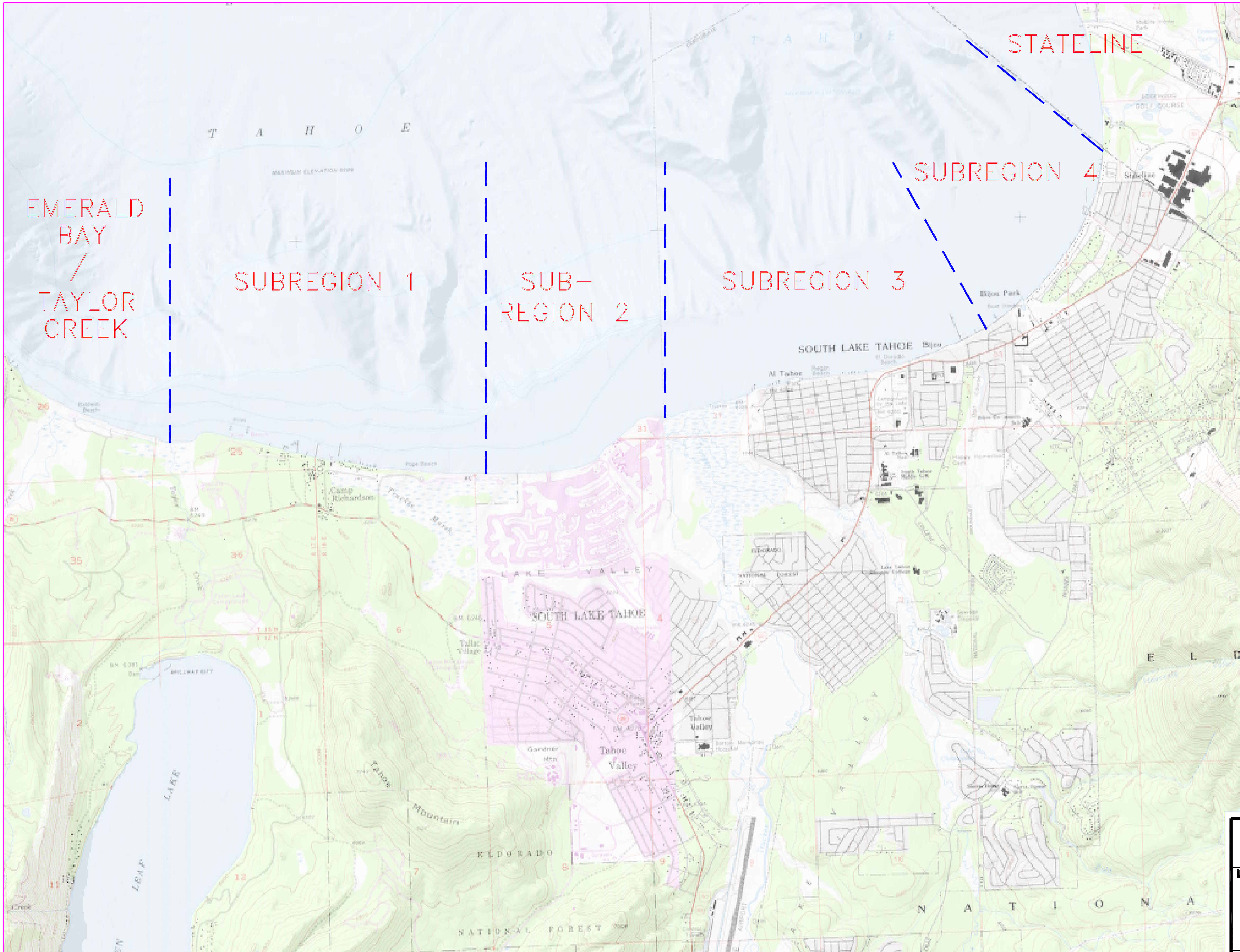
4.0 SOUTH LAKE TAHOE/STATELINE NUTRIENT LOADING

4.1 Description of Study Area

The aquifer that encompasses South Lake Tahoe, California and Stateline Nevada is, by far, the largest aquifer in the Lake Tahoe Basin. This is also where a majority of the development is located. It is bounded on the west by Emerald Bay and extends just north and east of Stateline Nevada. The watersheds in this area, counter-clockwise from west to east, include Eagle Creek, Cascade Creek, Tallac Creek, Taylor Creek, Camp Richardson, Upper Truckee River, Trout Creek, Bijou Creek, Bijou Park, Edgewood Creek and Burke Creek. The area from Fallen Leaf Lake to the California/Nevada border was numerically modeled because of the extensive data available for this region. During the modeling process, this area was divided into four subregions (Fenske 2003, Appendix B). See Figure 4-1 for the delineation of the subregions.

Land development in all but the Emerald Bay/Taylor Creek subregion of this area is extensive and consists of a wide variety of land uses. There are single family and multi-family residential neighborhoods intermixed with commercial complexes. Recreational sites such as golf courses, swimming beaches, campgrounds and parks also abound, as tourism is the main attraction to this area.



DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT,
CORPS OF ENGINEERS
OCTOBER 2003

LAKE TAHOE — CALIFORNIA/NEVADA

SOUTH LAKE TAHOE AREA

SUBREGION DELINEATION

SCALE: NOT TO SCALE — FIGURE: 4-1

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4.1.1 History of Development

The history presented is based on Lindstrom et al. (2000). Many of the historical activities described could have contributed to elevated nutrients in groundwater. Markets created by teamsters traveling through the South Lake Tahoe area in the mid 1850s – 1860s prompted the development of seasonal farming and ranching. As this started, large meadowlands were quickly preempted. By 1860, a pony express route was designated through the area over Echo Summit and Daggett Pass; a post office soon followed. This route was heavily used by passenger and freight wagon traffic en route to the Comstock during the early 1860s.

As shown by the 1870 "California Products of Agriculture" census, hay was a major business in the area in the 1860s. This census shows that 232 metric tons (228 tons) of hay were baled in the region. The 1875 "Resources and Wonders of Tahoe" publication cited that the South Lake Tahoe area was primarily a "hay and dairy producing center, dotted with fertile ranches" and that the ranchers contributed most of the 726 metric tons (800 tons) of hay cut along Tahoe's shoreline in 1875. An estimated 1,800 cows were grazed in the area by 1880, including a pasture on Barton Meadows near the lake shore.

A dairy ranch was in operation beginning in the late 1920s on a 6 square kilometer (1,600-acre) tract of land on the west side of the Upper Truckee River floodplain in what is now Gardner (Tahoe) Mountain, Tahoe Island Park, Tahoe Keys, and Tamarack Subdivision.

By the 1930s, the Meyers, Al Tahoe, and Bijou subdivisions were thriving, and additional lots were developed at Al Tahoe in the mid 1940s. The 1950s brought the expansion of the gaming industry, which was soon followed by a building boom. This brought on discussions about water and sewage problems as development put more pressure on the existing sewage disposal system. A temporary solution was found by spraying effluent directly onto the land near Pioneer Trail.

Heavenly Valley, a major ski resort, opened in 1956 drawing more tourism into the basin. Soon after, the Squaw Valley Winter Olympics were held, bringing even more attention and visitors to the area. The new subdivision developments of Tahoe Paradise, Golden Bear, and Meadow Lakes were established in the 1960s, and South Lake Tahoe became an incorporated city in 1965. Between 1960 and 1980 Tahoe's population multiplied five times, along with the construction of several major housing developments. The most notable and extensive was the Tahoe Keys subdivision, which required 3 square kilometers (750 acres) of functioning wetland at the mouth of the Upper Truckee River to be dredged and filled.

4.1.2 Local Geology

Ice Advance into the South Lake Tahoe Basin

Several glacial advances into the South Shore area correspond with those into the Upper Truckee Canyon. Burnett (1971) in mapping the area has identified moraines from these events. The Hobart and Donner glaciations flowed out of Christmas Valley and covered the Meyers area.

The ice would have been blocked to the north by Twin Peaks and Tahoe Mountain, and to the west by ice flowing into the Fallen Leaf Lake basin, which eventually resulted in a moraine being deposited between the two ice streams. The result was that ice flowed to the east, around the Twin Peaks and deposited the Airport Moraine, the sedimentary ridge adjacent to the South Lake Tahoe Airport. Burnett has mapped a Tahoe age-end moraine in the Meyers area just north of Tahoe Paradise, while Tioga age moraines have been identified near Meyers Grade. This indicates that Wisconsinan age ice advanced into the Meyers area at least twice.

Bedrock Geometry

The basin geometry is characterized by two deep subbasins that have been defined using detailed gravity surveys (Appendix A; Blum 1979, Bergsohn 2003). Both of these basins appear to reach depths in excess of 274 meters (900 ft) below the current land surface. One basin is centered below the Meyers area while the other is situated just south of the Tahoe Keys. A low that extends from the South Shore near Bijou towards the Airport probably corresponds to the Stateline Fault that has been mapped just offshore by Kent (2003). Tahoe Mountain and Twin Peaks are situated between these subbasins. A ridge to the west of the Meyers subbasin lies between this subbasin and a basin occupied by Fallen Leaf Lake and is mantled by morainal deposits.

Hydrogeology of the Meyers and South Lake Tahoe Area

The hydrologic basin that is occupied by Meyers and South Lake Tahoe is roughly triangular with its apex to the south near Meyers Grade. It extends northward to the south shore of Lake Tahoe where it runs from the west of Camp Richardson to Stateline, NV. The surface topography is generally smooth and gently dipping to the north. Near the lake, surface topography is low lying and poorly drained resulting in the Truckee and Pope marshes. Geologic mapping by Bonham and Burnett (1976) indicates that the surficial deposits are composed of lake and fluvial deposits. East of Twin Peaks, a terraced feature is cored by glacial moraine deposits and flanked by older lake deposits. Twin Peaks and Tahoe Mountain, which project above this depositional surface, are characterized by unweathered and weathered granite.

The stratigraphy of the sedimentary fill has been investigated in various phases over the past few decades. The most comprehensive investigation published to date was performed by Scott et al. (1978) in a report for the South Tahoe Public Utility District (STPUD). The investigation was conducted to evaluate potential water reserves for STPUD below South Lake Tahoe. Several of their geologic cross-sections are shown in Figure 4-3. An important feature in these sections is a preponderance of more or less continuous fine-grained units in the upper 30 meters (100 ft). There are several relatively thin units nearer the surface and a thick unit at 18 m (60 ft) to 30 m (100 ft) depth. Cross-sections prepared by Avalex (2002) also show thin, fine-grained units in the upper section and a thicker, more continuous unit at depth. These units dip gently to the north, towards Lake Tahoe.

Figure 4-2. South Lake Tahoe Geologic Transects (Einarson 2003, Scott et al. 1978)

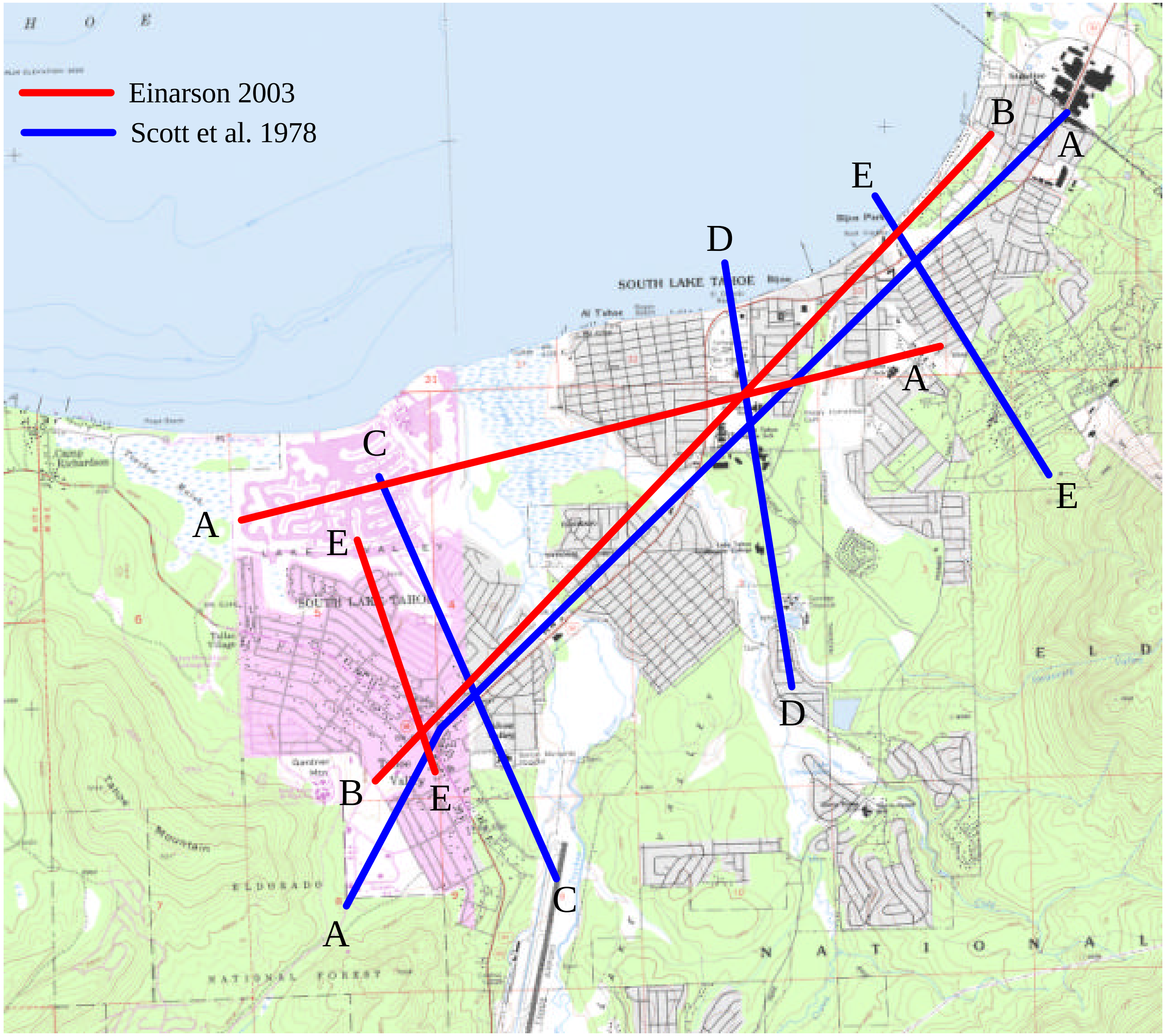
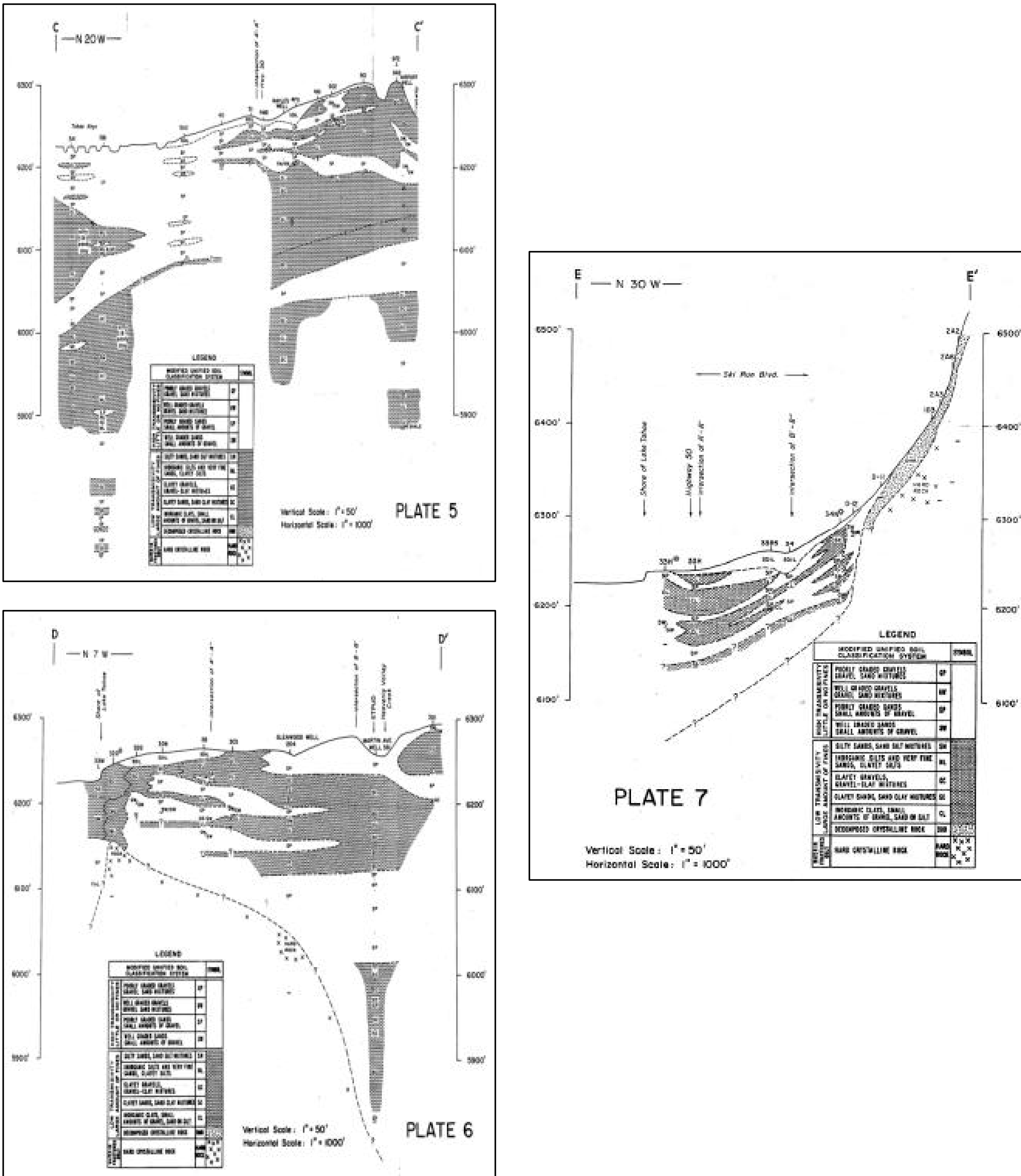


Figure 4-3. Geologic cross-sections of the South Lake Tahoe area from Scott et al. (1978). Zones shaded in gray indicate fine-grained units that are hydrologically significant.



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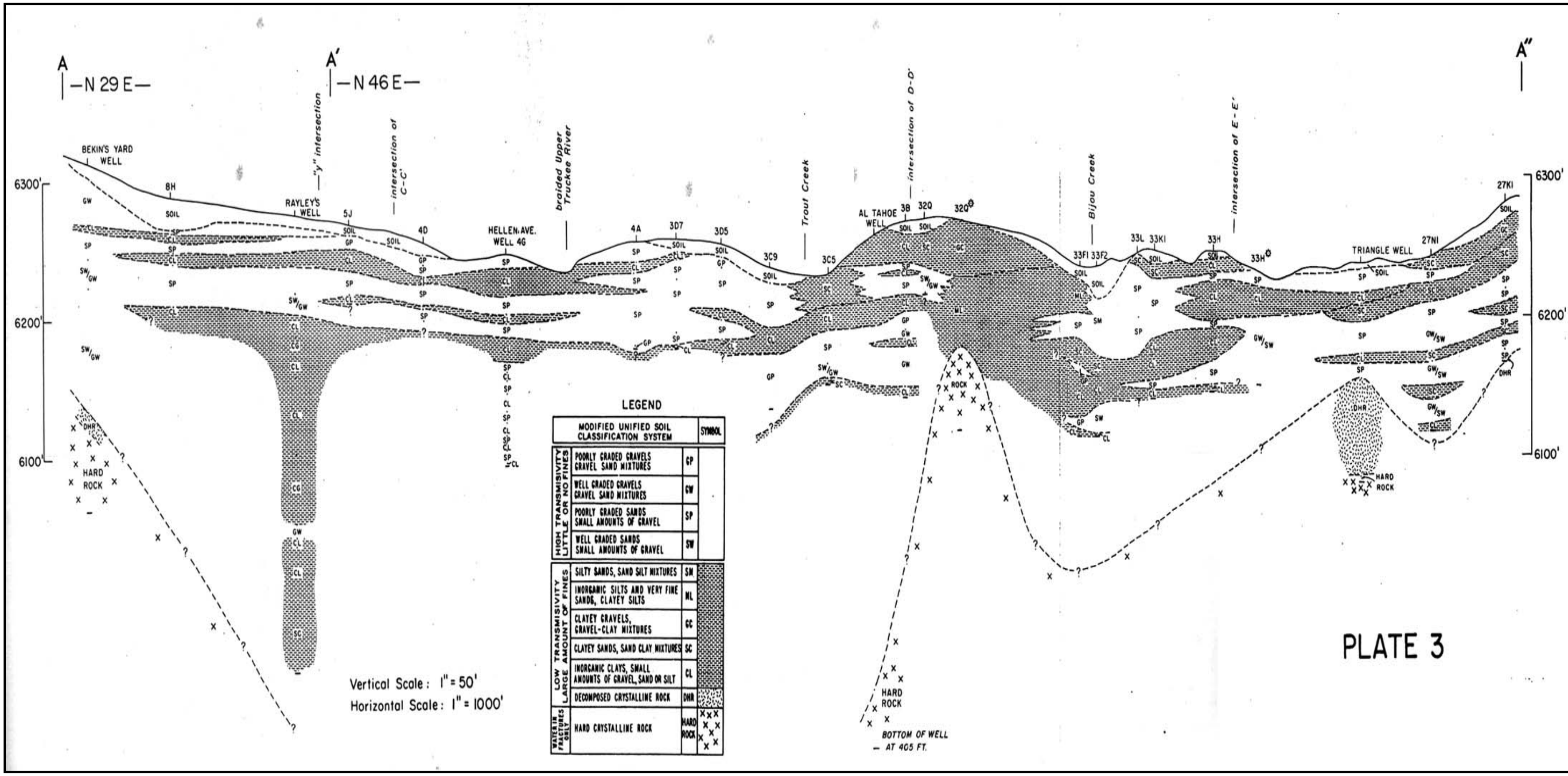
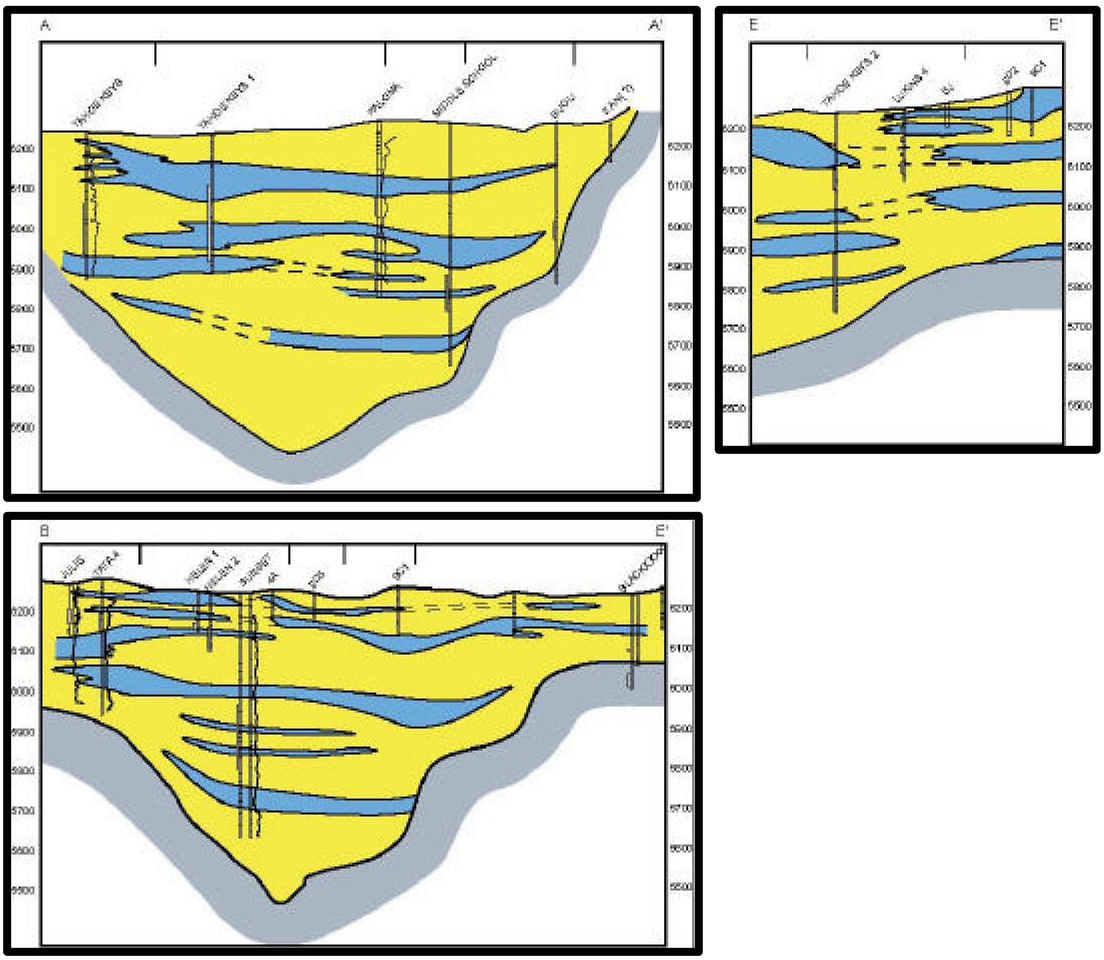


More recently, Einarson (2003) developed a series of geologic cross sections for the South Lake Tahoe and Meyers areas. Due to inconsistent lithologic logging techniques, also previously noted by Scott et al. (1978) who stated "the inconsistent nature of well log descriptions, especially in shallower wells", Einarson utilized borehole geophysical data collected by STPUD in their production wells. Borehole geophysical data represents a nonbiased source of information that can be used for stratigraphic correlation (Keys 1997). Examples of these cross-sections are presented in Figure 4-4. Deflections in the geophysical logs have been used to correlate several thick fine-grained units across the basin as well as other less continuous units. It should be noted that due to the nature of the data used, the fine stringers observed by Scott et al. (1978) and the environmental investigations near the "Y" area of South Lake Tahoe are not identified, but much thicker units have been detected. In his interpretation of these data, Einarson further alludes to these being correlative to the bright reflectors seen offshore by Hyne et al. (1972) and identified as marking the Hobart, Donner and Tahoe glacial events. Regardless of the chronologic interpretation, all of these data indicate that there are several more or less continuous fine-grained units under both South Lake Tahoe and the Meyers area that would impact downward infiltration of groundwater.

Figure 4-4. Geologic cross-sections derived from borehole geophysical logs by Einarson (2003). Blue indicates fine-grained units while yellow indicates sand and gravel.



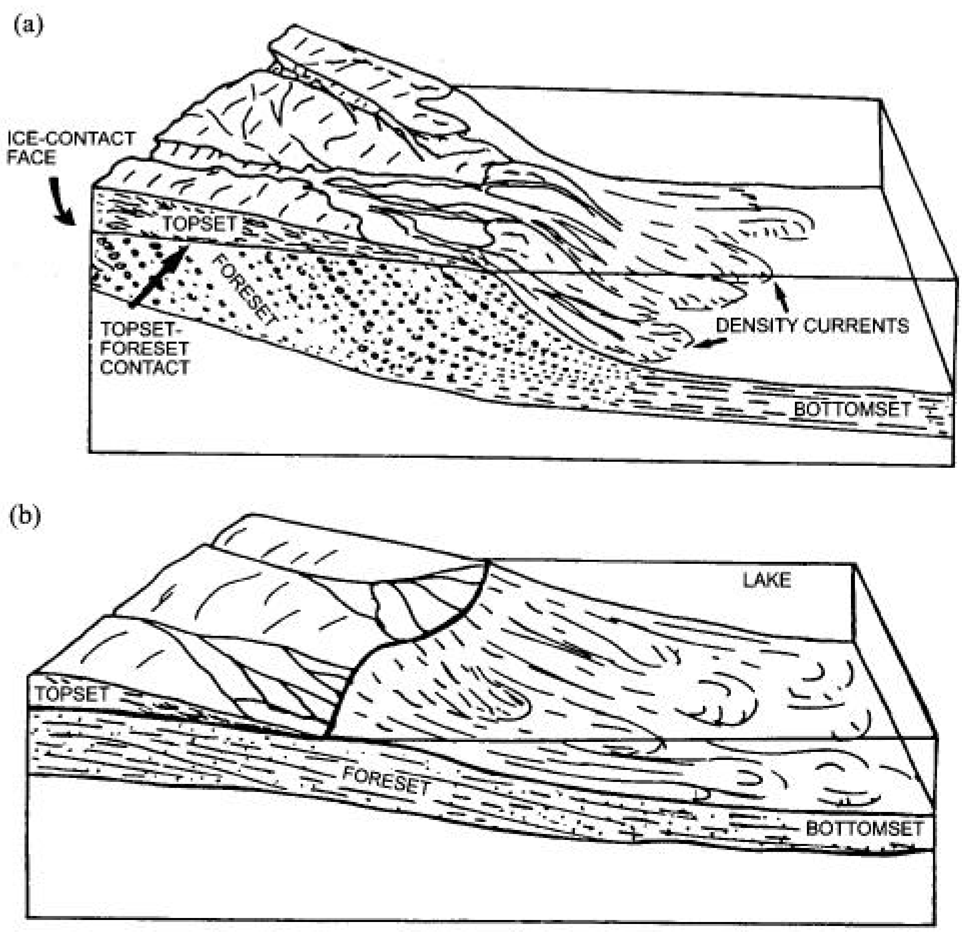
Conceptually, the majority of the deposits comprising the sedimentary fill in the South Lake Tahoe basin would have been deposited in a lacustrine environment. This interpretation is driven largely by the bedrock surface configuration as defined by gravity surveys conducted for STPUD (Blum 1979, Bergsohn 2003). These indicate that the floor of the subbasins below both Meyers and South Lake Tahoe are least 274 m (900 ft) below the land surface. For most of the Quaternary, the minimum lake level was controlled by the sill at Tahoe City near the mouth of the Truckee Canyon (~6223 ft) above mean sea level (m.s.l.). However, at least once, the lake level may have gone below this threshold, as is indicated by the submerged shoreline and *in situ* tree stumps (Figure 4-5). Conversely, there have also been several high stands dating back to the Pliocene, that measured up to at least 7000 ft above m.s.l. During the Quaternary, lake highstands between 18 m (60 ft) and 183 m (600 ft) above the current lake level have been correlated by Birkeland (1962, 1964) to ice damming events during glacial maxima. As a result, even at minimum lake level and compensating for current topography, the basin floor below Meyers was at a bathymetric depth of about 244 m (800 ft) and at least 274 m (900 ft) in South Lake Tahoe near the "Y." Thus, lacustrine processes must account for the majority of the sedimentary fill in both areas. Under these conditions, processes controlling underflow, suspension settling, and surge deposition would have predominated[1].

[1] Underflow: water denser than ambient lake water that flows along the bottom of the lake.
Suspension settling: the process of particles falling through the water column.
Surge deposition: Deposition of sediment that has been re-mobilized by sediment failure processes (e.g., debris flow, turbidite, etc.).

Figure 4-5. Submerged trees indicating former lower lake levels. From Linstrom et al. (2000).

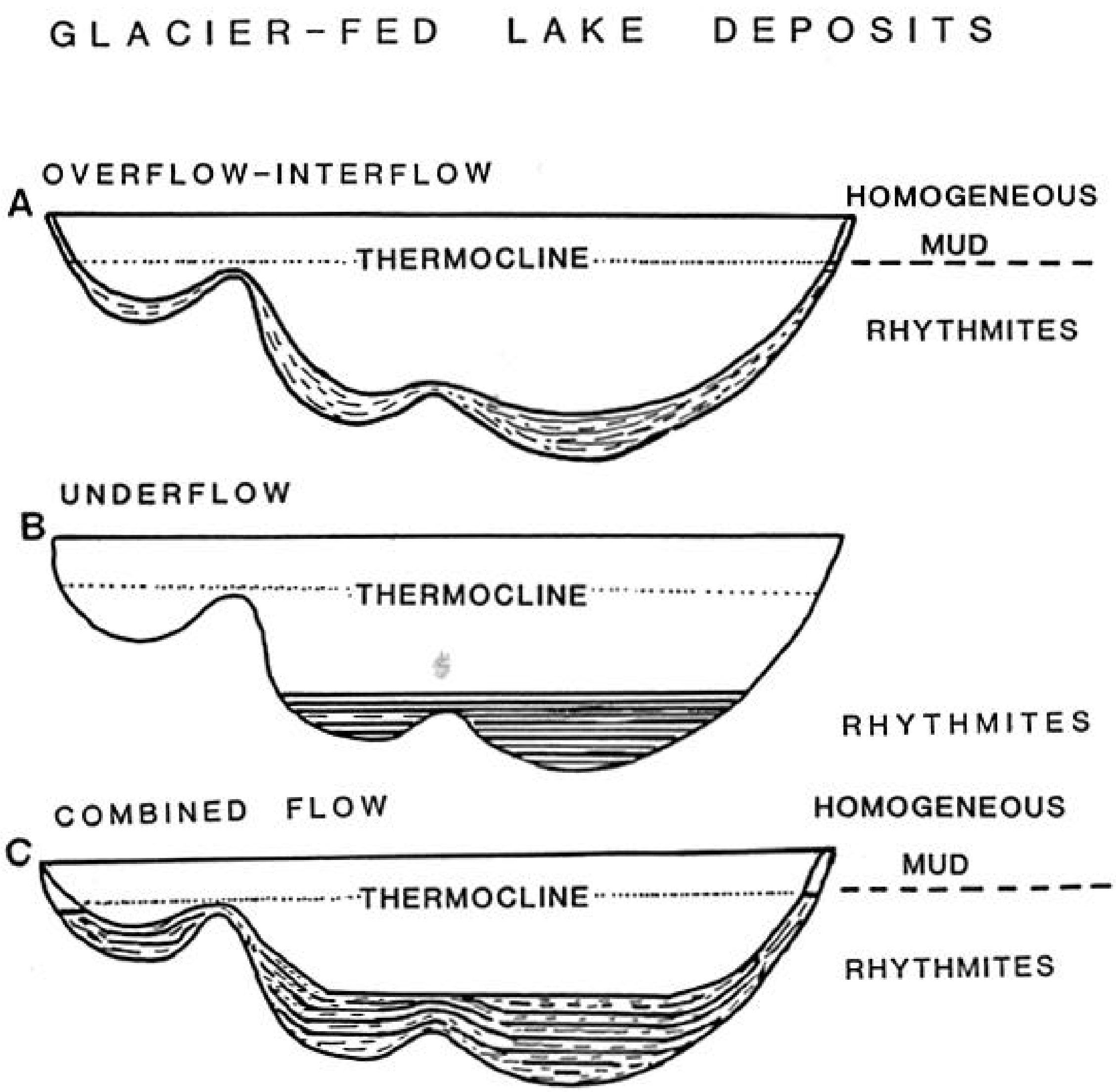
An understanding of the depositional processes aids in determining the geometry of the deposits. For the purpose of this study, two end members of deltaic systems are examined: proximal and distal (Figure 4-6). Deposition in the proximal deltaic environment is characterized by rapid deposition of coarse sediment where streams discharge into the low energy environment of the lake. This deposition results in periodic oversteepening and collapse along the delta front; the collapse produces surge type, density driven, sediment rich flows that transport material downgradient and into the more distal basin (Ashley 2002). Coarser material from the surge-type events is deposited along the cascading face, forming delta foresets, while the finer-grained material is transported into the deeper basin at turbidites and forms bottomsets. As the delta front progrades into the lake through successive deposition of foresets, fluvial deposition in the subaerial environment results in gradual aggradation and the formation of topsets. Such surge deposits would also have been interbedded with underflow and suspension settling deposits, especially in the bottomsets. Deposition in such an environment forms the typical “Gilbert Type” delta.

Figure 4-6. Ice-contact depositional environments from Ashley (2002). (a) Coarse-grained delta with high-angle foresets deposited in a "proximal" setting. Density underflows can be generated by inflowing meltwater or by foreset slumps. (b) Fine-grained delta, with low angle foresets that can form in the distal portion of an ice-contact delta or where the delta is separated from the ice by an outwash stream.



The distal deltaic environment is characterized by inflow from streams with a finer grained sediment load. Much of the sediment in such an environment can be transported into the lake in a coherent flow. The dynamics of the flows are dictated by the density stratification of the lake and relative density of the inflow (controlled by water temperature and sediment concentration). Inflow that is denser than the ambient lake water will flow along the lake bottom as an underflow (Ashley 1985). Lighter inflow will form interflows or overflows depending on where they achieve neutral buoyancy in the lake. In the case of underflows, the sediment is transported into the basin and pools in the topographic lows; sedimentation effectively bypasses bathymetric highs (Figure 4-7). Sediment in the overflows and interflows is released through suspension settling, which forms a blanket deposit that thins over highs and thickens in the lows.

Figure 4-7. Spatial variations in lake-bottom deposits as a function of dispersal mechanisms. (a) overflow-interflow, (b) underflow, and (c) combination overflow-interflow and underflow. From Ashley (1985).



It must also be realized that there is the potential for significant deposition in front of the Hobart, Donner and Tahoe glaciers, which would have terminated in the lake for significant periods of time. Deposition during these times would have been characterized by proximal subaqueous fans (Rust and Romanelli 1975, Shaw 1985). Deposition in this environment would have dictated rapid accumulation of coarse-grained glaciofluvial sediments where the stream discharged from the ice margin. Debris flows initiated by oversteepening and subsequent collapse, as well as fluctuations in the ice margin, would have distributed coarse material away from the ice margin. Density driven underflows would also have transported sand and silt away from the glacier margin. An important aspect here is that the streams would have discharged at or near the lake floor and would have aggraded as an ice-contact fan. If aggradation was able to progress to lake level, then it would have prograded as a fan-delta. We will ignore further discussion of these complications for this report, understanding that the formation of some of the sand and gravel sequences observed at depth (e.g., Scott et al. 1978, Einarson 2003) were likely deposited in this manner.

During interglacial periods, as well as the early onset and late stages of glaciation, sedimentary processes in the lake would have been dominated by fine-grained deposition. As glaciers were growing and shrinking, sediment loads in the tributary streams would have climbed dramatically (Lawson 1993) resulting in rapid accumulation of silty deposits, especially in basins like that below South Lake Tahoe. In the interglacial periods proper, sedimentation rates would be similar to those of today. Sediment would have been delivered to the lakes in underfit streams with low sediment concentrations. Minor delta progradation may have occurred near the shoreline while suspension settling occurred away from the shore. The result would have been widespread, continuous fine-grained blankets of silt and clay. These deposits would have been thickest over topographic lows and thinning over highs. The blankets also would have pinched towards the basin margin where wave-based activity would have winnowed the fine and coarse sediment introduced from the shore.

Based on this discussion, the stratigraphic sequence below Meyers and South Lake Tahoe is characterized by the interbedding of fine-grained lake sediments with coarse-grained sand and gravel. The fan and delta sedimentation during the glacial period would have prograded through coalescing fans. This can be pictured as a series of stacked sand and gravel lobes, the migration of lobes reflecting changes in sediment delivery through braided outwash channels and distributary channels on the fan in order to fill adjacent lows. The result would be a wedge of coarse-grained material that becomes bracketed by fine-grained units representing “quiet” water conditions. This sequence should repeat itself for each successive glaciation until the depositional surface is subaerially exposed.

Development of Model Layers

A six-layer model was developed for conceptualizing the hydrogeology of the South Lake Tahoe and Meyers areas (Appendix B). The goal was to provide relatively high resolution in the upper 46 m (150 ft) and then lump deeper units to behave as a reservoir in the computations. The rationale behind this is that Scott et al. (1978) and Einarson (2003) have demonstrated that thick, continuous fine-grained units exist at depth which impose considerable impedance to vertical flow. Therefore these zones should restrict flow contaminated by surface processes and anthropogenic inputs to the upper water bearing zones. Therefore, the upper 30 m (100 ft) were subdivided into four units of 8 m (25 ft) thickness. This first layer was used to account for higher groundwater elevations away from the shore. This layer was added that extended from 6,243 to 6,268 ft above m.s.l. Layers 2 through 6 are the layers which intersect Lake Tahoe, with the upper of these units starting at an elevation of 6,243 ft above m.s.l. (the approximate water level at the "Y"). Layer 5 was 15-meter (50-feet) thick and all the remaining sequences were lumped into a deep zone that extends to bedrock. The bedrock configuration was extrapolated from Bergsohn (2003).

Within each of these zones, variations in hydraulic conductivity were estimated based on relative percentages of fines versus coarse sand and gravel. The stratigraphic information used to do this for South Lake Tahoe was extracted from the geologic cross sections in Scott et al. (1978). In the Meyers area, these data were extracted from stratigraphic interpretation based on borehole geophysical logs. The hydrologic conductivity was placed in seven groups for each layer as defined in Table 4-1 and shown in Appendix B (Fenske 2003).

Table 4-1. Hydrologic Conductivity Estimates (m/day) Initial Values Used

		Conductivity	
Unit	Description	Horizontal	Vertical
A	Bedrock	0.5	0.06
B	Clean sand and gravel	39.6	6.1
C	Sand and gravel with less than 25% fines	15.2	0.15
D	Silty Sand	15.2	0.15
E	25 to 50% fines	1.52	0.06
F	50 to 75% fines	1.52	0.006
G	Greater than 75% fines	0.03	0.003

Notes:
1. 1 m/day = 3.2808 ft/day