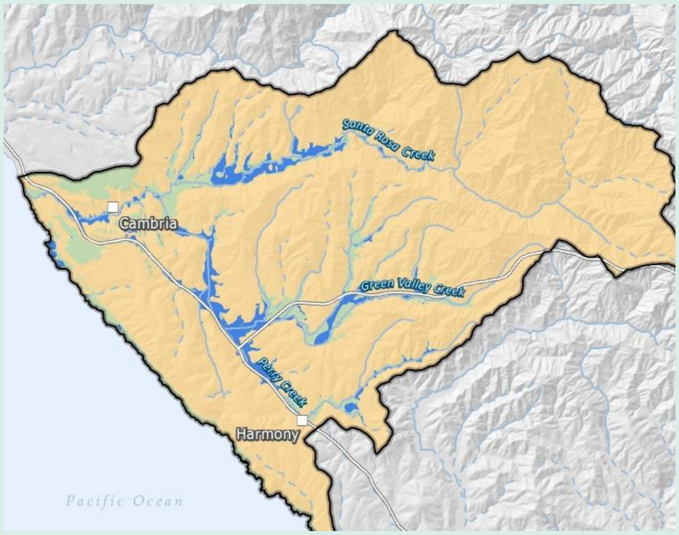
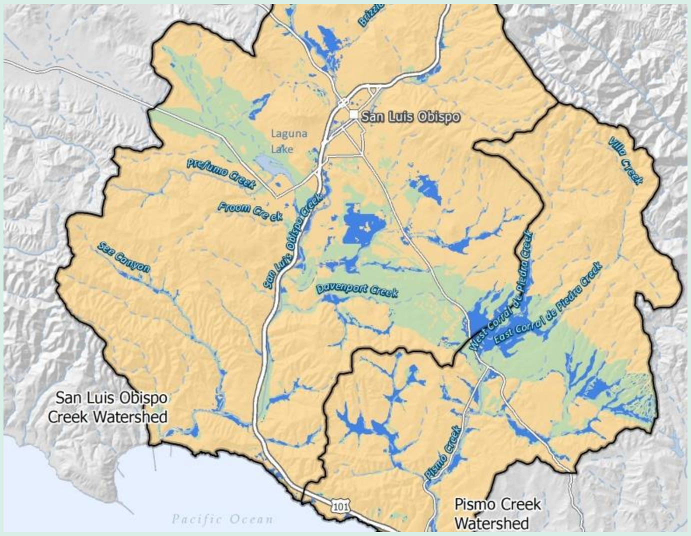
AMENDED FINAL TECHNICAL MEMORANDUM ◦ SEPTEMBER 2015

Percolation Zone Study of Pilot-Study Groundwater Basins in San Luis Obispo County, California





PREPARED FOR

Upper Salinas-Las Tablas RCD
65 South Main Street, Suite 107
Templeton, CA 93465

PREPARED BY

Stillwater Sciences
895 Napa Ave., Suite B-4
Morro Bay, CA 93442

Stillwater Sciences

Report Prepared by:

Glen Leverich, M.S., P.G.
Senior Geomorphologist
Stillwater Sciences
glen@stillwatersci.com

Ethan Bell, M.S.
Senior Fisheries Biologist
Stillwater Sciences
ethan@stillwatersci.com

Derek Booth, Ph.D., P.E., P.G.
Senior Geologist
Stillwater Sciences
dbooth@stillwatersci.com

Cover graphics:

Upper left: Map depicting the predicted relative potential of intrinsic percolation in the Santa Rosa Creek watershed (map by Stillwater Sciences).

Top right: Oblique aerial view of lower Santa Rosa Creek watershed near the town of Cambria and the confluence of the mainstem creek and Perry Creek (photo taken 7/27/2009 by Stillwater Sciences).

Bottom left: Ground view of spring baseflow in upper San Luis Obispo Creek near the city of San Luis Obispo (photo taken 4/17/2015 by Stillwater Sciences).

Bottom right: Map depicting the predicted relative potential of intrinsic percolation in the San Luis Obispo Creek and Pismo Creek watersheds (map by Stillwater Sciences).

Suggested citation:

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1 INTRODUCTION

In support of the joint effort by Upper Salinas-Las Tablas Resource Conservation District and Coastal San Luis Resource Conservation District (RCDs) in identifying opportunities for enhancing conservation of water resources, Stillwater Sciences presents here a summary of findings from our evaluation of percolation zones in two focus groundwater basins in San Luis Obispo County, California.

1.1 Study Background

The purpose of this project study was to fill a key data gap within the San Luis Obispo County Integrated Regional Water Management (IRWM) Plan: to locate areas with relatively high intrinsic percolation potential that, through management actions, could enhance local groundwater supplies for human and ecological benefits. The RCDs partnered to focus this resulting study on two pilot-study groundwater basins, identified by the California Department of Water Resources (CDWR) as the “Santa Rosa Valley” and “San Luis Obispo Valley” groundwater basins. Both basins host a mix of land-use types in their unique settings, while continuing to support important fish and wildlife habitats. Balancing resource needs for these often-conflicting interests thus requires a holistic, yet economical, approach to identify and prioritize management strategies aimed at resource conservation and enhancement, which was at the center of this project study. The results presented herein represent spatially explicit baseline information of intrinsic percolation potential intended to aid subsequent evaluations and prioritization of site-scale opportunities.

Groundwater recharge, or deep percolation, is defined as the downward movement of water reaching the water table within an aquifer (e.g., Freeze and Cherry 1979). Typically, recharge occurs via a diffusive process whereby precipitation distributed over a large area infiltrates the subsurface and percolates through the unsaturated zone to the water table, but can also occur via focused processes, such as seepage of water from surface-water bodies and channels (Healy 2010). Groundwater can then be discharged back to the surface in water bodies and stream channels, which, for the latter, serves as a principal source of baseflow during the drier seasons.

Groundwater withdrawals account for a substantial proportion of the county’s water supply for numerous land uses, most substantially for irrigation and public supply, which represented about 83% and 12%, respectively, of all groundwater use in recent years (Maupin et al. 2014). Given that water supply and streamflow are intrinsically linked with groundwater storage in the county’s shallow, unconfined aquifers, effective groundwater management is of paramount concern throughout the county, particularly during prolonged periods of drought like experienced in recent years. An informed understanding of the balance of natural groundwater recharge (i.e., aquifer input) and human consumption (e.g., aquifer depletion) is therefore necessary. Yet, quantification of recharge is poorly understood throughout much of the county, largely because of the inherent complexity in natural recharge processes and inconsistently reported human uses, thus requiring comprehensive monitoring often deemed infeasible for most water-use managers.

This study entailed compilation of numerous information sources to identify percolation-zone potential in the two basins. In conducting the evaluation, we made use of four recent studies:

- San Luis Obispo County Regional Instream Flow Assessment (Stillwater Sciences 2014).
- Hydromodification Control in the Central Coast Region of California (Booth et al. 2012).

- Santa Rosa Creek Watershed Management Plan (Stillwater Sciences et al. 2012).
- Pismo Creek Instream Flows Study (Stillwater Sciences et al. *In progress*).

1.2 Study Basins

The two study basins assessed in this study were: (1) the Santa Rosa Valley groundwater basin, and (2) the San Luis Obispo Valley groundwater basin. The geographic scope of the evaluation was expanded beyond their boundaries so as to include the entire surface-water catchments contributing to these two groundwater basins.

The Santa Rosa Valley groundwater basin is situated along the narrow, alluvial valleys traversed by Santa Rosa Creek and its two major tributaries, Perry and Green Valley creeks, near the town of Cambria (Figures 1 and 2). The San Luis Obispo Valley groundwater basin underlies the San Luis Obispo and Edna valleys, and transversely spans the upper reaches of San Luis Obispo and Pismo creeks near the city of San Luis Obispo (Figures 3 and 4).

Surface and groundwater resources have been previously studied in both basins, as documented in CDWR's Bulletin 118 on groundwater basins throughout the state (CDWR 2003, CDWR 2004a, 2004b). Two of the most useful publications on hydrogeological conditions in the basins were based on studies conducted in the early 1990s: a USGS study in Santa Rosa Valley groundwater basin (jointly with neighboring San Simeon Valley groundwater basin) (Yates and Van Konyenburg 1998); and a City of San Luis Obispo study in San Luis Obispo Valley groundwater basin (Boyle 1991, as cited in CDWR 2004b).

The Santa Rosa Valley groundwater basin and its contributing watershed receive between 20 and 40 inches of rainfall annually. Groundwater is recharged into the unconfined, ~100-ft-thick aquifer primarily from percolation of streamflow, but also infiltration of precipitation and excess irrigation flow (Yates and Van Konyenburg 1998, CDWR 2004a). The 1998 USGS study found the basin to be in slight overdraft by about 50 acre-feet per year (AFY), due to over-pumping for irrigation (agriculture) and municipal (town of Cambria) water uses. This demand is greatest in the summer and, coupled with seasonally decreased seepage from streamflow, can result in lowering the water table by about 10 to 30 feet below its normal depth of 10 to 20 feet below ground surface (Yates and Van Konyenburg 1998). The majority of the municipal water supply for Cambria currently comes from the adjacent San Simeon Valley groundwater basin (CCSD 2008). Wastewater is treated in Cambria, but exported to percolation ponds in lower San Simeon Creek watershed (CCSD 2008). An emergency brackish-water supply project (i.e., desalination) was recently constructed in the San Simeon Creek watershed to supplement Cambria's water supply.

The San Luis Obispo Valley groundwater basin and its contributing watershed receive less annual precipitation than does Santa Rosa Creek, ranging between 19 and 23 inches (CDWR 2004b). Groundwater is relatively shallow in this 50- to 100-ft-thick unconfined aquifer (Boyle 1991, as cited in CDWR 2004b). Groundwater levels reported from a well in Edna Valley near Pismo Creek have fluctuated between 5 and 80 feet below ground surface between 1958 and 1983 (Well: USGS 351258120364501 031S013E19H001M). Another well in Edna Valley exhibited a decline from 19 to 46 feet below ground surface since 2012 as a result of the recent drought conditions (Well: CDWR CASGEM 352001N1206071W001). Groundwater in the basin is recharged primarily by infiltration of precipitation on the valley, applied irrigation water, and streamflow (Boyle 1991, as cited in CDWR 2004b). A sizeable portion of the San Luis Obispo

Valley supporting urban developments with impervious surfaces currently inhibits deeper percolation (see land cover maps below). This basin is also considered to be in overdraft[1] due to over-pumping by agricultural, municipal, and industrial extractions. Municipal water supply for San Luis Obispo comes from both water imported from neighboring watersheds to the north and its water reclamation facility (SLOCFCWCD 2012). Treated wastewater generated by the City of San Luis Obispo is discharged into San Luis Obispo Creek, and is used to irrigate various sites, including parks, schools, sports fields, and commercial centers. The City continues to explore other approved uses and potential users of recycled water.

Channel incision, with attendant lowering of historic water-table levels, is also a ubiquitous characteristic in the study watersheds (TLCSLOC 1996, Stillwater et al. 2012). For example, intentional straightening and deepening of lower Perry Creek, the largest tributary to Santa Rosa Creek, in the 1870s (referred to as "Walker Ditch") permanently drained a seasonal lake, or "Estrada Laguna" as historically noted on the original rancho map (see Santa Rosa Creek Watershed Management Plan [Stillwater Sciences et al. 2012]). The man-made channel is now actively incising, as are other stream reaches in the study watersheds.

The study watersheds also support important habitat for native fish and wildlife, including the federally threatened South-Central California Coast steelhead (*Oncorhynchus mykiss)* (Stillwater Sciences et al. 2012, Stillwater Sciences 2014).

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[1] CDWR considers a groundwater basin to be in a state of "overdraft" when groundwater extraction has exceeded natural recharge causing groundwater levels to decline over a period of years and never fully recovers, even in wet years (CDWR 2003). Overdraft can lead to other adverse effects, including increased pumping costs, well failure, land subsidence, water quality degradation, and other environmental impacts.

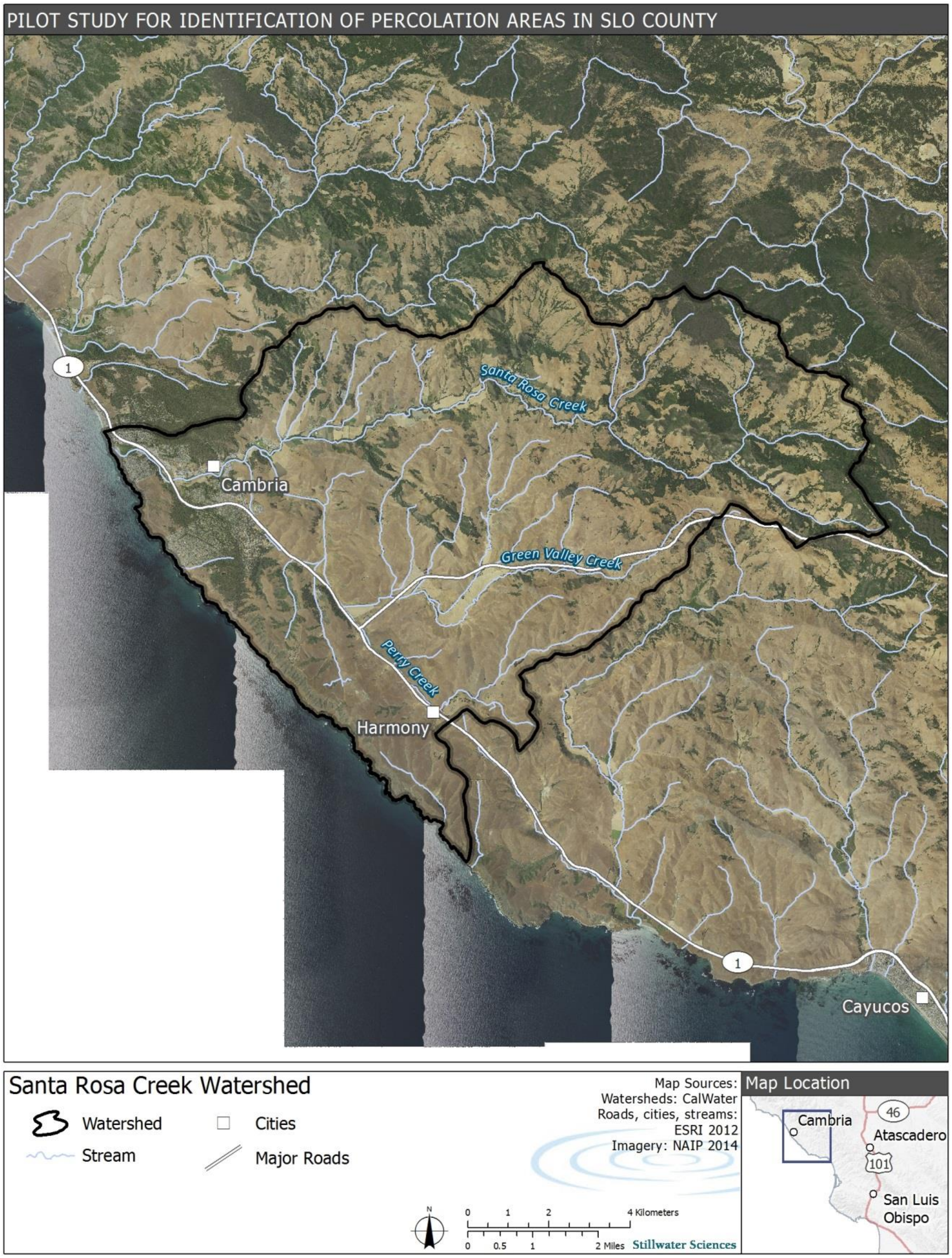


Figure 1. Base map of the Santa Rosa Creek watershed in San Luis Obispo County, California.

Figure 2. Hydrography, wells, and hydrologic monitoring stations in the Santa Rosa Creek watershed.

Figure 3. Base map of the San Luis Obispo Creek and Pismo Creek watersheds in San Luis Obispo County, California.

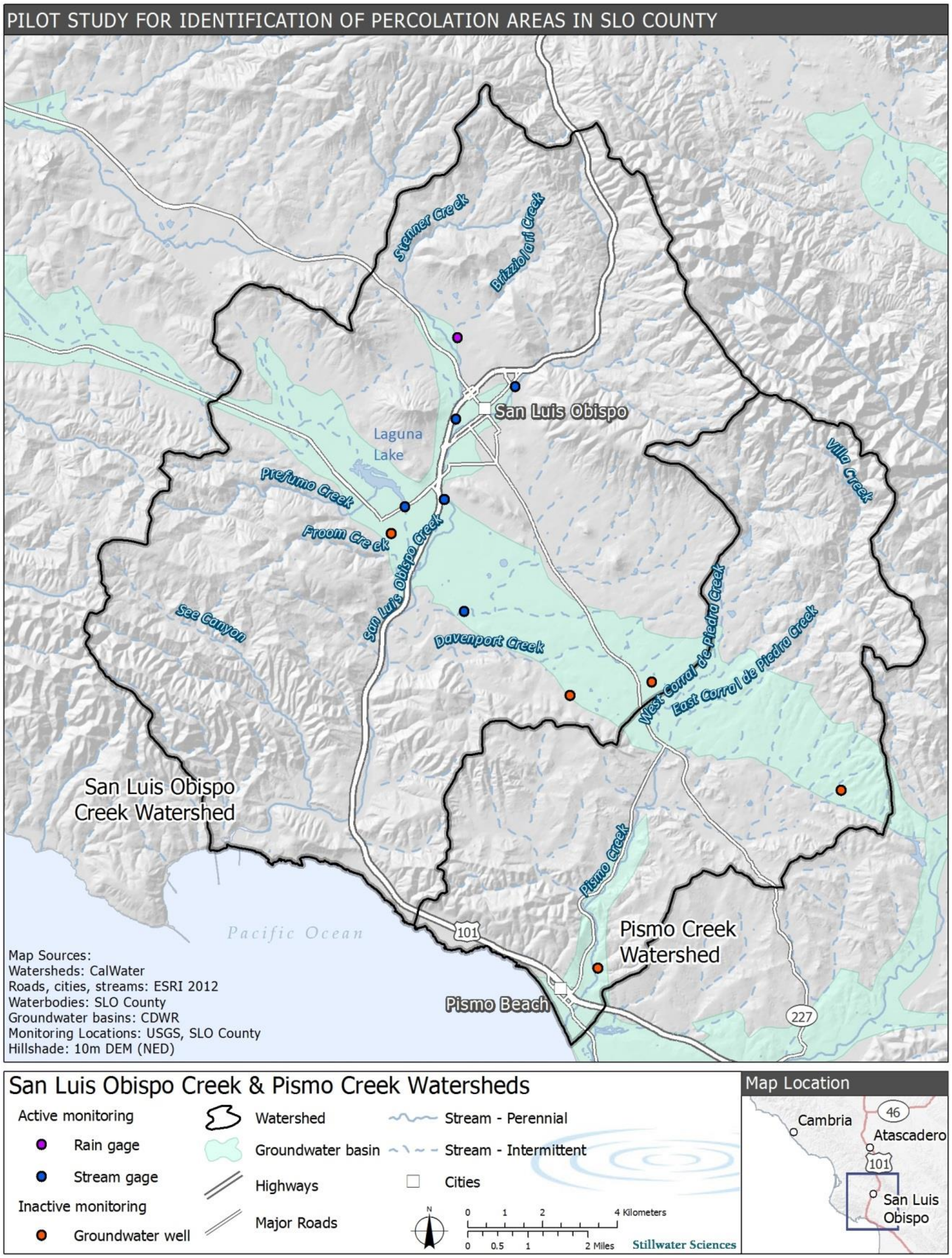


Figure 4. Hydrography, wells, and hydrologic monitoring stations in the San Luis Obispo Creek and Pismo Creek watersheds.

2 EVALUATION

Available information on hydrogeological conditions in the study basins was initially reviewed to begin the process of identifying spatial distributions of intrinsic percolation zones overlying an alluvial aquifer. Groundwater recharge is derived from deep percolation of precipitation, irrigation, and impounded surface waters. Key reviewed information included topography, hydrology (climate, surface water, and groundwater), geology, soils, vegetation, and land use.

The most obvious identified data source was CDWR's groundwater basin maps (see Figures 2 and 4), published for the entire state. However, there are two limitations with using this data source in this study. The first is that the purpose of the state's maps was to delineate groundwater basins, and not necessarily areas with intrinsic percolation potential at the ground surface. So, for example, urban developments with impervious surfaces are not part of the mapping criteria of the state's groundwater maps, but they do need to be considered when evaluating percolation potential. The second limitation is the regional scale of the state maps, which is too coarse for land-use planning at the much finer scale of a typical property parcel. The spatial extents of the 431 state-mapped groundwater basins were based on presence and areal extent of unconsolidated, alluvial sediments identified on 1:250,000 scale geologic maps (Appendix G in CDWR 2003). This coarseness reflects uncertainty of at least several hundred feet on the ground, which results in inescapable inaccuracies of the state's groundwater basin boundaries in the study watersheds when viewed at a finer scale. Besides matters of spatial precision relating to scale, there are also likely some outright errors in this representation, such as exclusion of tributary valleys and overly generous inclusion of obvious upland areas (see Figures 2 and 4).

We therefore developed and applied a repeatable, spatially explicit methodology to delineate the distribution of relative percolation potential within the study basins at a scale better suited to land-use planning application. We accomplished this by developing an intrinsic percolation (or groundwater recharge potential) map based on topography (slope), geology (mapped lithologic units), soils (hydrologic soil groups), and landcover (surface perviousness). The weighted combination of these determinants formed percolation landscape units, or "PLUs," that we subsequently used to identify areas with relative percolation potential across the entirety of the study watersheds. This methodology is consistent with the work by other researchers attempting to assess regional suitability for managed aquifer recharge (MAR), including the recent work by Russo et al. (2015) who also utilized spatial datasets characterizing topographic slope, surficial geology, soil infiltration capacity, and land use for their study in the Pajaro Valley groundwater basin in Santa Cruz and Monterey counties. Their study additionally quantified the relative effects of MAR activities on groundwater levels and sea-water intrusion, both principal concerns of water-supply managers in the Pajaro Valley.

2.1 Determinants of Intrinsic Percolation Potential

The following describes the environmental determinants considered to influence potential for intrinsic percolation in the study basins. The selected environmental factors were compiled in a Geographical Information System (GIS, ESRI® ArcGIS: ArcMap version 10.3) to enable discretization and ranking of their major attributes influencing groundwater recharge. Figures 5 through 12 display generalized slope, geology, soils, and landcover classes based on the classifications described below.

2.1.1 Topography

Classification of topography (slope) was based on the degree to which landscape slopes were considered to promote (e.g., low-lying valley floor) or inhibit (e.g., steep uplands) precipitation and runoff infiltration via overland flow and surface-water retention (Figures 5 and 6). Data were derived from the U.S. Geological Survey's National Elevation Dataset at 10-meter resolution (USGS 2015a). Discrete slope classes were classified based on those previously selected as part of our Central Coast Hydromodification study (Booth et al. 2012).

- 0–10%: low-lying lands, presumed to have least runoff potential and greatest infiltration potential based on slope alone.
- 10–40%: moderately sloping lands, with moderate runoff potential and moderate infiltration potential.
- >40%: steep lands, with greatest runoff potential and least infiltration potential.

2.1.2 Geology

Classification of geology was based on areal extent of mapped geologic deposits considered to influence percolation to relatively deep (i.e., 10s to 100s of feet) aquifers, recognizing that at least shallow infiltration of rainfall into the soil is inferred to be widespread on virtually any geologic material on all but the steepest slopes (or bare rock) (Figures 7 and 8). Polygon-based data were derived from the county-wide geologic map (SLOCPBD 2007) compiled by SLO County using original mapping of geologic units in the study basins by Durham (1968), Hall (1973a,b, 1974, 1976), Hall and Prior (1975), Dibblee (1971, 1972, 1974, 1999), Hall et al. (1979), Seiders (1982), McLean (1994, 1995). The scale of the compiled map is approximately 1:24,000, which is considerably more detailed than the state-wide 1:250,000 scale maps. Mapped lithologic units were divided into two categories based on their inferred ability to enable infiltration and host an unconfined aquifer that could store groundwater and support baseflow in streams or be readily accessible for human use.

- Alluvium (Quaternary-aged alluvial lithologic units): includes the following lithologic units that are assumed to enable infiltration and host an alluvial aquifer (unit-naming convention is based on that used in the source data compiled by SLO County): stream channel and terrace deposits, and valley alluvium (Qa, Qds, Qhc, Qt) and older alluvium (Qnm, Qoa, Qot). A few Quaternary-age units, such as artificial fill, landslide deposits, and beach sands, were excluded based on the assumption that these units' composition, location, and/or placement upon impermeable lithologic units or constructed barriers would hinder infiltration.
- Non-Alluvium: includes all other lithologic units contained in the source dataset that are assumed to hinder infiltration and/or does not host an alluvial aquifer.

2.1.3 Soils

Classification of soils was based on areal extent of mapped hydrologic soil classes (A, B, C, or D) considered to influence shallow percolation (Figures 9 and 10). The soil classes were used to further discriminate areas having high surface infiltration potential (e.g., gravelly or sandy loam) from those areas with low surface infiltration potential (e.g., clay). Polygon-based data were derived from the nationwide soils map published by the NRCS in their SSURGO Soils Database (NRCS 2007). The precise scale of mapped areas in the study watersheds is unknown, but can be assumed to be approximately 1:12,000 based on general guidance provided by NRCS.

Soils are pre-grouped in the source dataset according to their runoff potential (see also NRCS 2015). The soil properties considered by the NRCS to influence this potential are those that affect the minimum rate of water infiltration on a bare soil during periods after prolonged wetting when the soil is not frozen. These properties include depth to a seasonal high water table, the infiltration rate, and depth to a layer that significantly restricts the downward movement of water. The land-surface slope and the kind of plant cover are not considered but are separate factors in predicting runoff.

- Group A: these soils have a high infiltration rate even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels. They have a high rate of water transmission.
- Group B: these soils have a moderate infiltration rate when thoroughly wetted. They chiefly are moderately deep to deep, moderately well drained to well drained soils that have moderately fine to moderately coarse textures. They have a moderate rate of water transmission.
- Group C: these soils have a slow infiltration rate when thoroughly wetted. They chiefly are moderately fine to fine texture, and commonly have a layer that impedes downward movement of water. They have a slow rate of water transmission.
- Group D: these soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have a high swelling potential, soils that have a permanent high water table, soils that have a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. The have a very slow rate of water transmission.
- N/A (manually reassigned to Group C): these unclassified soil polygons in the SSURGO dataset are not rated or not available. Upon review, there are several isolated occurrences, albeit small in extent, of polygons with this designation. The majority coincide with the geologic unit designated in the SLO County dataset as “unnamed greywacke and interbedded shale and sand.” This geologic unit is further described in the source datasets (e.g., Hall and Prior [1975]) and other accounts (e.g., Chipping [1987]) as Franciscan mélange, an old and impermeable bedrock unit, which appears to coincide with Hydrologic Groups C and D. The unclassified polygons also appear in areas devoid of dense vegetative cover, or land-cover class “herbaceous” as described in the landcover dataset (see below). The unclassified polygons also appear in areas classified in the 10–40% slope class (see above). As such, it is reasonable to treat these polygons as having a slow infiltration rate, or Hydrologic Group C.

2.1.4 Landcover

Classification of landcover was based on areal extent of mapped landcover types considered to promote (e.g., forested cover) or inhibit (e.g., impervious urban surfaces) the infiltration of precipitation into the subsurface and overland flow (Figures 11 and 12). Data were derived from the National Land Cover Database of 2011 at 30-meter pixel resolution published by the Multi-Resolution Land Characteristics Consortium (Homer et al. 2012). Mapped landcover types were grouped into two categories based on their ability to enable or hinder infiltration of direct precipitation and local overland flow.

- Pervious (high-permeability land surface): utilizes the following cover classes that are assumed to enable infiltration of direct precipitation: Barren Land, Cultivated Crops, Deciduous Forest, Developed (Open Space), Emergent Herbaceous Wetlands, Evergreen Forest, Hay/Pasture, Herbaceous, Mixed Forest, Open Water, Shrub/Scrub, and Woody

Wetlands. These classes represent rural, unpaved areas of the study basins where infiltration is possible. The class of Open Water was included as all occurrences in the study watersheds appear to be constructed ponds or reservoirs that act, though likely not intentionally, to recharge the shallow aquifer. The class of Woody Wetlands was also included as all occurrences in the study watersheds appear to be located within riparian zones bordering stream channels and impounded water bodies that together act to recharge the shallow aquifer.

- Impervious (Low-permeability land surface): utilizes the following cover classes that are assumed to impede infiltration of direct precipitation: Developed (High, Medium, and Low Intensity). The "developed" classes predominantly represent those moderately to extensively urbanized areas of the study basins and its developed surroundings where impervious surfaces are prevalent and, thus, recharge potential is limited. However, developed areas can be underlain by an aquifer that can be recharged from adjacent, undeveloped surfaces.

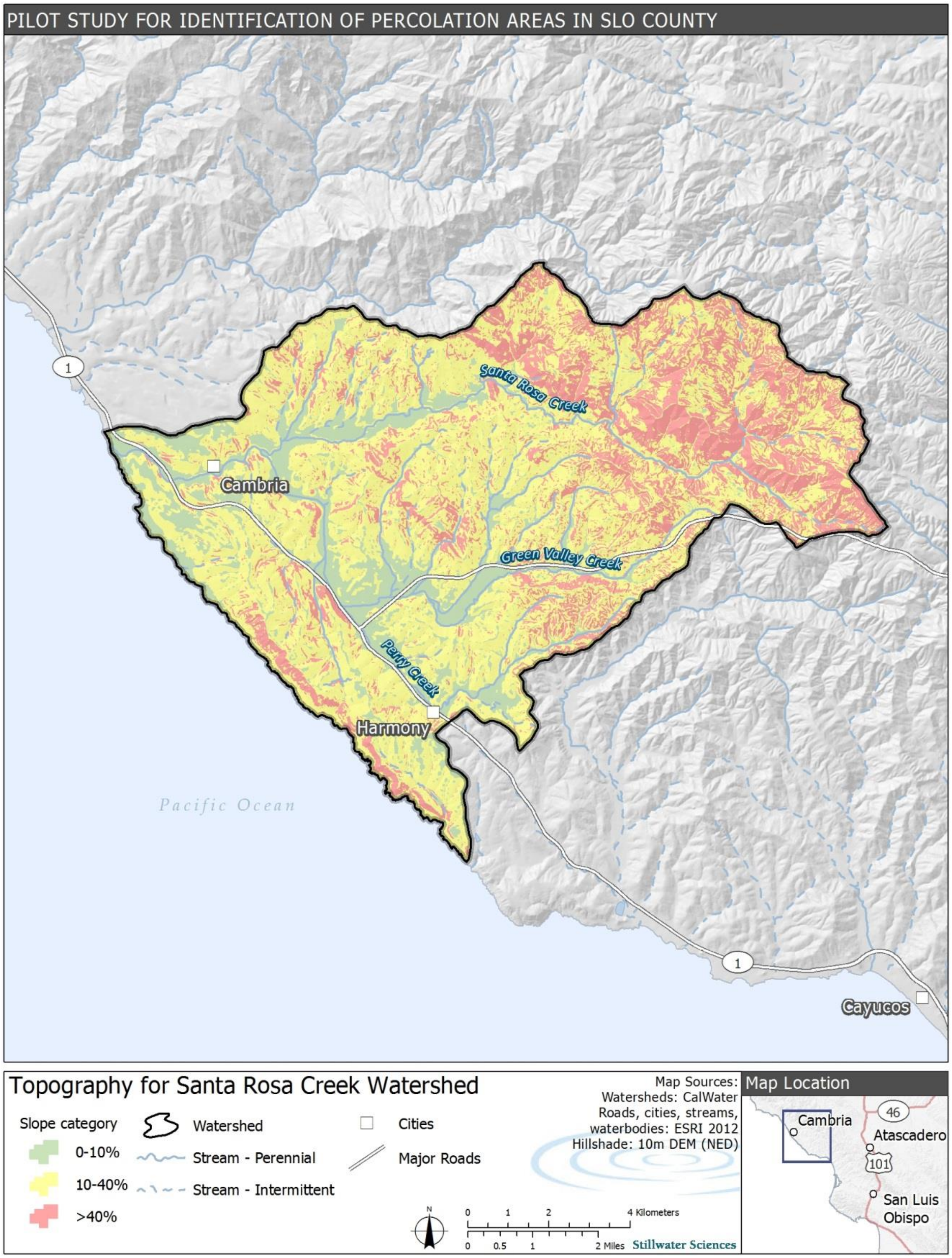


Figure 5. Generalized landscape slope classes used for the PLU analysis in the Santa Rosa Creek watershed.

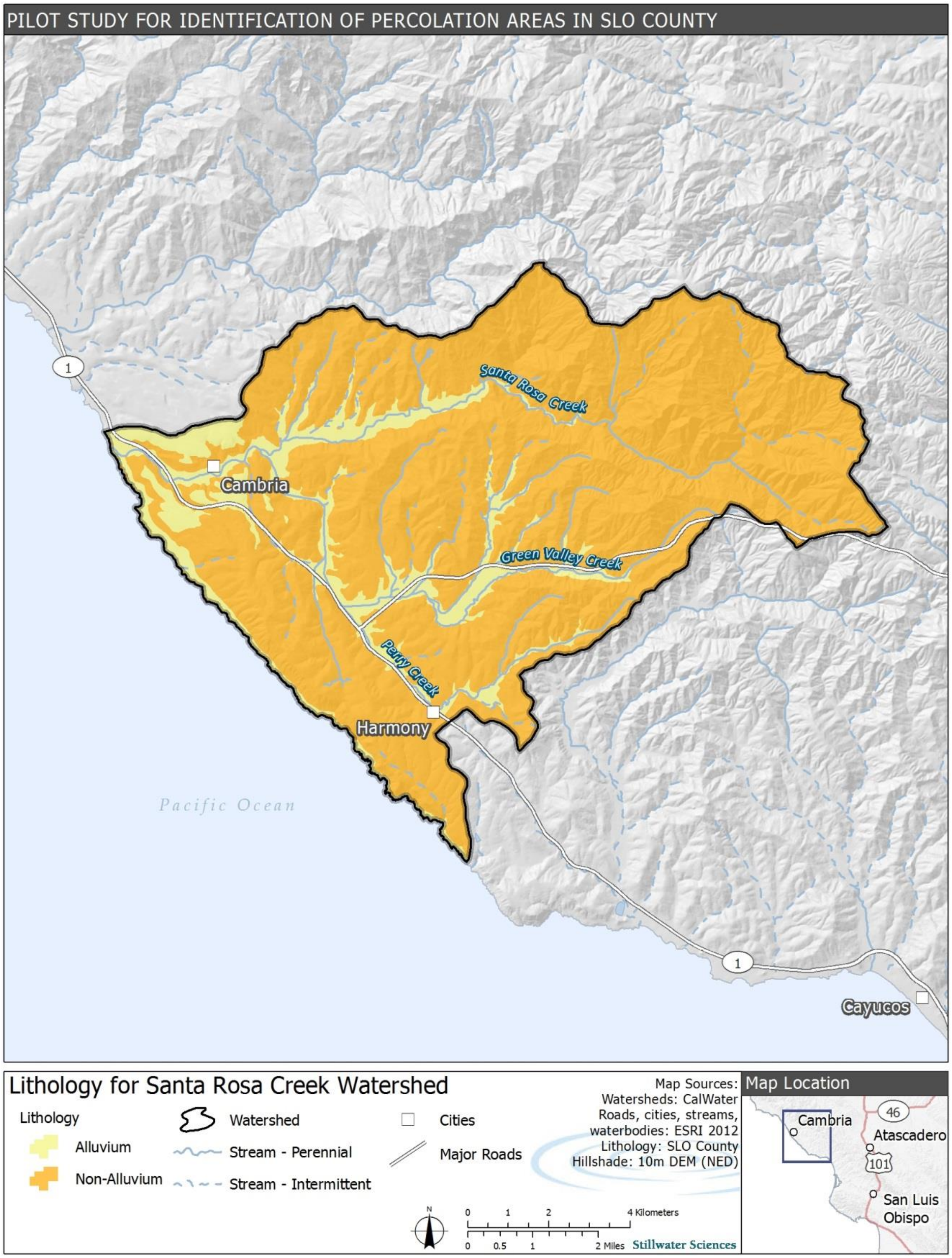


Figure 6. Generalized lithology classes used for the PLU analysis in the Santa Rosa Creek watershed.

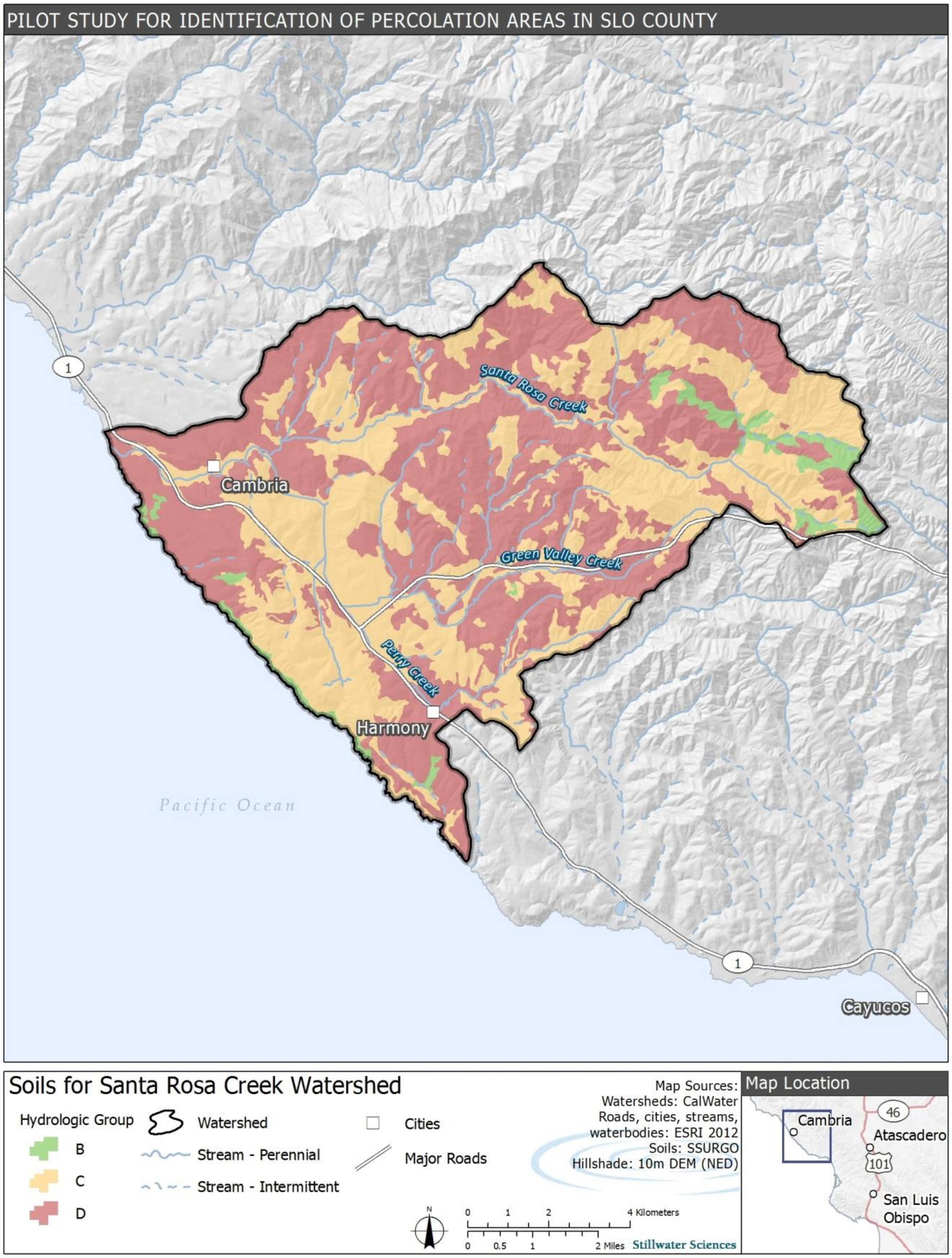


Figure 7. Generalized soil classes used for the PLU analysis in the Santa Rosa Creek watershed.

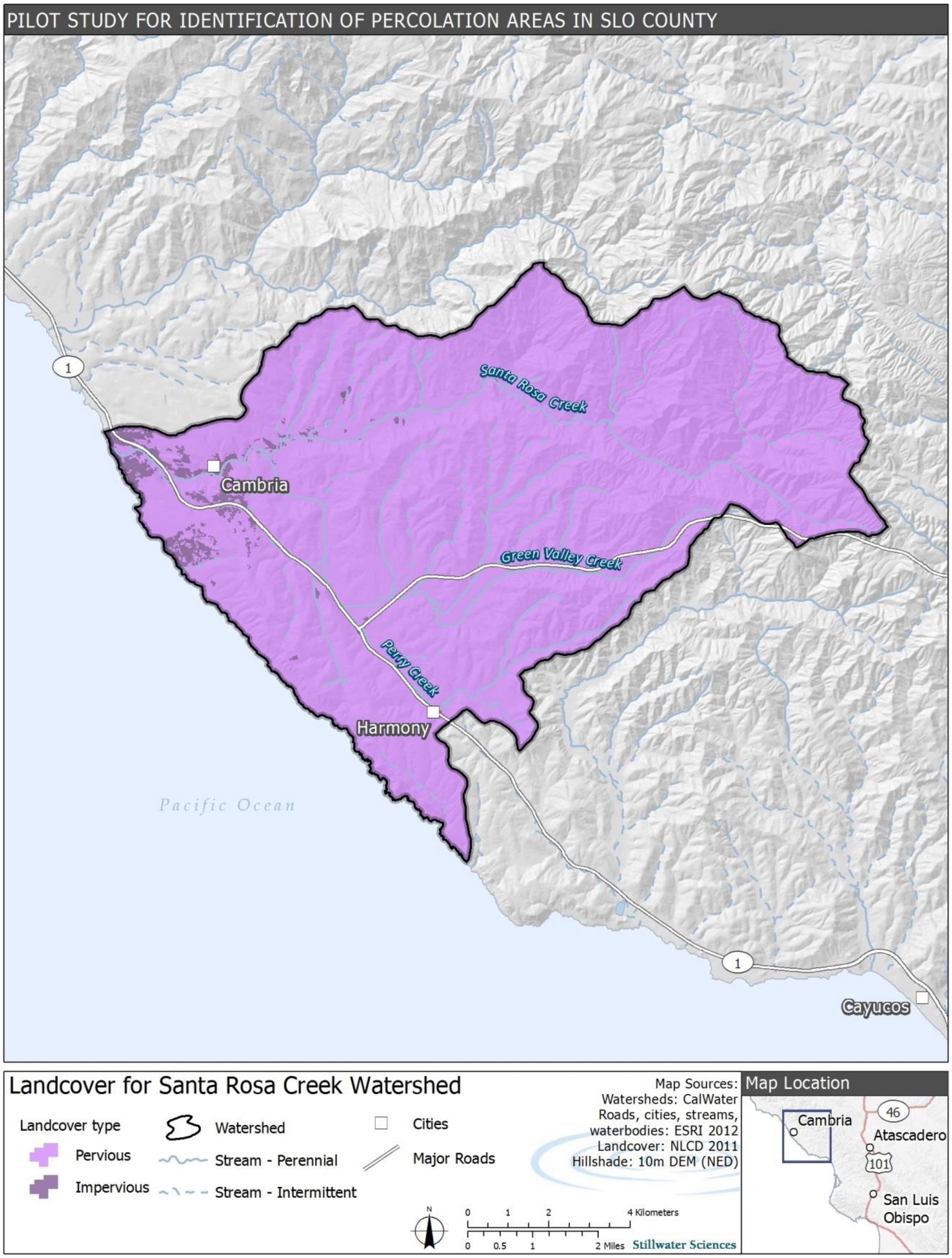
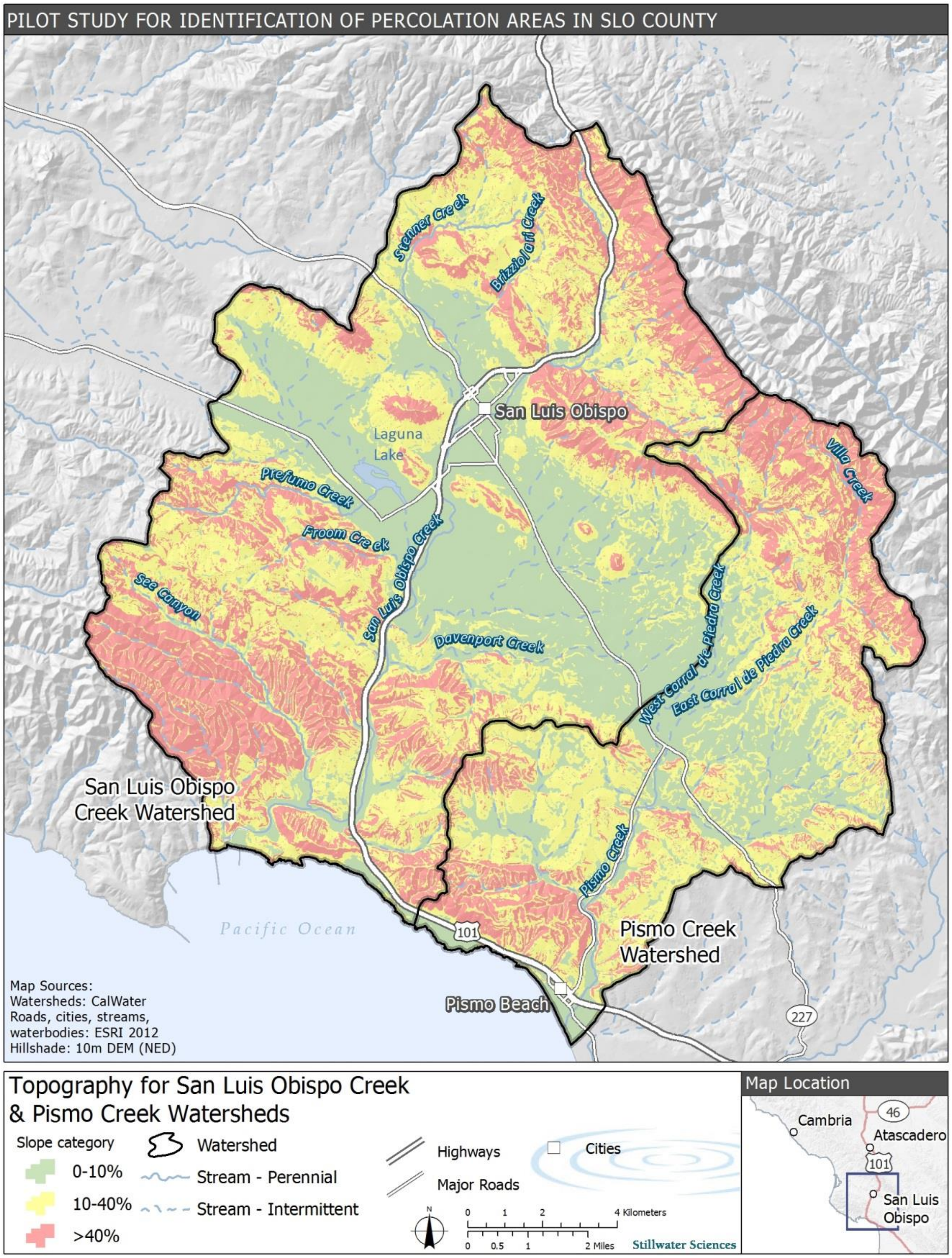
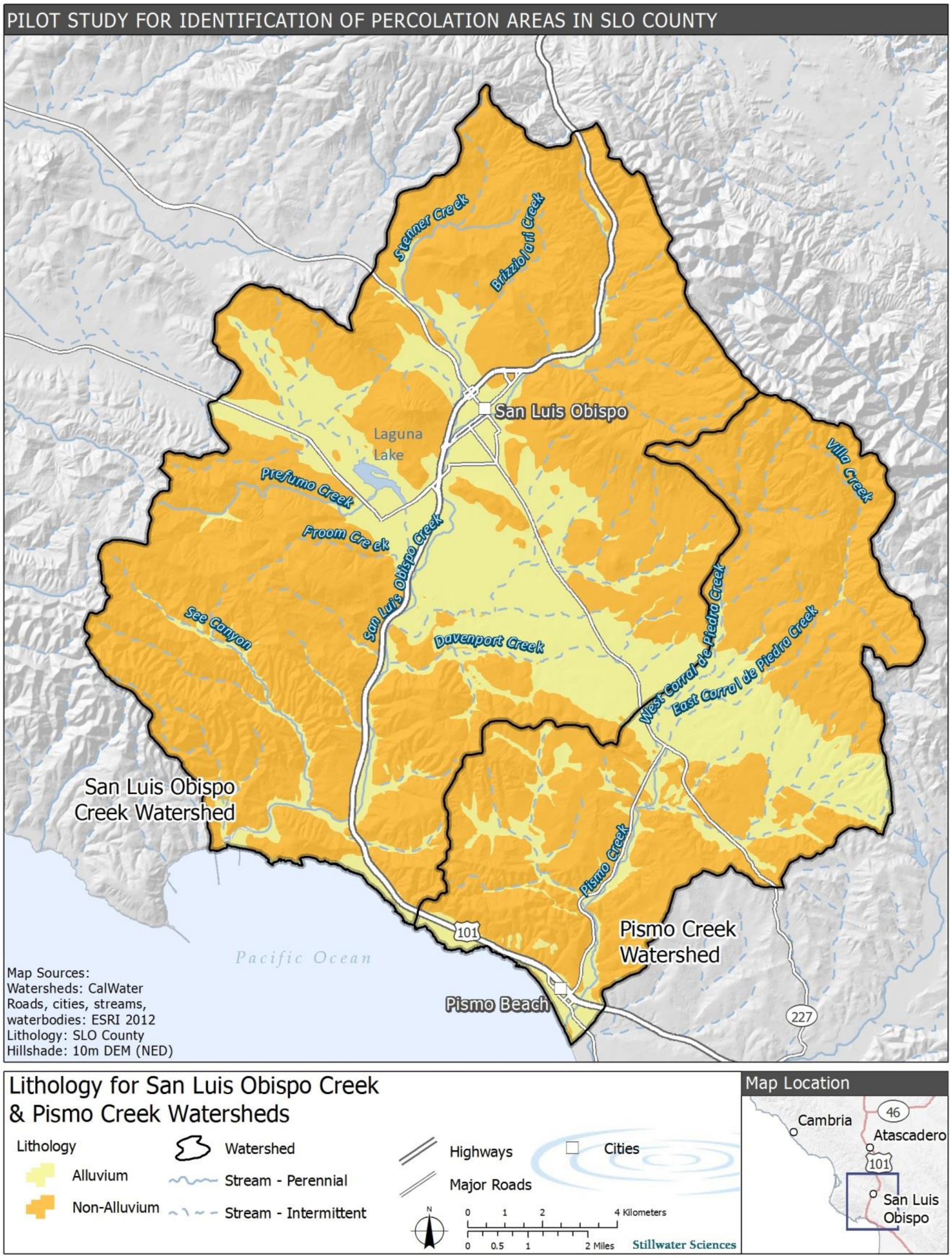


Figure 8. Generalized landcover classes used for the PLU analysis in the Santa Rosa Creek watershed.



Map Sources:
Watersheds: CalWater
Roads, cities, streams, waterbodies: ESRI 2012
Hillshade: 10m DEM (NED)

Figure 9. Generalized landscape slope classes used for the PLU analysis in the San Luis Obispo Creek and Pismo Creek watersheds.



Map Sources:
Watersheds: CalWater
Roads, cities, streams, waterbodies: ESRI 2012
Lithology: SLO County
Hillshade: 10m DEM (NED)

Figure 10. Generalized lithology classes used for the PLU analysis in the San Luis Obispo Creek and Pismo Creek watersheds.

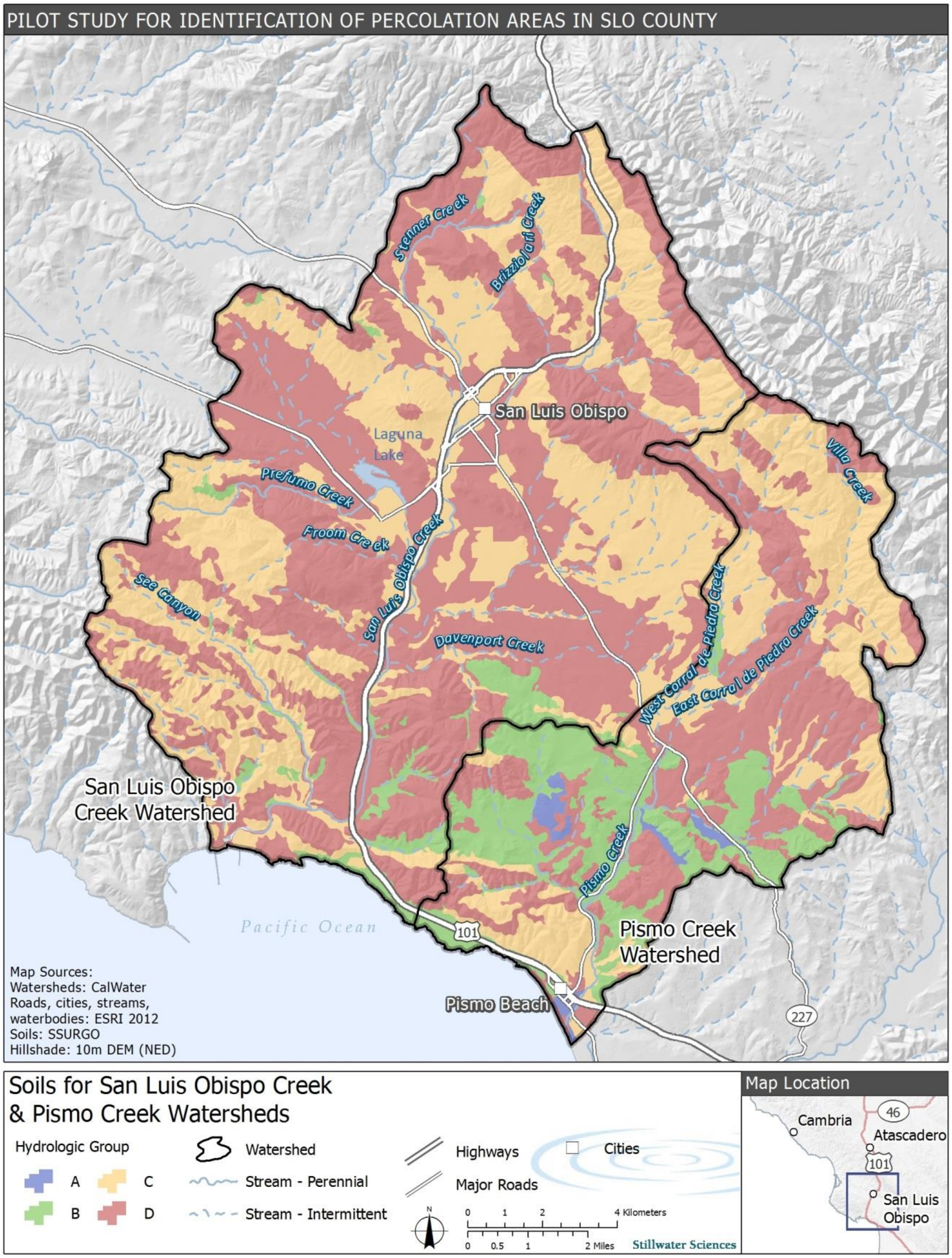


Figure 11. Generalized soil classes used for the PLU analysis in the San Luis Obispo Creek and Pismo Creek watersheds.

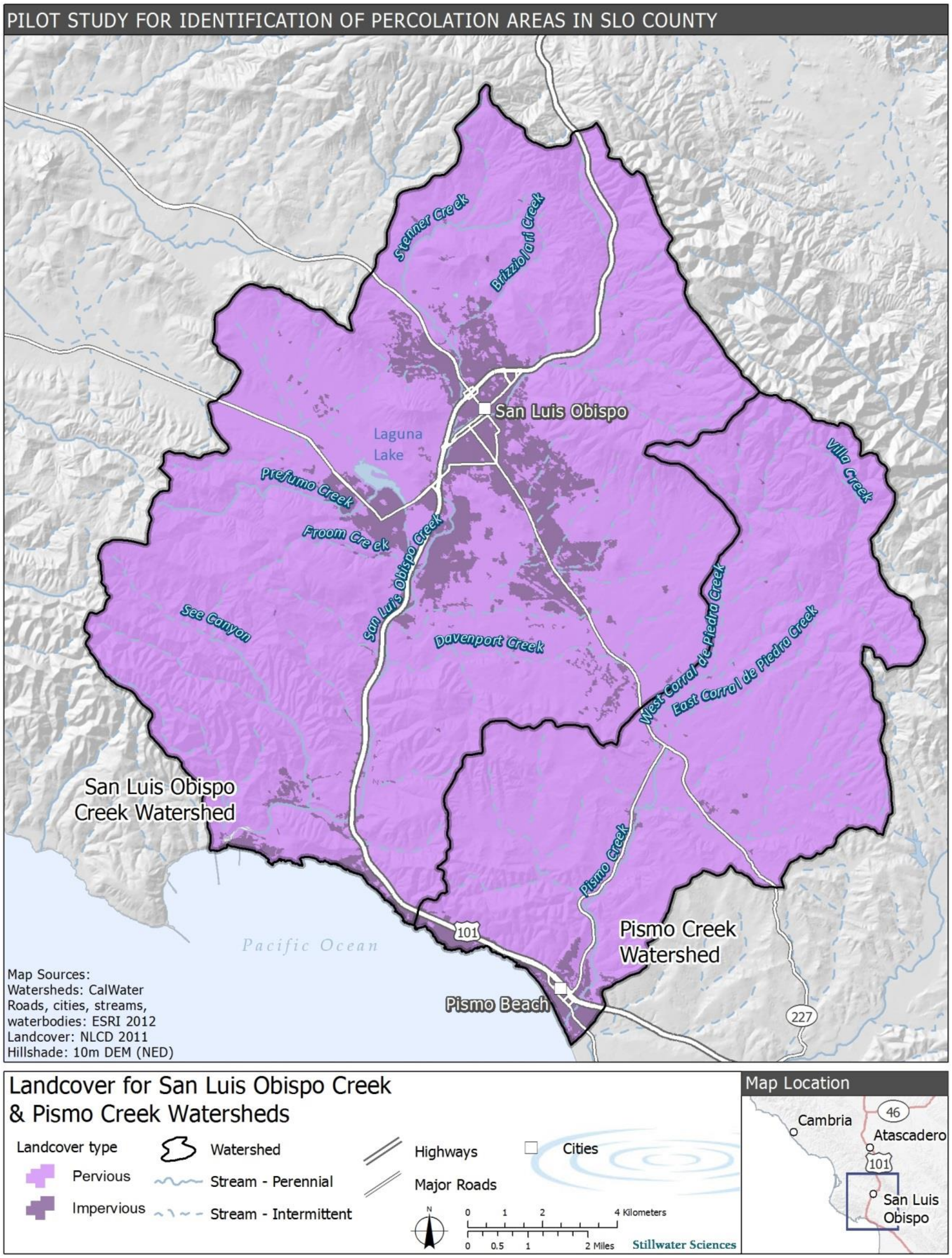


Figure 12. Generalized landcover classes used for the PLU analysis in the San Luis Obispo Creek and Pismo Creek watersheds.

2.2 Percolation Landscape Units

The discrete categories defined for these four environmental determinants (slope, geology, soils, and landcover) overlap into 48 possible percolation landscape units (PLUs). Each unit represents a unique combination of these factors that are judged to be the major determinants of intrinsic percolation, or groundwater recharge, potential. Only 14 of the possible combinations cover more than one percent of the total area of the study watersheds, and in total these 14 PLUs account for 94% of the total area (Table 1). The most dominant unit, "10–40%; non-Alluvium; D; Pervious," accounts for approximately one-fifth of the total area of the watersheds, which reflects moderately steep, rural uplands. These proportions are generally consistent across each of the study watersheds.

Relative proportions of each of the 48 PLUs in each of the watersheds are displayed graphically in Figure 13. Maps showing the distribution of the 48 PLU categories across the study watersheds are displayed in Figures 14 and 15.

Table 1. Percolation Landscape Units (PLUs) as a percent of total area of the study watersheds (representation 94% of the total area).

Percolation Landscape Units (slope; lithology; soil; landcover)	% of Santa Rosa Creek Watershed	% of San Luis Obispo Creek Watershed	% of Pismo Creek Watershed	% of Total Area of Watersheds
10-40%; non-Alluvium; D; Pervious	30	18	15	21
10-40%; non-Alluvium; C; Pervious	24	16	11	18
>40%; non-Alluvium; D; Pervious	12	16	11	14
>40%; non-Alluvium; C; Pervious	11	11	12	11
0-10%; Alluvium; D; Pervious	4	10	7	8
0-10%; Alluvium; C; Pervious	4	4	4	4
10-40%; non-Alluvium; B; Pervious	1.4	2	12	4
0-10%; non-Alluvium; D; Pervious	3	4	3	3
0-10%; non-Alluvium; C; Pervious	3	4	2	3
0-10%; Alluvium; D; Impervious	0.7	4	0.5	2
10-40%; Alluvium; D; Pervious	2	1.3	3	2
0-10%; Alluvium; C; Impervious	0.5	3	0.3	2
10-40%; Alluvium; C; Pervious	0.9	1.0	2	1.1
0-10%; Alluvium; B; Pervious	0.1	0.5	4	1.1

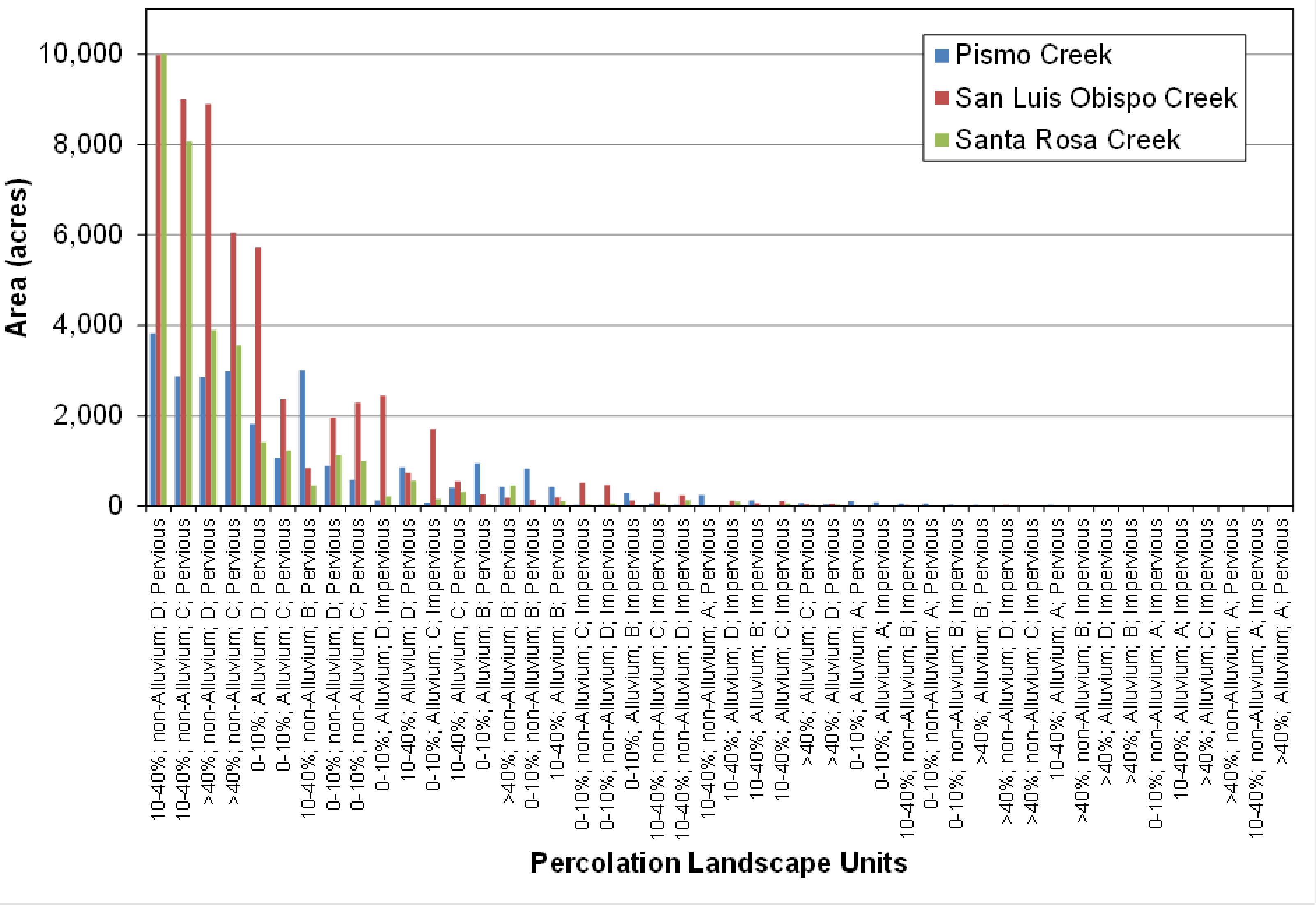


Figure 13. Relative proportions of each of the 48 PLUs in the study watersheds.

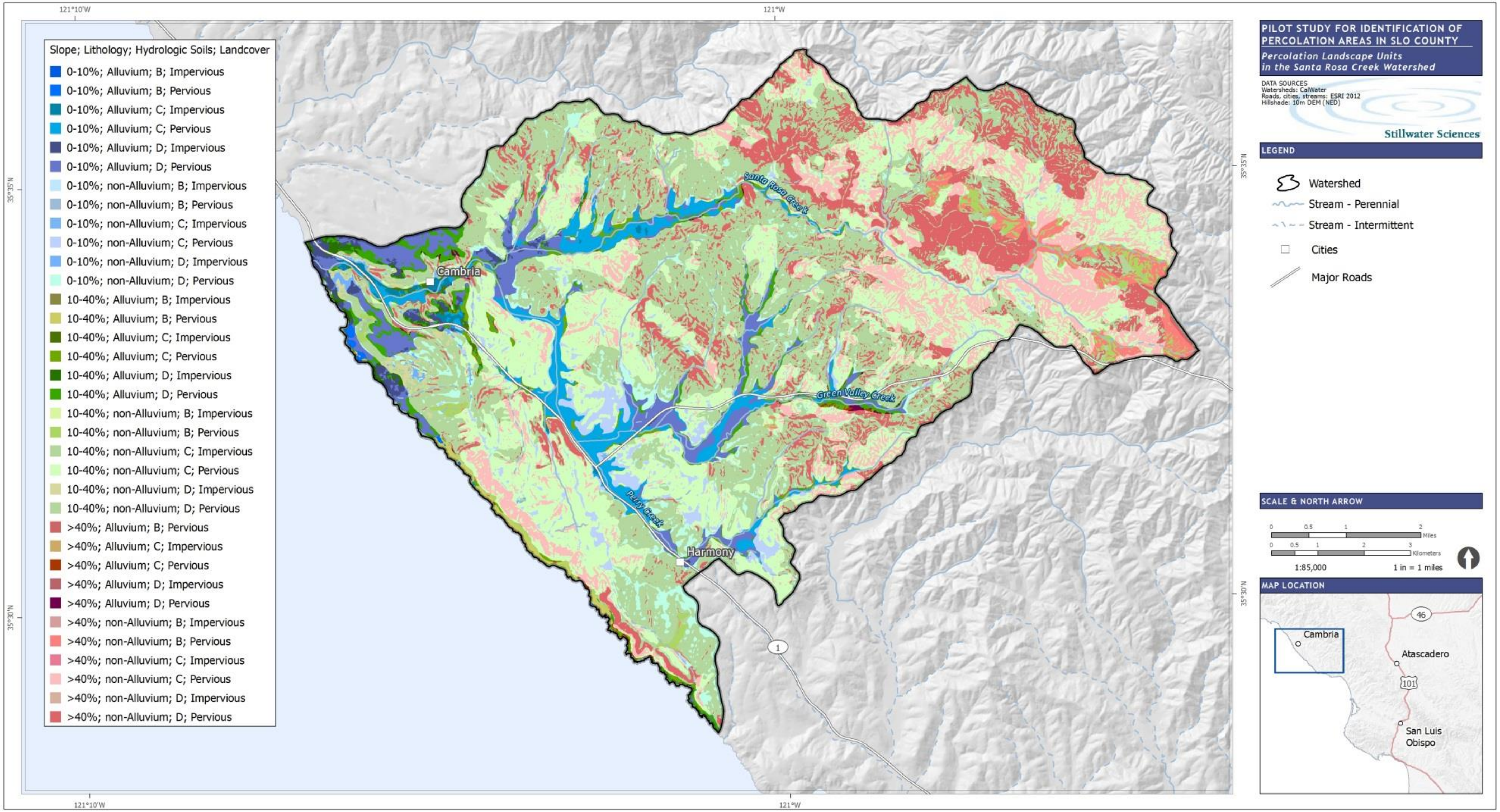


Figure 14. Percolation Landscape Units (PLUs) in the Santa Rosa Creek watershed.

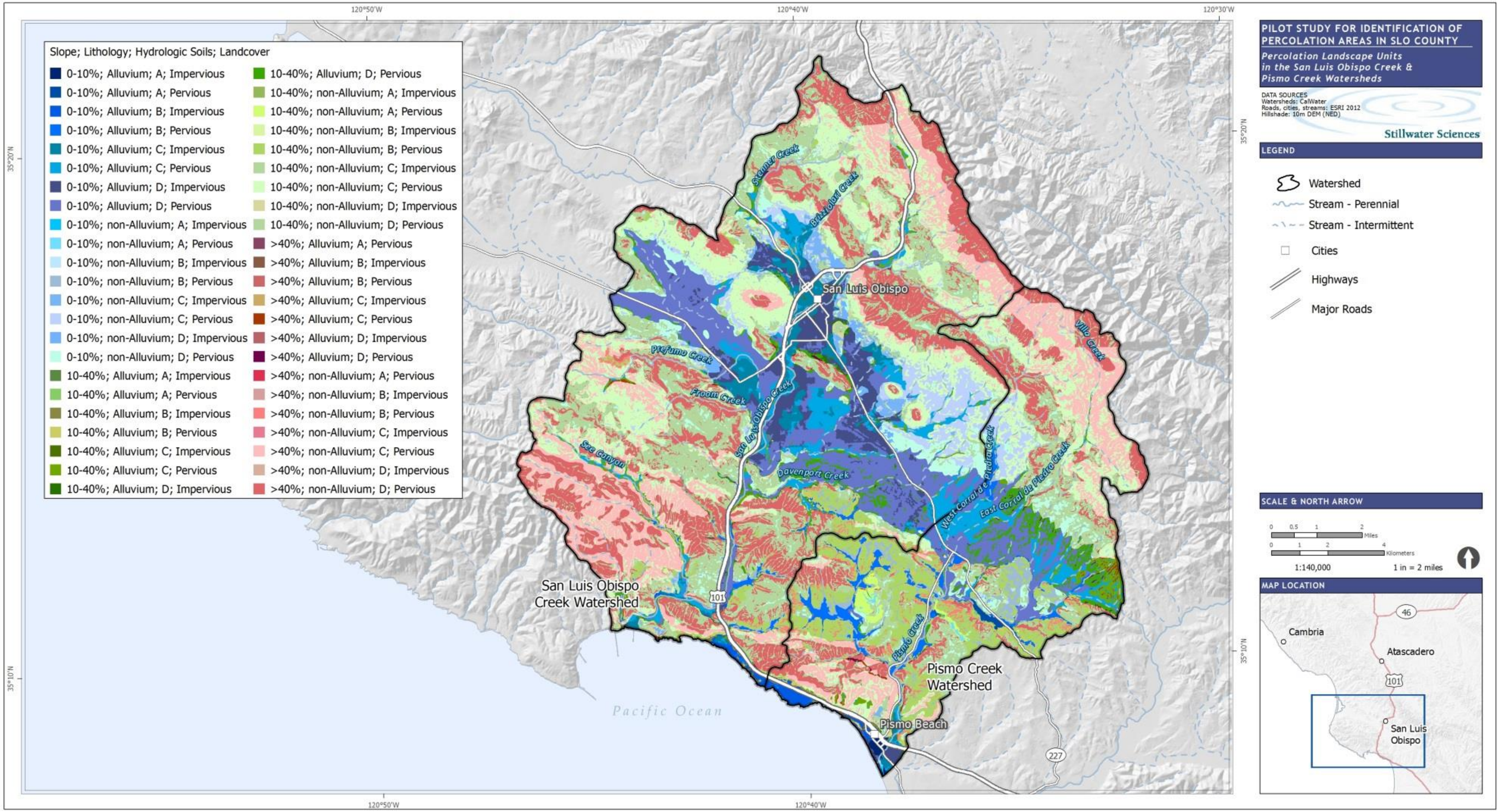


Figure 15. Percolation Landscape Units (PLUs) in the San Luis Obispo Creek and Pismo Creek watersheds.

The PLUs were ranked in order of assumed percolation potential, and then categorized into three relative rates—"High," "Medium," and "Low"—based on our understanding of the combined effects of the environmental determinants. PLUs composed of low slopes, alluvial lithologies, well-drained soils, and undeveloped land cover were considered to provide greater percolation rates, in contrast to lower percolation rates present within steeper, non-alluvial, poorly-drained, and developed portions of the landscape. As such, those PLUs best enabling deep infiltration were generally categorized as either High or Medium. Any PLUs composed of the steepest slopes (>40%), non-alluvial substrate, and/or developed land cover (i.e., impervious surface) were considered to inhibit groundwater-recharge potential regardless of any other environmental factors composing that PLU. The hydrologic soil groups were ultimately considered to be less influential in determining deeper infiltration potential. Thus, the higher infiltration classes (Groups A, B, and C) were together ranked only above the lowest infiltration class (Group D) but not distinguished separately from one another.

The assignments of relative percolation potential by type of PLU are listed in Table 2. The distribution of relative percolation potential category from Table 2 is shown in Figures 16 and 17 for the study watersheds.

In total, the areas categorized as "High" and "Medium" account for about 5% and 12%, respectively, of the total area of the watersheds. These areas represent those portions of the landscape characterized as being relatively flat, composed of geologically young alluvium and well-drained soils, and undeveloped. These areas tend to align with the mapped groundwater basins (but likely with greater spatial accuracy), suggesting that the criteria used to define these categories should be broadly applicable across other parts of the state, and that opportunities for percolation and groundwater recharge in these areas are, indeed, "high."

We also produced a map of the San Luis Obispo and Edna valleys showing the relative percolation potential without consideration of impervious surfaces (Figure 18). Specifically, eight Low PLUs were reclassified: three as High and five as Medium (see Table 2 and explanatory footnotes). This provides a reference point from which future modifications of existing urban developments could consider benefits of promoting groundwater recharge (see Conclusions below).

Table 2. Relative percolation potential by Percolation Landscape Units (PLUs) (n = 48).

Percolation Landscape Units (slope; lithology; soil; landcover)	Relative Percolation Potential	% of Santa Rosa Creek Watershed	% of San Luis Obispo Creek Watershed	% of Pismo Creek Watershed	% of Total Area of Watersheds
0-10%; Alluvium; A; Pervious	High	0	0	0.4	0.1
0-10%; Alluvium; B; Pervious	High	0.1	0.5	4	1.1
0-10%; Alluvium; C; Pervious	High	4	4	4	4
0-10%; Alluvium; D; Pervious	Medium	4	10	7	8
10-40%; Alluvium; A; Pervious	Medium	0	0	0.1	0.02
10-40%; Alluvium; B; Pervious	Medium	0.3	0.3	2	0.6
10-40%; Alluvium; C; Pervious	Medium	0.9	1.0	2	1.1
10-40%; Alluvium; D; Pervious	Medium	2	1	3	2
0-10%; Alluvium; A; Impervious [1]	Low	0	0	0.3	0.1
0-10%; non-Alluvium; A; Pervious	Low	0	0	0.2	0.1
0-10%; non-Alluvium; B; Pervious	Low	0.1	0.2	3	0.9

Percolation Landscape Units (slope; lithology; soil; landcover)	**Relative Percolation Potential**	**% of Santa Rosa Creek Watershed**	**% of San Luis Obispo Creek Watershed**	**% of Pismo Creek Watershed**	**% of Total Area of Watersheds**
0-10%; Alluvium; B; Impervious [1]	Low	0.001	0.2	1	0.4
>40%; Alluvium; A; Pervious	Low	0	0	0.001	0.0002
0-10%; non-Alluvium; C; Pervious	Low	3	4	2	3
0-10%; Alluvium; C; Impervious [1]	Low	0.5	3	0.3	2
>40%; Alluvium; B; Pervious	Low	0.01	0.02	0.1	0.03
0-10%; non-Alluvium; D; Pervious [2]	Low	3	4	3	3
0-10%; Alluvium; D; Impervious	Low	0.7	4	0.5	2
10-40%; non-Alluvium; A; Pervious	Low	0	0	1	0.2
>40%; Alluvium; C; Pervious	Low	0.1	0.1	0.3	0.1
10-40%; Alluvium; A; Impervious [2]	Low	0	0	0.02	0.004
10-40%; non-Alluvium; B; Pervious	Low	1	2	12	4
10-40%; Alluvium; B; Impervious [2]	Low	0.004	0.1	0.5	0.2
>40%; Alluvium; D; Pervious	Low	0.1	0.1	0.2	0.1
10-40%; non-Alluvium; C; Pervious	Low	24	16	11	18
10-40%; Alluvium; C; Impervious [2]	Low	0.2	0.2	0.04	0.1
10-40%; non-Alluvium; D; Pervious	Low	30	18	15	21
10-40%; Alluvium; D; Impervious [2]	Low	0.3	0.2	0.04	0.2
0-10%; non-Alluvium; A; Impervious	Low	0	0	0.02	0.005
0-10%; non-Alluvium; B; Impervious	Low	0	0.01	0.1	0.03
>40%; non-Alluvium; A; Pervious	Low	0	0	0.01	0.003
>40%; non-Alluvium; B; Pervious	Low	1	0.3	2	0.9
0-10%; non-Alluvium; C; Impervious	Low	0.1	1	0.1	0.5
>40%; Alluvium; B; Impervious	Low	0	0.003	0.02	0.01
>40%; non-Alluvium; C; Pervious	Low	11	11	12	11
0-10%; non-Alluvium; D; Impervious	Low	0.2	1	0.1	0.5
>40%; Alluvium; C; Impervious	Low	0.001	0.01	0.001	0.003
10-40%; non-Alluvium; A; Impervious	Low	0	0	0.01	0.002
>40%; non-Alluvium; D; Pervious	Low	12	16	11	14
10-40%; non-Alluvium; B; Impervious	Low	0.01	0.05	0.2	0.1
>40%; Alluvium; D; Impervious	Low	0.001	0.01	0.01	0.01
10-40%; non-Alluvium; C; Impervious	Low	0.1	0.6	0.2	0.4
10-40%; non-Alluvium; D; Impervious	Low	0.4	0.4	0.1	0.3
>40%; non-Alluvium; B; Impervious	Low	0.001	0.01	0.02	0.01
>40%; non-Alluvium; C; Impervious	Low	0.02	0.03	0.02	0.02
>40%; non-Alluvium; D; Impervious	Low	0.01	0.04	0.01	0.03

Table footnotes:

[1] PLU reclassified as High without consideration of impervious landcover in San Luis Obispo Valley groundwater basin.

[2] PLU reclassified as Medium without consideration of impervious landcover in San Luis Obispo Valley groundwater basin.

Figure 16. Predicted relative potential of intrinsic percolation in the Santa Rosa Creek watershed.

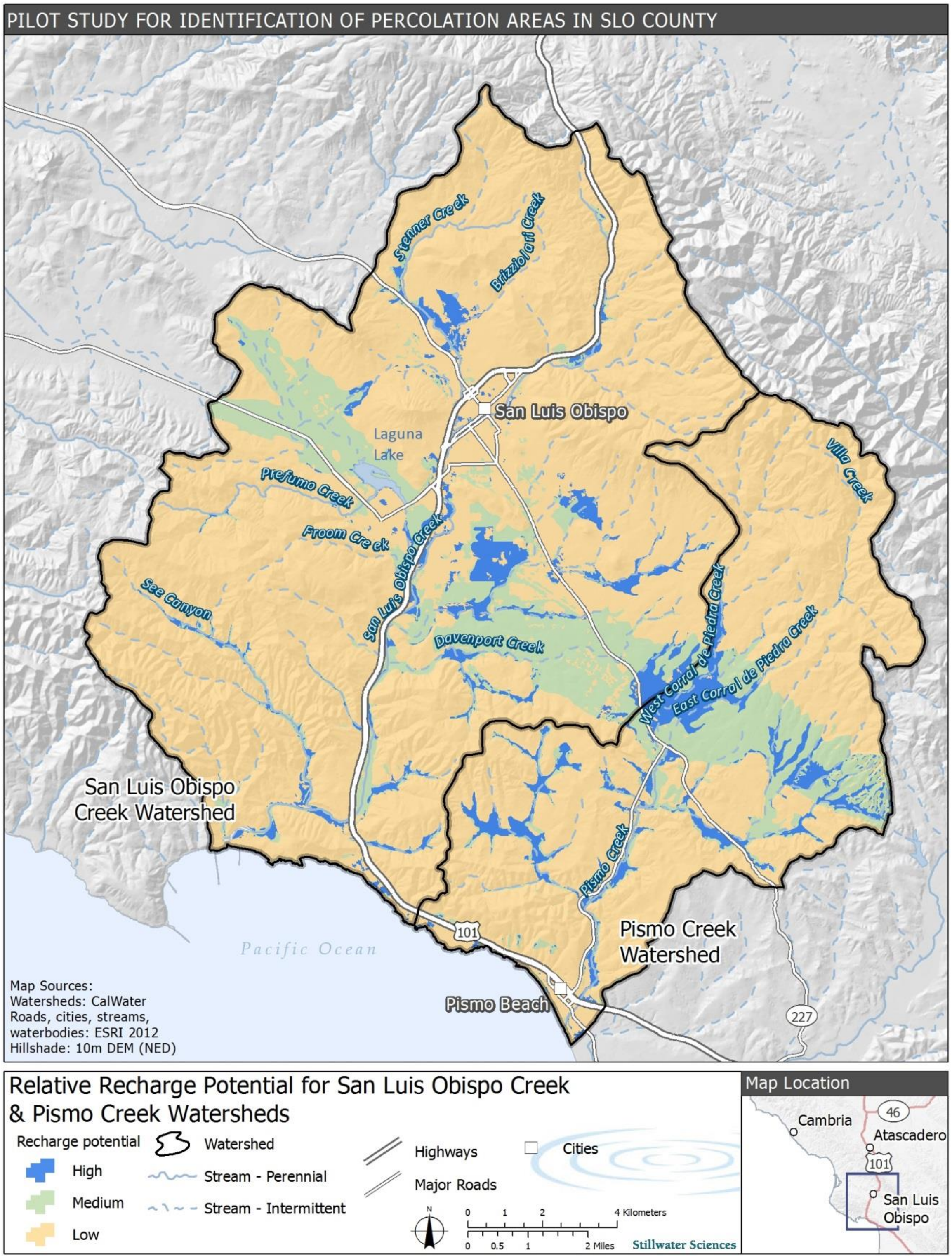


Figure 17. Predicted relative potential of intrinsic percolation in the San Luis Obispo Creek and Pismo Creek watersheds.

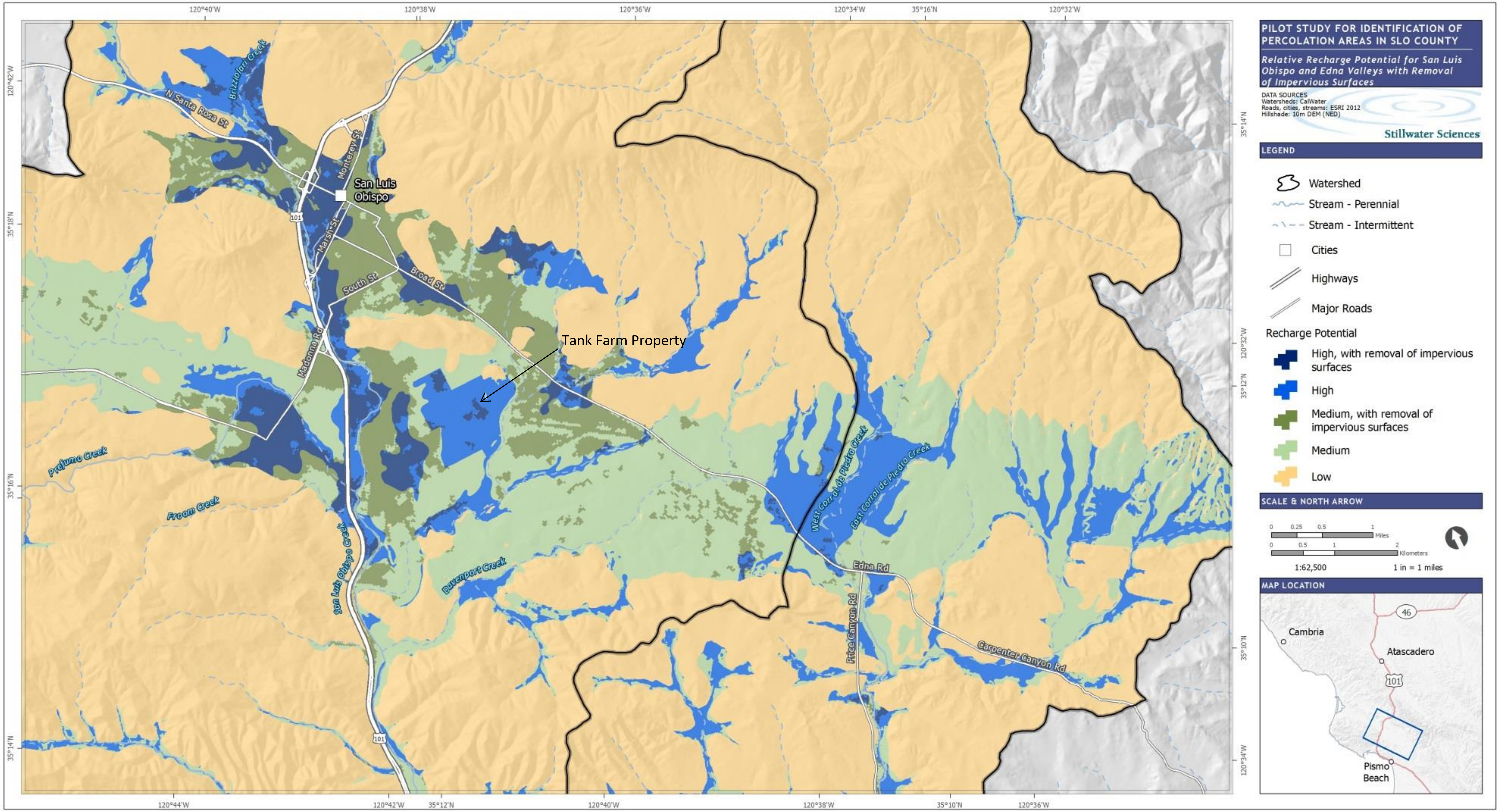


Figure 18. Predicted relative potential of intrinsic percolation with and without existing impervious surfaces in the upper San Luis Obispo Creek and Pismo Creek watersheds.

2.3 Fisheries Implications

The relative percolation potential areas identified above are intended to aid subsequent evaluations and prioritization of site-scale opportunities and, as such, some preliminary implications for fishery benefits can be inferred at this time using results from a previous study on instream flows performed throughout the county (Stillwater Sciences 2014). The Santa Rosa Creek, San Luis Obispo Creek, and Pismo Creek watersheds all support the federally threatened South-Central California Coast steelhead (*Oncorhynchus mykiss*). Results from a National Marine Fisheries Service (NMFS) analysis (Boughton and Goslin 2006) were used to delineate the stream channels within each watershed that have a high potential for steelhead rearing, based mostly on presence of suitable habitat and perennial flows, and those channels that have a potential to be dry for part of the year but still provide corridors for steelhead migrating from the ocean to suitable upstream spawning and rearing habitat. The potential steelhead habitat information has been superimposed upon the predicted relative potential of intrinsic percolation in the two study basins (Figures 19 and 20).

In the previous study on instream flows (Stillwater Sciences 2014), a preliminary estimate of the magnitude and timing of instream flows that would support steelhead in both of the study basins was developed. Predictive models based on field assessment and watershed characteristics estimated flow requirements at discrete sites, or “Analysis Points,” for both spring and summer rearing periods. The analysis found that flow requirements for steelhead are greater in spring, which is when growth is critical, than in summer, and greater in the lower portions of the watersheds where drainage area and stream channels are larger. The locations of the Analysis Points in the two study basins are shown in Figures 19 and 20. The estimated steelhead flow requirements at the Analysis Points are summarized in Table 3.

High steelhead rearing potential is prevalent along Santa Rosa Creek and its two main tributaries, Perry and Green Valley creeks, with the exception of the lowermost reach on Santa Rosa Creek between Cambria and the coast (Figure 19). On San Luis Obispo and Pismo creeks, high steelhead rearing potential is also prevalent throughout most of the watersheds, with exceptions where the creeks and/or their tributaries traverse San Luis Obispo and Edna valleys and become hydrologically “losing” reaches (Figure 20). These alluvial valley segments generally coincide with the broadest expanses of High and Medium percolation potential areas and, thus, rearing habitat suitability is low and the channels function almost exclusively as migratory routes during wetter months. This outcome supports conventional wisdom that steelhead rearing opportunities are concentrated in stream reaches with low percolation rates that exhibit more perennial flow conditions (i.e., hydrologically “gaining” reaches). Some implications for rearing enhancement opportunities are discussed below.

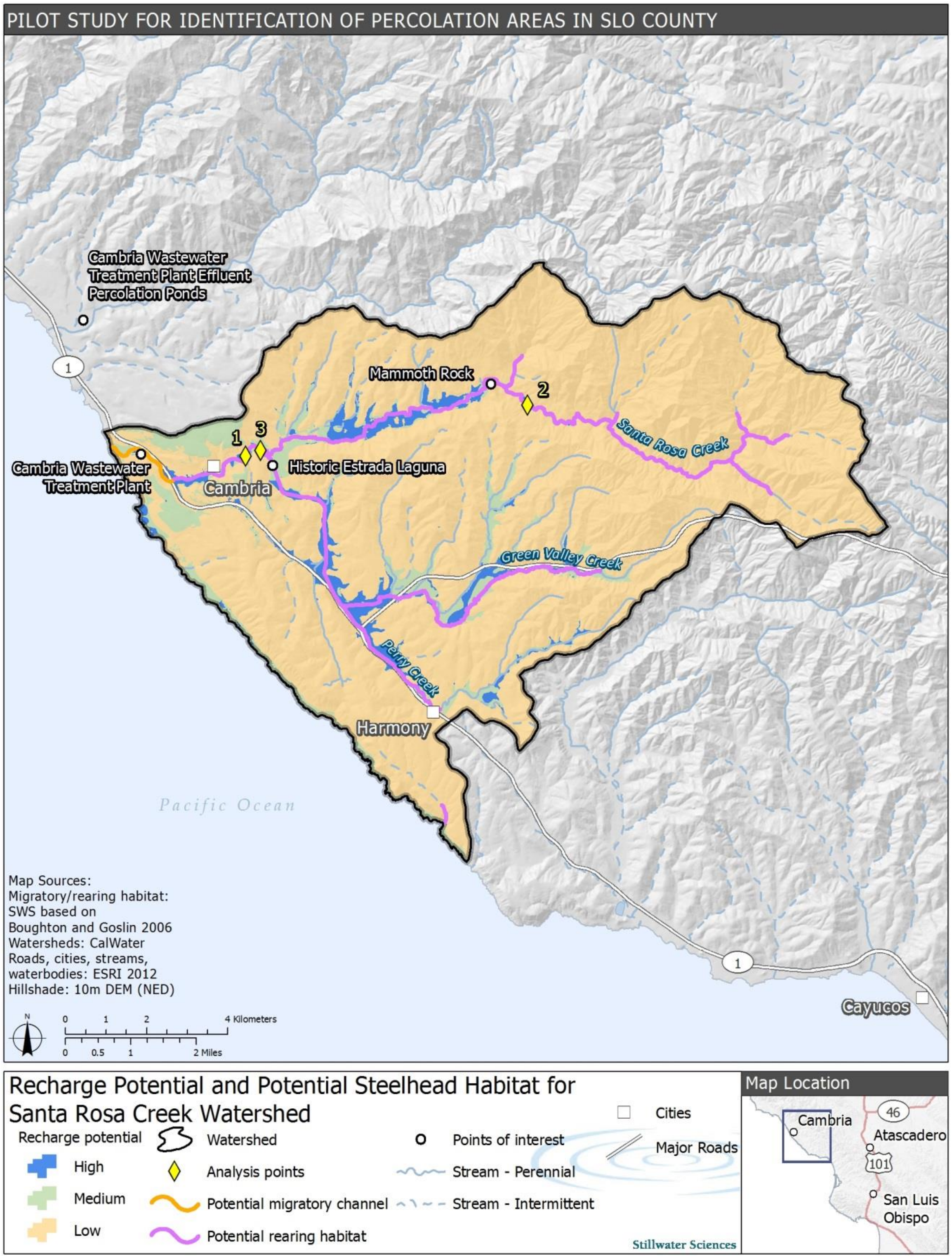


Figure 19. Potential steelhead habitat, analysis points, and predicted relative potential of intrinsic percolation in the Santa Rosa Creek watershed.

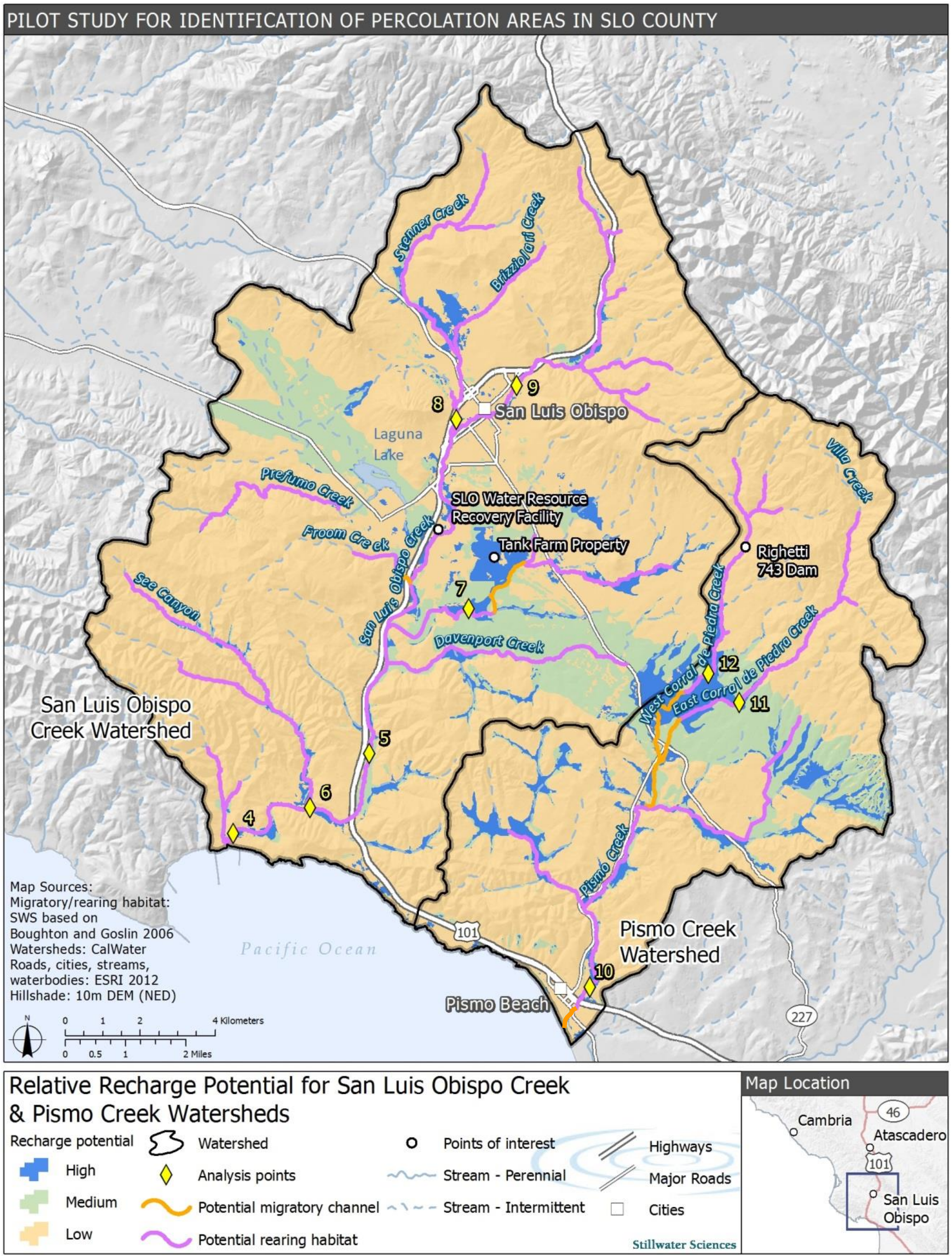


Figure 20. Potential steelhead habitat, analysis points, and predicted relative potential of intrinsic percolation in the San Luis Obispo Creek and Pismo Creek watersheds.

Table 3. Estimated flow requirements for steelhead rearing habitat at Analysis Points in the study watersheds (*adapted from Stillwater Sciences 2014*).

Analysis Point Name	Analysis Point Map Number	Flow requirements for Steelhead Rearing Habitat (reported in cubic feet per second)	
		Spring	Summer
Santa Rosa Creek Watershed			
Lower Santa Rosa Creek	1	13.3	1.2
Upper Santa Rosa Creek	2	9.2	0.2
Perry Creek	3	1.4	0.5
San Luis Obispo Creek Watershed			
San Luis Obispo Creek at Avila	4	4.3	1.2
Lower San Luis Obispo Creek	5	3.6	1.0
See Canyon Creek	6	0.7	0.3
East Fork San Luis Obispo Creek	7	0.8	0.3
Stenner Creek	8	0.9	0.3
Upper San Luis Obispo Creek	9	0.9	0.3
Pismo Creek Watershed			
Lower Pismo Creek	10	2.2	0.7
East Corral de Piedra Creek	11	0.6	0.3
West Corral de Piedra Creek	12	0.6	0.3

2.4 Data Products

The spatial data products presented in the above maps have been compiled in a compressed folder (.zip format) titled "SLO_PercStudy" for transmittal to the RCDs. It is important to note that the data presented herein are intended for natural resource planning and management by entities with knowledge of the source data and their mapping scale to avoid potential misapplication.

The data transmitted to the RCDs include the following:

- Maps—
    - Figure 1 (figxx_SRC_Basemap.jpg)
    - Figure 2 (figxx_SRC_Hydro.jpg)
    - Figure 3 (figxx_PismoSL_Basemap.jpg)
    - Figure 4 (figxx_PismoSL_Hydro.jpg)
    - Figure 5 (figxx_SRC_Topo.jpg)
    - Figure 6 (figxx_SRC_Geology.jpg)
    - Figure 7 (figxx_SRC_Soils.jpg)
    - Figure 8 (figxx_SRC_Landcover.jpg)
    - Figure 9 (figxx_PismoSL_Topo.jpg)
    - Figure 10 (figxx_PismoSL_Geology.jpg)
    - Figure 11 (figxx_PismoSL_Soils.jpg)
    - Figure 12 (figxx_PismoSL_Landcover.jpg)
    - Figure 14 (figxx_SRC_PLUs.jpg)
    - Figure 15 (figxx_PismoSL_PLUs.jpg)
    - Figure 16 (figxx_SRC_RechargePotential.jpg)
    - Figure 17 (figxx_PismoSL_RechargePotential.jpg)

  - Figure 18 (figxx_PismoSL_Zoom_RechargePotential.jpg, figxx_PismoSL_Zoom_RechargePotential_noUrban.jpg)
  - Figure 19 (figxx_SRC_RechargePotential_SteelheadHab.jpg)
  - Figure 20 (figxx_PismoSL_RechargePotential_SteelheadHab.jpg
- Shapefiles (.shp format) with attendant data files—
  - Watershed boundaries (WatershedBoundaries.shp)
  - Classified topography (Slope.shp)
  - Classified geology (Lithology.shp)
  - Classified hydrologic soil groups (HydroGroup.shp)
  - Classified landcover (Landcover.shp)
  - Percolation landscape units (PLU.shp)
  - Classified relative percolation potential (RechargePotential.shp)
  - Classified relative percolation potential without impervious surfaces (RechargePotential_noUrban.shp)
- ArcGIS project files—
  - Compatible with version 10.0, saved in subfolder “v10” (SLO_PercStudy.mxd)
  - Compatible with version 10.3, saved in subfolder “v103” (SLO_PercStudy.mxd)
- Google Earth files (.kmz format)—
  - Compiled shapefiles listed above (SLO_PercStudy.kmz)

3 DISCUSSION

This study was grant funded in order to improve data gaps within the San Luis Obispo County IRWM Plan, and to provide a framework and process for analyzing the intrinsic percolation potential in the two pilot-study groundwater basins. The following summarizes the major findings and recommendations of the study.

3.1 Major Findings

A. The evaluation resulted in a finer-scale, spatially explicit baseline of intrinsic percolation potential in the study watersheds than was previously available. The study applied a holistic, GIS-based approach similar to others conducted in the central coast region (e.g., Russo et al. 2015). The predicted High and Medium areas are largely concentrated over the CDWR-designated groundwater basin boundaries from Bulletin 118 (2003). The coarsest dataset used in the study was the raster-based landcover produced at 30-meter resolution (Figures 8 and 12), which denotes the minimum mapping unit in the percolation potential maps (Figures 16–18). This pixel size translates to approximately 0.22 acres.

B. Approximately 19,000 acres within the study watersheds have been identified as providing High and Medium potential for intrinsic percolation, or groundwater recharge. The High and Medium areas account for about 5% and 12%, respectively, of the total areas of the watersheds. The areas were concentrated along the alluvial valleys and floodplains of the mainstem and tributary streams (Figures 16–17) (see Opportunity Areas below).

C. In the Santa Rosa Creek watershed, the largest concentrations of High and Medium percolation-potential areas lie in the upper Santa Rosa Creek Valley and the lower Perry Creek Valley between the confluences with Green Valley Creek and Santa Rosa Creek (Figure 16). These areas are sparsely developed and currently support a mix of agricultural activities, namely crops and ranching. One key area is situated along lower Perry Creek, which historically supported a seasonal lake (Estrada Laguna) until permanently drained in the 1870s (see Opportunity Areas below).

D. In the San Luis Obispo Creek and Pismo Creek watersheds, High and Medium percolation-potential areas lie primarily in the San Luis Obispo-Edna Valley (excluding urban developments), but also along many of the floodplains of the major streams (Figure 17). Another 1,600 acres in San Luis Obispo Valley groundwater basin could theoretically provide High and Medium potential for groundwater recharge with removal of impervious surfaces associated with existing urban developments, particularly within the city boundaries of San Luis Obispo (Figure 18) (see Opportunity Areas below). Steelhead rearing potential has been previously identified along much of Santa Rosa, San Luis Obispo, and Pismo creeks and their major tributaries (Boughton and Goslin 2006, Stillwater Sciences 2014), with exceptions where the stream channels transition to a hydrologically "losing" condition in the broad alluvial valleys having the largest concentrations of High and Medium percolation potential, such as in San Luis Obispo and Edna valleys (see Figures 19 and 20). Opportunities for enhancing instream flows and, thus, steelhead rearing habitat suitability are therefore greater in the areas where the rearing potential and Low percolation potential coincide. Specific locations include the following reaches that have high intrinsic rearing habitat value and would benefit native steelhead populations (see Figures 19 and 20):

- Mainstem of upper Santa Rosa Creek upstream of Mammoth Rock,
- Stenner Creek in the San Luis Opispo Creek watershed upstream of San Luis Obispo Valley,
- Mainstem of San Luis Obispo Creek upstream of Cuesta Park,
- Laguna Lake in the San Luis Obispo Creek watershed (including Prefumo Creek),
- East Corral de Piedra Creek in the Pismo Creek watershed upstream of Edna Valley, and
- West Corral de Piedra Creek in the Pismo Creek watershed upstream of Edna Valley and downstream of Righetti 743 Dam.

Opportunities for enhancing instream flows in the "losing" reaches will continue to be limited. Additional discussion on recharge opportunities is presented below.

E. Overall, there appears to be much potential for enhancing conservation of water resources via promoting focused groundwater recharge in the study basins (and contributing watersheds) given the large amount of High and Medium percolation potential areas coinciding with various water- and land-uses that would benefit from increased water supply. (see Opportunity Areas below).

3.2 Recommendations

The following briefly summarizes identified recommendations for enhancing groundwater supplies for beneficial uses in the study watersheds. These recommendations are consistent with those contained in the existing watershed management and enhancement plans that include the study basins (TLCSLOC 2002, Stillwater et al. 2012, RCD-SLO 2014).

3.2.1 Opportunity areas

While the present study was primarily focused on developing a framework and process for analyzing the intrinsic percolation potential in the two pilot-study groundwater basins, the findings can already be used to begin identifying specific opportunities for actively promoting groundwater recharge with ancillary benefits to local water supply and instream habitat quality. Local groundwater/watershed management entities (e.g., the Groundwater Sustainability Agency to be formed by June 2017 for San Luis Obispo Valley) will need to develop basin management objectives and a groundwater sustainability plan, and then implement actions identified in the plan. The following briefly summarizes some opportunity areas that the management entities may wish to consider in their plans. Implementation of these conceptual actions would also satisfy several recommendations specified in the watershed management and enhancement plans for Santa Rosa Creek (Stillwater Sciences et al. 2012), San Luis Obispo Creek (TLCSLOC 2002), and Pismo Creek (CCSE 2009).

A. **Actively Managed Re-use of Treated Wastewater—**The proximity of a large extent of the High and Medium areas to major water supply and wastewater discharge operations in Cambria and San Luis Obispo presents an opportunity to directly, or actively, enhance local water supply by utilizing the existing stream channel network and available aquifer storage. One such concept could entail discharge of treated wastewater in the upper reach(es) of one or more tributaries where there is Low percolation potential, so that the imported water would flow through the stream channel with minimal losses to the subsurface. Rearing habitat suitability for steelhead would theoretically benefit from such a management action in those reaches. Water entering the valley reaches (i.e., San Luis Obispo/Edna valleys) would infiltrate and recharge the aquifer, which could potentially become available for consumptive uses of groundwater, and enhance instream flows farther downstream.

The city of San Luis Obispo currently treats wastewater to drinking water standards to allow for discharge into the creek. Because of the high quality of the treated water and current pressures for water conservation, the city is evaluating additional discharge points to increase their reuse distribution system. One possible re-use application could be to enhance groundwater storage via routing treated wastewater to a nearby new percolation system. The infiltrated water would augment the groundwater supply, which would potentially supplement local groundwater demands and enhance instream flows in downstream reaches of San Luis Obispo Creek. Percolation ponds are common in other treatment facilities around the state, including along lower San Simeon Creek where Cambria’s wastewater is discharged. Thus, a major benefit of managed percolation is improved water quality through denitrification during the infiltration process. The managed percolation concept is akin to the “Managed Aquifer Recharge,” or MAR, concept coined by Russo et al. (2015) to refer to aquifer recharge through infiltration basins that are natural depression areas or constructed retention areas within which diverted water is allowed to infiltrate into the subsurface over time.

Another managed recharge method utilized in the state includes use of injection-extraction wells as part of an Aquifer Storage and Recovery (ASR) method. The process simply entails injecting water pre-treated to potable standards into the water table through the ASR wells. Their design and operation are typically complex, however, and can be cost-prohibitive for smaller coastal communities. One example is the Las Posas Aquifer Storage and Recovery Project operated by the Calleguas Municipal Water District on the Oxnard Plain in Ventura County. Through injection of imported water to the local aquifer, this project has been designed to provide 300,000 acre-feet of additional groundwater storage (CMWD 2013). The Cambria Community Services District plans to soon expand their recycled water re-injection program along lower San Simeon Creek through use of injection wells, which will also improve operations at their nearby water-supply well field (RWQCB-CCR 2014).

B. **Restoration of Watershed Features—**A possible opportunity for indirectly, or passively, enhancing groundwater storage in both groundwater basins is broader restoration of watershed elements having a direct influence on runoff and infiltration potential. Such efforts could include management of upland vegetation and road networks, and restoration of impaired channel-floodplain reaches and wetlands. For example, restoration of the historic seasonal lake (Estrada Laguna) on lower Perry Creek in the Santa Rosa Valley (Figure 19) groundwater basin is recommended. This area was identified as supporting High and Medium percolation potential and is situated near Cambria. Thus, this effort could be a focused storage zone with appropriate modification of the lowland area that restores the lake to allow for a means to slow runoff from the Perry Creek subwatershed and enhance local groundwater recharge. Additionally, broader-scale application of stream restoration intended to reverse chronic channel incision in both study basins could potentially raise local water-table levels and increase groundwater storage in the local aquifers. These actions would have ancillary benefits to local and/or nearby steelhead rearing habitat.

C. **Removal of Impervious Surfaces—**As depicted in Figure 18, a sizeable portion of the San Luis Obispo Valley groundwater basin is overlain by urban developments with impervious cover that currently inhibit surface infiltration and deeper percolation. Approximately 1,600 acres of this area were predicted to host Low intrinsic percolation potential which could theoretically provide High or Medium potential for indirect, or passive, groundwater recharge opportunities with managed removal of impervious surfaces associated with existing urban developments, particularly within the city boundaries of San Luis Obispo. A means of mitigating the urban effect on groundwater recharge in the basin is partial replacement of paved surfaces with porous concrete and aggregate infiltration surfaces, and managing stormwater runoff with infiltration-promoting facilities such as rain gardens and bioswales. As with all such treatments, the potential for impairment of groundwater quality from contaminated runoff and infiltration should be assessed prior to implementing these urban-landscape elements.

   Conversely, expansion of urban areas has the potential to further reduce infiltration potential with increased construction of impervious surfaces. One anticipated change in land-use within the city limits of San Luis Obispo is the proposed remediation and land development with restoration elements at the 300-acre “Chevron Tank Farm” property—a decommissioned oil facility (City of San Luis Obispo 2013, see Figure 18). This presently vacant property was designated as exhibiting High percolation-potential due to absence of impervious surfaces and, while portions are proposed to include commercial and industrial business parks with impervious surfaces, the vast majority of the property is proposed to host open space and wetland creation that would potentially continue to offer High percolation potential.

3.2.2 Additional considerations and data needs

The following briefly describes additional considerations and data needs recommended for inclusion during any future expansion of the present study and/or feasibility assessment of specific management actions that have already been or have yet to be identified.

A. **Future Prioritization and Opportunities Identification—**Due to budget limitations, the present study did not rigorously evaluate percolation zones for opportunities or prioritize zones by benefit. However, to complete the “proof of concept” approach, the study should be extended to prioritize areas where percolation potential is determined to be High and Medium. Based on our past experience performing similar studies in the region, criteria may include:
   1. Water supply—increase or improve water-supply availability, reliability, and flexibility for multiple land uses and the environment;
   2. Ecosystem—improve ecosystem function and/or enhance aquatic and riparian habitat, especially for state and federally listed species;
   3. System sustainability—support energy and water efficiency and climate-change resiliency of water management systems and developed supplies, as well as the ability of stream systems to be maintained by natural processes;
   4. Water quality—improve water quality of surface water and/or groundwater;

5. Flood control—improve management of stormwater that contributes, directly or indirectly, to reduce flood hazards;
6. Agricultural/open space—preserve or enhance agricultural land use and open space;
7. Community benefits—create or enhance recreation, public access, and education opportunities.

B. **Develop a Water Balance—**Site-specific planning will require a more comprehensive understanding of the myriad physical processes influencing local hydrologic processes. A water-balance analysis is recommended for such applications to quantify existing water quantity and quality conditions and to model future scenarios, including project alternatives. An important step will be to quantify a basin's (or portion of a basin's) water balance (i.e., flux), water levels (i.e., storage), and changes over time. Specific parameters include precipitation, surface runoff, streamflow, aquifer characteristics, and groundwater recharge and discharge. Availability of local water-table levels was limited for the evaluation presented herein. While CDWR provides an online tool to query groundwater level data across the state and currently lists 30 wells in Santa Rosa Valley groundwater basin and 2 in San Luis Obispo Valley groundwater basin, only one of these well stations (in Edna Valley) has publically available data. We recommend collaborating with the county's water resources division, local water purveyors, and other groundwater-basin users to gain access to current well records, which will provide critical insight to groundwater conditions in the study basins.

C. **Coordination with IWRM Plan—**Efforts to promote groundwater recharge or further watershed/groundwater management studies in the area should be done in coordination with local groundwater management entities (e.g., the Groundwater Sustainability Agency to be formed by June 2017 for San Luis Obispo Valley) or other existing management frameworks (e.g., Flood Control Zone 9 efforts) as well as local landowners and other community organizers. Interested stakeholders should consider integrating protection and enhancement of High and Medium potential percolation zones with other water resources management projects and programs.

3.3 Proof-of-Concept Evaluation

This pilot study served as a "proof-of-concept" effort that developed a repeatable approach to producing spatially explicit baseline information of intrinsic percolation (or groundwater recharge) potential in the two pilot-study groundwater basins. The analysis depended entirely upon available spatial information and past studies. Acquisition and use of other existing spatial information would have helped to qualify the findings (e.g., groundwater-level data). This product alone provides a visual tool to communicate to land users important percolation zones, and could be used as a step toward more focused assessments.

Due to budget limitation, intrinsic percolation areas were not rigorously evaluated or prioritized for opportunities. However, as acknowledged above, this is an important step that would greatly strengthen subsequent evaluations and prioritization of site-scale opportunities for enhancing groundwater recharge.

The pilot study cost $20,000 and built upon existing datasets held by Stillwater Sciences. The opportunities identification and prioritization step would have cost an additional $10,000. If the full approach (percolation potential and prioritization) was completed for all 21 groundwater basins in the County, it is estimated to cost $55,000 not including project administration.

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