SYNTHESIS OF EXISTING INFORMATION

FINAL AUGUST, 2011

INFILTRATION BMP DESIGN & MAINTENANCE STUDY

TAHOE REGIONAL PLANNING AGENCY

2NDNATURE
ecosystem science + design

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EXECUTIVE SUMMARY

This synthesis is the initial task of a Tahoe Regional Planning Agency (TRPA) funded effort to improve the technical guidance on how to optimize infiltration BMP implementation, design and maintenance strategies to protect beneficial uses and most effectively contribute to sustained FSP stormwater load reductions to Lake Tahoe. The technical research findings will be used to expand the existing TRPA BMP Handbook design and maintenance guidance for infiltration BMPs in the Tahoe Basin. This document intended to advise managers on the implementation and risks of infiltrating stormwater via infiltration BMPs in the Tahoe Basin by providing the scientific basis to support pollutant-specific assessment of stormwater discharge to groundwater regulations; evaluating soil characteristics with the potential to affect subsurface pollutant transport; and identifying key factors influencing decline and failure of stormwater infiltration BMPs.

Pollutant Transport Risks and Research Priorities

Pollutant constituents relevant to TRPA regulations (oil and grease, turbidity, total iron, total nitrogen, dissolved nitrogen, total phosphorus, dissolved phosphorus) were evaluated individually to identify potential risks to groundwater quality or lake clarity due to infiltration based on existing knowledge of their geochemical behavior, Tahoe specific data, and stormwater infiltration studies from the scientific literature. Evidence of transport and contamination risks for each pollutant constituent are summarized in table ES. 1, along with research priority rankings for lake clarity and groundwater quality concerns (see table 5.1 for an explanation of research priority ratings). The information available indicates that the majority of pollutant constituents such as oil and grease, fine sediment particles (FSP), particulate phosphorous or particulate nitrogen will be trapped within the upper vertical portions of the soil column where infiltration occurs and extensive migration of particulate pollutants in the subsurface is unlikely, while soil properties and groundwater dynamics may affect transport of dissolved pollutants (see table ES. 1).

Table ES. 1 Summary of evidence for transport risks and research priority ranking

Constituent	Geochemical and empirical evidence	GW Research Priority	Key additional points	Lake Clarity Research Priority	Key additional points
Oil and Grease	• Hydrophobic pollutant with a high affinity for soil adsorption and relatively immobile in subsurface under all conditions • Constituents likely to be retained in topmost soil layers of infiltration BMPs • Concentrations low in Tahoe Basin stormwater relative to current standard	LOW	No drinking water standard for oil and grease	LOW	Not a pollutant of concern in the Lake Tahoe TMDL

Constituent	**Geochemical and empirical evidence**	**GW Research Priority**	**Key additional points**	**Lake Clarity Research Priority**	**Key additional points**
Total Iron	• High affinity to adhere to soil particles • Studies indicate accumulation primarily in top few cm of soil • No available stormwater data for review • Highest recent groundwater well measurement 3x below drinking water standard	LOW		LOW	Not mentioned in the Lake Tahoe TMDL though past research suggested potential iron limitation with some primary producer communities
Total Nitrogen (TN)	• Majority of constituent concentrations are particulate species • Particulate constituents not mobile in subsurface	LOW	No drinking water standard for TN	LOW	Only 12.5% of Lake TN budget delivered via groundwater (all of which is DN)
Dissolved Nitrogen (DN)	• Conservative pollutant highly mobile in the subsurface • Sewage exfiltration may be a higher annual source of DN to groundwater than stormwater infiltration • Evidence of DN groundwater enrichment in Tahoe urban areas • STPUD groundwater wells contain an average nitrate as N concentration < 1 mg/L, over 10x below drinking water standards	MOD		MOD	Currently DN is not the limiting nutrient for algal growth in Lake Tahoe
Total Phosphorus (TP)	• Majority of constituent concentrations are particulate species • Particulate constituents not mobile in subsurface	LOW	No drinking water standard for TP	LOW	Only 15% of Lake TP budget delivered to the lake via groundwater (all of which is DP)
Dissolved Phosphorus (DP)	• High affinity to adsorb to soil particles • Tahoe infiltration studies suggest minimal horizontal migration • Sewage exfiltration may be a larger annual source of DP to groundwater than stormwater infiltration • May travel intermediate distances in low cation exchange capacity (CEC) soils • STPUD water supply wells < 0.04 mg/L	LOW	No drinking water standard for DP species	HIGH	Phosphorus is the limiting nutrient for algal production in Lake Tahoe and therefore primary nutrient of concern for Lake Tahoe TMDL

Constituent	Geochemical and empirical evidence	GW Research Priority	Key additional points	Lake Clarity Research Priority	Key additional points
Fine Sediment Particles (FSP) + Turbidity	• Turbidity is not a pollutant and rather an optical property of water • Preliminary research indicates turbidity may be a useful proxy for FSP concentrations • Potential for some FSP transport through coarse Tahoe Basin soils • Loading of turbid water will reduce performance of infiltration BMPs soils over time • Highest STPUD water supply wells turbidity measurements are nearly 10x below drinking water standard	LOW	No drinking water standard for FSP	HIGH	FSP Identified as primary pollutant impairing lake clarity in the TMDL

Soil properties (saturated hydraulic conductivity, texture, cation exchange capacity) vary throughout the basin and have the potential to affect transport potential of mobile (dissolved) pollutants. Soil properties and groundwater dynamics are mapped and the specifics of the spatial distribution of transport risks are discussed in detail in chapters III and IV. Generally, soils with higher K_{sat} values will infiltrate water more quickly and have a greater overall potential to transport water and (conservative) pollutants down gradient in the subsurface. While BMPs to infiltrate roadway, commercial and residential runoff are common in South Lake Tahoe, there is little evidence that stormwater infiltration BMPs substantially increase DP groundwater levels. Soils consisting of loamy coarse sand and coarse sand, and lower cation exchange capacities (CEC) will be conducive to movement of FSP with water in the subsurface. FSP transport to the Lake may only be a concern where the relatively coarse Christopher or Gefo soil series border Lake Tahoe since horizontal transport through less soil permeable soils are likely to retain most FSP before reaching Lake Tahoe. Select South Lake Tahoe urban areas where soils have relatively low CEC values have a higher potential risk of DP migration should chronic elevated levels of DP be introduced to these soils.

Subsurface waters with the greatest potential for immediate pollutant enrichment as a result of stormwater infiltration are the shallow groundwater zones beneath infiltration BMPs, rather than deep groundwater aquifers. The assumption that stormwater infiltration will have a greater likelihood to contaminate groundwater when introduced into a saturated soil column (i.e., elevated shallow groundwater elevations) may not be generally applicable given the typical concentration ranges observed in the Tahoe Basin for constituents considered. Soil moisture levels have a negligible influence on the fate and transport of the pollutants since a saturated soil column will effectively filter and retain particulate pollutants as well as remove hydrophobic pollutants such as oil and grease. Additionally, areas with shallow groundwater tables will experience significantly reduced vertical flux of water during spring and winter due to reduced infiltration capacity of the saturated soils.

Recommendations

The review of existing information resulted in the following policy recommendations for TRPA and LRWQCB:

1. **Align LRWQCB and TRPA vertical groundwater separation regulations.** Consistent vertical separation regulations between the Basin Plan and TRPA would make infiltration BMP sizing, design and permitting more efficient.

2. **Continue nutrient source control efforts.** Practices to minimize application and runoff of phosphorous-rich fertilizers and maintenance of sewer systems to minimize exfiltration will greatly reduce the likelihood of increasing future stormwater DP concentrations and localized subsurface DP migration**.**

Specific research priorities identified based on existing knowledge gaps include:

3. **Complete controlled bench studies of FSP and DP migration via Christopher and Gefo soils.** The Christopher and Gefo soils comprise over 20% of the Tahoe Basin urban area. These soils are the coarsest soil series and therefore expected to have the highest potential to allow FSP migration due to higher porosity and DP migration due to relatively low CEC values.
4. **Complete DN and DP pollutant loading budgets to Lake Tahoe.** The appropriate pollutant mass balance to adequately evaluate the relative contribution of groundwater loading of N and P to Lake Tahoe is needed to augment the existing TMDL. Since only dissolved nutrient constituents are mobile in the subsurface, the existing loading contributions from groundwater of 12.5% and 15% of TN and TP, respectively, are underestimates of the relative role groundwater contributes to these biologically available fractions of critical nutrients driving lake primary production.

Factors affecting BMP Performance

The uncertainty surrounding infiltration BMP effectiveness and performance decline over time is a critical knowledge gap in the understanding of pollutant movement within the Tahoe Basin. A review of existing scientific literature, technical reports, and other information sources resulted in the consistent identification of a number of key factors contributing to infiltration BMP failure and poor performance which are listed in table ES.2. The siting and design, maintenance, and cold climate issues listed in table ES.2 will serve as the starting point for the remainder of this research which will investigate the factors contributing to performance decline and failure of infiltration BMPs throughout the Tahoe Basin to generate setting specific design and maintenance recommendations.

Table ES.2. Factors affecting infiltration BMP failure and performance decline

Siting and Design Issues	• High sediment loads in stormwater runoff are not addressed, leading to frequent clogging. • Inadequate site assessments lead to a less effective design • General design and installation flaws
Maintenance Issues	• Inspection and maintenance plan is not followed, funded, or was never developed • Maintenance actions are poorly defined and not prescriptive enough to facilitate agreement or understanding as to what actions are implemented • Lack of condition assessments to determine when maintenance should be performed due to declined performance beyond acceptable range • Unrealistic inspection and maintenance plan, resulting in only partial or minimal compliance • Lack of maintenance access
Cold Climate Considerations	• Frozen soils or inlets blocked by ice causing ineffective winter performance • Use of Infiltration BMPs as snow storage areas reduces performance

I. INTRODUCTION

This synthesis is the preliminary task of a Tahoe Regional Planning Agency (TRPA) funded effort to improve the technical guidance on how to optimize infiltration BMP implementation, design and maintenance strategies to protect beneficial uses and most effectively contribute to sustained FSP stormwater load reductions to Lake Tahoe. The technical research findings will be used to expand the existing TRPA BMP Handbook (TRPA 1988) design and maintenance guidance for infiltration BMPs in the Tahoe Basin.

PURPOSE OF SYNTHESIS

This document is a synthesis of existing knowledge to educate and advise managers on the implementation and risks of infiltrating stormwater via infiltration BMPs in the Tahoe Basin. Its purpose within the context of the overall TRPA funded effort is three-fold:

1. <u>Provide the scientific basis to support assessment of regulations regarding stormwater discharge to groundwater.</u> The Water Quality Control Plan for the Lahontan Region (Basin Plan; LRWQCB 1995) and Tahoe Regional Planning Agency (Code of Ordinances; TRPA 1987) provide a number of water quality standards and control measures for surface and ground waters to protect beneficial uses. Stormwater infiltration is one of the primary treatment processes utilized in the Tahoe Basin to reduce stormwater pollutant loads and meet the long-term Lake Tahoe TMDL goals (LRWQCB and NDEP 2010). There is a practical need to evaluate the potential risk to groundwater contamination and/or the risk of transport of critical pollutants of concern to the Lake via shallow groundwater as a result of stormwater infiltration practices. The conclusions from this synthesis are intended to provide the technical rationale to inform assessment or modification to the TRPA and Basin Plan standards that aim to protect groundwater quality and pollutant loading to the Lake via groundwater as a result of stormwater infiltration BMPs.

2. <u>Identify and evaluate soil characteristics associated with subsurface pollutant transport and potential groundwater contamination.</u> There has been some question in the Tahoe Basin as to whether soil structure and mineralogy should influence infiltration BMP design to manage the risk to groundwater contamination and reduce the potential subsurface transport of pollutants to Lake Tahoe. This synthesis draws upon hydrogeologic processes, geochemical principles, relevant stormwater management literature, and Tahoe Basin specific datasets. It provides technical guidance for the critical characteristics of the native soils that may need to be considered during infiltration BMP design and management in order to protect the identified groundwater quality and lake clarity.

3. <u>Review the key factors identified in existing research that influence performance decline and/or failure of stormwater infiltration BMPs.</u> One of the primary purposes of infiltration BMP installation and maintenance is to reduce surface water loading of fine sediment particles (FSP < 16 μm) to Lake Tahoe. FSP has been determined to be the primary pollutant causing the reduced clarity of the Lake (Swift et al. 2006) and sustained annual reductions in FSP loading from urban stormwater is the priority implementation strategy to restore the clarity of Lake Tahoe (LRWQCB and NDEP 2009). The key factors influencing performance declines in infiltration BMPs are identified from this synthesis in an effort to prioritize existing data gaps and inform the approach of the subsequent data collection phase of this research.

TAHOE BASIN STORMWATER INFILTRATION REGULATIONS

To provide the context for reassessment of stormwater discharge to groundwater regulations we briefly review the regulations relevant to stormwater infiltration BMPs. An infiltration BMP is intended to reduce stormwater volumes as a result of infiltration. In the LRWQCB Basin Plan (LRWQCB 1995; p 5.6-2), an infiltration BMP (system) is defined: "*Infiltration systems include, but are not limited to, trenches, dry wells, ponds, vaults, porous pavement and paving stones*". The TRPA BMP Handbook states that an infiltration BMP system "*consists of structures used to infiltrate runoff rapidly and to facilitate the percolation through the subsoil*" and lists specific planning criteria for infiltration trenches, french drains, and dry wells (TRPA 1988; p. 95).

The TRPA and the Lahontan Regional Water Quality Control Board (LRWQCB) Basin Plan have similar regulations dictating requirements for discharge of infiltration features to groundwater within the Tahoe Basin. This synthesis specifically addresses the risk of each pollutant listed in Table 1.1 to compromise groundwater quality and lake clarity via subsurface pollutant transport. Declines in groundwater quality from stormwater infiltration have the potential to negatively affect several relevant water supply beneficial uses defined by the LRWQCB (municipal and domestic water supply, groundwater recharge). Lake clarity may be degraded via subsurface pollutant transport to the Lake, defined in terms of groundwater beneficial uses by LRWQCB as 'freshwater replenishment to surface waters'.

The two specific components of TRPA Code of Ordinances and Basin Plan Standards to be addressed are:

a. Basin Plan and TRPA constituent maximum discharge limits to groundwater via infiltration BMPs for five specific pollutants (see Table 1.1).
b. The need for vertical separation between stormwater infiltration features and seasonally high groundwater. While LRWQCB requires five feet vertical separation between the bottom of infiltration features and seasonal high groundwater levels to meet effluent limits (LRWQCB 1995; p 5.6-2), the TRPA recommends 12 inches vertical separation (TRPA 1988; p. 96).

Table 1.1. Constituent maximum concentration limits for runoff discharged to infiltration systems (LRWQCB 1995; p 5.6-4). The TRPA Code of Ordinances (TRPA, 1987) includes the same numeric criteria in their standards for discharges to groundwater (p. 81.2)

Pollutant	Maximum concentration
Oil and Grease	40 mg/l
Turbidity	200 NTU
Total Iron	4 mg/l
Total Nitrogen as N (TN)	5 mg/l
Total Phosphate as P; measured as total phosphorous (TP)	1 mg/l

DOCUMENT STRUCTURE

The synthesis takes a step-wise approach to evaluating the potential risk associated with specific pollutants to impair groundwater quality and lake clarity and focusing subsequent research:

- Section II (Pollutant Geochemistry and Tahoe Basin Conditions) defines each pollutant listed in Table 1.1 and evaluates the pollutant geochemical behavior of these constituents in a subsurface environment. The geochemical fate and transport of each pollutant is explained with a synthesis of existing Tahoe stormwater and/or groundwater quality data to better quantify existing conditions relative to the potential risks to groundwater quality and lake clarity.

- Section III (Influence of Soil Type on Pollutant Transport) builds upon the pollutant geochemistry and considers the potential influence that Tahoe native soil characteristics have on pollutant transport risks
- Section IV (Effects of Shallow Groundwater on Stormwater Infiltration) evaluates the potential implications to groundwater resources and pollutant loading to the Lake if infiltration systems are constructed in areas of elevated seasonal groundwater.
- Section V (Pollutant Research Priorities and Recommendations) summarizes the key points for each pollutant identified in Sections II-IV and outlines risks to groundwater quality or pollutant loading to Lake Tahoe via groundwater for each relevant pollutant constituent. Pollutants are categorized by research priority to understand transport risks based on the information currently available.
- Section VI (Key Factors Affecting BMP Performance) summarizes existing practices and available literature regarding infiltration BMP design, performance and maintenance concerns in the Tahoe Basin and beyond. These findings will drive the subsequent research prioritization and data collection for this TRPA research effort.

II. POLLUTANT GEOCHEMISTRY AND TAHOE BASIN CONDITIONS

Section II presents an overview of physical and chemical factors that control subsurface migration of pollutants listed in Table 1.1. Previously collected Tahoe Basin stormwater and groundwater datasets are used to provide empirical evidence of stormwater loading, typical groundwater concentrations, pollutant mobility, and contamination potential.

OIL AND GREASE

POLLUTANT FORMS AND SOURCES

Unlike most environmental pollutants, oil and grease is not a unique chemical entity, but is a mixture of chemical species that varies from source to source. The likely sources of oil and grease in Tahoe stormwater include highways, parking lots, automobile repair shops, and other concentrated areas of automobile oil leaks. Oil and grease is a measure of all of the carbon and hydrocarbon compounds within a water sample, and is specifically defined by the method used to measure it. Oil and grease is hydrophobic and has the natural tendency to float on the water surface under quiescent conditions, as the density of oil and grease is substantially less than that of water.

Bulk carbon and hydrocarbon compounds have a very high affinity to adhere to soil particles and are not easily conveyed with infiltrating stormwater through the subsurface (Weiss et al. 2008). In addition, heavy carbon and hydrocarbon compounds are preferred carbon sources for microbes and there is a high decomposition/respiration rate of these compounds by bacteria in intermittently saturated environments (Leahy and Colwell 1990).

STORMWATER AND GROUNDWATER DATA

2NDNATURE (2006A) conducted a controlled study to determine if the infiltration of hydrocarbon compounds in urban stormwater posed a threat to shallow groundwater quality in the Tahoe Basin. The study included an evaluation of the surface water/shallow groundwater interactions of hydrocarbon compounds (including oil and grease) and nutrient species in two dry basins located in South Lake Tahoe. First flush stormwater samples were collected over two water years from two urban catchments with land uses expected to have relatively elevated oil and grease sources for the Tahoe Basin. The "first flush" phenomena is defined as the initial period of stormwater runoff during which the concentration and load of pollutants is substantially higher than during the later stages of the runoff event (e.g., Schiff and Tiefenthaler 2010). The "first flush" of pollutants from urban surfaces during rain events has been well documented, and an accepted quantitative definition is that 80% of the pollutant load will be transported in the first 30% of the event runoff volume (Bertrand-Krajewski et al. 1998). Of the 15 samples collected from stormwater runoff events spanning two water years (2004-2005), the mean oil and grease concentration was 15 mg/L and the maximum was 21 mg/L (2NDNATURE 2006A), 50% below the current Basin Plan standard of 40 mg/L (see Table 1.1). Stormwater monitoring resulted in consistent detections of heavy petroleum hydrocarbons (TEPH and TPH-diesel), and low level detections of VOC's, primarily toluene and xylenes, were observed in approximately 20% of the stormwater samples collected. Other key petroleum constituents (benzene, ethylbenzene, and oxygenates; MtBE, TAME, TBA) that are 3 to 4 orders of magnitude more mobile in the subsurface than oil and grease were not detected in any of the surface water samples collected.

Also as part of the 2NDNATURE (2006A) research, shallow groundwater wells (screened at the top of the water table) surrounding the areas of expected infiltration influence were monitored during infiltration events to determine if pollutants detected in the infiltrating stormwater were transported laterally and downgradient in the subsurface. Only one of the 68 shallow groundwater samples collected as part of the research had a detection of oil and grease (3.9 mg/L). Researchers suspected that the single oil and grease detection was due to contamination of the groundwater well during sampling. None of the 12 monitoring wells installed for the project contained detectable levels of hydrocarbons, VOCs or oxygenates following the analysis of 68 shallow groundwater samples collected in locations potentially impacted by stormwater infiltration.

Stormwater research conducted outside of the Tahoe Basin supports the notion that oil and grease are largely immobile in the subsurface (Weiss et al. 2008). Barraud et al. (1999) investigated the effectiveness of two different infiltration chambers - one was 2 years old and the other was 30 years old - and the potential impact on the soil and groundwater in France. The authors concluded that hydrocarbon concentrations were very high in the first few centimeters of soil and attenuated rapidly with depth. Hsieh and Davis (2005) tested laboratory column rain gardens with sandy and sandy loam media and found greater than 96% removal of oils and grease (introduced as used motor oil through synthetic stormwater). The results of their field study found that removal efficiency of oils and greases from a synthetic stormwater was nearly 100 percent and 99% removal was observed during a natural rain event.

SUMMARY OF FINDINGS

While data is limited in the Basin it is reasonable to assume that given the rural nature and the limited area of industrial land practices in the Tahoe Basin, oil and grease concentrations in stormwater would not frequently exceed the concentrations observed by 2NDNATURE (2006A). Compared to these values it is unlikely that oil and grease pose a risk to groundwater contamination via infiltration of stormwater due to the propensity for oil and grease to adhere to soil particles and the high decomposition/respiration rate of these compounds. While oil and grease are not mobile in the subsurface, long term contamination may become a risk as the pollutants accumulate in the soil media (Barraud et al. 1999), which may affect soil pollutant retention characteristics. Infiltration BMP designs that include pre-treatment where concentrations are sufficiently high, as recommended in the TRPA BMP Handbook (TRPA, 1988), will help to ameliorate the accumulation problem.

TURBIDITY

POLLUTANT FORMS AND SOURCES

Turbidity is a measure of the degree to which water loses its transparency due to the presence of suspended particulates. Turbidity is an optical measure reported in either Nephelometric Turbidity Units (NTU) or Formazin Turbidity Units (FAU) depending upon the type of optical probe used, with NTU or FAU values increasing proportionally with the concentration of suspended organic or inorganic material contained within the column of water evaluated. The suspended particles clouding the water may be due to such inorganic substances as clay, rock flour, silt, calcium carbonate, silica, iron, manganese, sulfur, or industrial wastes, or caused by organic substances such as various microorganisms, finely divided vegetable or animal matter, grease, fat, oil, etc. While turbidity is affected by suspended particles, it is not sensitive to concentrations of dissolved constituents (smaller than 0.45 μm) since they do not cause light to be scattered or absorbed (Spellman 2008).

Turbidity has been used as a popular cost-effective proxy for a variety of surface water quality parameters in the Tahoe Basin. Turbidity transects have been used to track the temporal and spatial clarity of Lake Tahoe's nearshore environments (Taylor et al. 2003). Laboratory analyses of particulates including total suspended solids (TSS) and suspended sediment concentrations (SSC) have been found to strongly correlate with turbidity in a variety of aquatic systems (e.g., Gippel 1995, Packman et al. 1999), including work performed on Tahoe streams to estimate sediment loads (2NDNATURE 2006B, Stubblefield et al. 2006). Recent research in the Tahoe Basin has demonstrated a strong correlation between FSP concentrations (mass per unit volume) and turbidity in Tahoe Basin: 1) streams (2NDNATURE 2011); 2) runoff produced from rain simulations on roads (2NDNATURE and NHC 2010); and 3) stormwater (2NDNATURE 2009).

GROUNDWATER DATA

The South Tahoe Public Utility District (STPUD) supplies drinking water to the South Lake Tahoe via groundwater extractions and routinely measures turbidity as a potential indication of elevated microorganisms in the water supply. Recent STPUD turbidity results from their extraction wells are presented in Table 2.1, indicating consistently low groundwater turbidity values.

Table 2.1. Summary of average annual turbidity levels measured in STPUD water supply wells from 2003-2009 (http://www.stpud.us/h2oquality.html). The EPA Interim Primary Drinking Water Regulations recommend that turbidity less than 5 NTU (http://water.epa.gov/drink/contaminants/index.cfm).

Year	Average turbidity (NTU)
2003	0.53
2004	0.55
2005	0.55
2006	0.16
2007	0.55
2008	0.40
2009	0.51

SUMMARY OF FINDINGS

The current Basin Plan turbidity discharge standard for infiltration of stormwater is 200 NTU (see Table 1.1), which correlates to a relatively high concentration of suspended particulates in the stormwater. The risk of transfer of particles contained in stormwater to the shallow groundwater via infiltration is primarily controlled by the porosity of the soil column to which the waters are introduced (see Section III). Given the physical immobility of particulate pollutants, as measured by turbidity, the risk of impacts to groundwater quality or lake clarity as a result of infiltrating stormwater with elevated (> 200 NTU) turbidity levels is low and likely a greater concern to the performance decline of the infiltration BMP itself. Since turbidity is a property of water and not a pollutant, the remainder of this synthesis will focus upon fine sediment particles < 16 μm (FSP) because FSP is a primary pollutant of concern in the Tahoe Basin and preliminary research indicates FSP concentrations appear to be correlated to turbidity in water.

TOTAL IRON

POLLUTANT FORMS AND SOURCES

While total iron is not a primary pollutant of concern in the Tahoe Basin, there is a lack of information to precisely determine its importance in processes that may contribute to degradation of lake clarity. The Basin Plan infiltration discharge standards (see Table 1.1) were developed in the 1990's at a time when the current hypothesis was that the continued decline in lake clarity was primarily the result of cultural eutrophication due to an average increase in primary productivity of 5.6% per year in Lake Tahoe (Goldman 1988). Field and bioassay work conducted by the USGS in the early 1990's suggested that Lake Tahoe primary producer communities possessed a potential co-limitation for both phosphorous and iron availability (Chang et al. 1992). Additional research has led to an improved understanding of urban stormwater pollutants, including Swift et al. (2006) who found that fine inorganic particles in suspension play a greater annual and seasonal role of impairing the lake clarity than organic particles such as phytoplankton and algae. The most recent 2010 Lake Tahoe TMDL document (LRWQCB and NDEP 2010) never mentions iron limitation of the Lake, indicating iron availability to primary producers is no longer a high priority. However, recent work in other oligatrophic lakes suggests that under certain conditions iron co-limitation may be an important factor for primary production (Vrede and Tranvik 2006), particularly at short but biologically meaningful timescales and even in lakes where phosphorus limitation dominates (Sterner 2008).

GROUNDWATER DATA

Data from Tahoe Basin wells indicate that total iron is not presently a concern in groundwater, which is supported by evidence from the scientific literature. Numerous field studies of infiltration features with a wide range of ages conducted in a variety of geographic settings around the world indicate that heavy metals accumulation occurs within the top few centimeters of soil (e.g., Barraud et al. 1999) and that concentrations attenuate rapidly with depth (Dierkes and Geiger 1999, Legret et al. 1999, Weiss et al. 2008). The STPUD supply of drinking water to the community of South Lake Tahoe is collected from 16 groundwater extraction wells located throughout the area. Comparisons of the STPUD annual average iron concentrations suggest that regional groundwater contamination of iron is not currently a problem (Table 2.2). The highest year in recent record was 2005, which had levels nearly 3 times below the drinking water standard and far below the Basin Plan standard of 4 mg/L.

Table 2.2. Summary of average annual iron concentrations measured in STPUD water supply wells from 2003-2009 (http://www.stpud.us/h2oquality.html). The current EPA maximum contaminant level for iron in drinking water is 0.3 mg/L, which is a secondary standard designed for human welfare (e.g. odor, taste) (http://water.epa.gov/drink/contaminants/index.cfm#Secondary).

Year	Average total iron concentration (mg/l)
2003	0.056
2004	0.055
2005	0.114
2006	0.037
2007	0.053
2008	0.053
2009	0.038

TOTAL NITROGEN

POLLUTANT FORMS AND SOURCES

Total nitrogen consists of both the dissolved and particulate forms of nitrogen (Figure 2.1). Only dissolved nitrogen species are of concern in groundwater due to the relative immobility of particulates in the subsurface environment. Dissolved inorganic nitrogen (DIN) is composed of nitrate (NO_3^-), nitrite (NO_2^-) and ammonia (NH_3), which are considered to be conservative pollutants due to their high solubility in water and low affinity to adhere to soil particles (Stumm and Morgan 1996). Dissolved organic nitrogen (DON) is physically small enough to migrate via groundwater and is bound or tied up in plant tissue, waste solids or other organic material that may be found at elevated concentrations in groundwater in close proximity to productive surface water environments, such as a wetlands, wet basins, or downgradient of a leaking septic or sewer systems. DON presence in shallow groundwater beyond these sources is unlikely due to organic decomposition and respiration back to inorganic compounds. Dissolved nitrogen (DN) is the sum of DON and DIN.

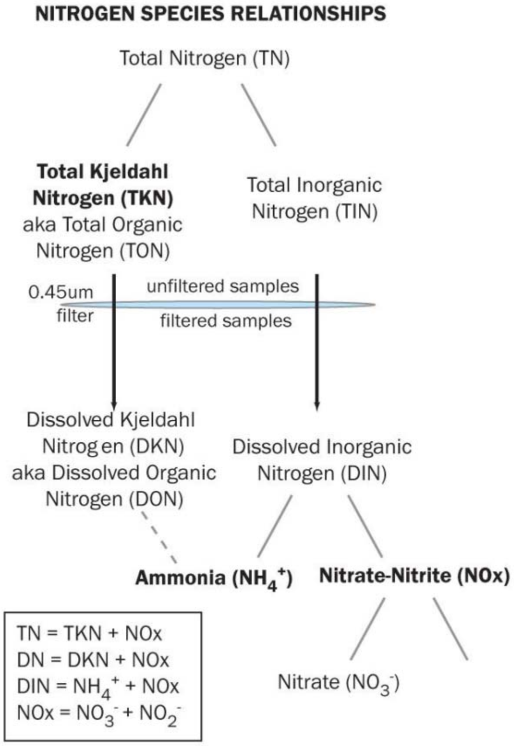


Figure 2.1 Nitrogen species relationships

Nitrate is the predominant nitrogen constituent in groundwater and nitrate contamination in groundwater is common. DIN species are a necessary nutrient for biological growth in surface waters and can stimulate algal growth, a known contributing factor to the decline of Lake Tahoe clarity (LRWQCB and NDEP 2010). However, the supply of phosphorous (not nitrogen) is the nutrient limiting primary production in Lake Tahoe (LRWQCB and NDEP 2010) and therefore, current management strategies prioritize the reduction of phosphorous loads over nitrogen in an effort to reduce the primary production rates in Lake Tahoe. In addition, while primary production rates in Lake Tahoe are currently higher than the pre-development levels, recent research indicates that the suspension of fine inorganic particles are the primary cause of Lake Tahoe’s continued clarity decline (Swift et al. 2006, LRWQCB and NDEP 2010).

In the context of the Lake Tahoe TMDL, mass balance estimates of the relative sources of average annual loading of TN to Lake Tahoe suggest over 50% is from the direct atmospheric deposition in the form of nitrate (NO_3^-) (LRWQCB and NDEP 2010, USDA 2000, California ARB 2006). The groundwater contribution to Lake Tahoe average annual total nitrogen load is estimated to be 15% (LRWQCB and NDEP 2010). The two primary sources of DIN to groundwater in the Tahoe Basin are sewage exfiltration (USACE 2003) and the infiltration of urban stormwater

(USACE 2003, LRWQCB and NDEP 2010). Dissolved inorganic nitrogen pollution in urban stormwater can be generated from atmospheric deposition onto impervious surfaces, fertilizer applications, automobile exhaust, fires, and industrial activities. Infiltration of urban stormwater is the main process by which land use generated DIN is introduced to the shallow groundwater. Recreational land uses, such as golf courses and ball fields, that are subjected to chronic fertilizer applications have also been identified as areas where adjacent surface water detention features possess elevated DIN concentrations (USACE 2003, 2NDNATURE 2008). Catchments with a greater fraction of impervious surfaces and relatively higher automobile traffic correlate with relatively higher DIN stormwater concentrations (Pitt et al. 1996).

STORMWATER DATA

A number of Tahoe specific research efforts have evaluated the fate and transport of nitrogen in urban stormwater introduced to infiltration BMPs. A substantial range in DIN ($NO_3^- + NH_4^+$) concentrations have been measured in Tahoe urban stormwater, from less than 0.05 mg/L in low density residential areas (SH+G 2003, USACE 2003) to over 3 mg/L in areas with high automobile traffic and high distribution and density of impervious surfaces (2NDNATURE 2006B, 2NDNATURE 2006A) or from irrigation runoff of a fertilized ball field (2NDNATURE 2007). A comprehensive synthesis of existing BMP performance evaluations indicates the stormwater infiltration discharge standard of 5 mg/L of total nitrogen was commonly exceeded in urban catchments containing a high proportion of impervious surfaces or recreational land uses in close proximity to sampling sites (2NDNATURE 2006B). The primary sources of nitrate in Tahoe Basin urban stormwater are common in all urban areas (Pitt et al. 1996). Table 2.3 lists TN and DN event mean concentrations (EMCs) for stormwater by land use, with average EMCs over the entire urbanized portion of the Tahoe Basin for TN (2.9 mg/L) and DN (0.37 mg/L).

Table 2.3. Tahoe Basin Urban Area Nitrogen EMC values by land use. (Source: LRWQCB and NDEP 2008)

Urban Land Use	TN EMC (mg/L)	DN EMC (mg/L)
Residential Single Family – Pervious	1.8	0.14
Residential Multi Family – Pervious	2.8	0.42
CICU – Pervious	2.5	0.29
Vegetation Turf	4.9	0.49
Residential Single Family – Impervious	1.8	0.14
Residential Multi Family – Impervious	2.8	0.42
CICU – Impervious	2.5	0.29
Primary Roads	3.9	0.72
Secondary Roads	2.8	0.42
Average Tahoe Basin Urban Area EMC	**2.9**	**0.37**

Since only the DIN fraction of TN is mobile in the subsurface environment, it is useful to estimate the portion the DIN from the observed TN data for comparison with the TN regulatory standard. The average DIN stormwater concentration in the studies where TN typically exceeded 5 mg/L was 0.65 mg/L, or 13% of the total nitrogen (2NDNATURE 2006B). Thus we can approximately equate the 5 mg/L TN standard to a 0.65 mg/L DIN. Over the past 8 years, 2NDNATURE has collected and analyzed over 2000 stormwater samples for different forms of nitrogen for a variety of research efforts within the Tahoe Basin. If we assume that the 2NDNATURE stormwater dataset is a representative sample for the Tahoe Basin, then DIN stormwater concentrations exceed the 0.65 mg/L DIN infiltration standard (5 mg/L TN equivalent) approximately 50% of the time.

GROUNDWATER DATA

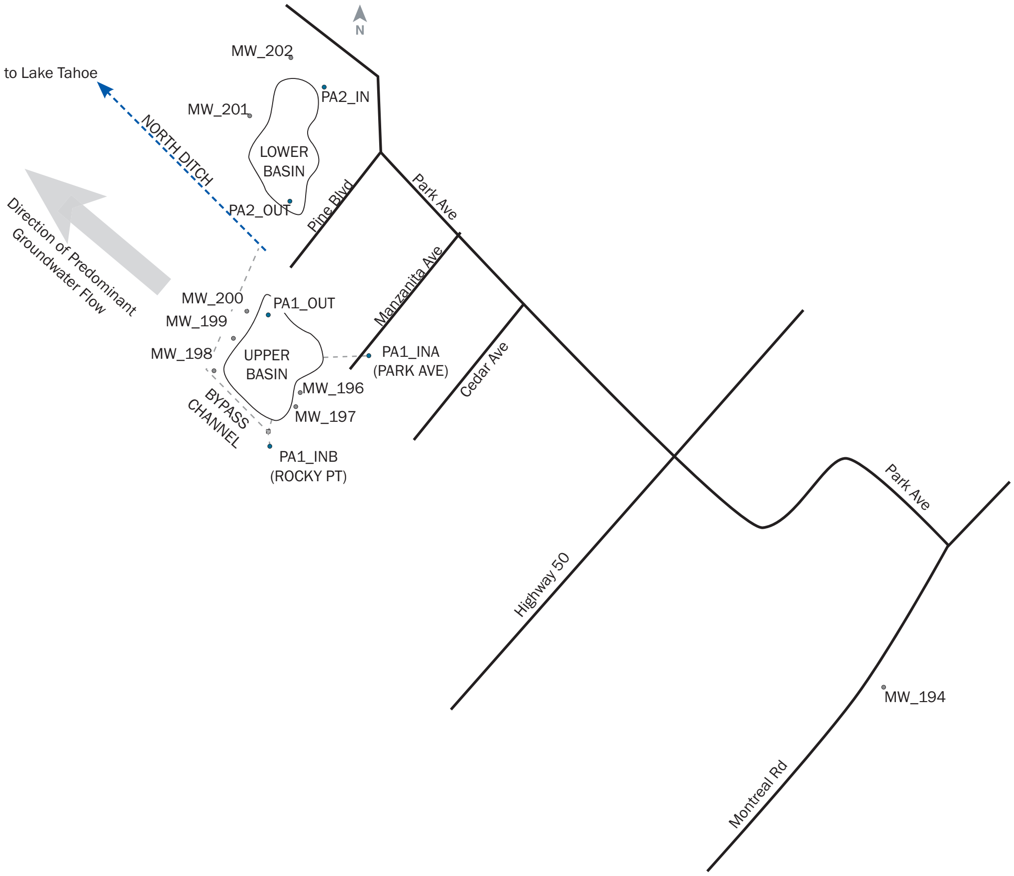
Typical groundwater DIN concentrations in Lake Tahoe urban areas range from 0.06 to 0.90 mg/L with concentrations increasing in groundwater aquifers downgradient of urban land uses (USACE 2003). Table 2.4 presents the average annual groundwater nitrate concentrations as measured from STPUD supply wells from 2003 to 2009. Comparison with the State of California maximum contaminant limit for nitrate (as N) in drinking of 10 mg/L shows that well concentrations are far below this standard.

Table 2.4 Summary of average annual nitrate concentrations measured in STPUD water supply wells from 2003-2009 (http://www.stpud.us/h2oquality.html). The California and EPA maximum contaminant level for nitrate in drinking water is 10 mg/L (http://water.epa.gov/drink/contaminants/index.cfm)

Year	Average Nitrate as N Concentration (mg/l)
2003	0.25
2004	0.25
2005	0.30
2006	0.27
2007	0.26
2008	0.28
2009	0.27

The USACE (2003) groundwater evaluation specifically addressed the relative enrichment of groundwater DIN levels as a result of urban land uses in five regions around the Lake. The USACE estimated the ambient groundwater concentrations of DIN to be approximately 0.16 mg/L, though the actual ambient concentration does vary as a result of geologic and soil differences around the Tahoe Basin. Through a comparison of the ambient 0.16 mg/L groundwater DIN to the average stormwater DIN concentrations of 0.6 mg/L measured in this study, it is apparent that the urban land uses have resulted in an increase of the natural shallow groundwater DIN concentrations in the Tahoe Basin (USACE 2003). Infiltration BMP specific evaluations conducted by 2NDNATURE identified relatively higher average DIN concentrations in groundwater wells located downgradient of an infiltration BMP relative to the average DIN concentrations measured in shallow monitoring wells located upgradient (2NDNATURE 2006A, 2NDNATURE 2007). These findings are expected given the mobility of the DIN in soils and the relatively higher DIN concentrations in stormwater relative to groundwater at the three infiltration BMP sites studied and supported by a number of comprehensive groundwater evaluations (e.g., Thodal 1997).

The 2NDNATURE (2008) surface water/groundwater research conducted on the Park Avenue Basins, located just south of Stateline in the Rocky Point drainage yielded slightly different results. Two shallow monitoring wells located upgradient of the infiltration BMPs possessed average DIN concentrations > 2 mg/L with nitrate contributing more than 90% of the DIN. The DIN and NOx concentrations measured in monitoring wells located downgradient of the infiltration BMP were consistently an order of magnitude lower than 2 mg/L. A regional monitoring well located approximately 0.5 miles upgradient of the infiltration BMPs had an average DIN concentration of 0.04 mg/L, two orders of magnitude lower than the wells installed at the upgradient boundary of the infiltration BMPs (Figure 2.2). It was hypothesized that a leak in a nearby sewage line may have been the source of excessive nitrate measured in the shallow wells upgradient of the BMP.



General site configuration of surface water and groundwater research conducted from 2005-2007 at Park Avenue Basins. MW indicates shallow monitoring well (< 30 ft below ground surface) installed to investigate potential influence of infiltration BMPs on shallow groundwater quality (2NDNATURE 2008)

Note: drawing is not to scale.

PARK AVENUE STUDY SITE, SOUTH LAKE, CA

FIGURE 2.2

The USACE (2003B) identified sewage exfiltration, or the overflow or leakage of sewage through joints or cracks in sewage pipes, as an annual anthropogenic source of nutrients to groundwater and eventually Lake Tahoe. While the estimate of the annual loading to Lake Tahoe from sewage exfiltration was 0.4% of TN, there were a number of limitations and dated assumptions with their estimates. Accordingly, the USACE (2003) did recommend a substantial testing program be required to provide significantly better data regarding Basin-wide sewage exfiltration conditions.

SUMMARY OF FINDINGS

Infiltration discharge standards for nitrogen in the Tahoe Basin should be clearly grounded in our understanding of pollutant behavior in soil. Geochemical characteristics of total nitrogen suggest at a minimum the infiltration discharge standards should specify the nitrogen species that are common in stormwater and potentially mobile once introduced to the subsurface, namely NO_3^- and NH_4^+, rather than TN. Tahoe stormwater data suggests that that a DIN infiltration discharge standard of 0.65 mg/L (corresponding to the TN standard of 5 mg/L) is regularly exceeded in stormwater introduced to infiltration BMPs, which appears to enhance shallow groundwater DIN concentrations in urban areas. The TMDL analysis (LRWQCB and NDEP 2010) indicates that risks to lake clarity from stormwater infiltration are low since 1) nitrogen is a secondary pollutant of concern with respect to lake clarity and 2) the annual loading estimates from groundwater are only 15% of the annual nitrogen loading to Lake Tahoe. Reported nitrate levels in STPUD wells are well below the drinking water standard (10 mg/L) and are much lower than nitrate concentrations measured in areas influenced by much denser urban development or agricultural lands (Burrow et al. 2010). There is potential for sewage exfiltration to be the primary source of DIN to shallow groundwater given the extremely high levels of nitrate in human waste and the aging state of the Tahoe Basin sewage system (USACE 2003B). While the data indicate that no nitrate problem currently exists, the mobility of DN in groundwater warrants the risks to the beneficial use ‘domestic and municipal water supply’ should be further evaluated.

TOTAL PHOSPHOROUS

POLLUTANT FORMS AND SOURCES

Phosphorus (Figure 2.3) is a somewhat unique pollutant in that it is an essential element for Lake Tahoe primary production, has low solubility, and is not toxic in and of itself, but may have detrimental effects on water quality at quite low concentrations because it stimulates algal growth. Soluble reactive phosphorous (SRP, aka orthophosphate or phosphate[1]; see Figure 2.3) is the inorganic dissolved phosphorous (DP) species that exists naturally, but can also be generated from anthropogenic sources including, but not limited to, partially treated and untreated sewage, detergents, agricultural runoff, and application of fertilizers. SRP is readily available for photosynthetic organisms and is typically found in very low concentrations in unpolluted waters. DP includes organic and inorganic dissolved phosphorous species and is the phosphorous species listed in the Lake Tahoe TMDL (LRWQCB and NDPE 2010). Organic phosphate is phosphate bound to or tied up in plant tissue, waste solids, or other organic material. After decomposition (i.e., respiration), the phosphorus contained in the organic matter can be mineralized back into biologically available inorganic forms. In the subsurface, inorganic phosphate (SRP) has a high affinity to adsorb to small particles in the soil, and these adsorbed phosphate ions are held on active sites on the surfaces of soil particles.

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[1] Phosphate is $H_2PO_4^-$, HPO_4^{2-}, or PO_4^{3-}, depending on the pH of the water.

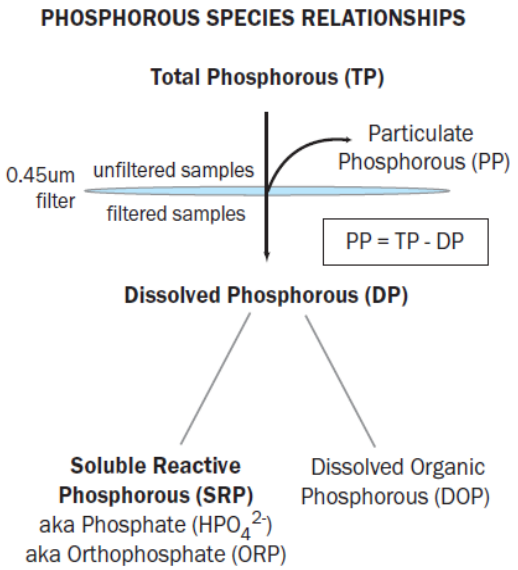

Figure 2.3 Phosphorus species relationships

During the natural process of weathering, rocks can gradually release phosphorus as phosphate ions, which are soluble in water. Lake Tahoe granitic and volcanic deposits have a relatively high natural content of phosphorous (USDA 2000, USDA-NRCS 2007), and prior to human development of the Tahoe Basin, the Lake was nitrogen limited due to this natural enrichment of phosphorus in the local soils (USDA 2000). The USACE (2003) estimated that approximately 61% of the average annual DP loading to Lake Tahoe from groundwater was the result of natural, non-anthropogenic sources. This indicates approximately 1,500 kg/yr of anthropogenic DP is introduced to groundwater via anthropogenic sources such as sewage exfiltration or infiltration from urban land uses (USACE 2003). The largest sources of anthropogenic phosphorus in the Tahoe Basin are expected to be chronic fertilizer applications on recreational and residential lands and local sewage exfiltration from leaking sewage systems (USACE 2003, LRWQCB and NDEP 2008).

STORMWATER DATA

The Lake Tahoe TMDL (LRWQCB and NDEP 2010) reported that total phosphorous delivery to the Lake is primarily from urban stormwater runoff (38% of the total annual load) and only 15% is delivered via groundwater. Table 2.5 lists TP and DP estimated event mean concentrations (EMCs) for stormwater by land use, with average EMCs over the entire urbanized portion of the Basin for TP (0.84 mg/L) and DP (0.14 mg/L). Similar to the infiltration discharge standards for total nitrogen (see Table 1.1), only dissolved phosphorous species are mobile in the subsurface and are typically a small fraction of total phosphorous in Tahoe stormwater. Using a compiled Tahoe Basin urban catchment stormwater dataset (2NDNATURE 2006B), the average DP:TP ratio was determined to be less than 15%. With this proportionality, the TP infiltration discharge standard of 1 mg/L (see Table 1.1) corresponds to a DP concentration of 0.15 mg/L, which is used for comparative purposes below.

Tahoe Basin stormwater has a wide range of DP concentrations that may be attributed to differences in land use types and conditions. Water quality monitoring efforts have reported DP in stormwater less than 0.05 mg/L in residential land use areas (SH+G 2003) to over 1.4 mg/L in areas downstream of fertilized surfaces and industrial land uses (2NDNATURE 2006A and 2007, Heyveart 2005). A controlled multi-year evaluation of tile drain effluent from a phosphorus-rich fertilized ball field reported average annual SRP and DP concentrations of 0.72 and 0.81

mg/L, respectively. Months following the transition to a phosphorous-free fertilizer product, SRP and DP average annual values at the same site were reduced to 0.31 and 0.37 mg/L respectively (2NDNATURE 2007). A water quality monitoring site that accepts predominantly commercial runoff, but also includes high traffic primary roads and residential area possessed average DP concentrations of 0.12mg/L (2NDNATURE 2008). A synthesis of treatment BMP effectiveness compiled the project EMCs at the inlets to 18 treatment BMPs throughout the Tahoe Basin monitored between 2000 and 2006 (2NDNATURE 2006B), and the average DP EMC of all of the sites that represent mixed urban catchments is 0.097 mg/L. The measured DP stormwater concentrations from urban catchments are consistent with the average DP EMCs of 0.14 mg/L (see Table 2.5) utilized by the Lake Tahoe TMDL pollutant load modeling efforts (LRWQCB and NDEP 2010).

Table 2.5. Tahoe Basin Urban Area Phosphorus EMC values by land use. (Source: LRWQCB and NDEP 2008)

Urban Land Use	TP EMC (mg/L)	DP EMC (mg/L)
Residential Single Family – Pervious	0.47	0.14
Residential Multi Family – Pervious	0.59	0.14
CICU – Pervious	0.70	0.08
Vegetation Turf	1.5	0.26
Residential Single Family – Impervious	0.47	0.14
Residential Multi Family – Impervious	0.59	0.14
CICU – Impervious	0.70	0.078
Primary Roads	1.98	0.096
Secondary Roads	0.59	0.14
Average Tahoe Basin Urban Area EMC	**0.84**	**0.14**

Infiltration BMPs predominantly infiltrate runoff generated from some combination of commercial, residential and road runoff, thus it is reasonable to assume typical stormwater concentrations introduced to the majority of infiltration BMPs are in the range of 0.14 mg/L of DP.

GROUNDWATER DATA

The typical groundwater DP concentrations in Lake Tahoe urban areas range from 0.03 to 0.12 mg/L, with a correlation between presence of human land use and relatively higher DP concentrations (USACE 2003). STPUD annual monitoring of groundwater extracted from South Lake Tahoe from 2003-2009 shows an average SRP concentration on the order of 0.03 mg/L and total (unfiltered) phosphorous average of 0.04 mg/L suggesting that the groundwater DP concentration as represented by STPUD water supply wells is < 0.04 mg/L (http://www.stpud.us/h2oquality.html). There is currently no numeric drinking water standard provided by the State of California or the USEPA[2], and so no comparisons are made here.

A number of Tahoe specific research efforts have evaluated the fate and transport of phosphorous in urban stormwater introduced to infiltration BMPs, and existing data indicates little evidence that stormwater with even relatively high phosphate levels infiltrated via BMPs are resulting in localized groundwater enrichment of DP. In industrial South Lake Tahoe catchments by the South Y, average DP groundwater concentrations ranged from 0.023 to 0.034 mg/L in shallow monitoring wells upgradient of dry basins and the wells downgradient from the

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[2] http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/index.cfm#strategy

BMPs averaged 0.026 mg/L of DP (2NDNATURE 2006A), indicating no enrichment in the wells downgradient of the infiltration BMPs. In a separate study, groundwater samples collected from monitoring wells surrounding a highly fertilized turf surface in Incline Village displayed a decreasing trend moving away from the turf surface. The wells surrounding the field and the associated wet basin averaged 0.03 mg/L DP and wells less than 300 ft downgradient were consistently lower during each sampling event and averaged 0.017 mg/L DP (2NDNATURE 2007). Comparisons of the soil series present at each of the sites indicated soils at the Incline Village site possessed characteristics that have a higher affinity for phosphorous retention than the soils located beneath the Park Avenue Basins. More details of potential soil influences on pollutant transport are presented in Section III (Influence of Soil Type on Pollutant Transport).

SUMMARY OF FINDINGS

The geochemical characteristics of total phosphorus (TP) dictate that infiltration discharge standards should specify the phosphorus species common in stormwater and potentially mobile once introduced to the subsurface, DP ($H_2PO_4^-$, HPO_4^{2-}, or PO_4^{3-}), rather than TP. The data suggest that the greatest source of DP to stormwater is phosphate containing fertilizers, with measured maximum concentrations on the order of 1 mg/L DP, and raw sewage which typically contains a dissolved phosphorous concentration of 8-10 mg/L (Freedman 1995). Tahoe stormwater data suggests that that a DP infiltration discharge standard of 0.15 mg/L (corresponding to the TP standard of 1 mg/L) is regularly exceeded in stormwater introduced to infiltration BMPs. However, there is little evidence that ambient groundwater in surrounding areas is DP enhanced. The limited event based surface water/groundwater interaction datasets suggest that even at a site with relatively elevated DP concentration (2NDNATURE 2007), Tahoe soils appeared to absorb and retard DP migration in the subsurface. Thus, DP migration does not appear to pose a high risk to lake clarity via subsurface migration. However, it must be noted that the possibility for localized risks of phosphate migration in the subsurface do exist where elevated concentration of DP are chronically introduced and soil adsorption sites become saturated with respect to phosphate.

POLLUTANTS REQUIRING FURTHER ASSESSMENT

In order for a pollutant to pose a viable risk to degrade groundwater quality, it must remain in solution and have a high transport capability both vertically and horizontally within the aquifer. The potential risk of a number of pollutants can be discounted based on the geochemical behavior of the pollutants and extensive documentation of effective soil pollutant retention presented throughout Section II. The very high affinity for oil and grease to adhere to soil particles will prevent them from transport as a result of stormwater infiltration regardless of soil characteristics or moisture conditions (Hsieh and Davis 2005). The majority of particulate pollutants such as suspended sediment, particulate phosphorous or particulate nitrogen will be trapped within the upper vertical portions of the soil column where infiltration occurs and extensive horizontal migration of particulate pollutants in the subsurface is unlikely. In addition to the Tahoe specific data presented, numerous field studies at infiltration features with a wide age range have indicated rapid attenuation of pollutants with depth, particularly for hydrocarbons, trace metals, and other non-conservative pollutants (Legret et al. 1999, Dierkes and Geiger 1999, Barraud et al. 1999). Given these considerations, Section III (Influence of Soil Type on Pollutant Transport) addresses the influence of soil types on pollutant transport for the subset of those pollutants listed in Table 1.1 that have potential for subsurface mobility: fine sediment particles (as a component of turbidity), the dissolved portion of total nitrogen, and the dissolved portion of total phosphorus.

III. INFLUENCE OF SOIL TYPE ON POLLUTANT TRANSPORT

There has been some question whether soil type may affect the potential risk to groundwater quality or pollutant loading to Lake Tahoe as a result of stormwater infiltration. Section III evaluates the influence of soil type characteristics for determining risks of groundwater contamination or lake clarity degradation via subsurface pollutant transport. Such information is critical for location, design, and sizing of infiltration BMPs in the Basin. A series of maps of the relevant soil properties are presented to facilitate assessment of spatial distribution of pollutant transport risks.

TAHOE BASIN SOIL SERIES AND K_{SAT}

Tahoe Basin urban areas consist of a range of native volcanic and granitic derived soil series (Figure 3.1) formed by a number of factors including climate, parent material, topography, presence of organisms, and time of formation. Subsurface pollutant transport is affected by chemical and physical interactions between these soil series, pollutants, and water. The processes involved are dependent on soil characteristics such as composition, texture, and hydraulic conductivity that vary across the basin with the different soil series. The reader should refer to the soil series maps for urban areas throughout the Tahoe Basin in Figure 3.1 where specific soil types are mentioned in the following discussion of properties affecting pollutant transport.

A critical soil property affecting pollutant transport potential for the soil series mapped in Figure 3.1 is the surface saturated hydraulic conductivity (K_{sat}) of the soils, which is defined as the ease at which water can move through a saturated soil column and is directly related to the intrinsic permeability of the soil. Soils with higher K_{sat} values will infiltrate water more quickly and have a greater overall potential to transport water and (conservative) pollutants downgradient in the subsurface. Whether or not pollutants are actually transported more efficiently in soils with high K_{sat} will depend on the pollutant's mobility in the subsurface, so that high K_{sat} soils do not necessarily indicate greater risks of pollutant transport depending on the behavior of individual pollutants. Measurements of K_{sat} using an amoozemeter or a double ring infiltrometer provide some basis for estimation of saturated hydraulic conductivity, but there is not an accepted standard method. Since measurements are difficult to make and are only available for relatively few soils, estimates of saturated hydraulic conductivity are based on soil properties observed in the field, particularly structure, porosity, and texture (USDA-NRCS 2007). Importantly, K_{sat} is the single soil parameter included in TRPA's BMP spreadsheet tool (http://www.tahoebmp.org/Default.aspx) to determine adequate BMP sizing based on contributing runoff and expected infiltration rates.

K_{sat} values for Tahoe urban soil series are listed in Table 3.1 and mapped in Figure 3.2. The K_{sat} values for each soil unit were obtained from the PLRM database (nhc et al. 2009) and created using a depth-weighted aggregation calculation of the K_{sat} data per soil map unit for the first 0.5 meters of data contained within the Tahoe Soil Survey (USDA-NRCS 2007)[3]. If the soil series presented in Table 3.1 consisted of more than one map unit, the K_{sat} values were integrated using a spatial weighting based on the total area of each unit to determine the integrated value presented in Table 3.1.

Soil K_{sat} values vary throughout the Tahoe Basin and most urban areas along the lakeshore have a diverse mix that range from low (<3.85 in/hour) to high (>6.90 in/hour) K_{sat} soils (see Figure 3.2). While substantial small scale

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[3] The values used here don't account for potential urban impacts to the soil (compaction) that can reduce the average Ksat values shown. PLRM currently has an algorithm that does this based on the land use associated with the soil for the specific project area.

spatial heterogeneity in K_{sat} is apparent, a few generalizations can be made from the patterns mapped in Figures 3.2. The northwest portion of the lakeshore from Dollar Point to Tahoe Vista is composed largely of soils with low K_{sat} values, while from Tahoe Vista to Kings Beach are mostly high K_{sat} soils (see Figure 3.2B). Incline Village is dominated by moderate K_{sat} soils in lower lying areas nearest the Lake, with some areas of high K_{sat} soils in the upper areas along State Route 431 (see Figure 3.2A). Along the west and shore, the areas adjacent to Meeks Bay and Rubicon Bay have the highest K_{sat} soils (see Figure 3.2C). High K_{sat} soils in the south shore are along Highway 50 and Pioneer Trail Road (see Figure 3.2D) and Meyers (see Figure 3.2E), with low K_{sat} soils surrounding the Tahoe Keys and the Upper Truckee River drainage.

Table 3.1 Tahoe Basin urban soil series are presented from highest to lowest relative integrated K_{sat}. The % of urban area and soil series and NRCS map units are also provided. Soil series corresponding to the 'high' category (> 6.90 in/hour) mapped in Figure 3.2 are highlighted in blue.

Urban Soil Series	NRCS Map Units	% of Urban Area	Integrated K_{sat} (mm/s)
Marla	7471	5%	13.5
Christopher-Gefo	7444	10%	12.0
Meeks	7481-7489	7%	12.0
Celio	7431	1%	11.8
Christopher	7441-7443	4%	11.6
Gefo	7452-7451	1%	11.0
Jorge-Tahoma	7156-7157	1%	7.9
Tahoma	7221	2%	6.8
Ubaj	7541	2%	6.6
Cagwin-Rock	7411-7414	7%	5.4
Kingsbeach	7161	5%	5.0
Kneeridge	7171-7174	4%	4.9
Jabu	7461-7462	6%	4.8
Oneidas	7492	1%	4.8
Inville	7141-7143	10%	4.7
Cassenai	7421-7424, 7427	8%	4.6
Paige	7181-7183	2%	4.5
Tallac	7521-7526	5%	4.0
Tahoma-Jorge	7222	4%	3.8
Waca	7231-7233	1%	3.6
Jorge	7151-7153, 7154-7155	7%	3.2
Tahoe Complex	7041	2%	2.1
Oxyaquic Xerorthents	7051	2%	1.4
Watah Peat	7071	1%	1.3

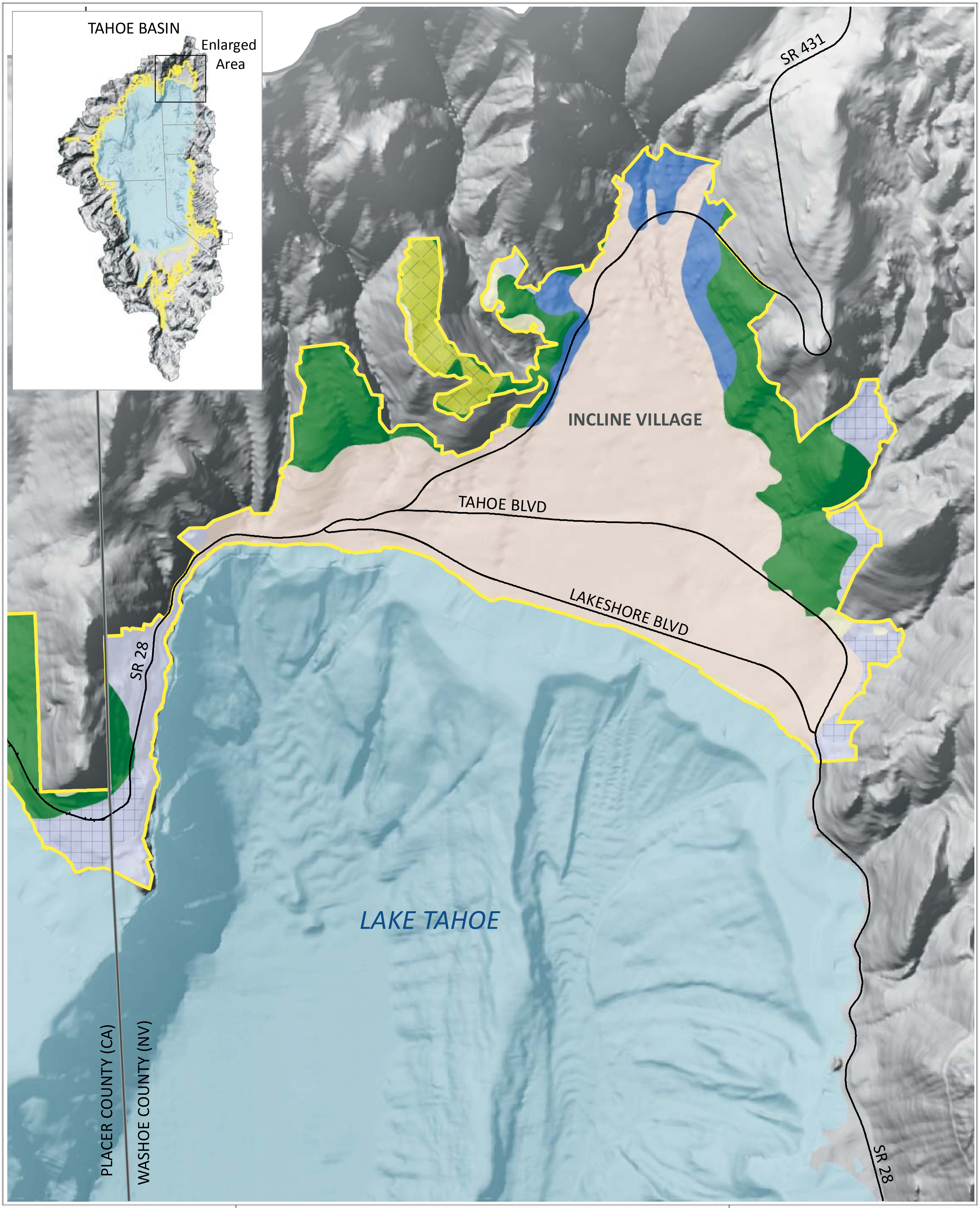

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Figure 3.1A: Soil Series for Washoe County; Tahoe Basin Urban Area (See Figure 3.1G for soils series and map unit)

Data Source: USDA-NRCS 2007

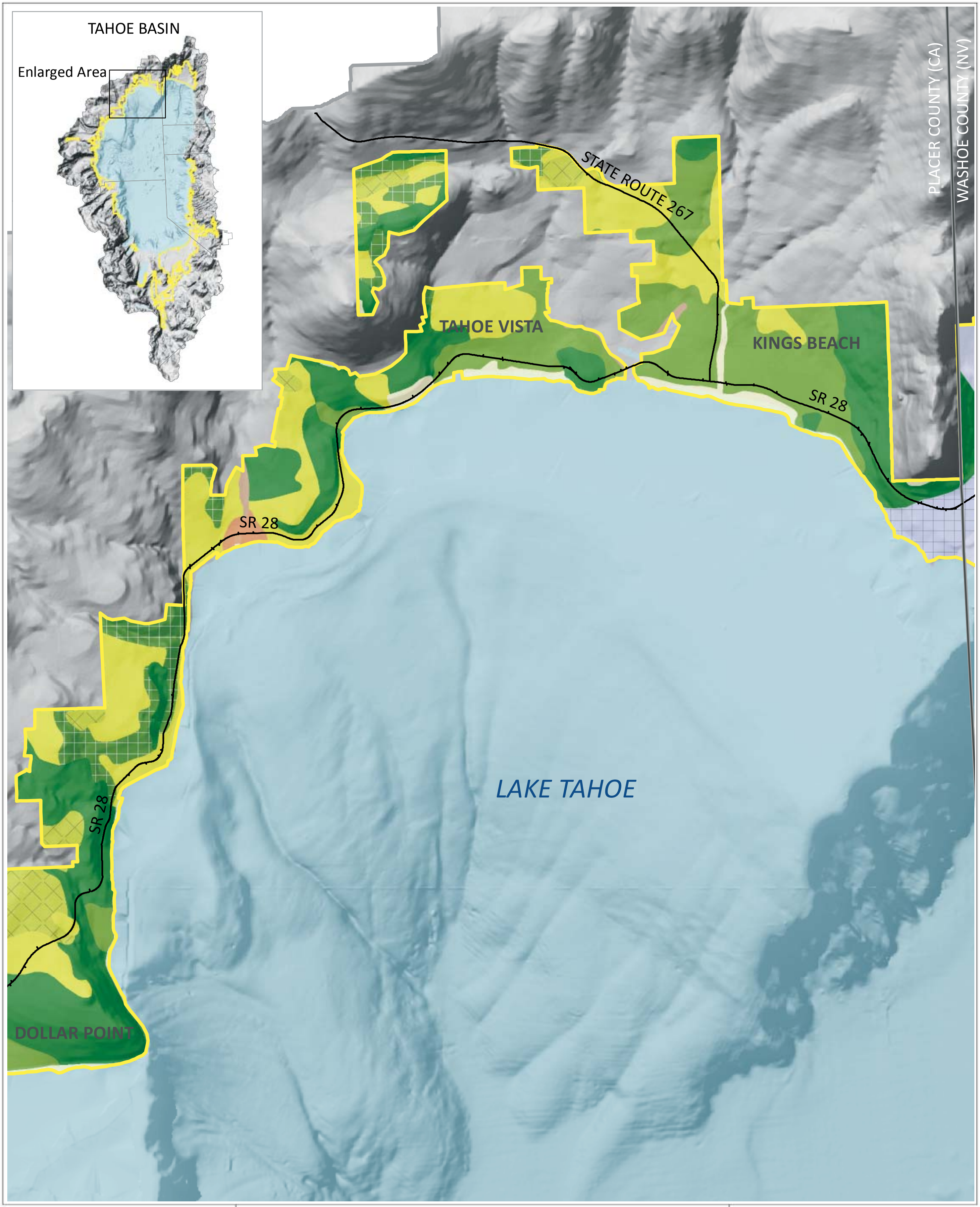

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Figure 3.1B: Soil Series for Tahoe Vista/Kings Beach; Tahoe Basin Urban Area (See Figure 3.1G for soils series and mapunit)
Data Source: USDA-NRCS 2007

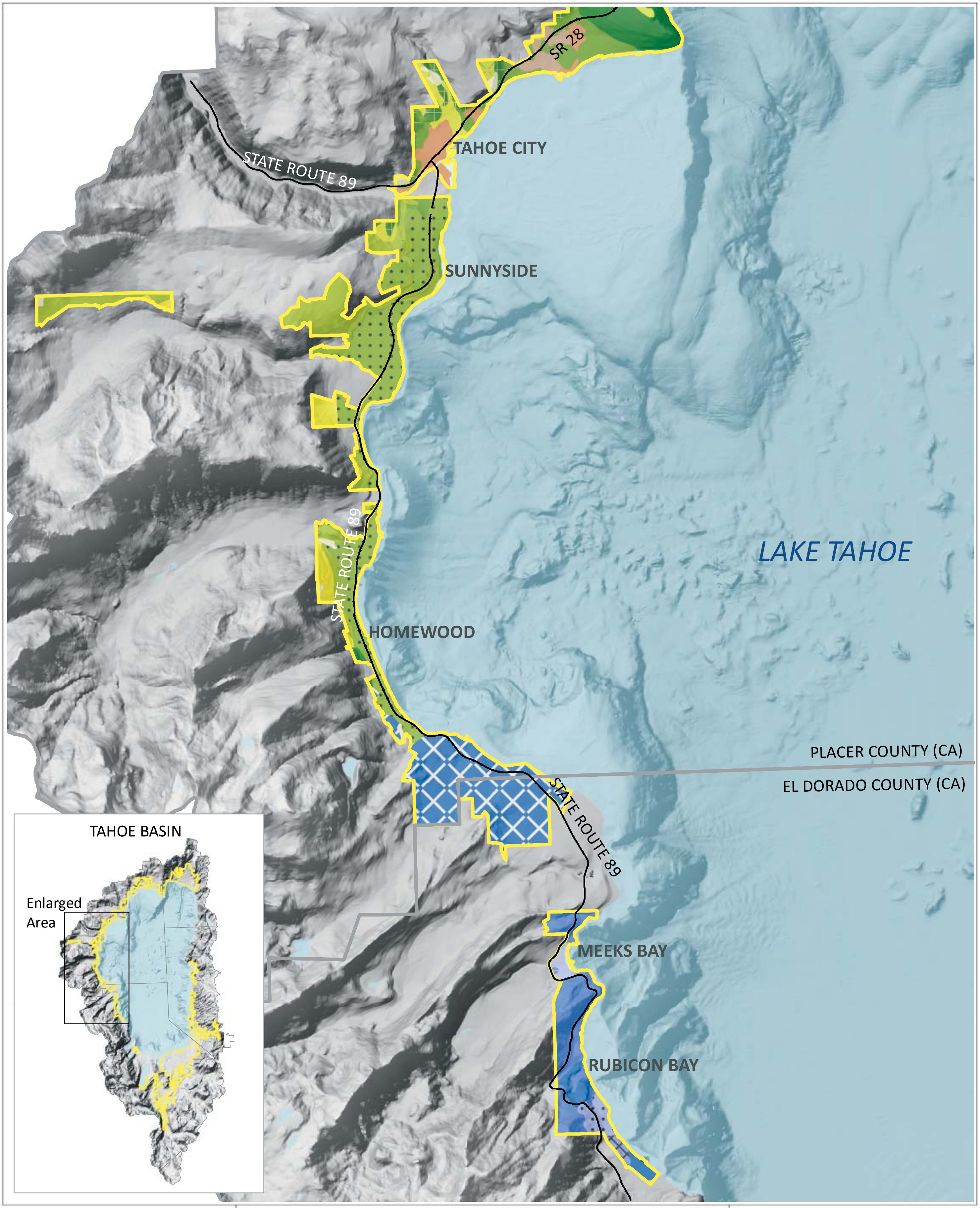

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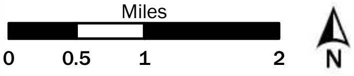
Figure 3.1C: Soil Series for West Shore; Tahoe Basin Urban Area (See Figure 3.1G for soils series and map unit legend.)
Data Source: USDA-NRCS 2007



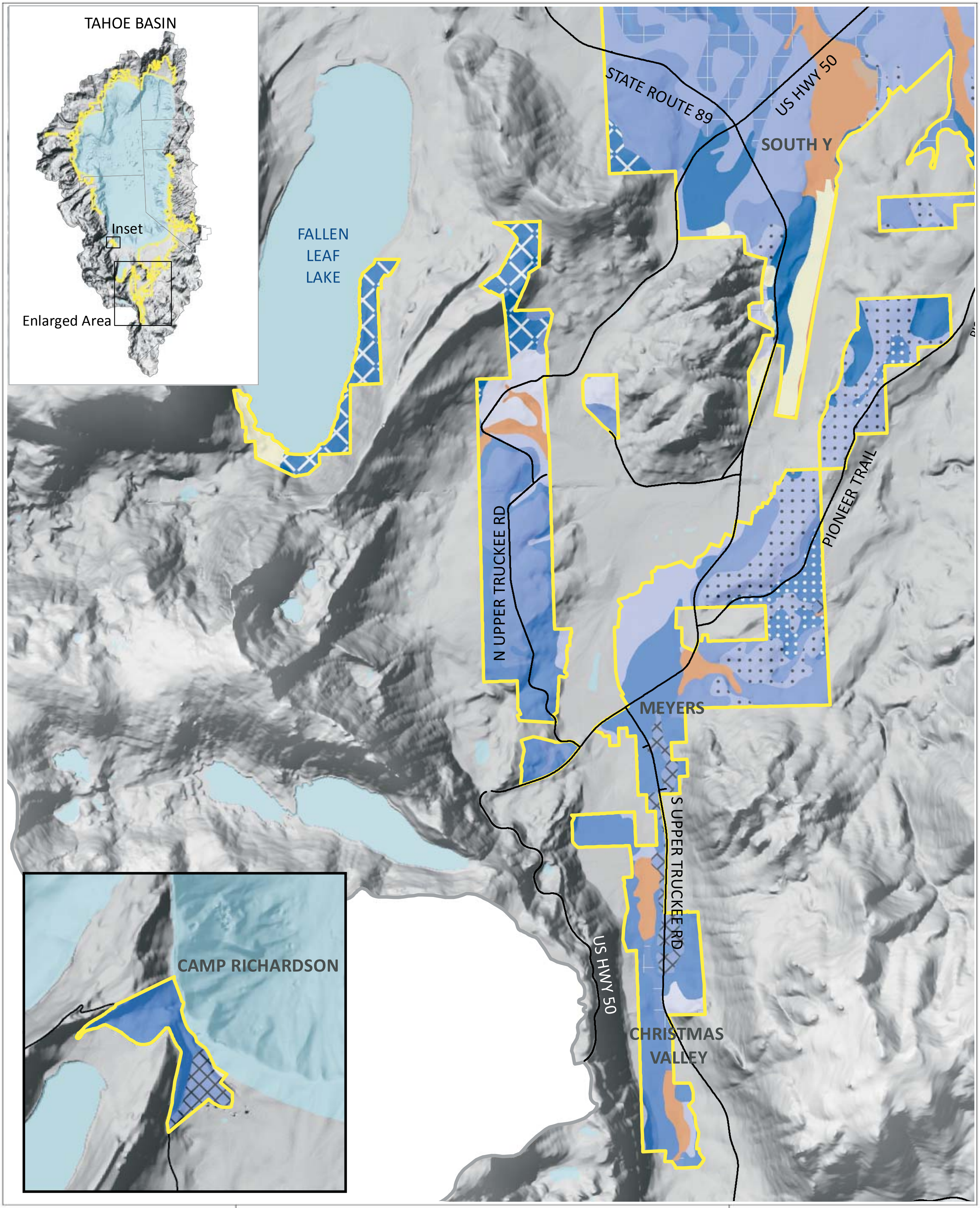


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Figure 3.1D: Soil Series for Meyers; Tahoe Basin Urban Area
(See Figure 3.1G for soils series and map unit legend.)
Data Source: USDA-NRCS 2007

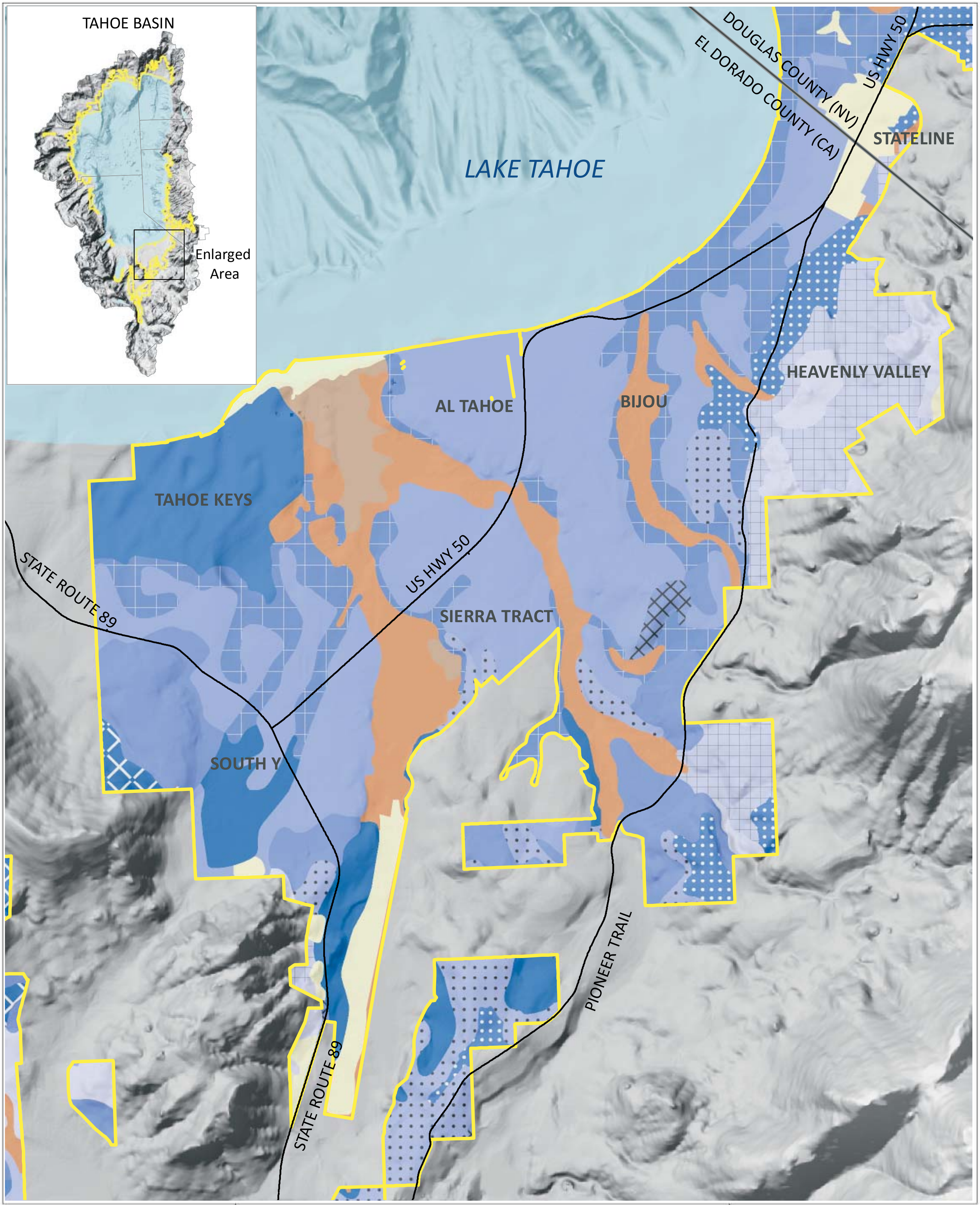

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Figure 3.1E: Soil Series for City of South Lake Tahoe; Tahoe Basin Urban Area (See Figure 3.1G for soils series and map
Data Source: USDA-NRCS 2007

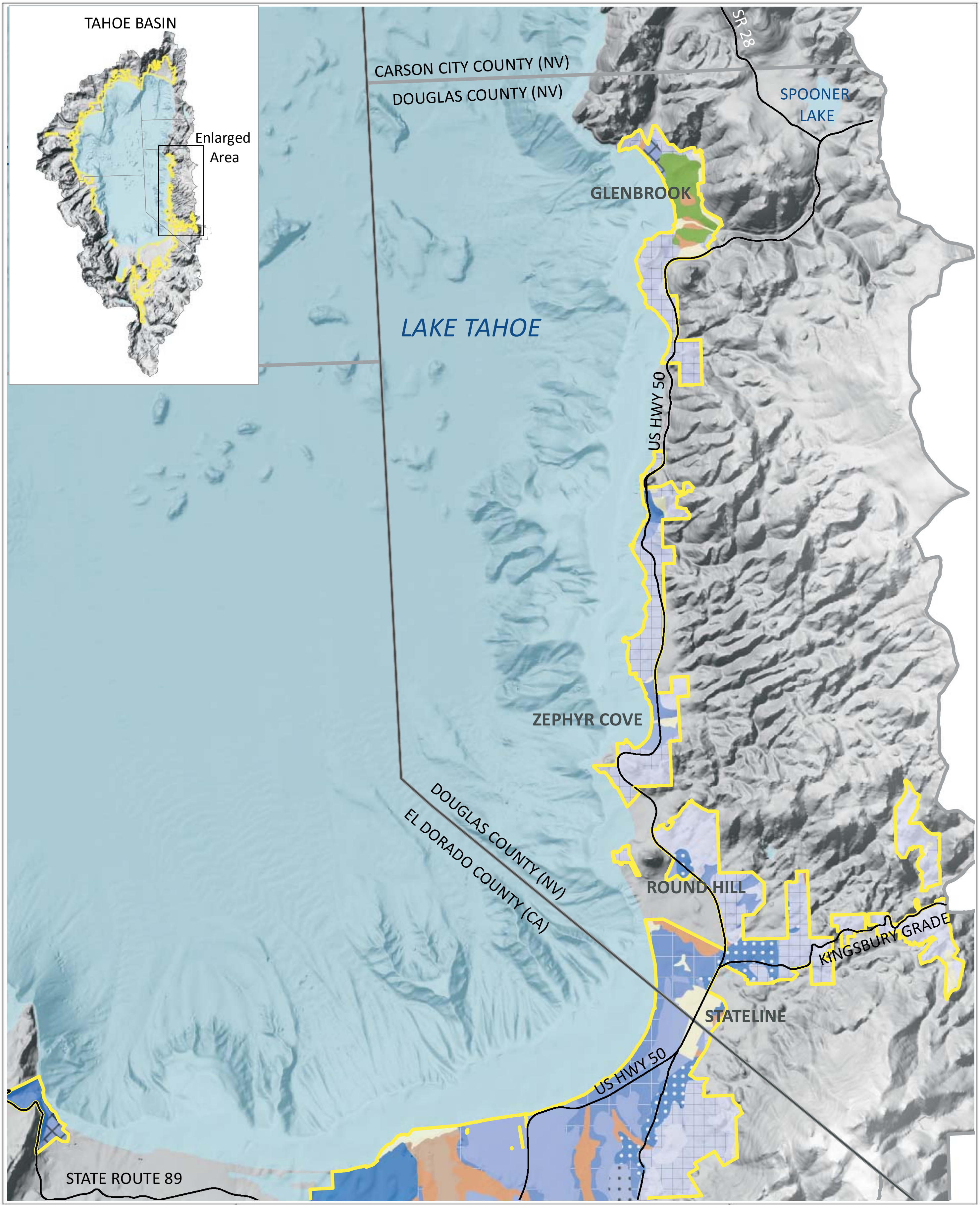

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Figure 3.1F: Soil Series for East Shore; Tahoe Basin Urban Area (See Figure 3.1G for soils series and map unit legend.)
Data Source: USDA-NRCS 2007

Urban soil types by soil series are presented. NRCS respective map units included in each soil series are indicated.

SOIL SERIES (MAP UNITS)

⬜ Tahoe Basin Urban Area

Urban Soils - Granitic

- 🟦 Cagwin-Rock (7411-7414)
- ▦ Cassenai (7421-7424, 7427)
- 🟦 Celio (7431)
- ▒ Christopher (7441-7443)
- 🟦 Christopher-Gefo (7444)
- ▩ Gefo (7451-7452)
- 🟦 Jabu (7461-7462)
- ▦ Marla (7471)
- 🟦 Meeks (7481-7489)
- ▒ Oneidas (7491-7492)
- 🟦 Oxyaquic Xerorthents (7051)
- ▩ Tallac (7521-7526)
- 🟦 Ubaj (7541)

Urban Soils - Volcanic

- 🟩 Jorge (7151-7155)
- ▦ Jorge-Tahoma (7156-7157)
- 🟩 Kingsbeach (7161)
- ▒ Kneeridge (7171-7174)
- 🟩 Paige (7181-7183)
- ▩ Tahoma (7221)
- 🟨 Tahoma-Jorge (7222)
- 🟨 Waca (7231-7233)

Urban Soils - Mixed

- ⬜ Inville (7143-7143)
- 🟧 Tahoe complex (7221)
- 🟫 Watah peat (7071)

Urban Soils - Other

- ⬜ Other Soils

Data Source: USDA-NRCS 2007

SOIL TEXTURE

cos - coarse sand
lcos - loamy coarse sand
cosl - coarse sandy loam
sl - sandy loam
l - loam
cl - clay loam
sic - silty clay

↓ decreasing porosity

Figure 3.1G: Soil Series and Soil Texture Legend; Tahoe Basin Urban Area

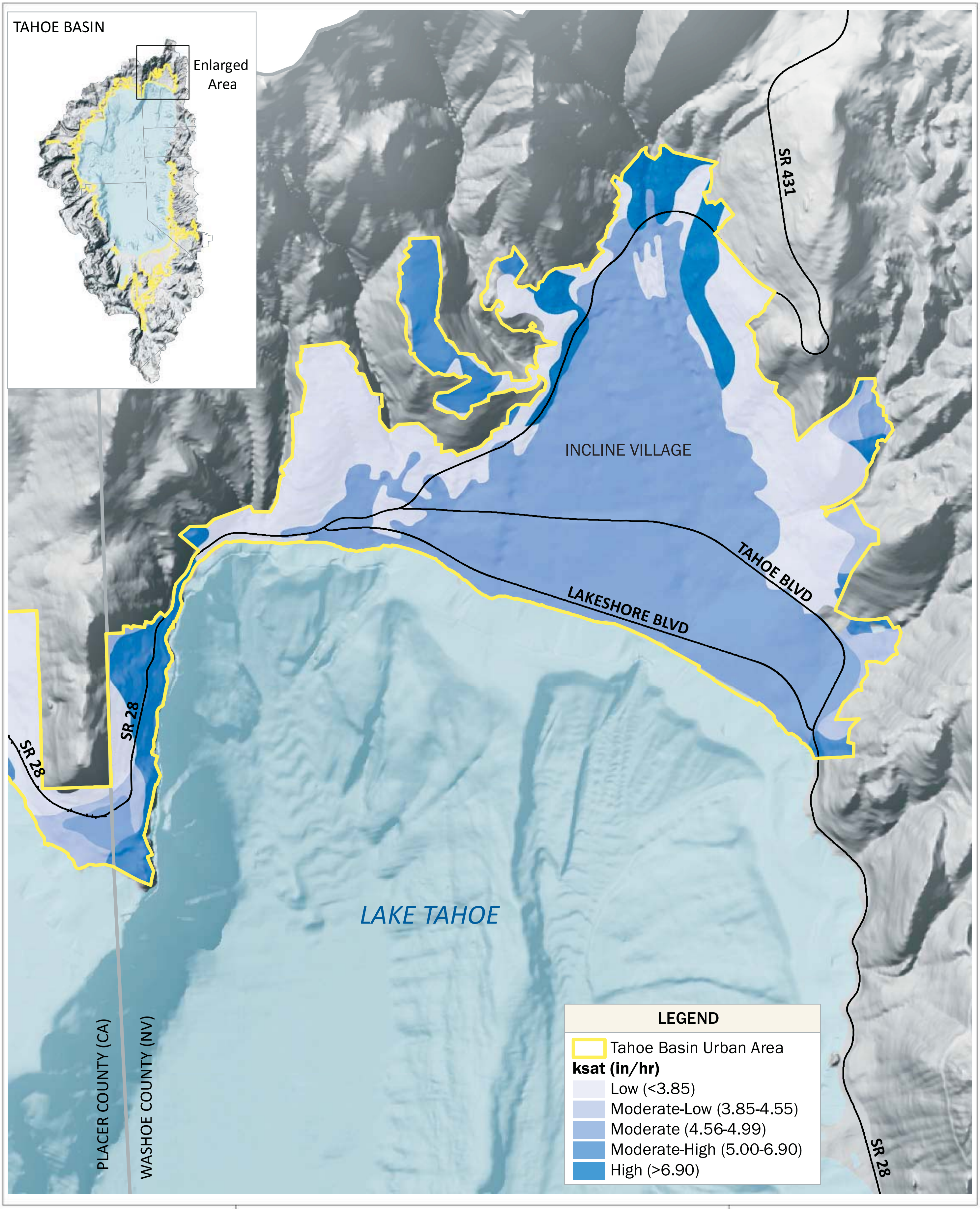

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Figure 3.2A: Tahoe Basin Urban Soils Ksat Values - Incline Village
Data Source: USDA-NRCS 2007

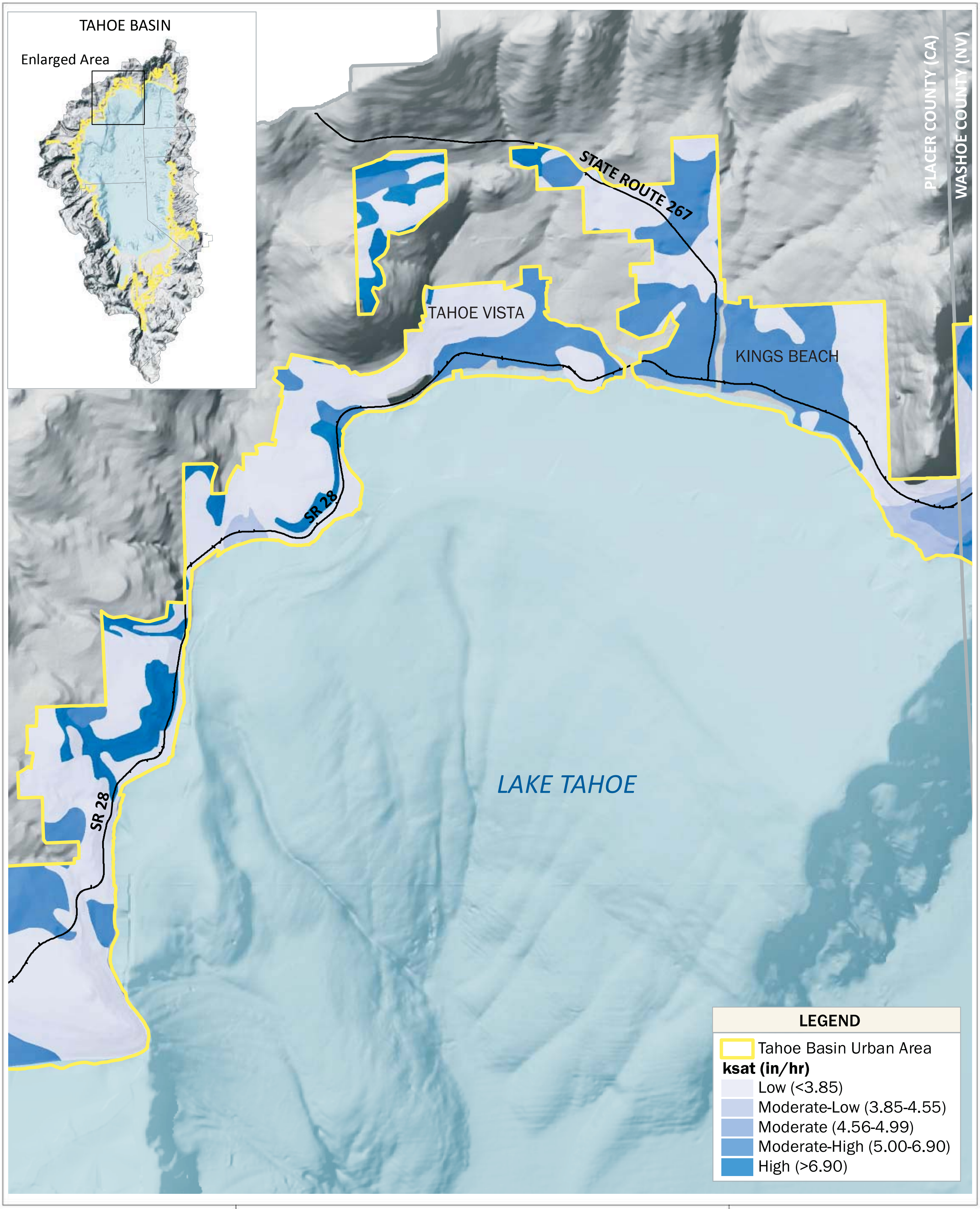

Figure 3.2B: Tahoe Basin Urban Soils Ksat Values - Tahoe Vista/Kings Beach
Data Source: USDA-NRCS 2007

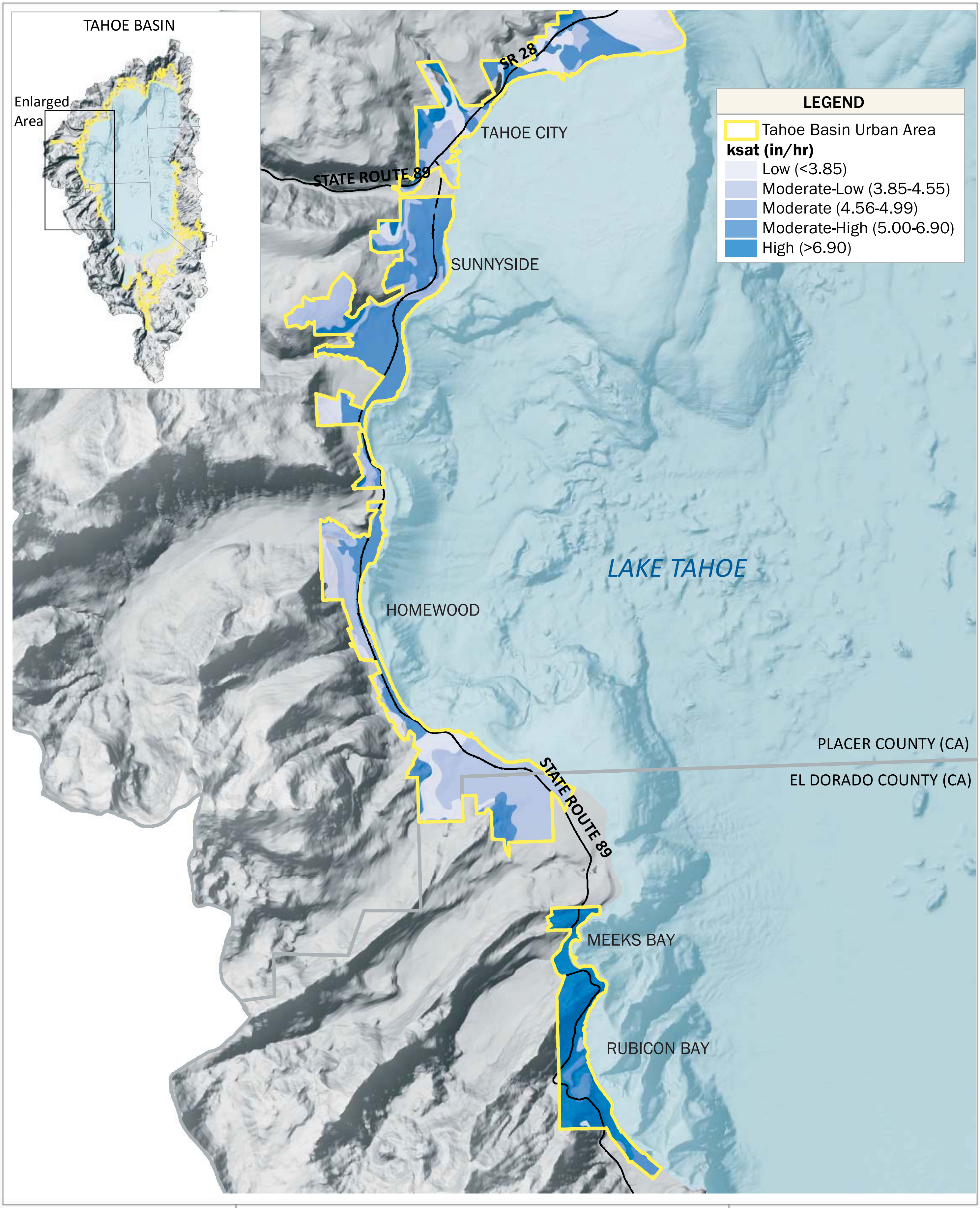

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Figure 3.2C: Tahoe Basin Urban Soils Ksat Values - West Shore
Data Source: USDA-NRCS 2007

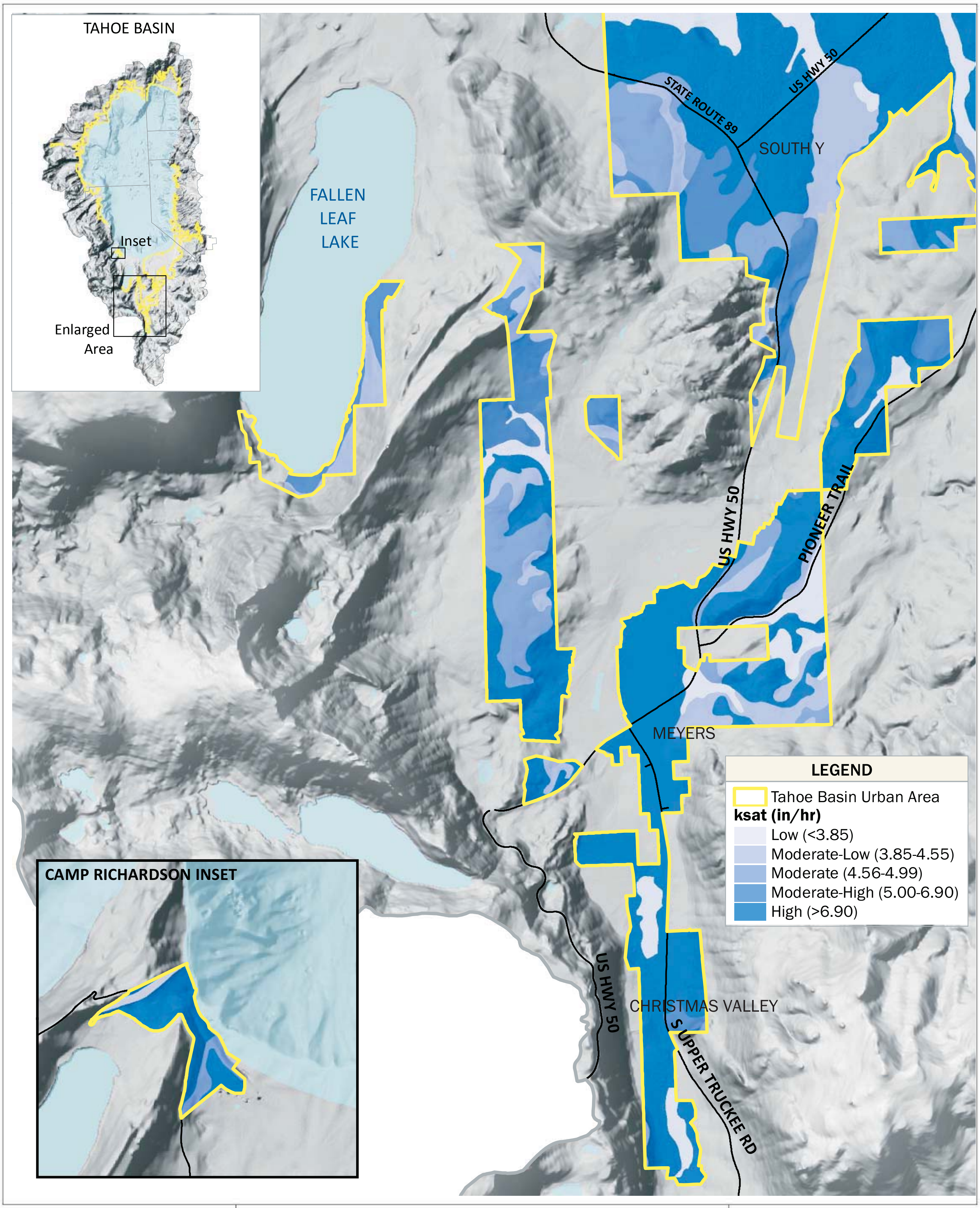

Figure 3. 2D: Tahoe Basin Urban Soils Ksat Values - Lower South Shore
Data Source: USDA-NRCS 2007

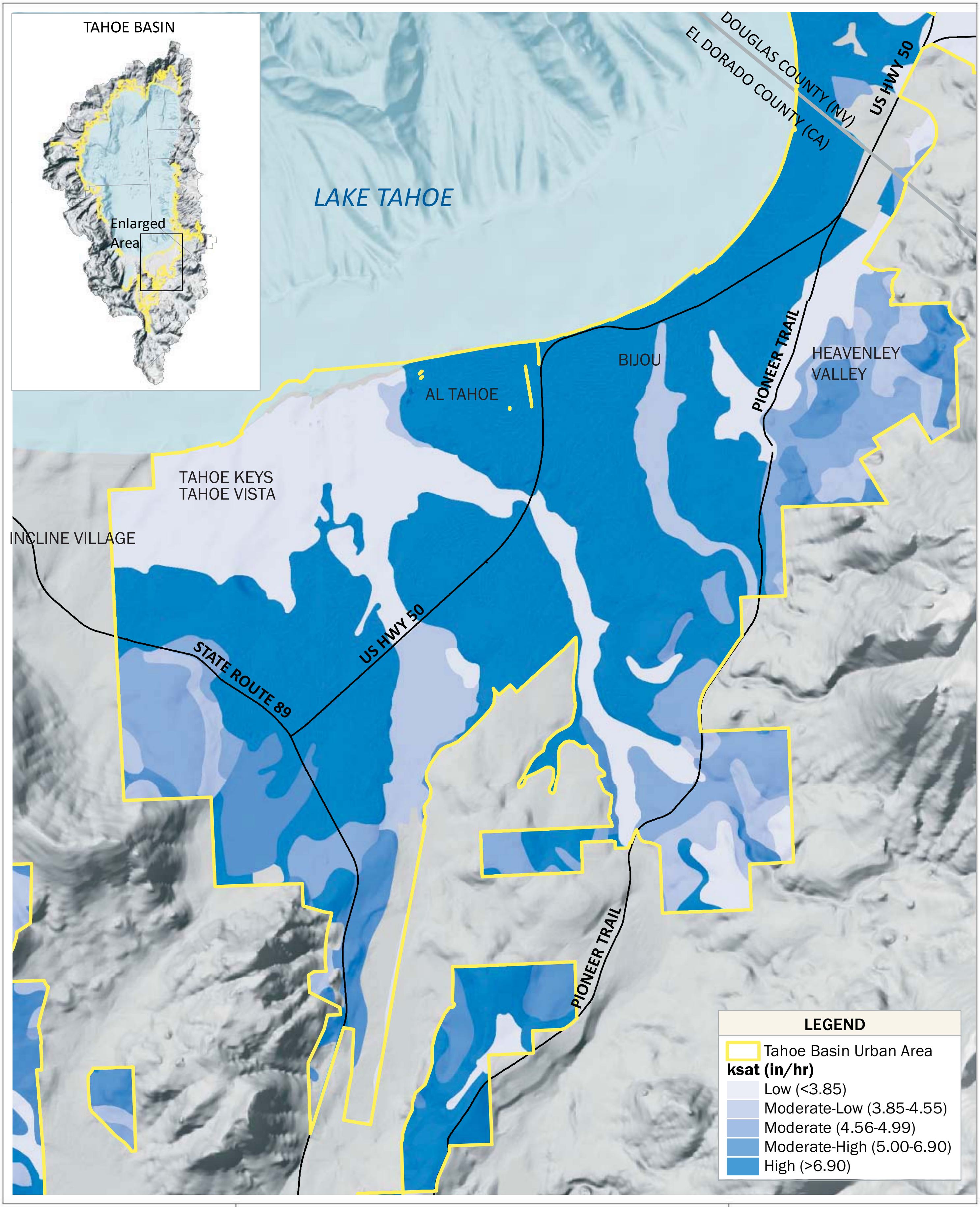

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Figure 3.2E: Tahoe Basin Urban Soils Ksat Values - Upper South Shore
Data Source: USDA-NRCS 2007

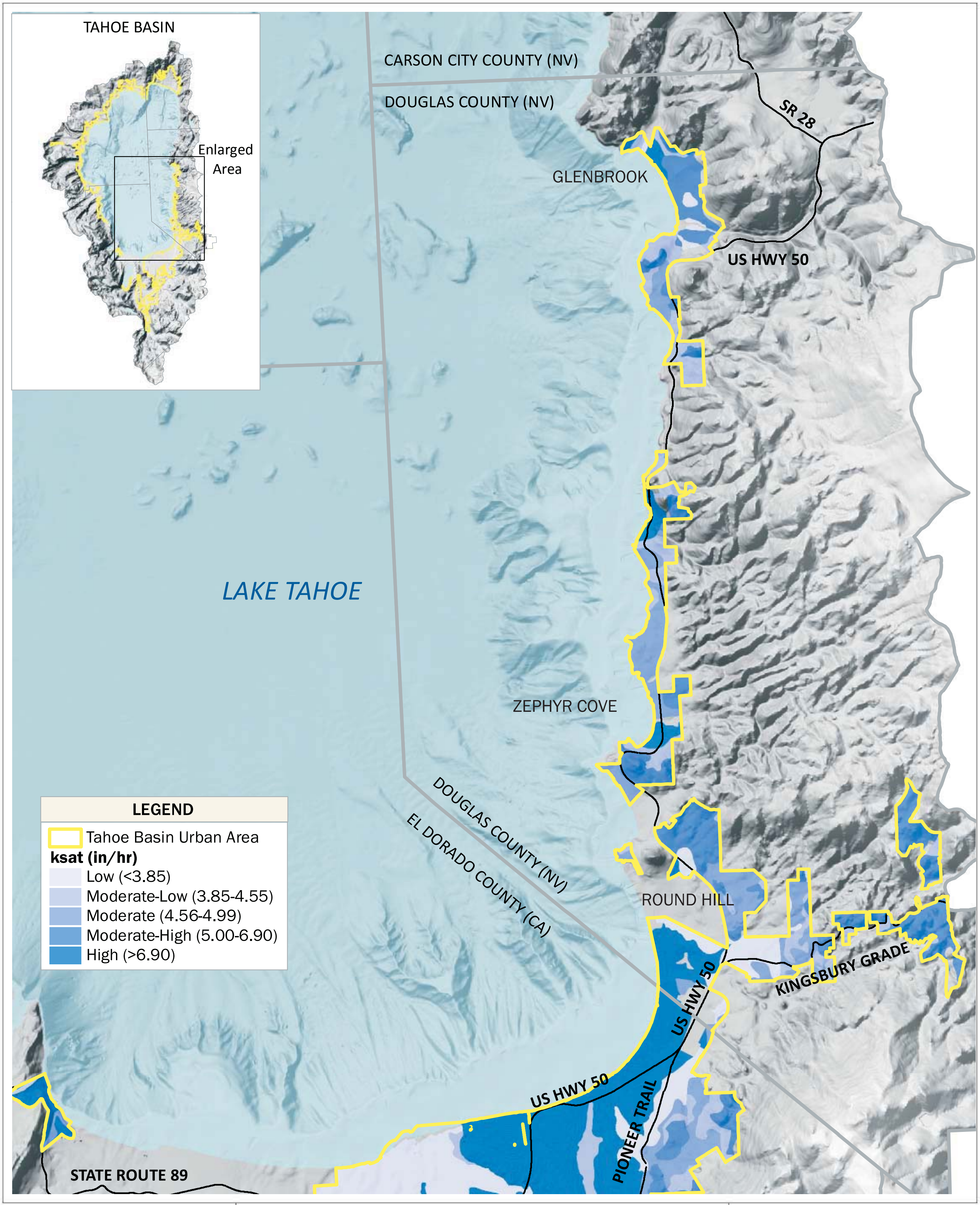

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Figure 3.2F: Tahoe Basin Urban Soils Ksat Values - East Shore
Data Source: USDA-NRCS 2007

FINE SEDIMENT PARTICLES (< 16μM IN DIAMETER)

Transport of fine sediment particles (FSP) in the subsurface is controlled primarily by the physical pore size of the soil and the degree of connectivity of those pore spaces, since the movement of FSP will be limited to movement through soil pores that are larger than 16 μm in diameter. Measurable soil parameters that correlate with pore size include grain size and distribution, texture, hydraulic conductivity, and saturated hydraulic conductivity (K_{sat}). In this analysis, soil texture is used to infer the relative risk of FSP subsurface migration in urban areas.

TAHOE BASIN SOIL TEXTURE

Table 3.2 compares the grain size diameter of fine sediment particles (16 μm) to the USDA particle size definitions (USDA-NRCS 2011) for typical soil classifications ranging from clay to gravel. The risk of FSP transport through a soil column of a specific size increases with increasing grain size (see Table 3.2). It is reasonable to assume the majority of FSP is immobile in soils dominated by grains silt sized or smaller. The potential for some transport exists when FSP is introduced to sand and coarser media. However, native soils possess a mixture of the pure medium size breaks presented in Table 3.2 and varying degrees of grain size sorting. A poorly sorted soil contains a well distributed mixture of grain sizes which effectively reduces the porosity and permeability of the soil from that of a well sorted soil consisting of a more homogenous grain size distribution (Figure 3.3). Therefore, soil texture and sorting is critical in evaluating the potential for FSP to migrate within a soil type. Soil textures are classified by the fractions of each soil separate (sand, silt, and clay) present in a soil and typically are named for the primary constituent particle size or a combination of the most abundant particles sizes (e.g., "sandy clay" would be composed of more clay than sand). The term “loam” indicates a roughly equal concentration of sand, silt, and clay, such that a clay loam suggests a poorly sorted soil slightly dominated by clay, rather than sand or silt. A loam soil is not expected to transmit FSP well due to the effective interlocking of grains and high likelihood that fine sediment particles introduced will be trapped and retained. Table 3.3 presents the common textures of soils found in Tahoe urban areas in order of decreasing porosity, or relative potential efficiency for FSP migration.

Table 3.2. Comparison of USDA soil separate grain size diameters with the Lake Tahoe TMDL definition of the critical pollutant, fine sediment particles (FSP).

Medium	**Grain size diameter (μm)**
FSP[1]	*< 16*
Clay[2]	< 2
Silt[2]	< 50
Fine sand[2]	< 250
Medium sand[2]	< 500
Coarse sand	< 1000
Very coarse sand[2]	< 2,000
Gravel[2]	< 7,500

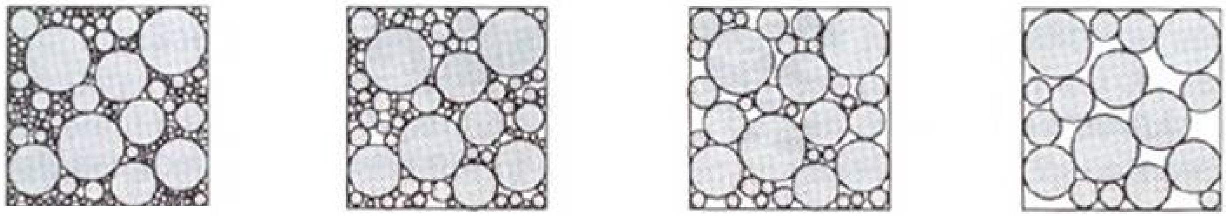
[1] Fine sediment particles (FSP) defined by the Lake Tahoe TMDL (LRWQCB and NDEP 2010).

[2] The maximum diameter from the NRCS Soil Properties and Qualities, USDA particle size definitions. http://soils.usda.gov/technical/handbook/contents/part618.html

Table 3.3. Soil texture codes common in Tahoe Basin urban soils, ranked by relative porosity based on the grain size and degree of sorting. The relative porosity is a proxy for the potential relative risk of FSP migration.

	Texture code	Description
Higher porosity	cos	coarse sand
↓	lcos	loamy coarse sand
	cosl	coarse sandy loam
	sl	sandy loam
	l	loam
	cl	clay loam
Lower porosity	sic	silty clay

Figure 3.3. Schematics illustrating the range of grain size distribution. A “loam” texture indicates a relatively even distribution of sand, silt and clay, or a moderate to poorly sorted soil texture. Many urban soils in the Tahoe Basin are loams.



Poorly sorted
Low porosity

Moderately sorted
Low to moderate porosity

Well sorted
Moderate to high porosity

Very well sorted
High porosity

The soil textures occurring in Tahoe Basin urban areas are presented in Table 3.4 and mapped in Figure 3.4. FSP introduced to an infiltration BMP must migrate through a number of different soil series with different textures and travel substantial distances horizontally in order to be transported from the point of infiltration to Lake Tahoe. While the predominant grain size of the loamy coarse sand soils may be as much 2 orders of magnitude larger than FSP (see Table 3.2), the presence of maller grains sizes within all of the Tahoe urban soils may minimize the risk of FSP migration due to filtration of the fines and retention within the soil column. The saturated hydraulic conductivity of Tahoe urban soils range from 13.5 mm/sec to < 1.0 mm/s (see Table 3.1), which are typical of silty, fine grained sands. Table 3.4 demonstrates that lower porosity based on soil texture (see Table 3.3) does not necessarily correspond to lower K_{sat} values (see Table 3.1), since a number of relatively fine grained poorly sorted soils have K_{sat} values above 5 mm/sec. This suggests that a number of Tahoe urban soils can transmit water relatively effectively, but due to their poorly sorted texture, most soils in urban areas will not efficiently transmit FSP horizontally long distances.

Table 3.4 Tahoe Basin urban soil series are presented from highest to lowest relative potential FSP migration risk by the relative porosity of the soil texture based on the combination of grain size and degree of sorting (see Figure 3.3 and Table 3.3). The % of urban area and NRCS map units are also provided. Soil series mapped with textures that have high potential for FSP migration are highlighted in pink (see Figure 3.4).

Soil Series	NRCS Map Units	% of urban area	Soil Texture
Christopher-Gefo	7444	10%	lcos-cos
Christopher	7441-7443	4%	lcos-cos
Gefo	7452-7451	1%	lcos-cos
Meeks	7481-7489	7%	lcos
Celio	7431	1%	lcos
Cagwin-Rock	7411-7414	7%	lcos
Cassenai	7421-7424,7427	8%	lcos
Watah peat	7071	1%	lcos-sl
Marla	7471	5%	lcos-cl
Jabu	7461-7462	6%	lcos-sic
Kneeridge	7171-7174	4%	cosl
Oneidas	7492	1%	cosl
Tallac	7521-7526	5%	cosl
Waca	7231-7233	1%	cosl
Inville	7141-7143	10%	cosl-sl
Paige	7181-7183	2%	sl-cosl
Oxyaquic Xerorthents	7051	2%	sl-cosl
Jorge	7151-7155	7%	sl-l
Jorge-Tahoma	7156-7157	1%	sl-cl
Tahoma	7221	2%	sl-cl
Ubaj	7541	2%	sl-cl
Kingsbeach	7161	5%	sl-cl
Tahoma-Jorge	7222	4%	sl-cl
Tahoe Complex	7041	2%	cl-sl

FSP TRANSPORT POTENTIAL

The highest potential for FSP migration is within the coarsest Tahoe urban soils, consisting of loamy coarse sand (lcos)- coarse sand (cos), particularly the Christopher and Gefo series. Since FSP is the primary pollutant of concern with respect to lake clarity, transport to the Lake may only be a concern where the relatively coarse Christopher or Gefo soil series border Lake Tahoe. Table 3.5 lists the areas where this occurs and provides the dominant land use types and potential relative FSP loads in stormwater based on land use type and distribution. In instances where FSP loads may be introduced to the subsurface porous soils but require horizontal transport through less soil permeable soils to reach Lake Tahoe, it is reasonable to assume that FSP will be retained within the finer horizons and significant loading to Lake Tahoe will be unlikely.

Table 3.5. Locations (and maps) where coarse textured soils in urban areas border Lake Tahoe that can be considered the greatest potential risk for FSP transport to the Lake as a result of stormwater infiltration. Dominant land uses and the potential relative FSP loads in stormwater are also provided.

Map	Location	Dominant Land Use Type	Relative Stormwater FSP loads
Figure 3.4A	Highway 28 at north shore state border	Commercial	High
Figure 3.4C	Rubicon Bay	Single Family Residential	Low
Figure 3.4E	Bijou	Commercial Residential High Risk Roads	High

The available soil data supports the hypothesis that there is not substantial FSP loading occurring via groundwater. In fact, the Lake Tahoe TMDL assumed that fine inorganic particles are immobile in the subsurface and thus groundwater is not an annual source of this pollutant to the Lake (LRWQCB and NDEP 2010). However, controlled bench studies to evaluate the potential vertical migration of FSP via Christopher and Gefo soils could be conducted to test this hypothesis since infiltration BMPs that are constructed as excavated pits and filled with coarse material would experience some transport. The process of filtration and capture of particulates introduced is expected to gradually reduce porosity where the particles accumulate, thereby preventing the migration of subsequently delivered particulates.

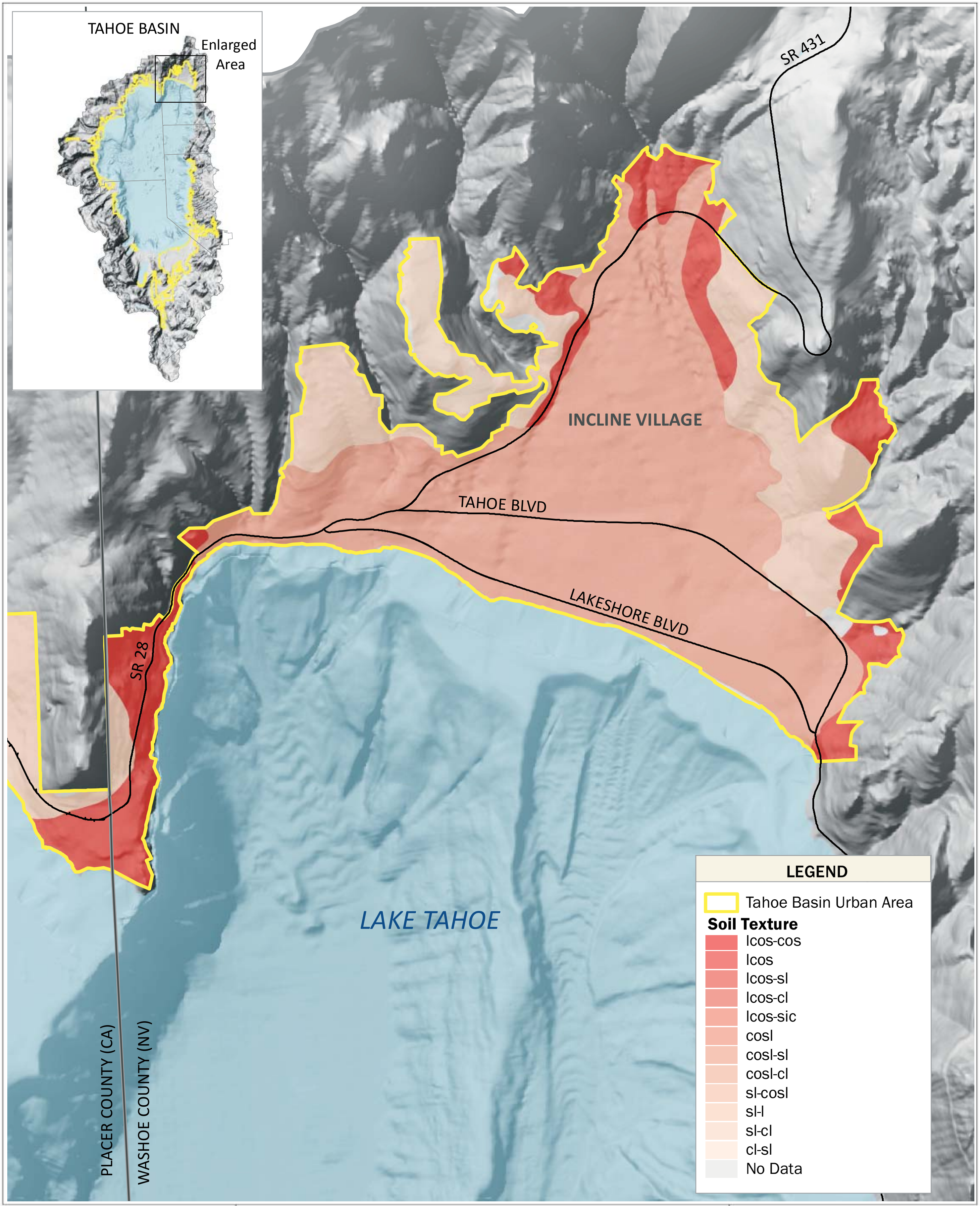


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Figure 3.4A: Soil Texture for Washoe County; Tahoe Basin Urban Area (See Figure 3.1G for texture definitions.)

Data Source: USDA-NRCS 2007

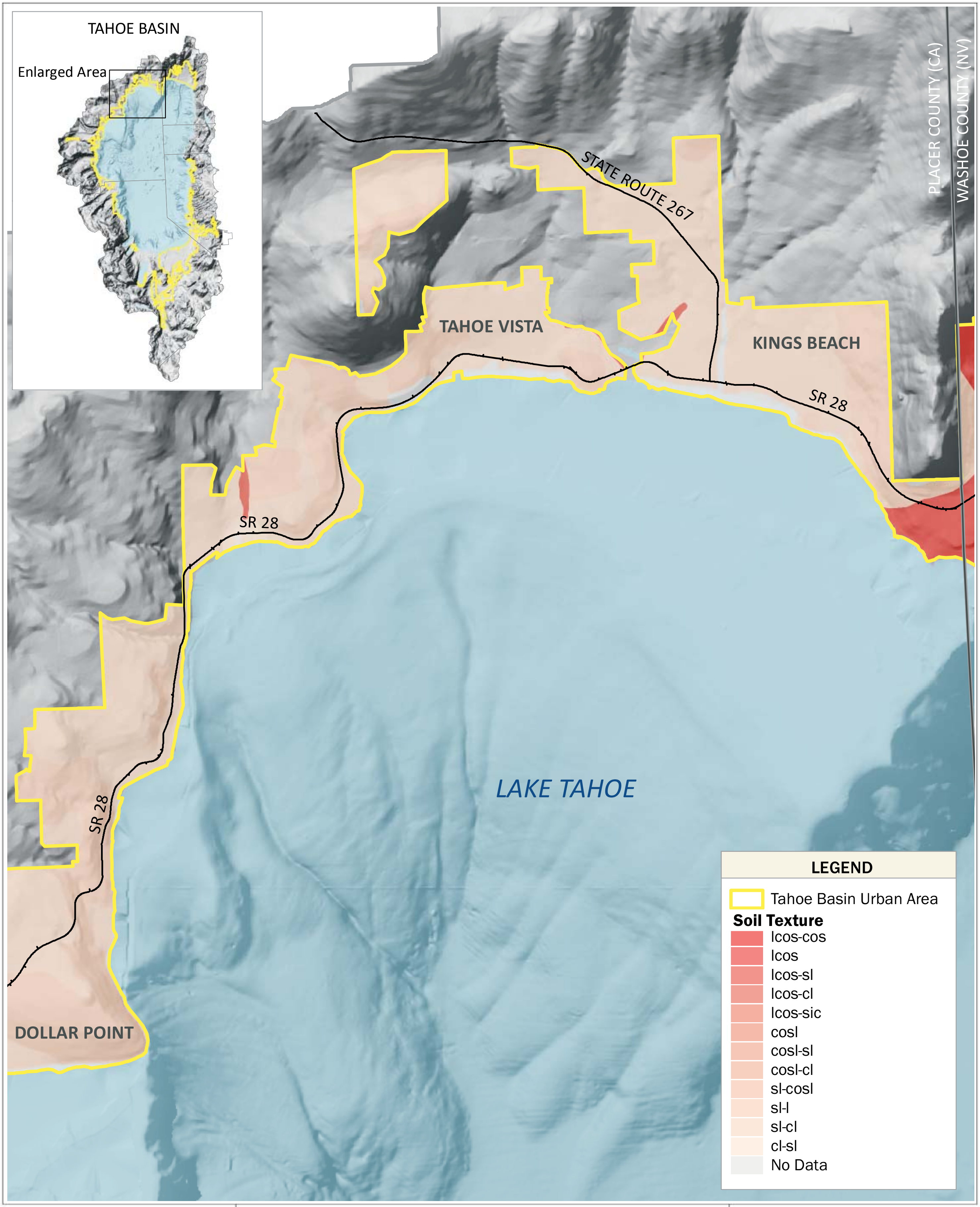

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Figure 3.4B: Soil Texture for Tahoe Vista/Kings Beach; Tahoe Basin Urban Area (See Figure 3.1G for texture definitions.)
Data Source: USDA-NRCS 2007

Miles
0 0.25 0.5 1
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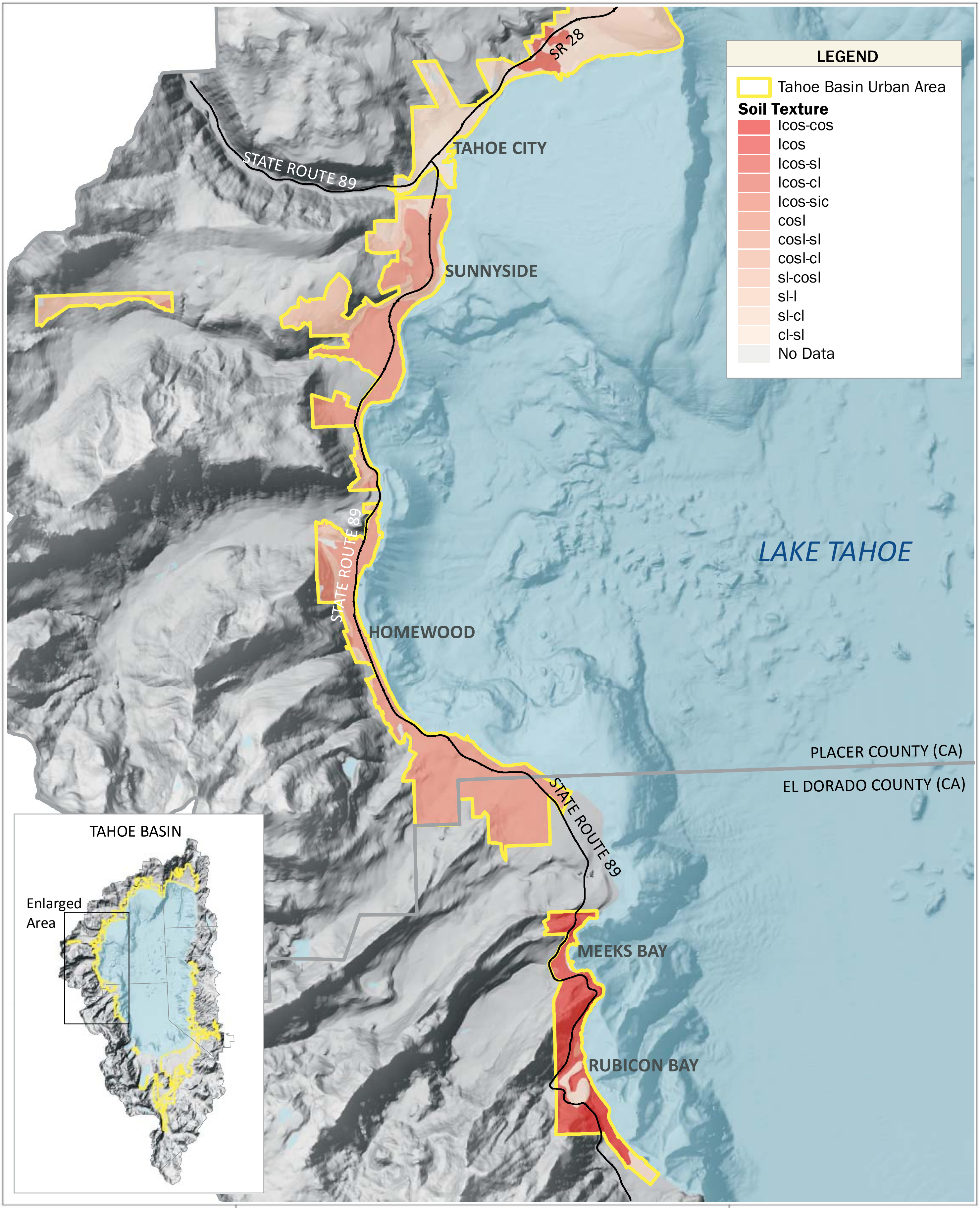

Figure 3.4C: Soil Texture for West Shore; Tahoe Basin Urban Area (See Figure 3.1G for texture definitions.)
Data Source: USDA-NRCS 2007

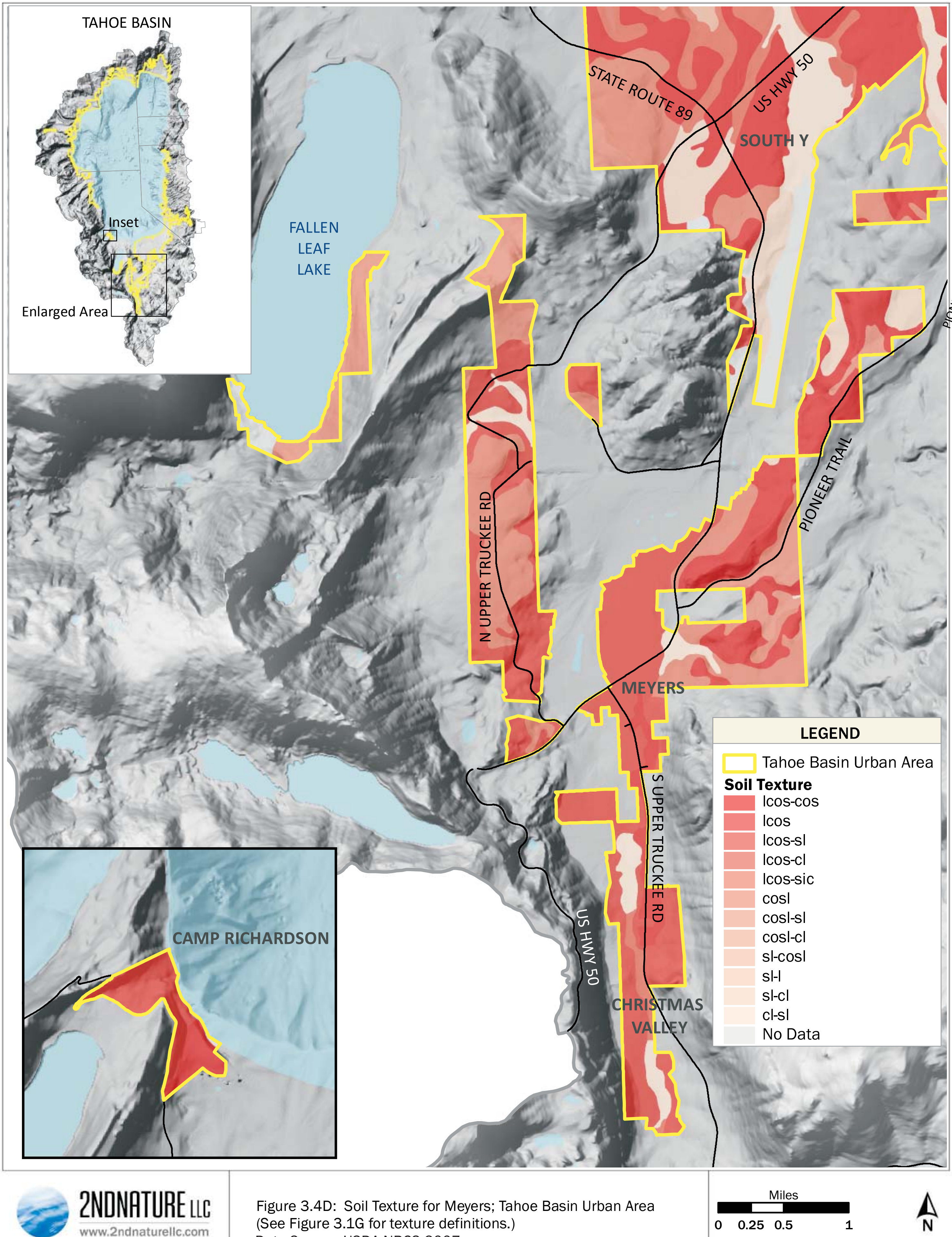

Figure 3.4D: Soil Texture for Meyers; Tahoe Basin Urban Area
(See Figure 3.1G for texture definitions.)
Data Source: USDA-NRCS 2007

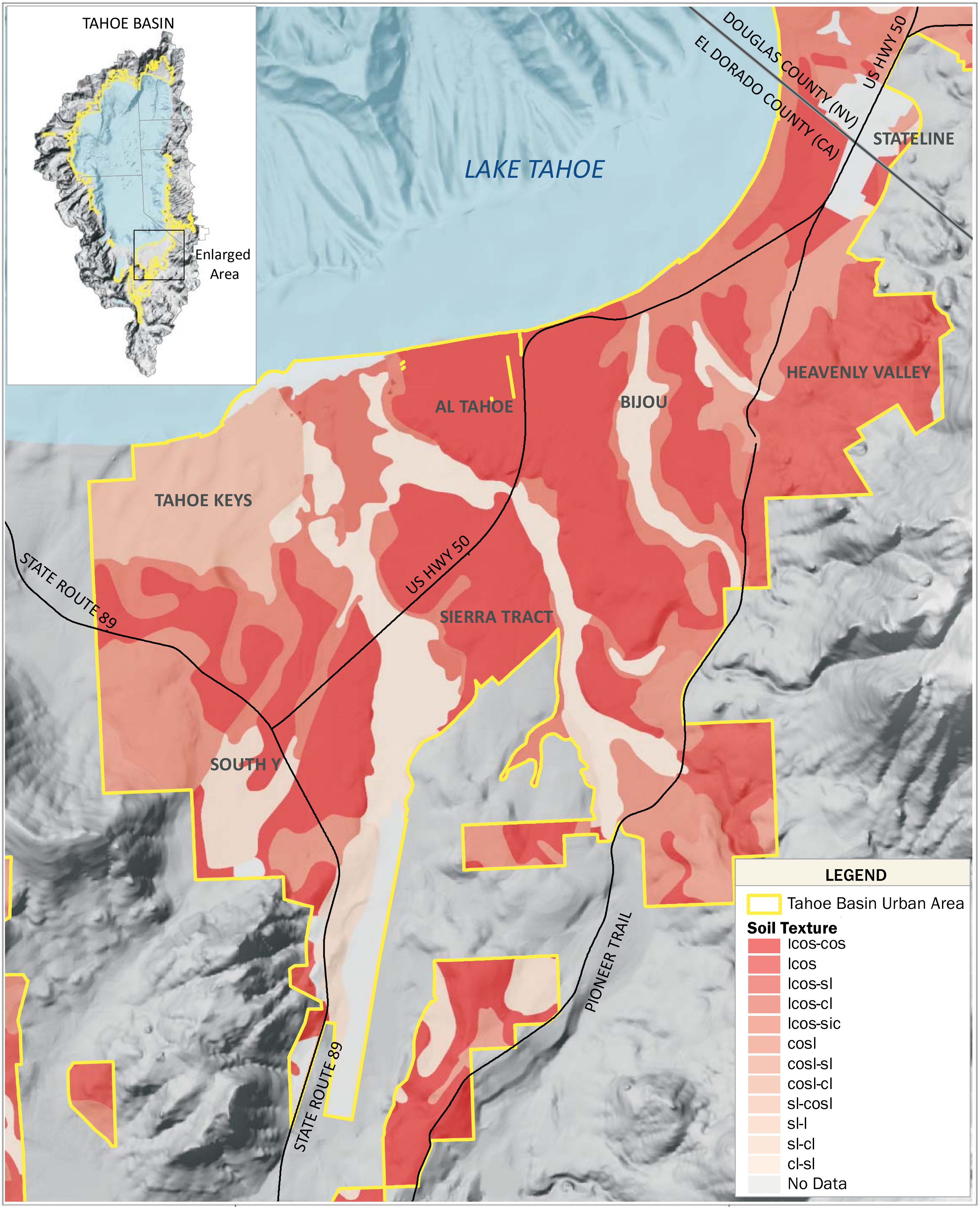

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Figure 3.4E: Soil Texture for City of South Lake Tahoe; Tahoe Basin Urban Area (See Figure 3.1G for texture definitions.)
Data Source: USDA-NRCS 2007

Miles
0 0.25 0.5 1
N

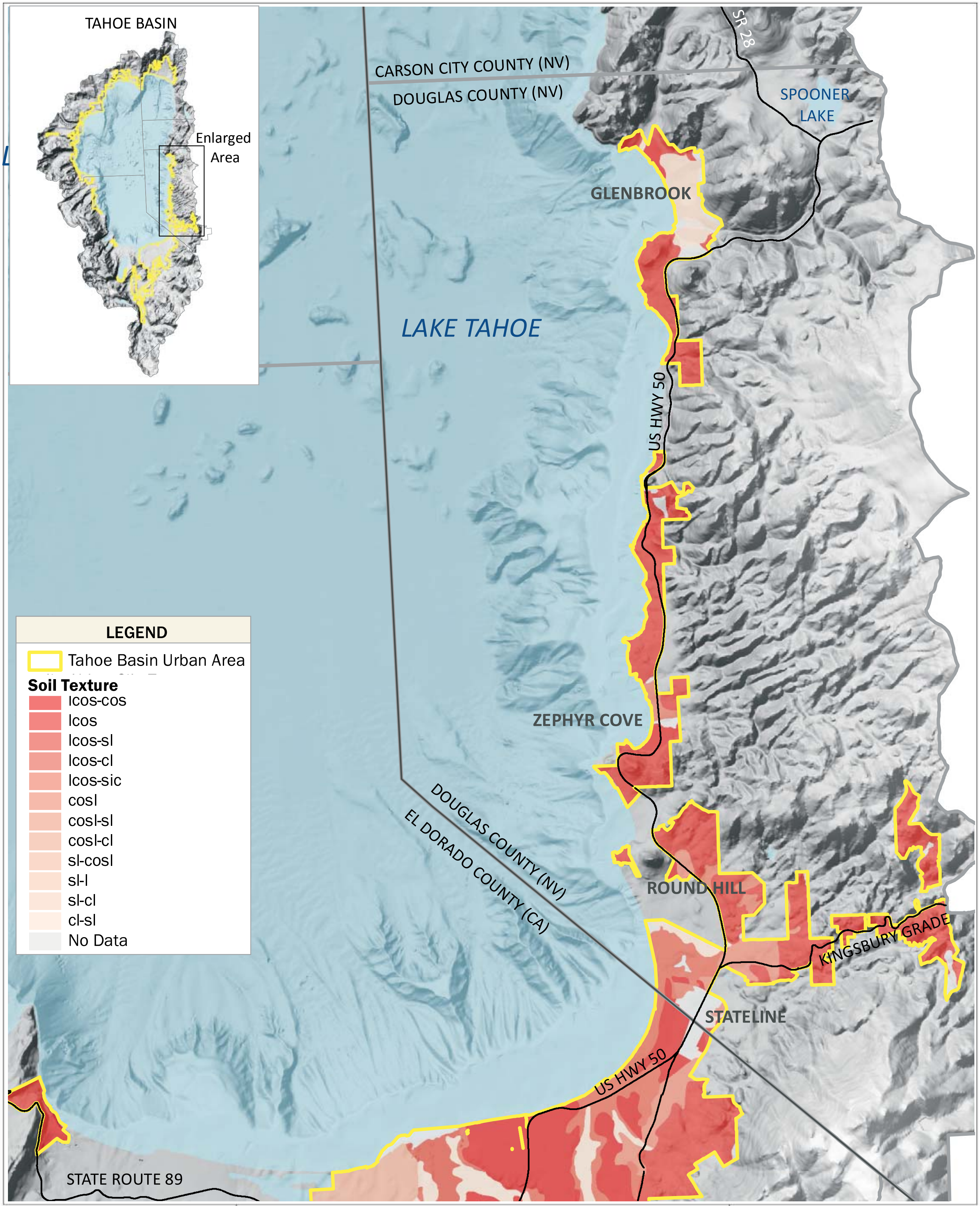

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Figure 3.4F: Soil Texture for East Shore; Tahoe Basin Urban Area (See Figure 3.1G for texture definitions.)
Data Source: USDA-NRCS 2007

DISSOLVED PHOSPHOROUS

Dissolved phosphorous (DP) consists of organic and inorganic species. The organic DP will slowly be respired into inorganic phosphorous, which can take the form of the ions HPO_4^{2-} or H_2PO^{4-} in stormwater or groundwater depending upon the pH of the system. As already described, DP is soluble in water but has a high affinity to adsorb to soil particles. Most soils have a very large capacity to retain phosphate, resulting in minimal transport of phosphorous with groundwater migration. Soils differ in their phosphate holding capacity, and the extent of SRP adsorption capacity is dependent upon grain size, pH, organic content, oxygen conditions, SRP-loading rates, and cation exchange capacity (CEC). The relative capacity of soils to retain phosphorous can be inferred from the grain size and CEC, which are discussed below.

GRAIN SIZE AND CATION EXCHANGE CAPACITY (CEC)

Fine-textured soils can hold many times more phosphate compared to coarse textured soils (Senarath et al. 2010). This is mostly due to the more inert character of sand particles, as compared to negatively-charged clay particles. Phosphate has a particularly high affinity for aluminum hydroxides $Al(OH)_3$ and iron hydroxides $Fe(OH)_3$ (Stumm and Morgan 1996). The slow transport of SRP in the subsurface is referred to as retardation, as phosphate ions can adsorb to and desorb from clay particles over time, greatly reducing the rate and distance of travel of SRP. As the concentration of phosphate ions in solution increases, there will be a rise in the amount of phosphate adsorbed to soil particles following principles of basic diffusion to balance the concentrations (Stumm and Morgan 1996). If the residence time of the water/soil interaction is longer than the kinetics associated with phosphorus adsorption/desorption rates, then phosphorus concentrations will diffuse from locations of higher concentration to lower concentration.

The CEC is the capacity of a soil to exchange cations between soil and water which affects the ability of soils to retain pollutants, so that a soil with a higher CEC has a greater ability to retain DP. Table 3.6 presents the CEC, texture and % clay of the Tahoe urban soils, aggregated by soil series. Table 3.6 is sorted from the combined lowest CEC and % clay to highest, where these two parameters are a proxy for relative phosphate retention. Soils that possess lower CEC and % clay having a relatively higher potential for DP to migrate through the soil with water. A depth weighted aggregation calculation was used to reduce the % clay and CEC Soil Survey dataset (USDA-NRCS 2007) to a single % clay and CEC value for each soil map unit. If a soil series consisted of multiple map units, the map unit values of the same series were averaged using a spatial weighting of the relative area of each unit to provide a single CEC and % clay value for each soil series. The soil series that possess CEC values < 5 meq/100 g are relatively coarse grained and possess relatively little clay and therefore are expected to have the higher relative potential for DP migration (highlighted in brown in Table 3.6). These soils series collectively represent approximately 30% of the Tahoe urban areas. Figure 3.5 maps the distribution of the CEC soil values throughout the Tahoe Basin urban area, with coarser soils typically possessing lower capability to retain phosphorous. Figures 3.5D and 3.5E illustrate the abundance of soils with relatively low phosphorous retention capabilities in the South Lake Tahoe area.

Table 3.6. Cation exchange capacity (CEC), texture, and composition of Tahoe Basin soil series. Soil series with low CEC values and % clay have a relatively higher potential for DP to migrate through the soil and are highlighted in brown.

Soil Series	Map Unit	% of urban area	CEC (meq/100g)	Texture	% Clay
Cassenai	7421-7424,7427	8%	2.3	lcos	2.5
Celio	7431	1%	3.1	lcos	2.2
Christopher	7441-7443	4%	2.6	lcos-cos	2.8
Christopher-Gefo	7444	10%	2.9	lcos-cos	3.6
Gefo	7452-7451	1%	3.4	lcos-cos	4.5
Meeks	7481-7489	7%	4.3	lcos	5
Cagwin-Rock	7411-7414	7%	5	lcos	4.5
Tahoma	7221	2%	5	sl-cl	5
Tallac	7521-7526	5%	5.7	cosl	6
Marla	7471	5%	6	lcos-cl	10.2
Jabu	7461-7462	6%	7.7	lcos-sic	8.9
Paige	7181-7183	2%	10.4	sl-cosl	6.9
Inville	7141-7143	10%	9.3	cosl-sl	9.2
Oneidas	7492	1%	9.3	cosl	9.2
Kneeridge	7171-7174	4%	11.8	cosl	7
Oxyaquic Xerorthents	7051	2%	12	sl-cosl	7.3
Tahoe Complex	7041	2%	15	cl-sl	11.5
Waca	7231-7233	1%	21.6	cosl	5
Jorge	7151-7155	7%	15.2	sl-l	14.1
Jorge-Tahoma	7156-7157	1%	17.7	sl-cl	15.3
Tahoma-Jorge	7222	4%	17.7	sl-cl	16.1
Watah peat	7071	1%	31	lcos-sl	4
Kingsbeach	7161	5%	14.8	sl-cl	30.2
Ubaj	7541	2%	19.6	sl-cl	37.6

DP TRANSPORT POTENTIAL

Typically, phosphorus breakthrough would occur in soils subjected to chronic fertilizer applications, sewage exfiltration, or septic system effluent, which possess DP concentrations and loading rates orders of magnitude higher than those typically observed in Tahoe Basin stormwater (< 1 mg/L). The urban areas of South Lake Tahoe are highly developed and presence of infiltration BMPs to infiltrate roadway, commercial and residential runoff are common. There is little evidence that stormwater infiltration BMPs substantially increase DP groundwater levels. However, the ability of soils to retain phosphorus can be exceeded if elevated loading occurs over time. Given the soil characteristics, select South Lake Tahoe urban areas where soils have relatively low CEC values have a higher potential risk of DP migration should chronic elevated levels of DP be introduced to these soils, but additional research would better constrain this risk. Source controls to minimize runoff to infiltration will help to ameliorate risks of enhanced local DP levels in areas where soil characteristics are more likely to permit DP migration.

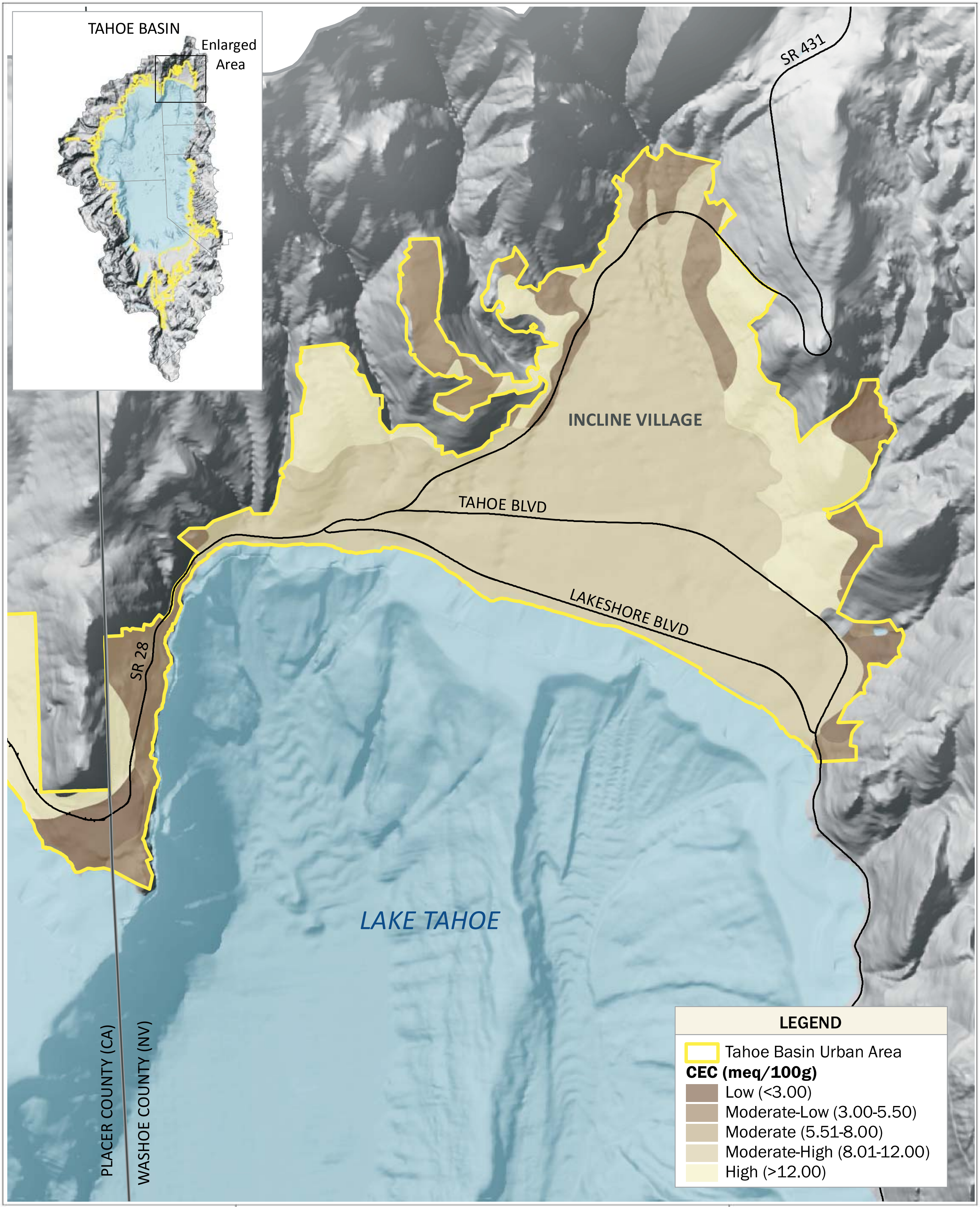

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Figure 3.5A: Soil CEC Values for Washoe County; Tahoe Basin Urban Area
Data Source: USDA-NRCS 2007

Miles
0 0.25 0.5 1
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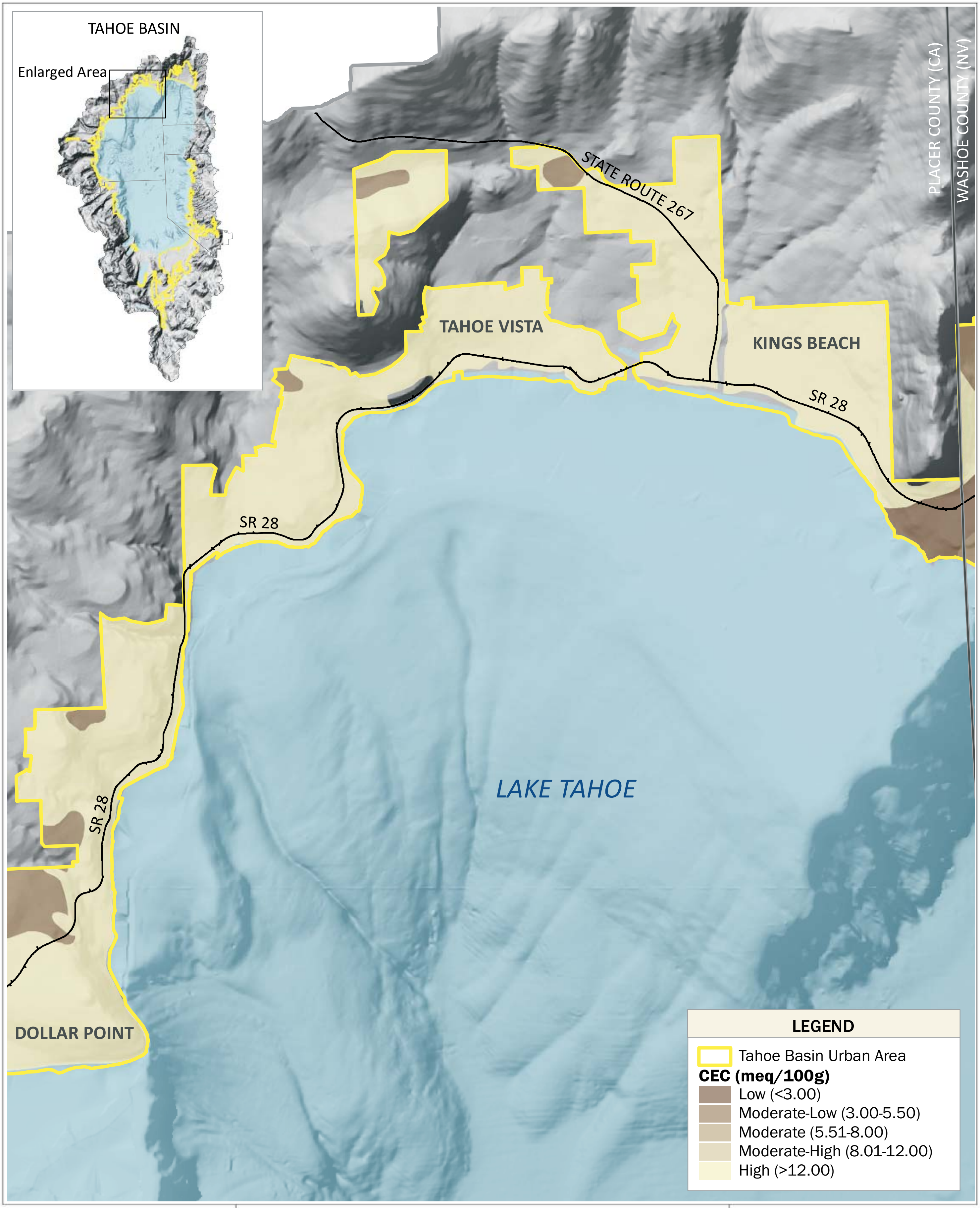

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Figure 3.5B: Soil CEC Values for Tahoe Vista/Kings Beach; Tahoe Basin Urban Area
Data Source: USDA-NRCS 2007

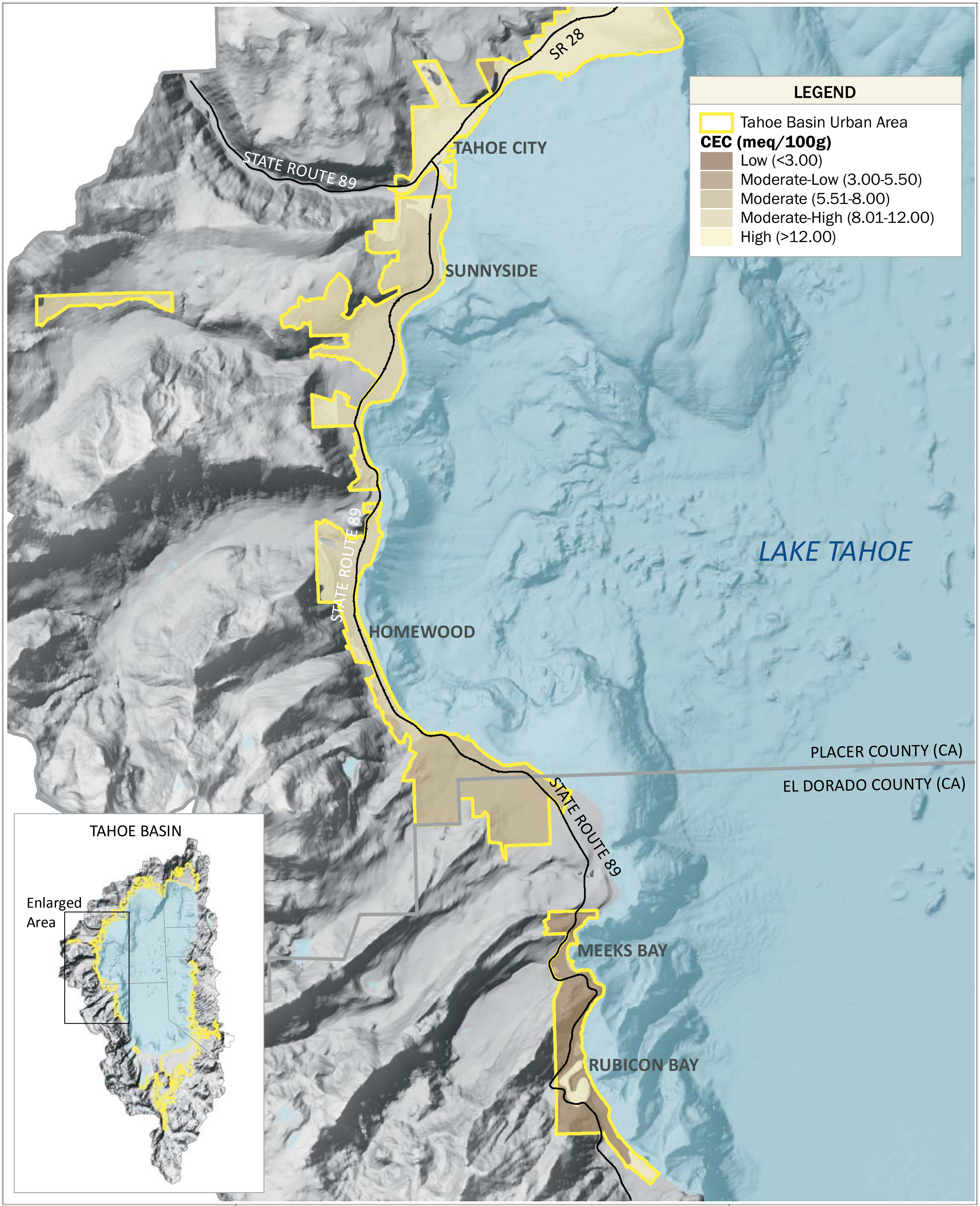

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Figure 3.5C: Soil CEC Values for West Shore; Tahoe Basin Urban Area
Data Source: USDA-NRCS 2007

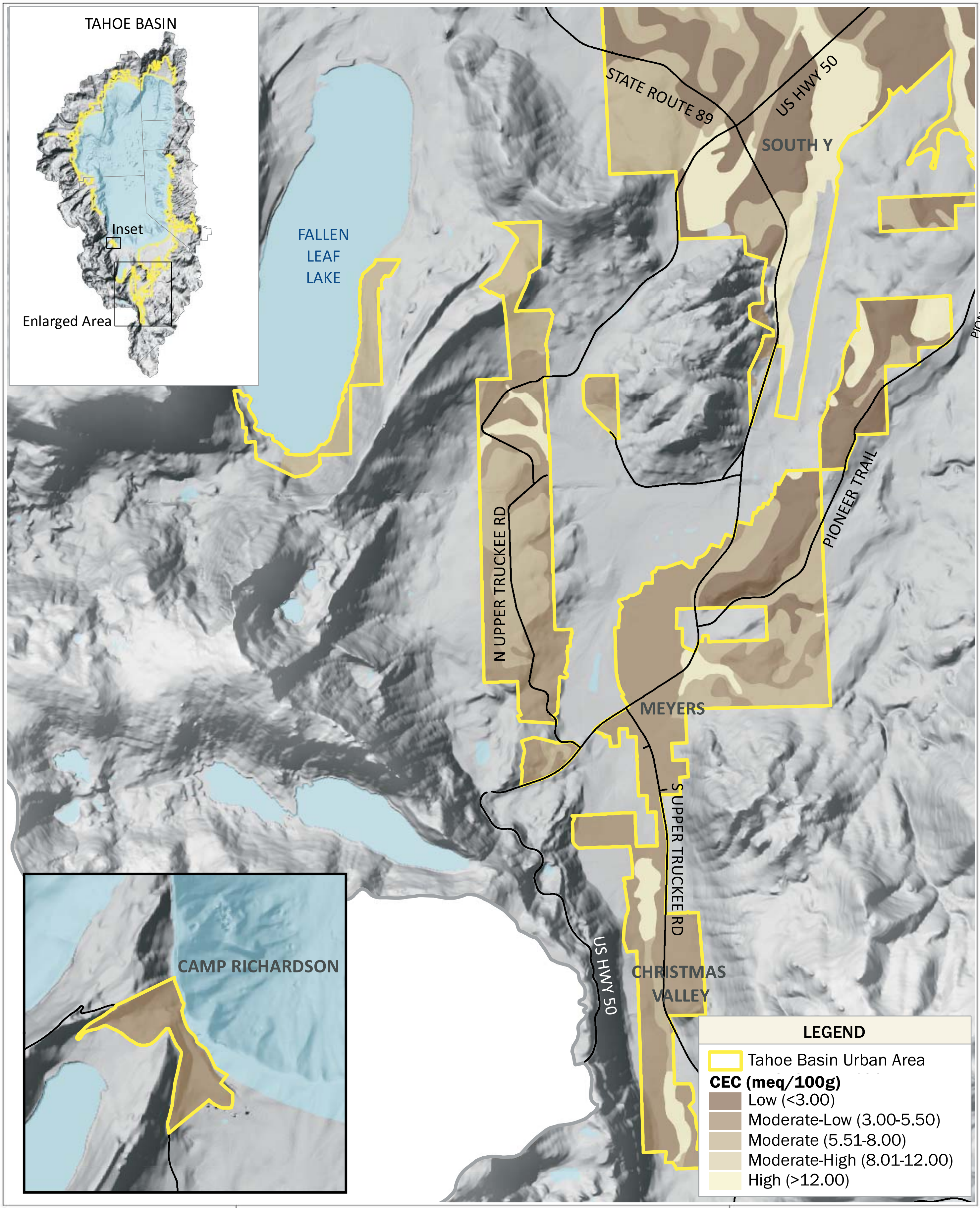

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Figure 3.5D: Soil CEC Values for Meyers; Tahoe Basin Urban Area
Data Source: USDA-NRCS 2007

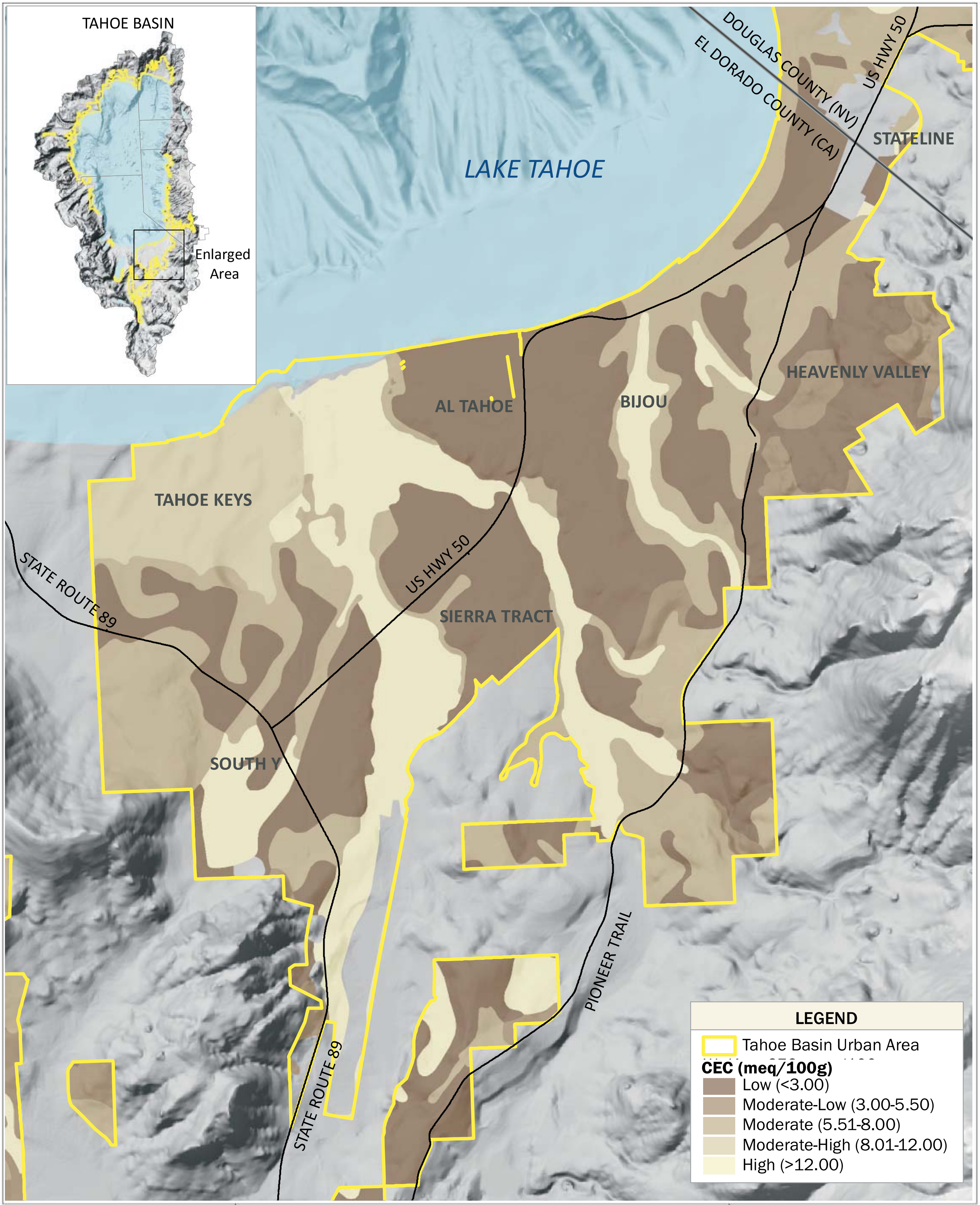

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Figure 3.: Soil CEC Values for City of South Lake Tahoe; Tahoe Basin Urban Area
Data Source: USDA-NRCS 2007

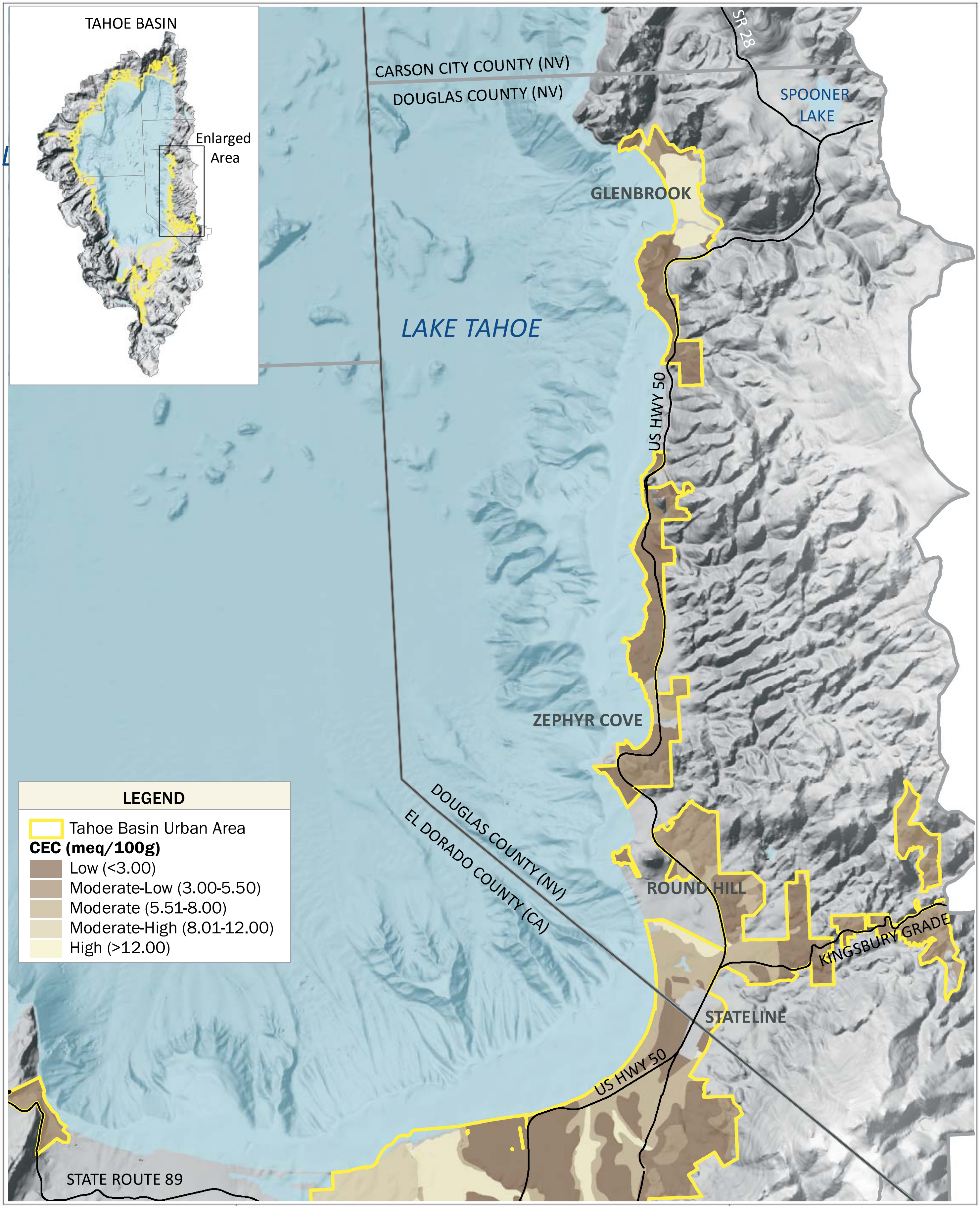

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Figure 3.5F: Soil CEC Values for East Shore; Tahoe Basin Urban Area
Data Source: USDA-NRCS 2007

DISSOLVED NITROGEN

SOIL TYPE INFLUENCES

Dissolved nitrogen (DN) is a conservative pollutant, so wherever water is infiltrated or moves more efficiently in the subsurface, DN movement will be enhanced. DN also consists of organic and inorganic species (see Figure 2.1), with nitrate being the most common in groundwater systems and also the most mobile. The areas mapped in Figure 3.2 with high K_{sat} soils will enhance DN movement horizontally towards the streams and Lake Tahoe and downward towards groundwater aquifers. The areas shown in Figure 3.2 that pose the greatest potential risk of enhanced DN transport are listed in Table 3.7.

Table 3.7. Locations (and maps) where K_{sat} in urban areas border Lake Tahoe and can be considered the greatest potential risk for DN transport to groundwater aquifers and the Lake as a result of stormwater infiltration.

Map	Location	Dominant Land Use Type	Transport Destination of Concern
Figure 3.2A	Incline Village along Hwy 431	Single Family Residential	Groundwater Aquifers
Figure 3.2D	S. Upper Truckee Road at Pioneer Trail	Single Family Residential	Groundwater Aquifers
Figure 3.2E	Bijou, Tahoe Valley, Meyers	Mixed Commercial Single Family Residential	Groundwater Aquifers
Figure 3.2F	Kingsbury	Single Family Residential	Groundwater Aquifers
Figure 3.2C	Meeks	Single Family Residential	Lake Tahoe
Figure 3.2C	Tahoe City	Mixed Commercial Single Family Residential	Lake Tahoe
Figure 3.2E	South Lake	Mixed Commercial Single Family Residential	Lake Tahoe

Soil texture is expected to play a minimal role in the relative potential migration risk of DN. Similar to phosphorus nitrogen retention by soils will be slightly higher as the grain size of the soil decreases due to the increase in the surface area to volume ratio of the soil media, but the high mobility of DN in the subsurface makes the relative influence of soil characteristics inconsequential.

DN TRANSPORT POTENTIAL

There is some evidence that stormwater infiltration BMPs will substantially increase DN groundwater levels and highly developed areas such as South Lake Tahoe with aging sewer systems and many fertilized surfaces may contribute relatively larger nitrogen loads to shallow groundwater. While movement of DN with infiltrated stormwater to groundwater aquifers may be more efficient in higher K_{sat} soils, DN transport efficiency is minimally affected by other soil characteristics. Low lying areas of the Tahoe Basin closer to streams, wetlands, and the Lake pose the greatest risk of DN transport to the Lake, since water will spend less time in soil before reaching surface waters and high K_{sat} soils will shorten this residence time (see Table 3.7 and Figure 3.2). Upland areas of the basin shown in Figure 3.2 and listed in Table 3.7 may pose a relatively greater risk for DN groundwater contamination, depending on the specific aquifer configuration and subsurface flow pathways of a given area. Since DN concentrations in stormwater are relatively low in comparison to raw sewage or beneath fertilized surfaces, stormwater infiltration even in areas with high K_{sat} soils may be a less important source contributing to groundwater contamination or lake clarity decline. Although still a concern, dissolved nitrogen is currently a lower priority pollutant with respect to lake clarity compared to DP and FSP. Source control measures such as fertilizer management plans and regular sewage line testing and maintenance will help to maintain the relatively low nitrogen groundwater concentrations in the Tahoe Basin.

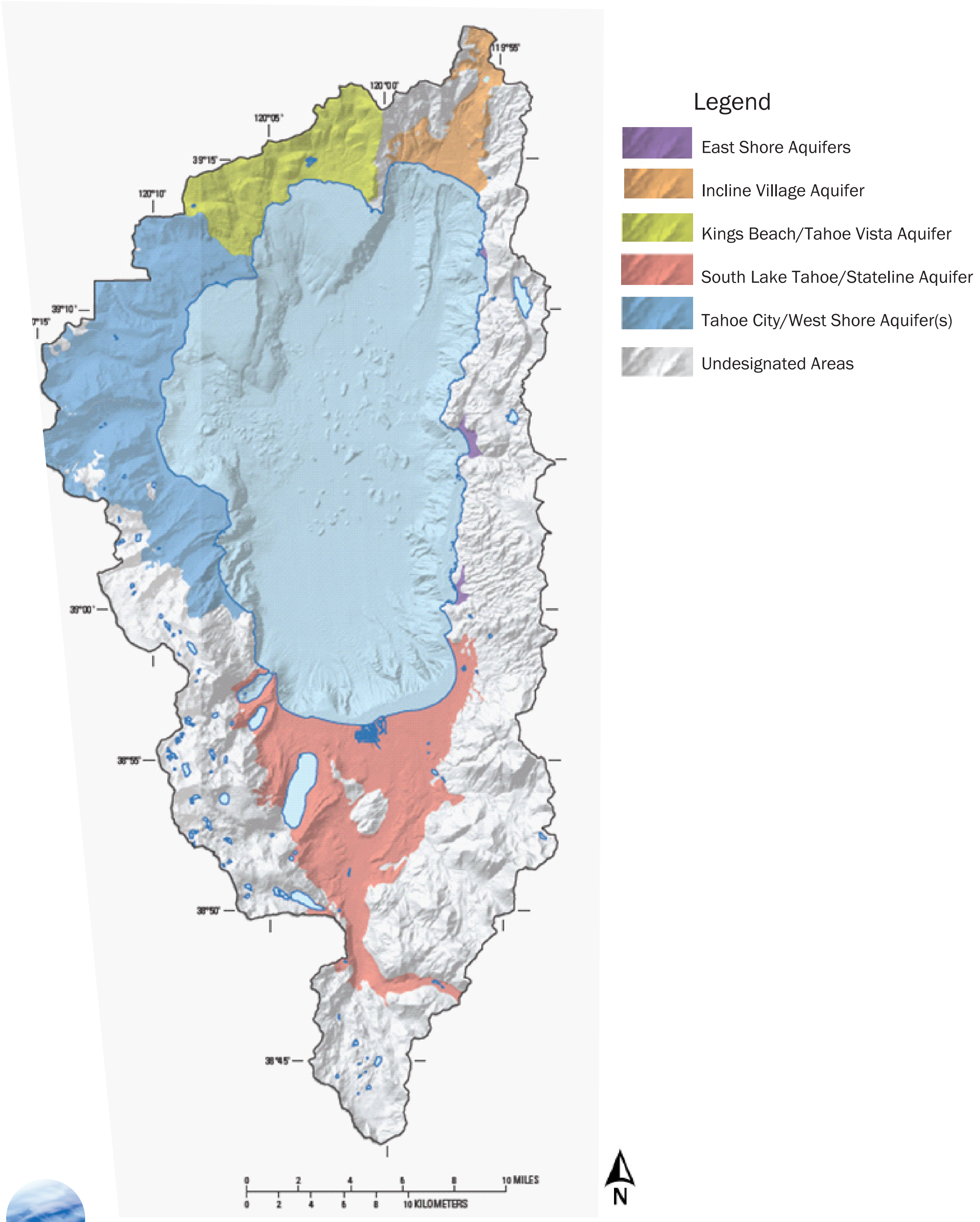
IV. EFFECTS OF SHALLOW GROUNDWATER ON STORMWATER INFILTRATION

Groundwater aquifers in the Tahoe differ in their hydrogeologic characteristics and fluctuate during the year with changes in precipitation. The structure and seasonal dynamics of these aquifers will influence the degree of vulnerability these aquifers have to contamination from infiltrating urban stormwater. Section IV provides an overview of the influence of groundwater reservoir interactions and seasonal dynamics on risks to groundwater quality and lake clarity.

SHALLOW V. DEEP GROUNDWATER

The shallow groundwater zones beneath infiltration BMPs, rather than deep groundwater aquifers, are the subsurface waters with the greatest potential for immediate pollutant enrichment as a result of stormwater infiltration. The principal deep aquifers in the Tahoe Basin can extend hundreds of feet below surface (USACE 2003). A US Army Corps of Engineers (USACE) study (2003) delineated five aquifer areas around the Lake—South Lake Tahoe/Stateline, Tahoe City/West Shore, Tahoe Vista/Kings Beach, Incline Village, and East Shore, which are shown in Figure 4.1 (Plume et al. 2009). The principal alluvial aquifers that occupy these areas are composed of heterogeneous deposits of clay, silt, sand, gravel and boulders that are interbedded with well sorted clay and sand (Tumbusch et al. 2007). In the South Lake Tahoe/Stateline area, which relies on groundwater wells for public supply, interbedded coarse and fine-grained deposits likely result in a multi-layered aquifer system that includes a shallow, unconfined (water-table) aquifer and one or more deeper confined aquifers (Plume et al. 2009). Figure 4.2 schematically illustrates the depth relationships between zones of shallow subsurface flow where most stormwater pollutant movement potential exists, typical principal basin aquifer depths, and typical water supply well depths.

Water supply wells typically draw from aquifers far below shallow groundwater zones where we would expect most stormwater pollutant transport to occur (see Figure 4.2). While there is not Tahoe Basin specific data to confirm this behavior of stormwater in the subsurface, examples in other regions are available to support this assumption. For example, Datry et al. (2004) investigated water quality impacts beneath a 8073 ft^2 infiltration basin in Lyon, France and found that groundwater at a depth of 3.3 ft below the water table consisted almost entirely of stormwater and that stormwater did not penetrate to depths greater than 9.9 ft below the water table. When soils are saturated or nearly saturated, vertical water movement will be minimal since pore spaces between soil grains are mostly filled. Given the close proximity of urban areas to the lake shoreline, it is unlikely that pollutants infiltrated with urban stormwater would migrate vertically hundreds of feet prior to travelling the necessary horizontal distance required to reach a surface water body or the Lake. Rather, pollutants infiltrated in these areas will reach surface waters or the Lake via movement in the shallow subsurface. The greatest volume of recharge to groundwater aquifers is expected to occur in the upland portions of the watershed, where there is very little to no development. There is particularly high confidence that little groundwater recharge from stormwater will occur in locations where continuous confining layers are present that physically separate the shallow groundwater table from deeper aquifers, as in South Lake Tahoe. Thus, it is reasonable to assume that the shallow groundwater zones beneath and/or downgradient of the urban areas in the Tahoe Basin are the most susceptible to potential contamination risk from stormwater infiltration BMPs.



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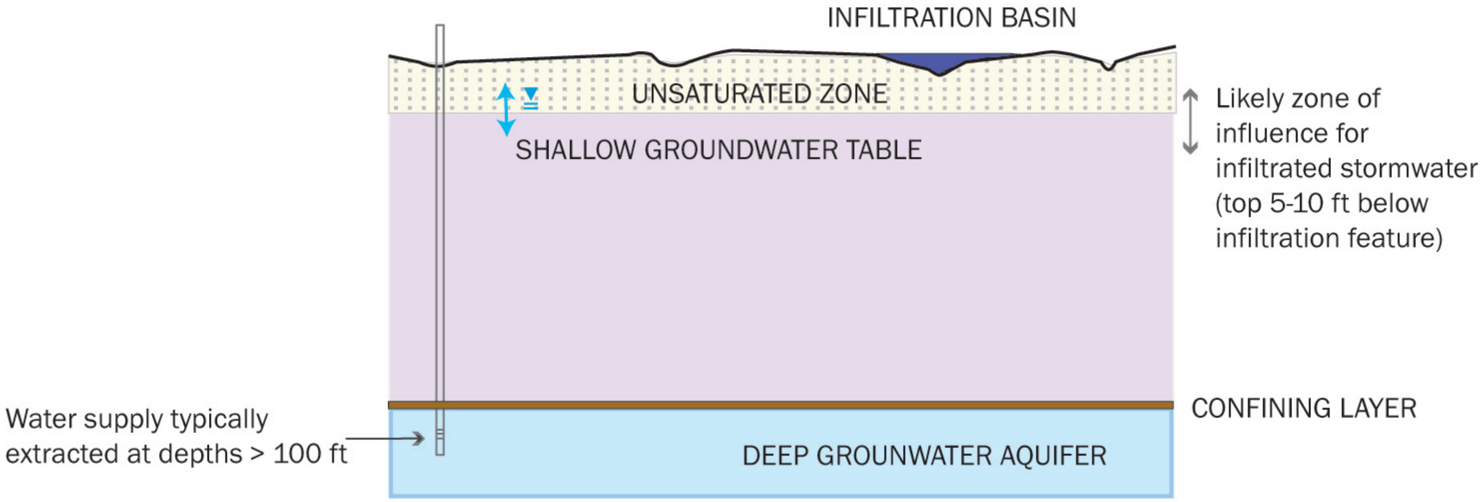
GROUNDWATER AQUIFER AREA MAP FOR THE TAHOE BASIN.
MODIFIED FROM PLUME ET AL. 2009

FIGURE 4.1



Likely zone of influence for infiltrated stormwater (top 5-10 ft below infiltration feature)

Water supply typically extracted at depths > 100 ft

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TAHOE BASIN GROUDWATER ZONE RELATIONSHIPS

FIGURE 4.2

SHALLOW GROUNDWATER FLUCTUATIONS

Areas with relatively high water tables have greater potential for mixing shallow groundwater with stormwater that infiltrates from the surface, which has been noted in the Basin Plan as a factor that may enhance pollutant transport to groundwater (LRWQCB 1995). Consequently, efforts have been made to include high groundwater and soil properties in decisions of infiltration BMP placement. Figure 4.3 is a map created by the Natural Resources Conservation Service (NRCS) that shows high groundwater areas (depth to seasonal high water table < 1.73 ft) in the Tahoe Basin along with rock/shallow soil areas (< 2 in depth), and soils grouped by their K_{sat} values (similar to the data shown in detail in Figure 3.2). Areas are represented in green if K_{sat} rates are high (>=13 in/hr) and pink where K_{sat} values are low (<=1 in/hr); beige areas area indicate intermediate K_{sat} soils (>1 in/hr and < 13 in/hr) that do not include areas of shallow groundwater or shallow/rocky soils.[4] Figure 4.3 combines a number of elements that may be considered risk factors for stormwater infiltration and subsurface migration. Areas with high stormwater transport potential to deep groundwater aquifers are likely constrained to those locations higher in the watershed upgradient from highly conductive soils. Areas that fit this description are very small patches east of Glenbrook along the east shore and south of Pioneer Trail in South Lake Tahoe (see Figure 4.3).

Groundwater levels fluctuate throughout the year in the Tahoe Basin, which may affect the potential for stormwater to mix with groundwater. During times of the year when groundwater is high, the vertical distance pollutants travel to reach groundwater aquifers is shorter. Groundwater levels and recharge timing are affected by local topography, subsurface geology and soil characteristics, but they generally are explained by seasonal rainfall and temperature variations. The seasonal groundwater elevation trend follows the alpine climate of relatively wet springs and dry summers with elevations receding in the summer, followed by gradual late winter early spring recharge and an annual peak during spring snowmelt conditions (2NDNATURE 2006A, 2NDNATURE 2007, 2NDNATURE 2008). Table 4.1 lists the fraction of annual runoff delivered to the Lake seasonally from urban areas as modeled by a 20-year hydrologic simulation using the Pollutant Load Reduction Model (PLRM, nhc et al. 2009). Table 4.1 illustrates that over 79% of the urban runoff occurs between December and May each year, indicating the greatest annual proportion urban stormwater will be also be mobilized during these months.

Table 4.1. Seasonal fractions of annual runoff in urban areas of the Tahoe Basin

Season	Fraction of Annual Runoff
Winter (Dec – Feb)	37%
Spring (March- May)	42%
Summer (June – Aug)	6%
Fall (Sept-Nov)	15%

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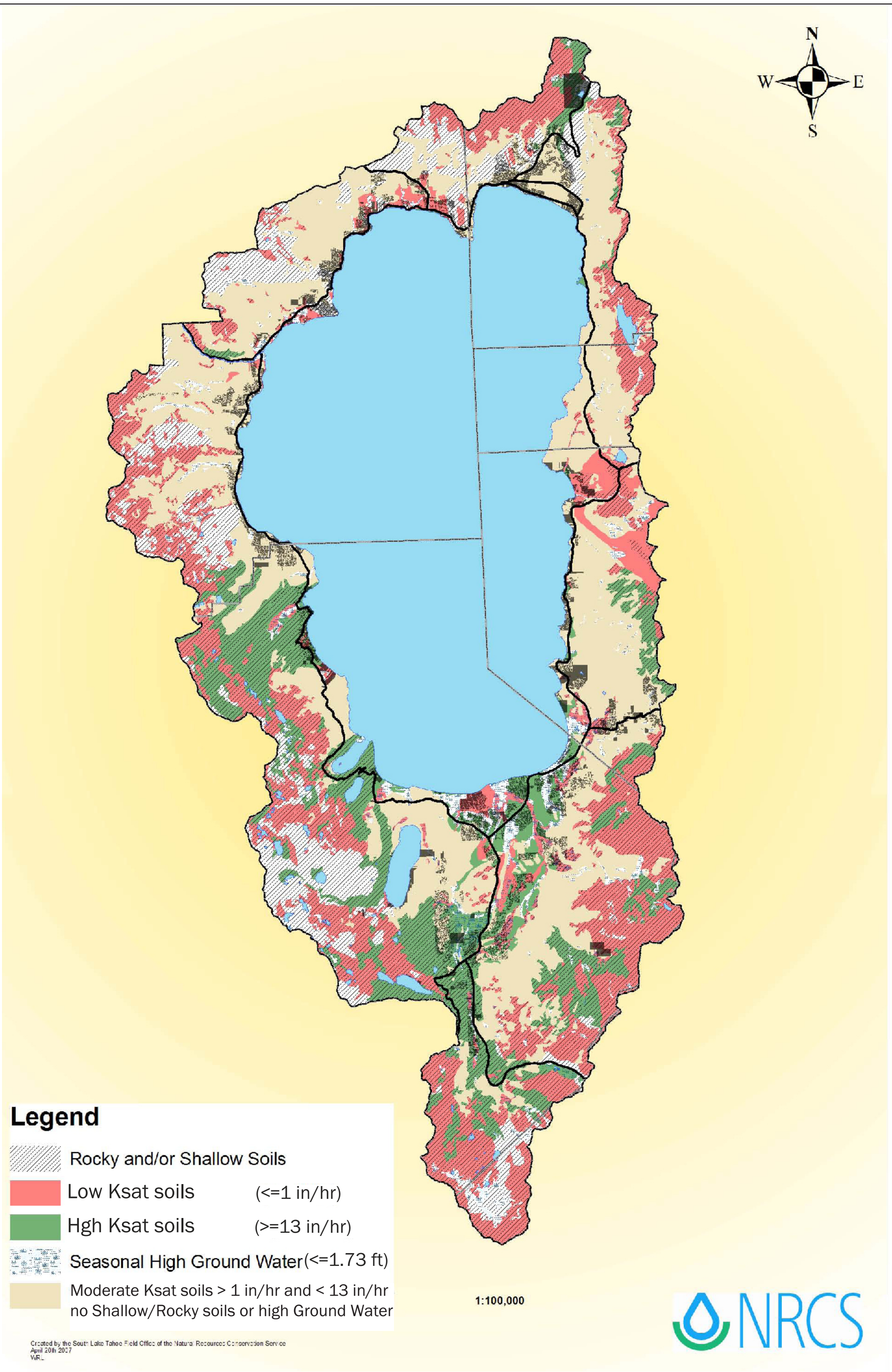
[4] Note that the K_{sat} categories are defined differently for Figure 4.3 than they are in Figure 3.2.



Created by the South Lake Tahoe Field Office of the Natural Resources Conservation Service
April 20th 2007
WRL

DATA SOURCE: USDA-NRCS 2007

TAHOE BASIN SOIL KSAT AND HIGH GROUNDWATER AREAS

FIGURE 4.3

Winter and spring seasons are when the potential for mixing of stormwater with groundwater is highest and this seasonal risk of mixing will vary from year to year. The maximum and duration of shallow groundwater elevations are influenced by the winter and spring total precipitation with drier years typically resulting in relatively lower peak shallow groundwater elevations (2NDNATURE 2008). Figure 4.4 illustrates seasonal and inter-annual variations in groundwater from 2005 to 2008 at the Park Avenue detention basin in South Lake Tahoe. Note the peaks in winter and spring months and the gradual lowering of groundwater levels throughout summer and fall months.

In areas where the unsaturated zone (or vertical separation) is thin, infiltration BMPs can result in localized groundwater mounding. This effect is illustrated in Figure 4.5 using a time series of groundwater elevations from shallow monitoring wells surrounding Eloise Dry Basin in South Lake Tahoe (2NDNATURE 2006). During times of localized soil saturation beneath the Eloise Dry Basin, when the basin was at capacity, the surface water inflow and outflow to the Basin were determined to be at steady-state (i.e., equal) (2NDNATURE 2006). Two other Tahoe Basin dry basins studied for surface water/groundwater interactions did not exhibit the same mounding during the peak of lake level snowmelt. This difference may be explained by the relatively greater depth to the peak elevation of shallow groundwater table or thicker minimum unsaturated zone at the other two sites (2NDNATURE 2006A, 2NDNATURE 2008).

VERTICAL SEPARATION OF INFILTRATION FEATURES FROM GROUNDWATER

ASSESSMENT OF CURRENT STANDARDS RATIONALE

Both the Water Quality Control Plan for the Lahontan Region (Basin Plan; LRWQCB 1995) and the TRPA Code of Ordinances include vertical separation requirements for constructing infiltration BMPs to protect groundwater beneficial uses. Below is an excerpt from the Basin Plan providing the rationale for the vertical separation standard:

> *"Since runoff is treated by infiltration through vegetation and soil layers, the effluent limits are greater for discharges to infiltration systems [than those for surface water systems]. Locating infiltration systems in areas of high ground water may result in ground water contamination and reduced percolation rates. Therefore, discharges to infiltration systems located in areas where the separation between the highest anticipated ground water level and the bottom of the infiltration system is less than five (5) feet may be required to meet the effluent limits for stormwater discharges to surface waters."* p. 5.6-2

Similarly the TRPA Code of Ordinances states:

> *"Where there is a direct hydrologic connection between ground and surface waters, discharges to groundwater shall meet the standards for surface runoff. A direct hydrologic connection is presumed to exist wherever, by virtue of proximity to a surface water body, nature of soils, or slope or gradient, and the residence time of runoff water discharged into the ground is too short to remove pollutants from the runoff."* (TRPA, p. 82.2.B) [5].
>
> Accordingly, the TRPA BMP Handbook planning criteria recommends a distance 12 inches between the bottom of dry wells and seasonal high groundwater (TRPA 1988, p. 96)[6].

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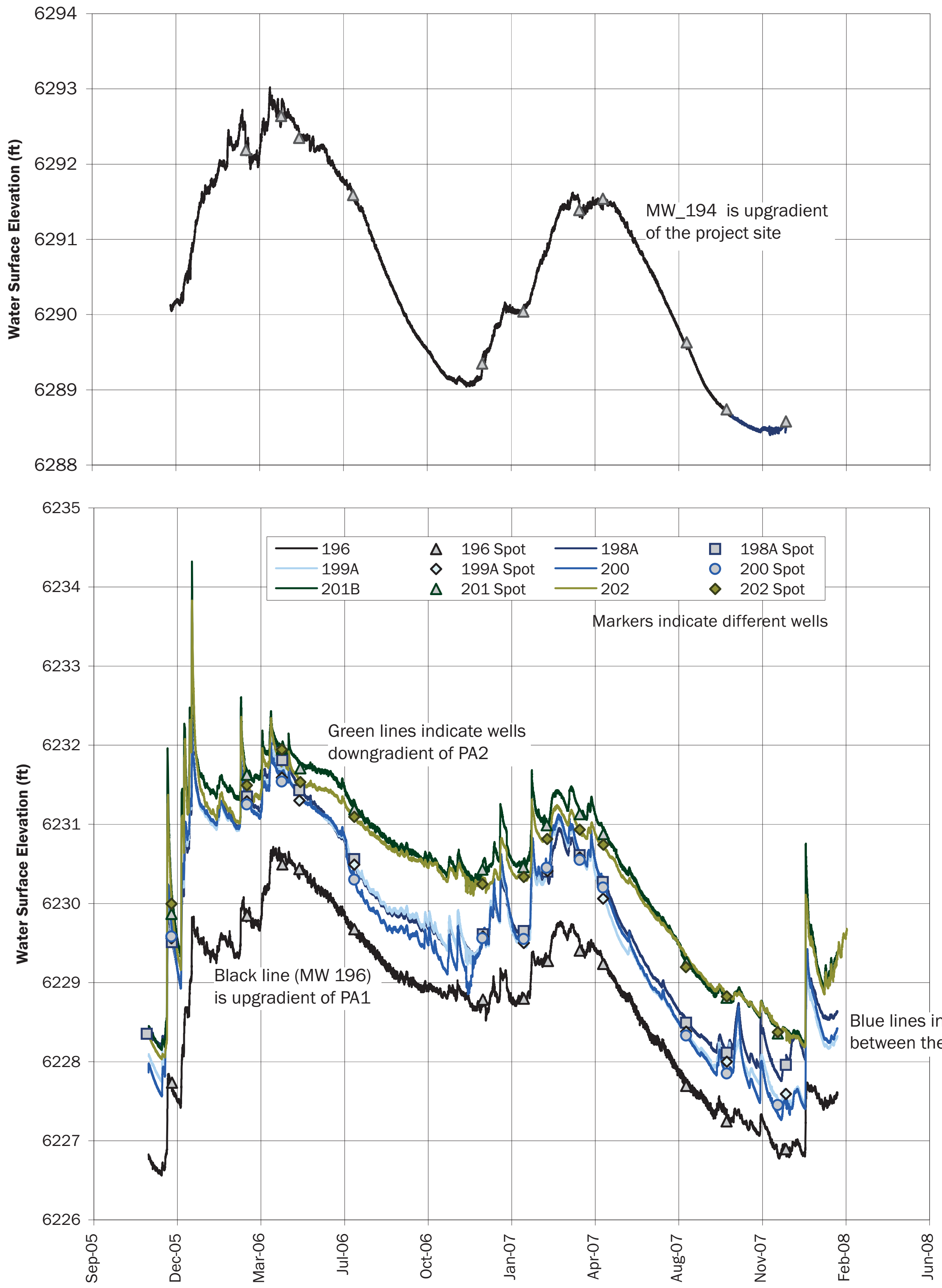
[5] http://www.trpa.org/default.aspx?tabid=172 accessed April, 2011

[6] http://www.trpa.org/documents/about_trpa/scenic/DRG.pdf accessed April, 2011



SOURCE: 2NDNATURE 2008

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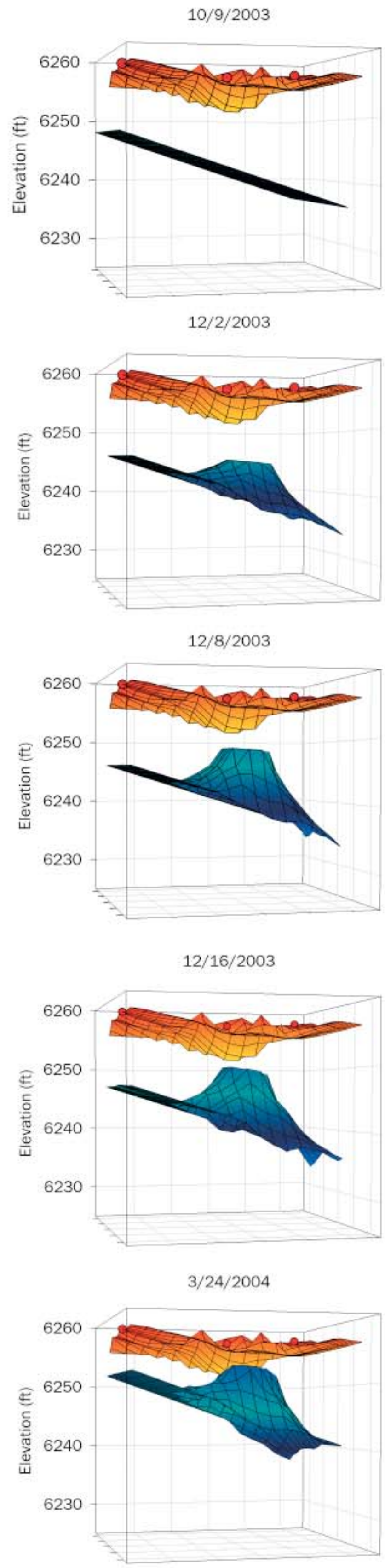
REPRESENTATIVE SEASONAL SHALLOW GROUNDWATER
ELEVATIONS EVATIONS ADJACENT TO INFILTRATION BASINS
(PARK AVENUE BASINS,SOUTH LAKE TAHOE, CA)

FIGURE 4.4



A 3-D rendering of groundwater levels from fall 2003 to spring 2004 at Eloise Dry Basin illustrates the seasonal localized groundwater mounding effect in winter and spring.

SOURCE: 2NDNATURE 2006

EXAMPLE OF LOCAL GROUNDWATER ENHANCEMENT
(ELOISE DRY BASIN, SOUTH LAKE , CA)

FIGURE 4.5

The assumption that stormwater infiltration will have a greater likelihood to contaminate groundwater when introduced into a saturated soil column (i.e., elevated shallow groundwater elevations) may not be generally applicable given the relevant pollutant constituents and typical concentration ranges observed in the Tahoe Basin. First, soil moisture levels have a negligible influence on the fate and transport of the pollutants and associated constituents presented in Table 1.1 (and detailed in Section II). A saturated soil column will effectively filter and retain particulate pollutants as well as remove hydrophobic pollutants such as oil and grease. The fate and transport of FSP in a saturated soil column will be controlled by soil texture and sorting regardless of saturation levels. Similarly, saturated soil conditions have a negligible influence on the cation exchange capacity (CEC) and adsorption of dissolved phosphorous of various soils. Nitrate will remain relatively mobile with water whether introduced to saturated or unsaturated soils.

Second, while areas with shallow groundwater tables will experience significantly reduced vertical flux of water during spring and winter due to reduced infiltration capacity of the saturated soils, these areas will allow some infiltration of surface water during drier conditions. The infiltration of water into the unsaturated zone is influenced by both gravity and moisture potential, where moisture potential increases with decreasing soil moisture and drier soils will infiltrate water faster than soils that have a lower moisture potential. Since the infiltration performance of BMPs in high groundwater areas may be reduced during winter and spring due to local soil saturation (2NDNATURE 2006A), they are not likely to pose a risk of groundwater contamination during these times. However, when conditions are drier and the soil has some moisture potential, infiltration of stormwater and movement through the soil will attenuate pollutant concentrations compared to running off directly to surface waters.

WATER QUALITY PROTECTION TRADE-OFFS

Given the current understanding of pollutant geochemical behavior and existing empirical data for Tahoe Basin stormwater, the vertical separation standards are likely to increase the annual stormwater loading of pollutants to surface waters with a minimal reduction of risk to groundwater quality. Infiltration BMP standards should not treat risks to surface and groundwater quality in isolation of one another, but should permit an integrated assessment of potential trade-offs between surface and groundwater risks. Induced stormwater infiltration during the summer through fall will reduce stormwater volumes and pollutant loads to Lake Tahoe, particularly FSP and DP. During spring seasonal high groundwater conditions, soil infiltration capacity will be significantly reduced throughout the Tahoe Basin so that in locations where the vertical separation is minimal, pollutant loads are more efficiently delivered to surface waters than vertically infiltrated to shallow groundwater. While nitrate is highly mobile in the subsurface, the current groundwater concentrations are nearly ten times below state maximum contaminant levels and nitrate is not currently the limiting nutrient for Lake Tahoe primary producers. In addition, most locations where seasonal high groundwater exists are in close proximity to the Lake. Given that groundwater supply wells are typically screened and extract water from depths greater than 100ft below the ground surface there is a minimal chance of infiltrated pollutants (DN) to migrate vertically to these depths prior to horizontal delivery to the surface waters.

Vertical separation standards should not result in missed opportunities to efficiently implement solutions that may have the greatest overall water quality benefits. Since performance of stormwater infiltration BMPs may be lessened during high groundwater conditions at some locations, groundwater levels are an appropriate guiding factor for determining optimal stormwater infiltration BMP installment locations. However, this information should be used in combination with other factors such as stormwater pollutant concentrations, consequences of surface stormwater conveyance, cost savings of opportunistic BMP implementations, and the pollutant removal efficiency and volume of soil available.

V. POLLUTANT RESEARCH NEEDS AND RECOMMENDATIONS

STORMWATER INFILTRATION RESEARCH PRIORITIES

Below we provide recommendations for each pollutant constituent based on the risks identified in the previous chapters to groundwater quality and lake clarity and their associated beneficial uses defined in the Basin Plan. The research priority designated in tables 5.1 and 5.2 are based on constituent geochemistry, soil properties, Tahoe Basin stormwater data, and seasonal groundwater dynamics presented in Sections II-IV. Research priorities are ranked to identify topics and constituents where additional information is necessary to better understand how stormwater infiltration practices in the Tahoe Basin may 1) increase the potential risk of contamination to groundwater quality, or 2) impact lake clarity.

Table 5.1. Research priority categories for groundwater quality and lake clarity degradation due to stormwater infiltration and associated recommendations.

Research Priority	Groundwater Quality	Lake Clarity	Recommendation
LOW	Substantial geochemical and empirical evidence indicate that constituent is unlikely to degrade groundwater quality as a result of stormwater infiltration.	Substantial geochemical and empirical evidence indicate that constituent is not highly mobile in the subsurface and is expected to pose little to no risk to lake clarity as a result of stormwater infiltration.	No additional research is required for high confidence that contamination risks are minimal
MOD	Geochemical behavior indicates that constituent has the potential to pose a risk to groundwater quality. Tahoe Basin datasets indicate that risks are moderated due to either constituent concentrations in groundwater well below drinking water standards, stormwater not being a primary source of constituent to groundwater, or minimal subsurface migration.	Geochemical behavior indicates that constituent has the potential to be mobile in the subsurface under select conditions. Tahoe Basin datasets suggest infiltration of stormwater is not likely to be a significant source of the constituent or the constituent is not currently identified as a primary pollutant of concern contributing to lake clarity decline.	Identify additional research required to increase confidence of risks and site specific trade-offs associated with stormwater infiltration.
HIGH	Limited geochemical or empirical evidence indicates that constituent is likely to degrade groundwater quality as a result of stormwater infiltration.	Limited geochemical or empirical evidence indicates that constituent may be mobile in the subsurface under select conditions and/or this constituent is a primary pollutant of concern contributing to lake clarity decline.	Prioritize additional research required to increase confidence that risks are minimal under certain conditions and clarify site specific trade-offs associated with stormwater infiltration.

Table 5.2. Summary of evidence for transport risks and research priority

Constituent	Geochemical and empirical evidence	GW Research Priority	Key additional points	Lake Clarity Research Priority	Key additional points
Oil and Grease	• Hydrophobic pollutant with a high affinity for soil adsorption and relatively immobile in subsurface under all conditions • Constituents likely to be retained in topmost soil layers of infiltration BMPs • Concentrations low in Tahoe Basin stormwater relative to current standard	LOW	No drinking water standard for oil and grease	LOW	Not a pollutant of concern in the Lake Tahoe TMDL
Total Iron	• High affinity to adhere to soil particles • Studies indicate accumulation primarily in top few cm of soil • No available stormwater data for review • Highest recent groundwater well measurement 3x below drinking water standard	LOW		LOW	Not mentioned in the Lake Tahoe TMDL though past research suggested potential iron limitation with some primary producer communities
Total Nitrogen (TN)	• Majority of constituent concentrations are particulate species • Particulate constituents not mobile in subsurface	LOW	No drinking water standard for TN	LOW	Only 12.5% of Lake TN budget delivered via groundwater (all of which is DN)
Dissolved Nitrogen (DN)	• Conservative pollutant highly mobile in the subsurface • Sewage exfiltration may be a higher annual source of DN to groundwater than stormwater infiltration • Evidence of DN groundwater enrichment in Tahoe urban areas • STPUD groundwater wells contain an average nitrate as N concentration < 1 mg/L, over 10x below drinking water standards	MOD		MOD	Currently DN is not the limiting nutrient for algal growth in Lake Tahoe
Total Phosphorus (TP)	• Majority of constituent concentrations are particulate species • Particulate constituents not mobile in subsurface	LOW	No drinking water standard for TP	LOW	Only 15% of Lake TP budget delivered to the lake via groundwater (all of which is DP)

Constituent	Geochemical and empirical evidence	GW Research Priority	Key additional points	Lake Clarity Research Priority	Key additional points
Dissolved Phosphorus (DP)	• High affinity to adsorb to soil particles • Tahoe infiltration studies suggest minimal horizontal migration • Sewage exfiltration may be a larger annual source of DP to groundwater than stormwater infiltration • May travel intermediate distances in low cation exchange capacity (CEC) soils • STPUD water supply wells < 0.04 mg/L	LOW	No drinking water standard for DP species	HIGH	Phosphorus is the limiting nutrient for algal production in Lake Tahoe and therefore primary nutrient of concern for Lake Tahoe TMDL
Fine Sediment Particles (FSP) + Turbidity	• Turbidity is not a pollutant and rather an optical property of water • Preliminary research indicates turbidity may be a useful proxy for FSP concentrations • Potential for some FSP transport through coarse Tahoe Basin soils • Loading of turbid water will reduce performance of infiltration BMPs soils over time • Highest STPUD water supply wells turbidity measurements are nearly 10x below drinking water standard	LOW	No drinking water standard for FSP	HIGH	FSP Identified as primary pollutant impairing lake clarity in the TMDL

VERTICAL SEPARATION STANDARD

There is no evidence that the treatment and removal of pollutants via soil/water interactions for the pollutants with infiltration discharge standards (listed in Table 1.1) is affected by the moisture content of soils at the base of an infiltration BMP. With respect to preserving lake clarity, it appears that the vertical separation standard will provide little benefit and may result in a net increase of pollutant deliver to Lake Tahoe via surface waters due to the restrictions on infiltration BMP implementation in some locations. With respect to groundwater quality, while dissolved nitrogen is the only constituent reviewed that may require further research to address concerns about groundwater contamination potential, there are other urban pollutants, such as pathogens, bacteria, or organic pollutants that can impair groundwater quality and cause human health concerns. A more comprehensive analysis of all potential pollutants, Tahoe Basin aquifers and recharge pathways should be evaluated in the future to fully assess the potential risk of discharging urban stormwater to locations with seasonally elevated groundwater. Additionally, alignment of the TRPA and LRWQCB vertical separation standards can streamline permitting requirements and may create new opportunities for infiltration BMP implementation.

RECOMMENDATIONS

The review of existing information resulted in the following policy recommendations for TRPA and LRWQCB:

1. **Align LRWQCB and TRPA vertical separation regulations.** Consistent vertical separation regulations between the Basin Plan and TRPA would make infiltration BMP sizing, design and permitting more

efficient. A recommended modification of both regulations to a reasonable standard of 2 ft may be sufficient to reduce uncertainty in the potential for no vertical separation during wet years and provide adequate water quality protection for other pollutants not evaluated herein. Deviations to lower or no separation could be approved on a case by case basis.

2. **Continue nutrient source control efforts.** Practices to minimize application and runoff of phosphorous-rich fertilizers and maintenance of sewer systems to minimize exfiltration will greatly reduce the likelihood of increasing future stormwater DP concentrations and localized subsurface DP migration.

Specific research priorities identified based on existing knowledge gaps include:

3. **Complete controlled bench studies of FSP and DP migration via Christopher and Gefo soils.** The Christopher and Gefo soils comprise over 20% of the Tahoe Basin urban area. These soils are the coarsest soil series and therefore expected to have the highest potential to allow FSP migration due to higher porosity and DP migration due to relatively low CEC values. If desired, controlled bench experiments can be conducted to quantify the relative vertical migration risk to improve our confidence that Tahoe Basin native soils provide adequate safety to retain and treat these two critical pollutants.

4. **Complete DN and DP pollutant loading budgets to Lake Tahoe.** The appropriate pollutant mass balance to adequately evaluate the relative contribution of groundwater loading of N and P to Lake Tahoe is needed to augment the existing TMDL. A dissolved nitrogen (DN) and dissolved phosphorous (DP) budget can be constructed using existing information and available datasets. Since only dissolved nutrient constituents are mobile in the subsurface, the existing loading contributions from groundwater of 12.5% and 15% of TN and TP, respectively, are underestimates of the relative role groundwater contributes to these biologically available fractions of critical nutrients driving lake primary production.

One of the greatest current areas of uncertainty are the factors controlling infiltration BMP performance decline and the site information required to prescribe adequate and reasonable maintenance actions and schedules for infiltration BMPs. Section VI (Key Factors Affecting Infiltration BMP Performance) reviews current Tahoe Basin infiltration BMP design and maintenance practices, supplements this information with review of available literature from other urban communities, and prioritizes our critical knowledge gaps that will be address by the remainder of this research.

VI. KEY FACTORS AFFECTING INFILTRATION BMP PERFORMANCE

This section identifies key factors affecting infiltration BMP performance. Identified factors will guide subsequent field work and analysis tasks to augment and improve design and maintenance guidance for Tahoe Basin Infiltration BMPs. Section VI:

- Provides a brief summary of current Tahoe Basin practice related to Infiltration BMPs
- Assesses the adequacy of the current Tahoe Basin 20-year 1-hour design standard
- Summarizes sources of information reviewed
- Presents key factors indentified that most strongly affect Infiltration BMP performance

CURRENT TAHOE BASIN PRACTICES

Current Tahoe Basin regulations require containment and treatment of the storm water runoff volume generated by a 20-year return period, 1-hour duration "design storm" from impervious surfaces. The calculation of runoff volume is made by multiplying the intensity of the 20-year 1-hour design storm (generally taken as one inch of precipitation in one hour) by the contributing impervious surface area. The 20-year 1-hour design standard is the primary regulatory requirement influencing the design of Infiltration BMPs in the Tahoe Basin. Additional regulatory requirements pertaining to the quality of infiltrated stormwater and separation from seasonally high groundwater are also in place, but these regulations primarily influence the siting of Infiltration BMPs and are addressed in other sections of this report.

Adherence to the 20-year 1-hour design standard is a regulatory requirement for all private and public parcels, as well as public right-of-ways. On private and public parcels, the 20-year 1-hour design standard is commonly met by constructing Infiltration BMPs to contain and infiltrate stormwater runoff. For public water quality improvement projects (WQIPs) targeting retrofit of public right-of-ways, improvements are typically designed using a "best practicable" approach that is nearly always affected by site or funding constraints. Public WQIPs may install Infiltration BMPs dependent upon project-specific opportunities and constraints for siting and maintaining the improvements.

Maintenance of Infiltration BMPs is a requirement in the Tahoe Basin. However, this requirement is rarely enforced and current guidance for appropriate maintenance practices and frequencies is very general. For example, TRPA's current Code of Ordinances requires that "BMPs shall be maintained to ensure their continued effectiveness" (Section 25.8). In addition, it appears that maintenance actions to restore infiltration performance of many BMP types (infiltration features, dry basins, and biofilters) are rarely implemented. A synthesis of 18 independent stormwater BMP effectiveness evaluations conducted in Tahoe Basin indicated many researchers noted effectiveness assessments were limited because the BMPs were not maintained to perform at acceptable conditions during the duration of evaluations (2NDNATURE 2006B).

Current Tahoe Basin BMP manuals (e.g., TRPA BMP Handbook, NDEP BMP Handbook) provide general guidance for designing and maintaining Infiltration BMPs, and were developed primarily from review and distillation of information from national literature sources. A review of national literature sources shows a lack of reliable short- and long-term performance monitoring data for infiltration BMPs. This lack of data is a constraint in development of comprehensive guidance for Infiltration BMPs, especially for appropriate maintenance practices.

ASSESSMENT OF TAHOE BASIN 20-YEAR 1-HOUR DESIGN STANDARD

The 20-year 1-hour storm design standard was assessed to estimate the average performance of Infiltration BMPs in Tahoe Basin for reducing stormwater runoff volumes relative to the standards of national practice. Figure 6.1 displays modeled output from the Pollutant Load Reduction Model (PLRM; nhc et al. 2009) demonstrating the performance of an Infiltration BMP for different design capacities at several study locations in the Tahoe Basin. Critical points for interpreting Figure 6.1 include:

- Performance results on the Y-axis are shown as the percentage of average annual surface runoff that an Infiltration BMP retains and infiltrates at a specific storage capacity.
    - Average annual results are summarized from an 18-year continuous simulation in PLRM.
    - The computations were made assuming an Infiltration BMP with a constant infiltration rate of 0.5 inches/hour over the 18-year continuous simulation.
    - The pervious infiltration area is 4.2% of the tributary impervious area, which is a standard assumption for the Infiltration Facility algorithm in PLRM.
- The results demonstrate variable performance by location in the Tahoe Basin for an Infiltration BMP with the same storage capacity and infiltration rate. The performance variability is caused by meteorologic variability (e.g., West Shore is wetter than the East Shore).
- The incremental performance benefit of increasing the storage capacity of an Infiltration BMP markedly declines for storage capacities larger than the current 20-year 1-hour design standard. For example, doubling storage capacity from 1-inch of precipitation to 2-inches increases average annual retention and infiltration by roughly 7% for the Tahoe Basin Average for the assumptions above.

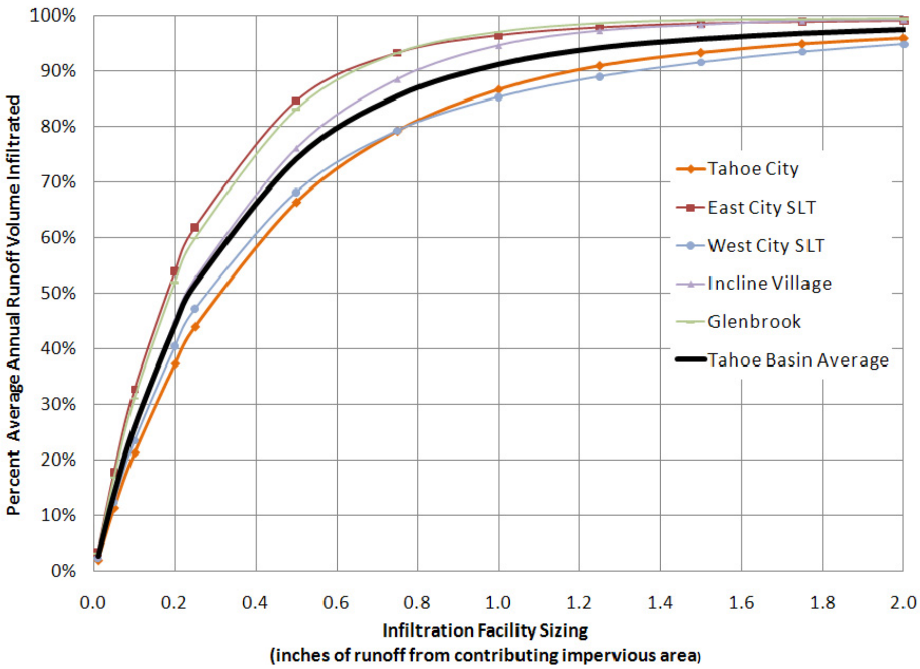


Figure 6.1. Infiltration facility performance varying by storage size and location

The most notable finding from the modeling analysis is that, for the assumptions above, the current 20-year 1-hour design standard retains and infiltrates roughly 90% of the annual stormwater runoff volume (see Tahoe Basin Average in Figure 6.1). This performance estimate is at the upper-end of typical standards for national practice for design of stormwater treatment facilities, which target capture and treatment of 80-90% of the average annual runoff volume (Roesner et al. 1998; Urbonas and Stahre 1993). Based on the results of the modeling analysis, the 20-year 1-hour design standard appears to be adequate, and further scrutiny of this standard as part of this research project is not recommended. The primary caveat regarding the results shown in Figure 6.1 is that the modeling analysis assumes an Infiltration BMP functions as designed throughout the entire time period simulated (which is 18 years). Based on the results of the national literature search and the observations of Tahoe Basin practitioners (as summarized below), this assumption may not be valid because a lack of maintenance was identified as a key factor contributing to poor Infiltration BMP performance.

INFORMATION SOURCES REVIEWED

A literature review was conducted to supplement our existing knowledge of the key factors affecting Infiltration BMP performance consisting of a reconnaissance level search of readily available information. This approach was taken to efficiently focus subsequent tasks of the project towards production of better design and maintenance criteria for Tahoe Basin Infiltration BMPs. Table 6.1 lists the primary sources of data and information reviewed from national sources, which consisted mostly of design manuals from cold climate regions within the United States with detailed Infiltration BMP guidance and design criteria. Within the Tahoe Basin, anecdotal information on Infiltration BMP performance was assessed through informal interviews with Tahoe Basin Resource Conservation District staff.

Table 6.1. Primary sources of information reviewed

TITLE	SOURCE	YEAR
Stormwater BMP Design Supplement for Cold Climates	US EPA	1997
The Use of BMPs in Urban Watersheds	US EPA	2004
Urban Storm Drainage Criteria Manual Volume 3 – BMPs	Denver Urban Drainage and Flood Control District	2010
Stormwater Management Manual for Eastern Washington	Washington State Department of Ecology	2004
Surface Water Management Manual	City of Tacoma, WA	2008
Iowa Stormwater Management Manual Version 3	Iowa State University	2009
National Pollutant Discharge Elimination System (NPDES) – Infiltration Basin	US EPA	2006
Storm Water Management for Maine Volume III - BMPs Technical Design Manual	Maine Department of Environmental Protection	2006
Designed to Fail Why Most Commonly Used Designs Will Fail and How to Fix Them	Comprehensive Environmental Inc.	2003
International Stormwater BMP Database – Technical Summary: Volume Reduction	International Stormwater BMP Database	2011
Pennsylvania Stormwater BMP Manual	Pennsylvania Department of Environmental Protection	2006
BMP Performance Criteria and Guidance for MCWD Rule N	Minnehaha Creek Watershed District	2003
Maintenance of Stormwater BMPs	Journal for Surface Water Quality Professionals – Stormwater	2008
Modifications on the Existing Design Parameters to Improve the Performance of Infiltration BMPs in Cold Climates	Washington State University	2008

KEY FACTORS IDENTIFIED

A number of key factors affecting Infiltration BMP performance were consistently identified among the various information sources reviewed. The most significant factors are listed below. Factors that were not consistently designated as significant were screened from the analysis and for brevity are not discussed below. All factors considered significant by Tahoe Basin practitioners are included below.

Siting and Design Issues

1. High sediment loads in stormwater runoff are not addressed, leading to frequent clogging.
    a. Incorrect selection of the type of Infiltration BMP, and/or inadequate siting and design within a drainage with heavy sediment and debris loads
    b. Lack of pretreatment system, or an inadequate pretreatment design
    c. Lack of adequate pollutant source controls upstream of Infiltration BMP
2. Inadequate site assessments lead to a less effective design.
    a. Installation in soils with lower actual K_{sat} than assumed in design
    b. Installation in areas with high seasonal groundwater resulting in lower than expected annual infiltrated runoff volumes
    c. Failure to identify a shallow restrictive subsurface layer that impedes infiltration
3. General design and installation flaws
    a. Runoff from the targeted impervious areas does not drain to the inlet of the Infiltration BMP.
    b. Soils compacted during construction are not rehabilitated before Infiltration BMP installation.

Maintenance Issues

1. Inspection and maintenance plan is not followed, funded, or was never developed.
2. Maintenance actions are poorly defined and not prescriptive enough to facilitate agreement or understanding as to what actions are implemented.
3. Lack of condition assessments to determine when maintenance should be performed due to declined performance beyond acceptable range
4. Unrealistic inspection and maintenance plan, resulting in only partial or minimal compliance
    a. Frequency of maintenance tasks overly burdensome or not linked to the condition of the Infiltration BMP
    b. Maintenance activities difficult to complete with available resources
5. Lack of maintenance access
    a. Maintenance locations difficult for equipment to reach
    b. Confined space entry tasks requiring personnel with special certifications and requiring special insurance requirements

Cold Climate Considerations

1. Frozen soils or inlets blocked by ice causing ineffective winter performance
2. Use of Infiltration BMPs as snow storage areas reduces performance
    a. Snow plowing equipment damages facility
    b. Piled snow blocks inlets, compacts soils within the infiltration area , and/or pollutants in snow clog the infiltration area

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