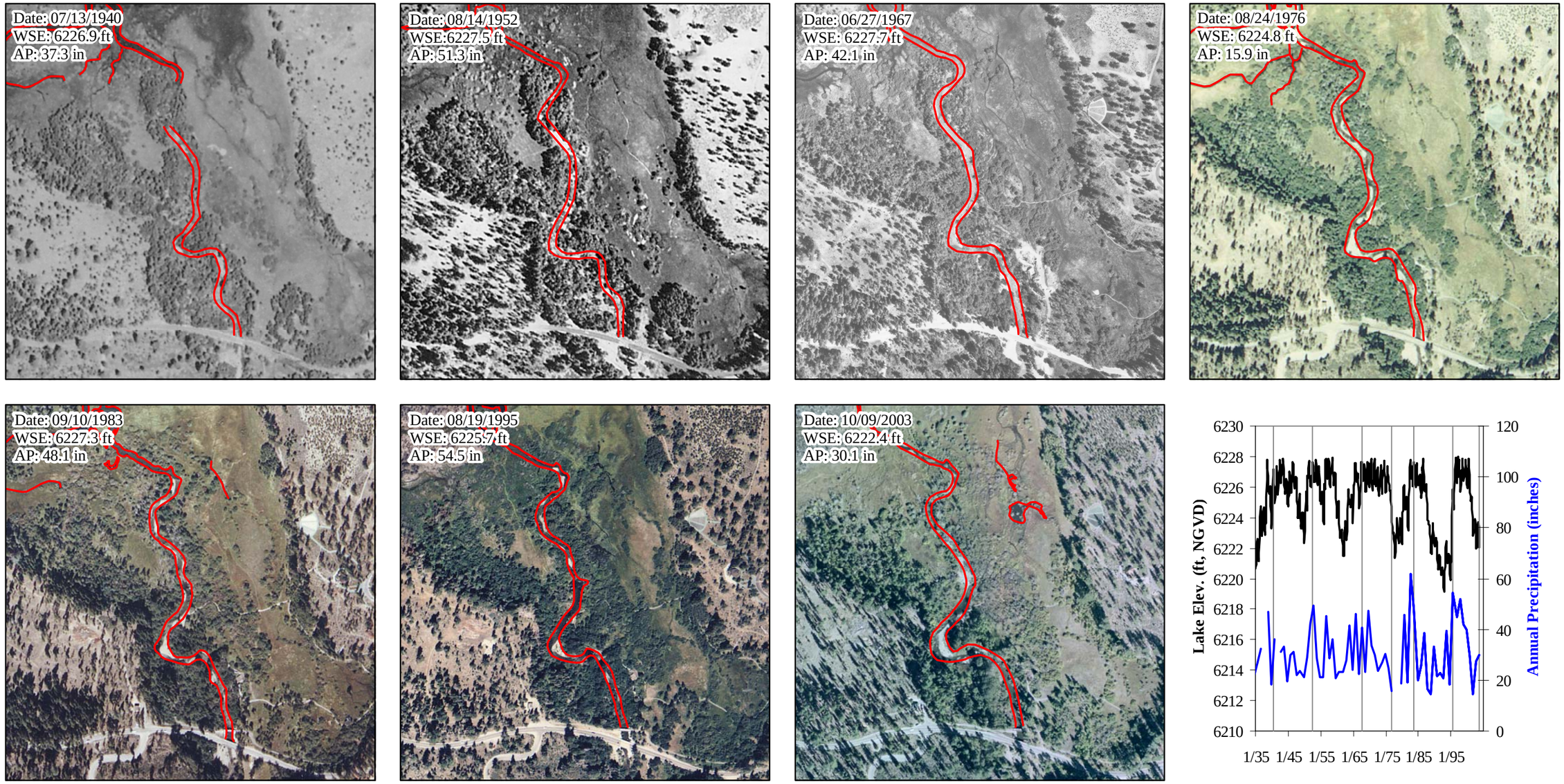
Mouth Dynamics: Tallac Creek

EXHIBIT 2.6-2

PWA EDAW



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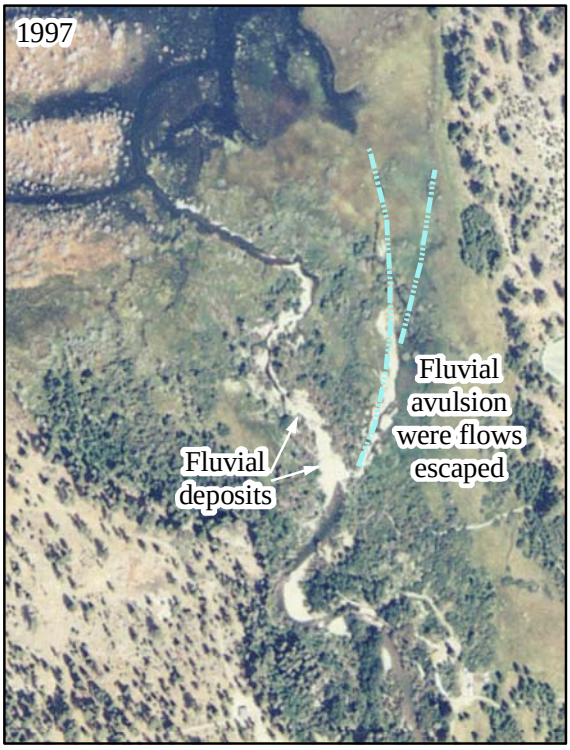
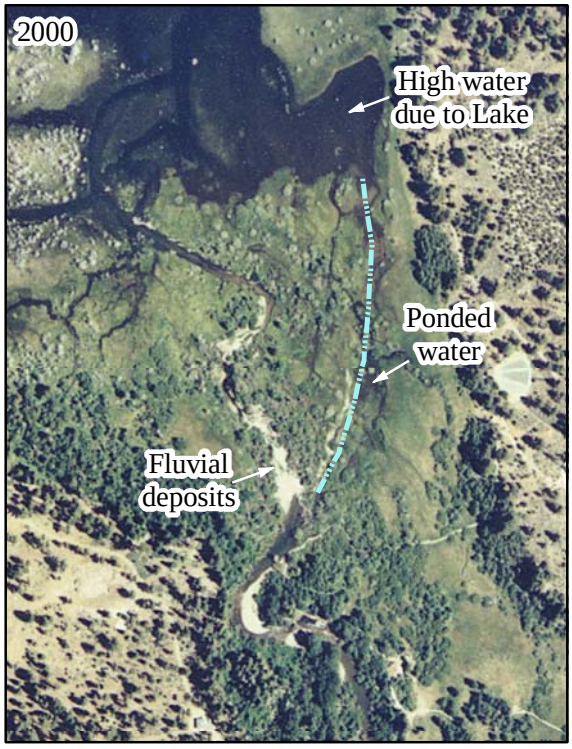
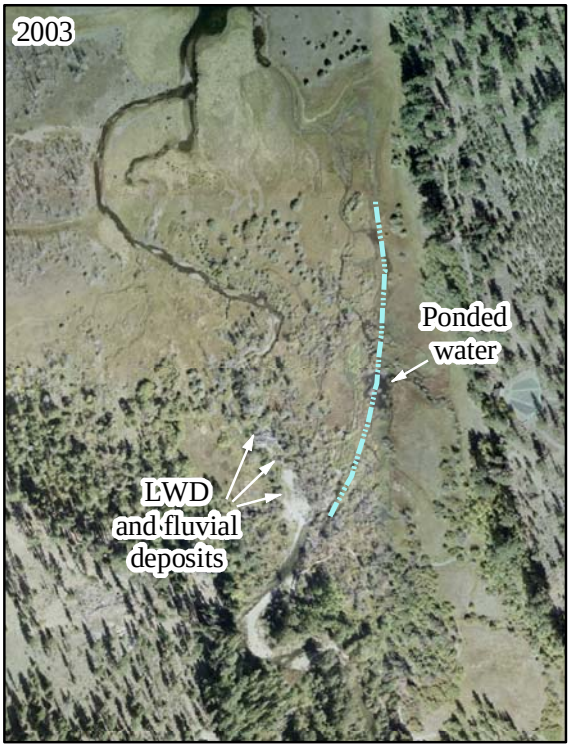
Channel Alignment: Taylor Creek

EXHIBIT 2.6-3

PWA EDAW





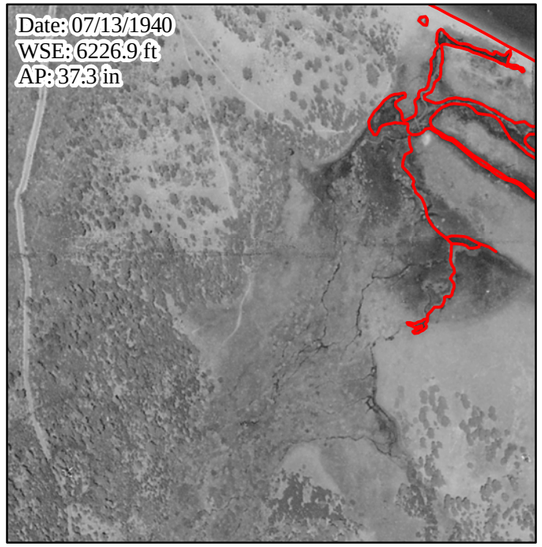


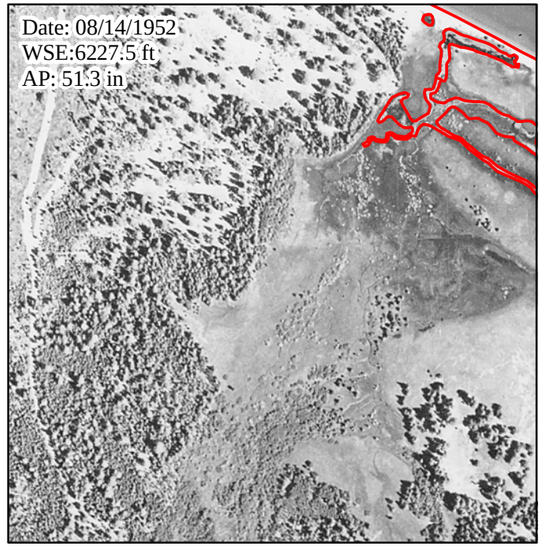
Taylor Creek Overbank Flows

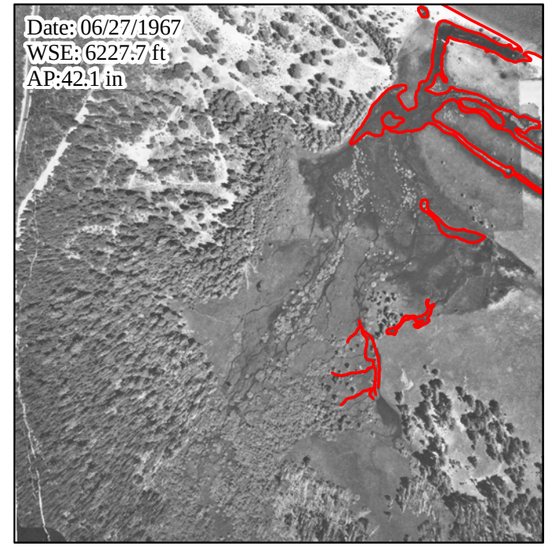
EXHIBIT 2.6-4

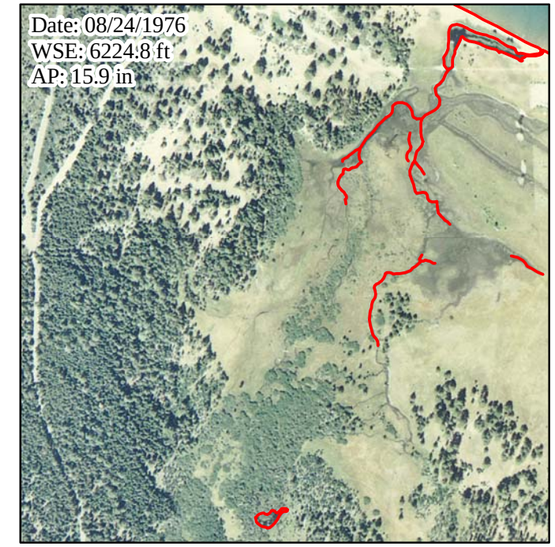
Taylor, Tallac, and Spring Creek Watershed EAR
U.S. Forest Service
P ?T???.01 01/04

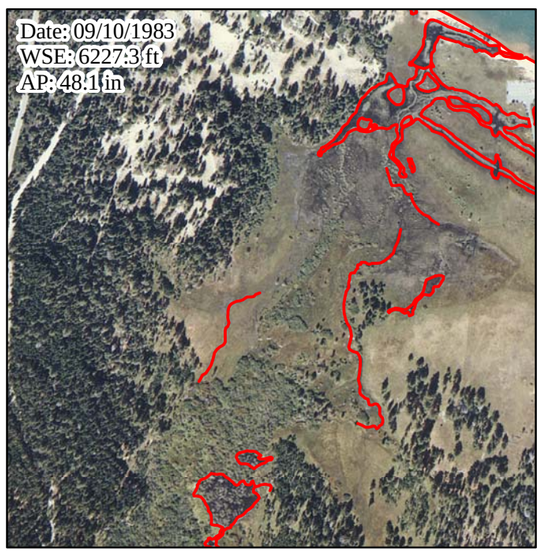
PWA Philip Williams & Associates Consultants in Hydrology
EDAW

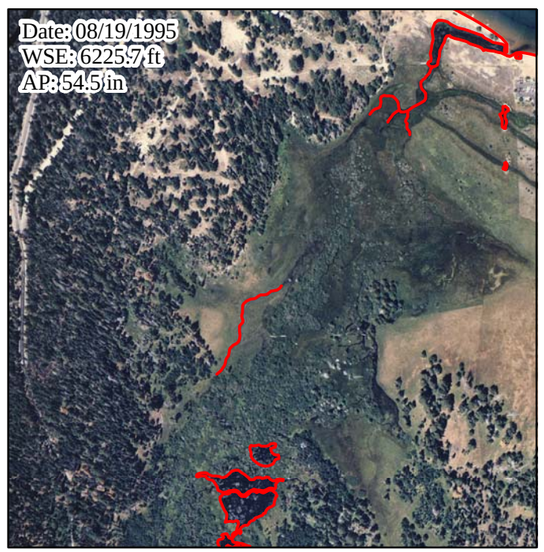


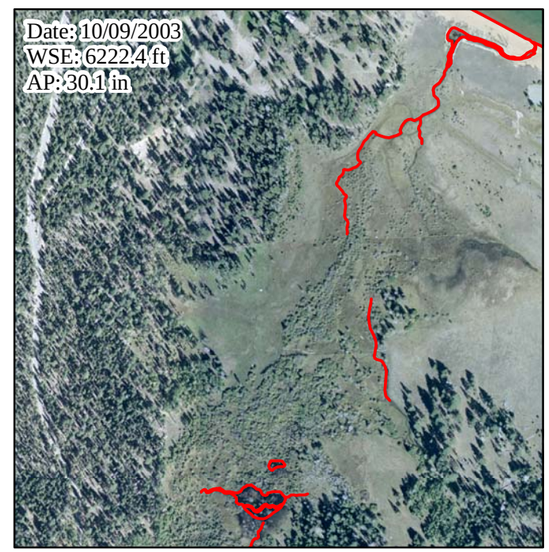


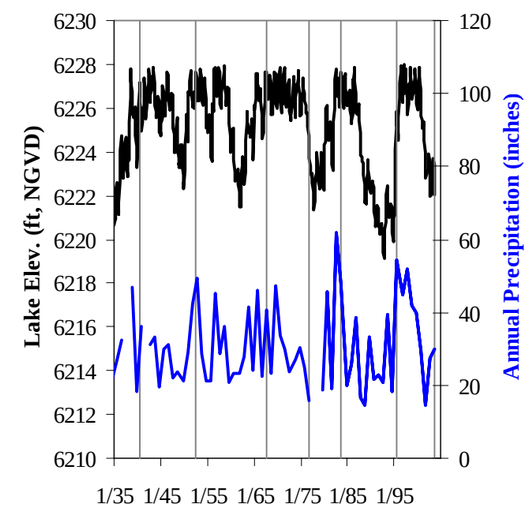












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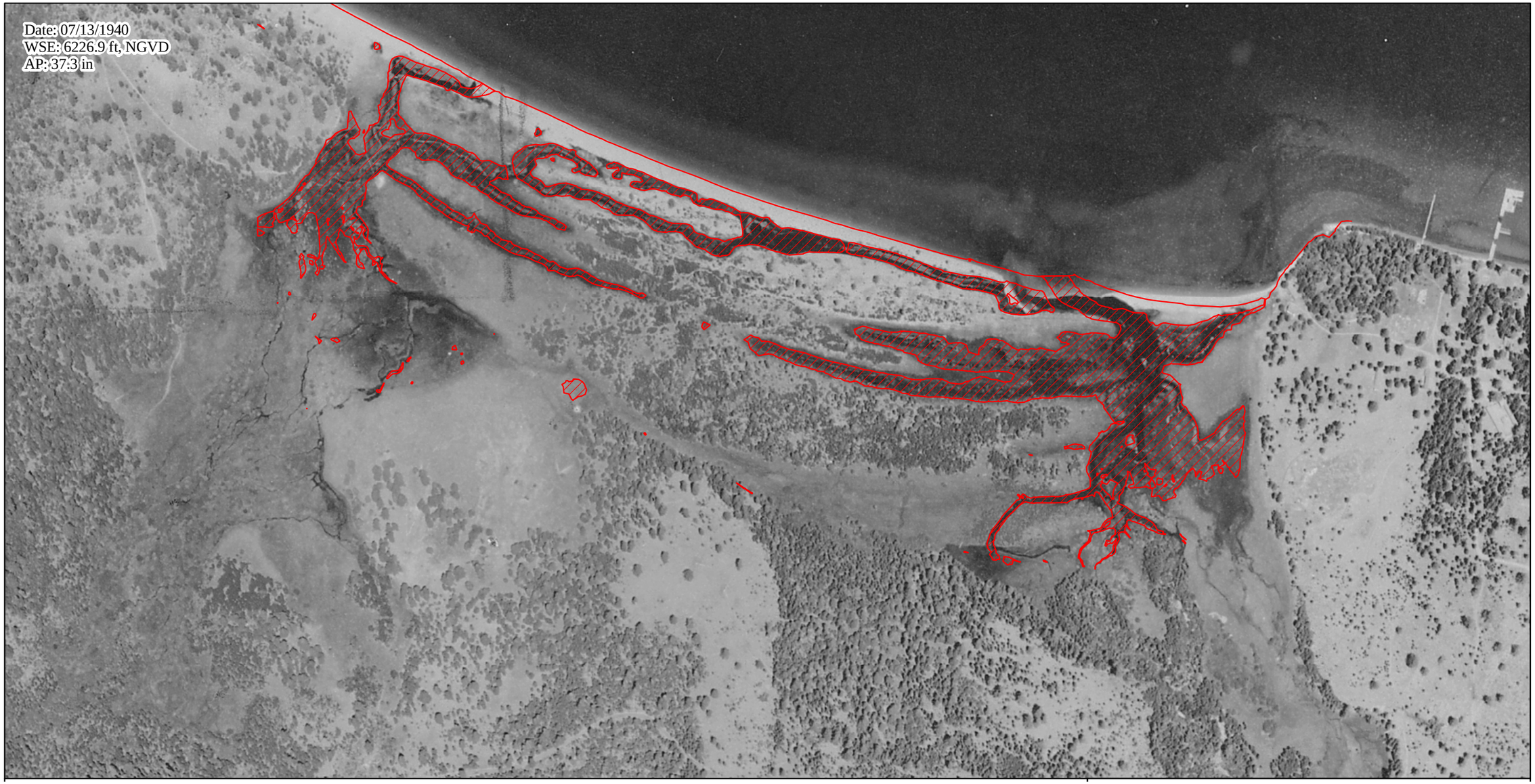
Channel Alignment: Tallac Creek

EXHIBIT 2.6-5

PWA EDAW



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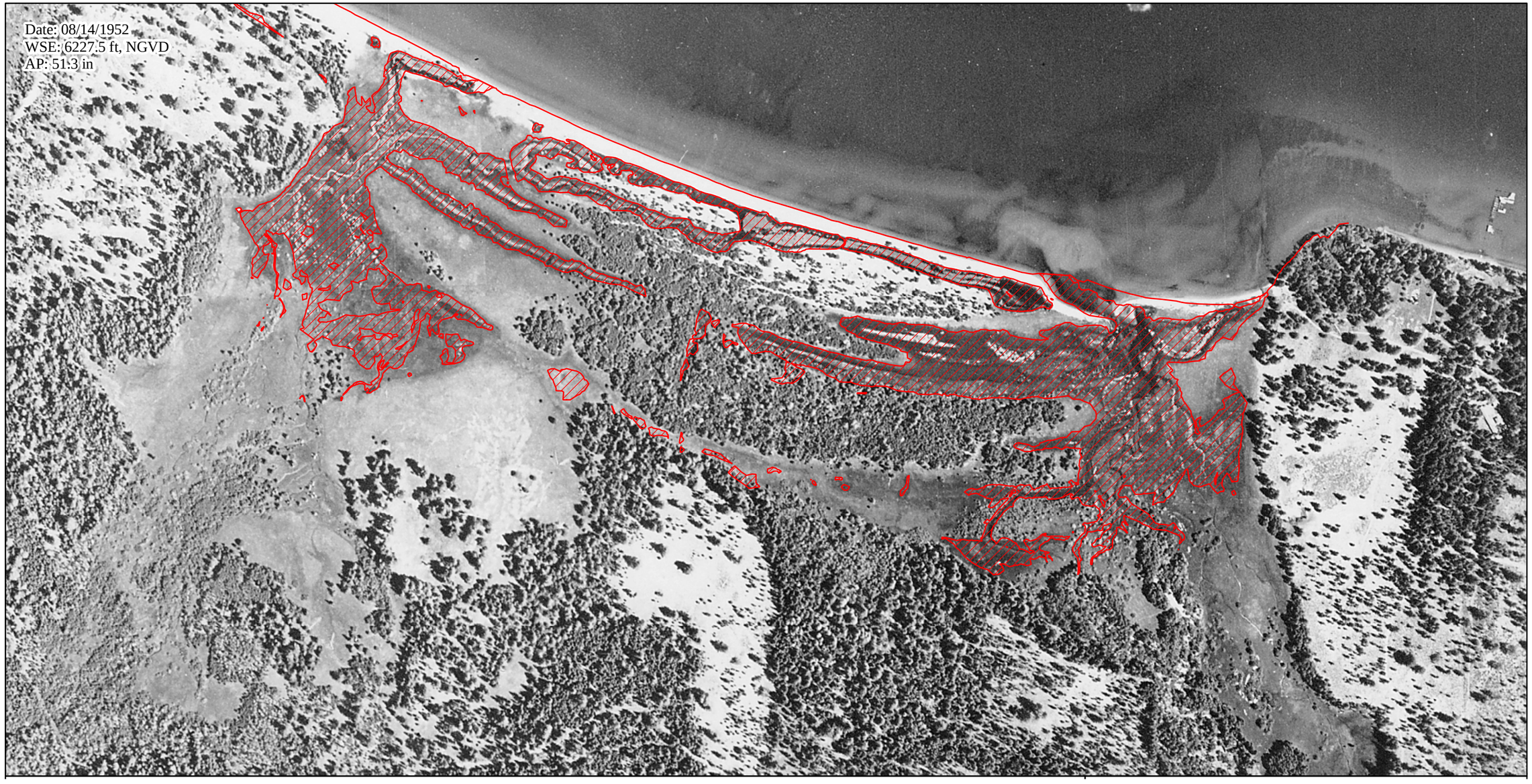
1940 Ortho with Theoretical Inundation Overlay

EXHIBIT 2.6-6



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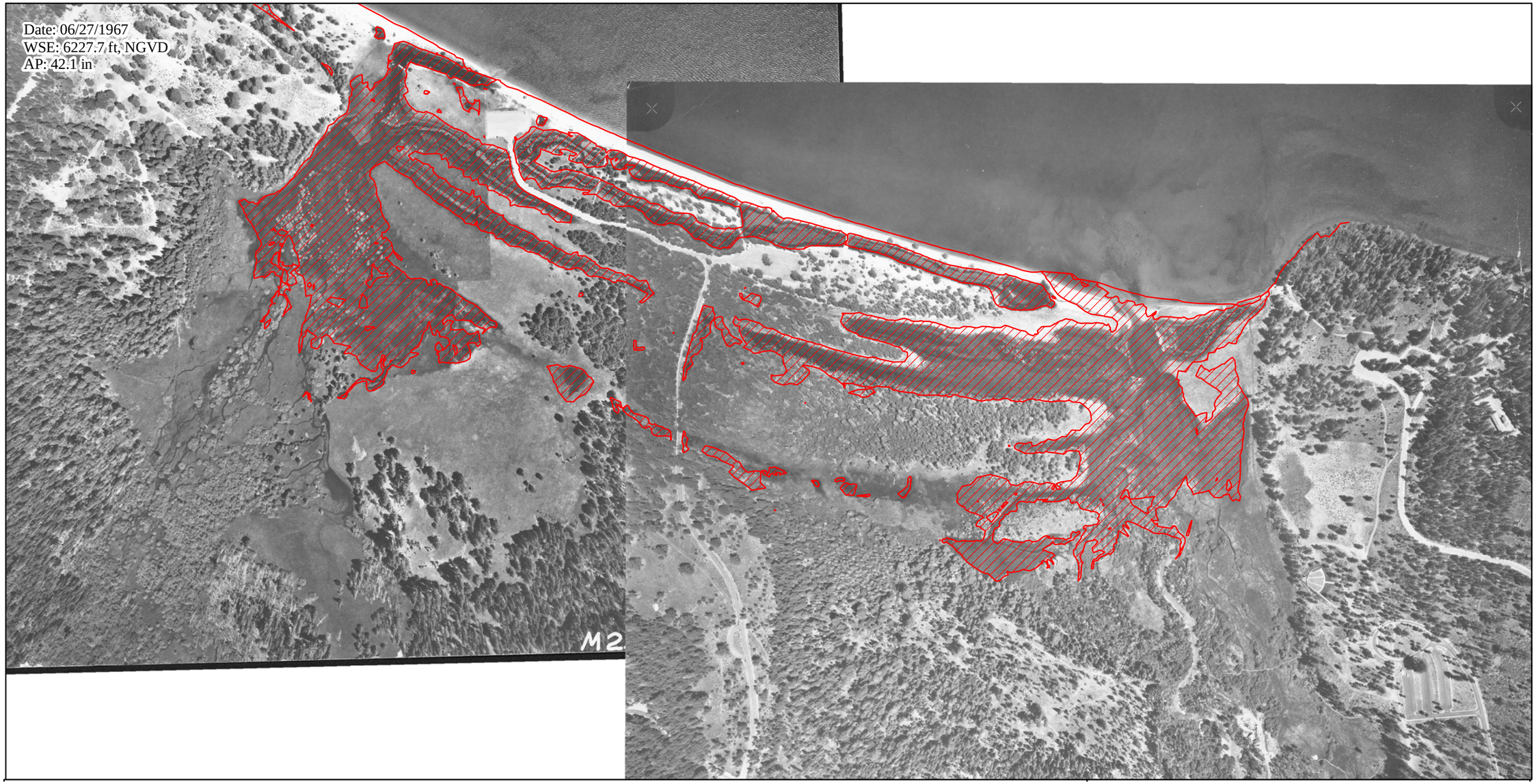
1952 Ortho with Theoretical Inundation Overlay

EXHIBIT 2.6-7



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1967 Ortho with Theoretical Inundation Overlay

EXHIBIT 2.6-8

Notes: Fallen Leaf Lake annual precipitation (AP) prior to 1980 was estimated based on correlation with Tahoe City annual precipitation for water years 1980 through 2003 (this study); annual precipitation is reported for each year for the period of October 1 through September 30; vertical lines on graph correlate to dates photographs were taken; red outline is based on a qualitative visual assessment of open water areas.
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1976 Ortho with Theoretical Inundation Overlay

EXHIBIT 2.6-9

Notes: Fallen Leaf Lake annual precipitation (AP) prior to 1980 was estimated based on correlation with Tahoe City annual precipitation for water years 1980 through 2003 (this study); annual precipitation is reported for each year for the period of October 1 through September 30; vertical lines on graph correlate to dates photographs were taken; red outline is based on a qualitative visual assessment of open water areas.
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1983 Ortho with Theoretical Inundation Overlay

EXHIBIT 2.6-10

Notes: Fallen Leaf Lake annual precipitation (AP) prior to 1980 was estimated based on correlation with Tahoe City annual precipitation for water years 1980 through 2003 (this study); annual precipitation is reported for each year for the period of October 1 through September 30; vertical lines on graph correlate to dates photographs were taken; red outline is based on a qualitative visual assessment of open water areas.
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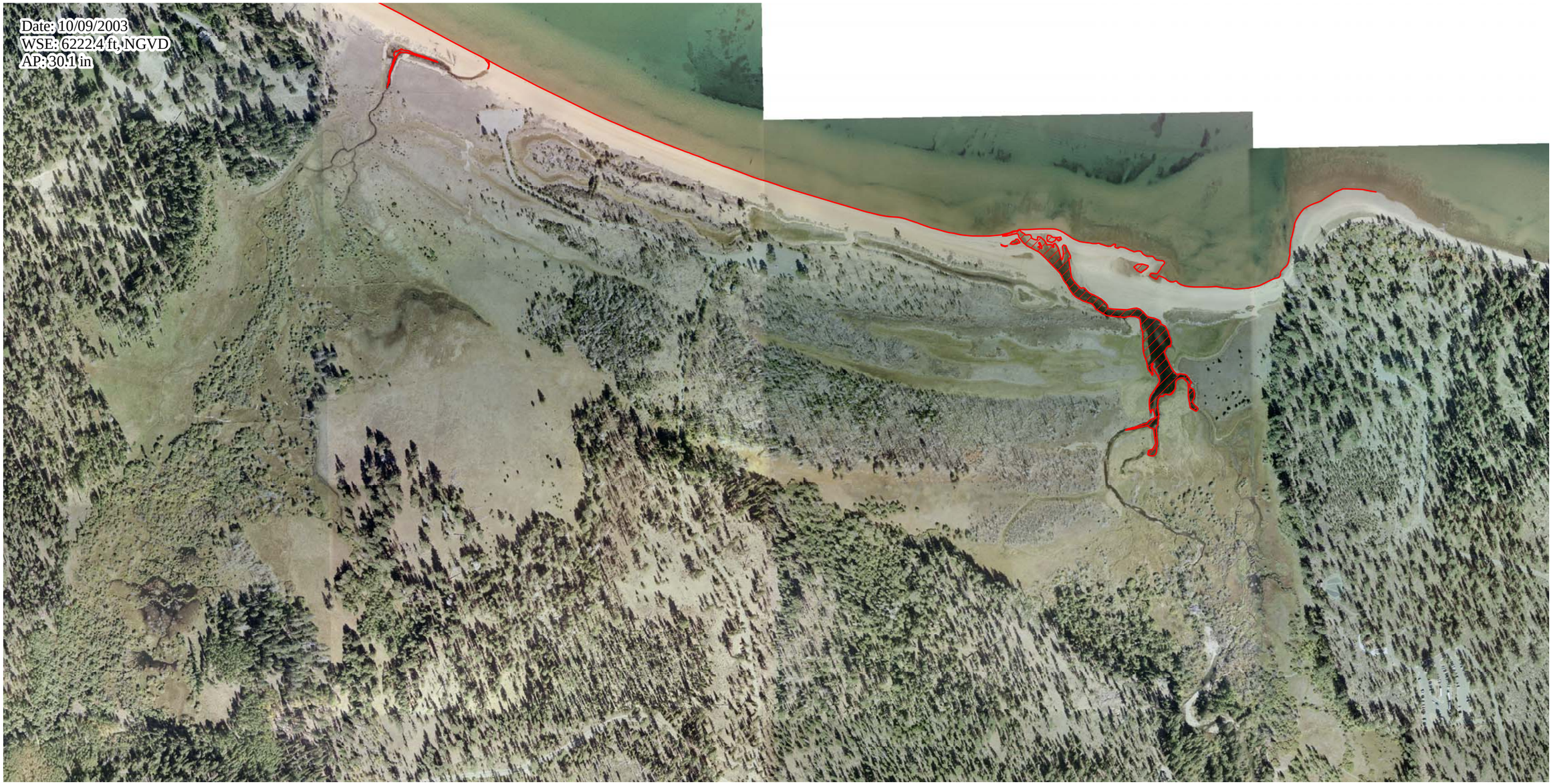
1995 Ortho with Theoretical Inundation Overlay

EXHIBIT 2.6-11



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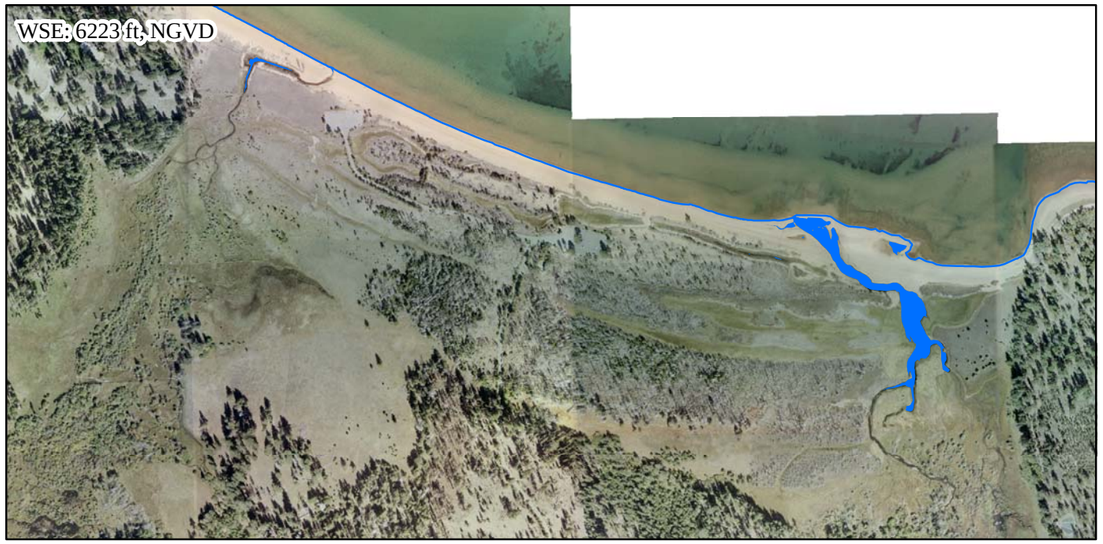
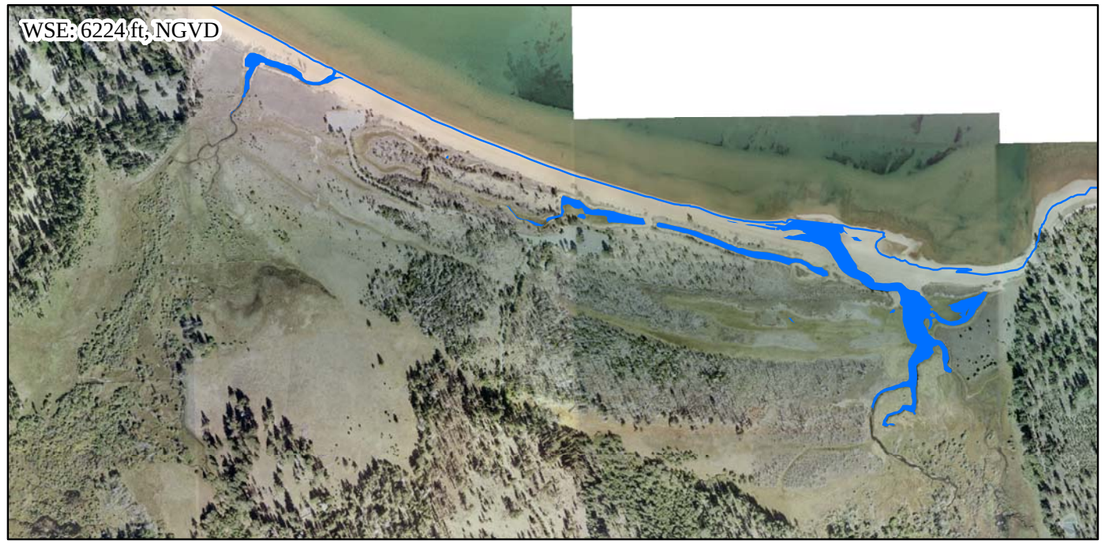
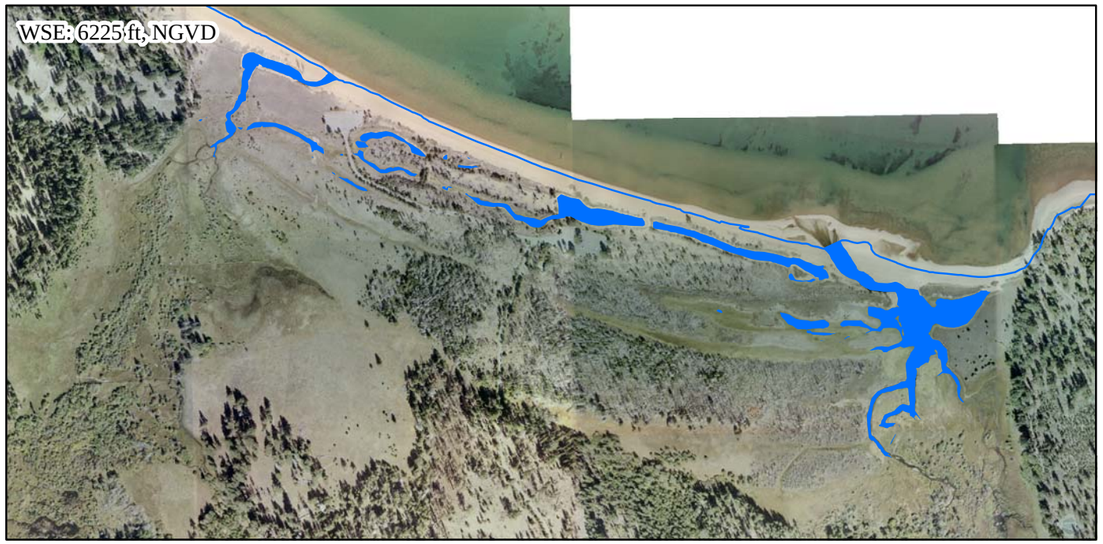
2003 Ortho with Theoretical Inundation Overlay

EXHIBIT 2.6-12







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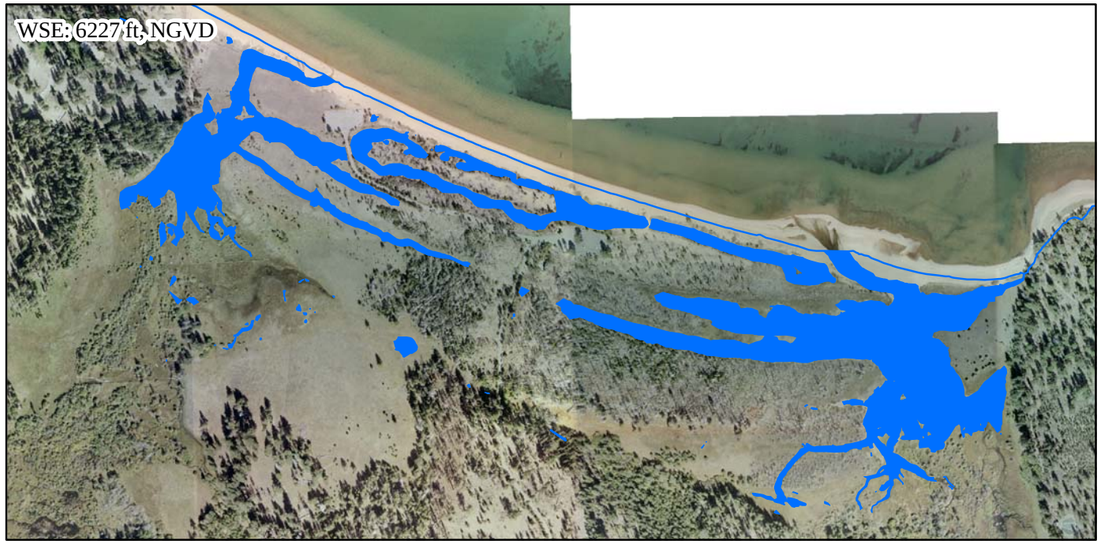
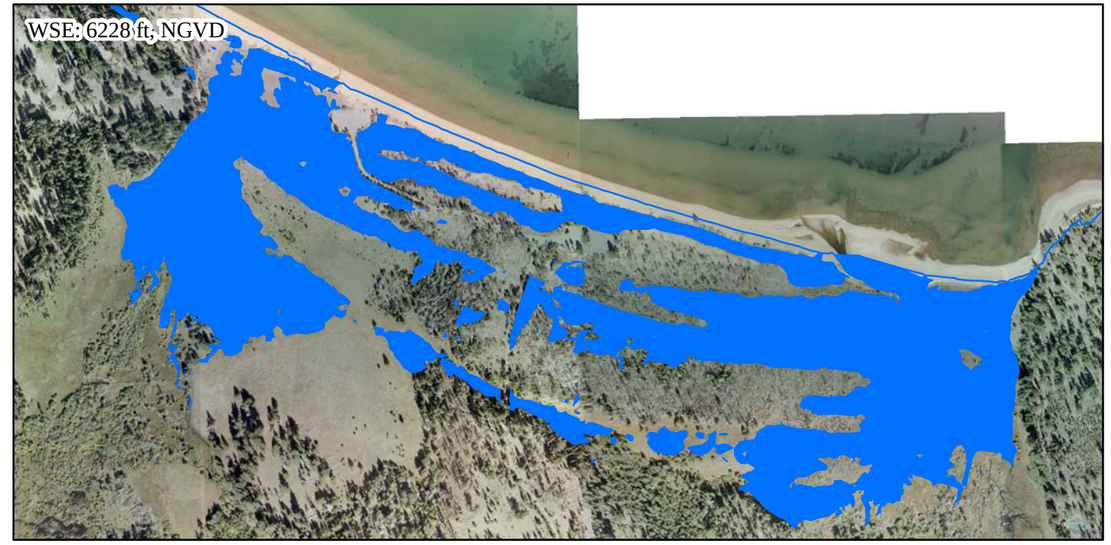
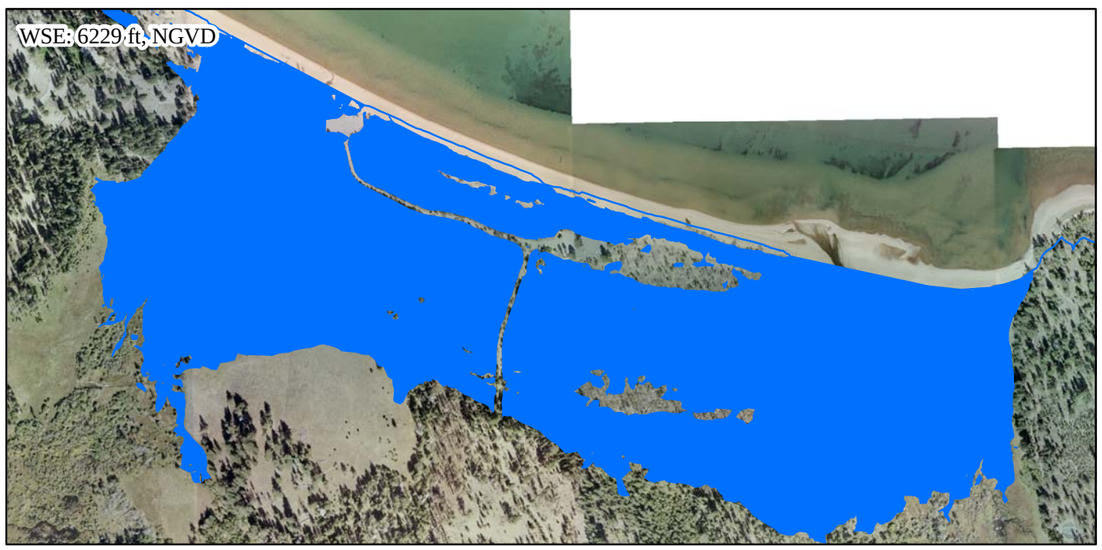
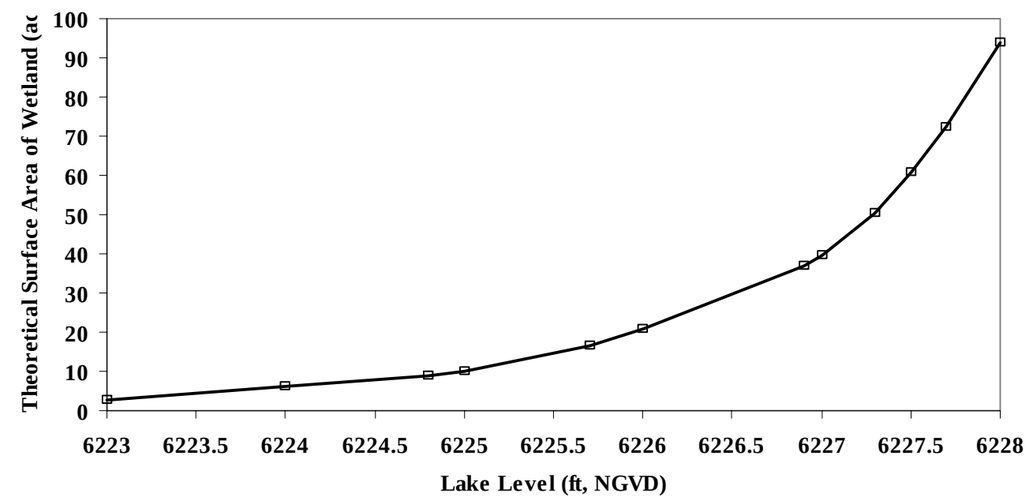
Theoretical Inundation due to Lake Level

EXHIBIT 2.6-13









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Theoretical Inundation due to Lake Level

EXHIBIT 2.6-14