

DRAFT ADDENDUM

TURLOCK GROUNDWATER BASIN GROUNDWATER MANAGEMENT PLAN

In 2008, the Turlock Groundwater Basin Association prepared a Groundwater Management Plan (GWMP) for the Turlock Groundwater Basin (TGBA, 2008). This Addendum provides supplemental information to that GWMP regarding the primary sources of recharge to the basin. This Addendum also provides maps of groundwater basin recharge areas to comply with Assembly Bill 359 (AB 359), adopted in 2011 after the GWMP had been prepared. Beginning January 1, 2013, AB 359 requires GWMPs to include a map identifying groundwater basin recharge areas. AB 359 defines a recharge area as “the area that supplies water to an aquifer in a groundwater basin and includes multiple wellhead protection areas.”

This Addendum expands the groundwater recharge discussion presented in Section 4 of the GWMP. In addition to summarizing recent and current patterns of groundwater recharge, supplemental datasets are analyzed to identify favorable areas for future recharge enhancement. Specifically, the addendum addresses the following objectives:

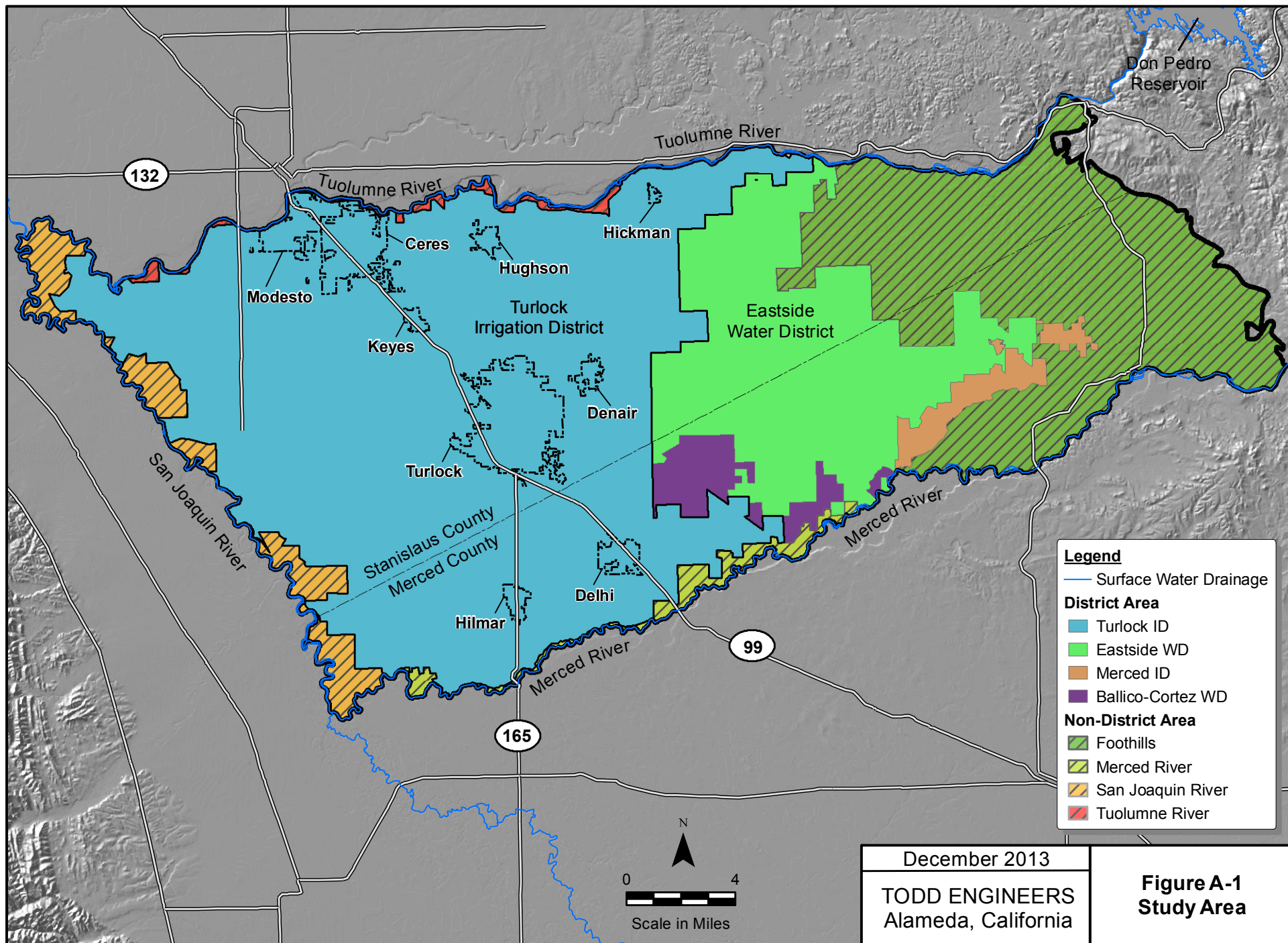
- Describe the natural soil and surficial geologic characteristics that control groundwater recharge across the basin;
- Discuss land use and water use practices that influence basin recharge;
- Provide basin-wide maps showing the current spatial distribution of recharge types and amounts as discussed in the GWMP; and
- Identify favorable areas for enhancing future groundwater recharge.

This Addendum includes several new figures and tables, but also refers to existing figures and text in the GWMP. Material from the GWMP is incorporated by reference and is not repeated herein. New figures and tables in this Addendum are numbered as A-1, A-2, etc. to avoid confusion and to more clearly identify the supplemental information. Figure A-1 of the Study Area is similar to Figure 1 in the GWMP, but is included as a reference base map for the new figures.

Figure A-1 shows the Turlock Groundwater Basin (basin), which represents the Study Area of both the GWMP and this Addendum. The basin lies on the eastern side of California’s San Joaquin Valley and includes portions of both Stanislaus and Merced Counties. As shown on Figure A-1, the basin is bounded by the Tuolumne River on the north, the Merced River on the south, and the San Joaquin River on the west. The western extent of the outcrop of crystalline basement rock in the Sierra Nevada foothills forms the eastern boundary of the basin.

GROUNDWATER RECHARGE

The GWMP (Section 4.1.4) presents results of a water budget study conducted in 2003 and updated in 2007 that estimates recharge in the basin from 1997 to 2006. As summarized in the GWMP, groundwater recharge within the basin occurs as a result of crop irrigation, urban landscape irrigation, precipitation, percolation from the Tuolumne and Merced rivers, leakage from Turlock Lake, underflow from the Sierra Nevada foothills, and upward seepage from deep geologic fractures.



During this period, total basin recharge was estimated at approximately 520,000 acre-feet per year (AF/yr). Approximately 72 percent of the total groundwater recharge is from irrigation on agricultural lands. For the Turlock Irrigation District (TID) and Merced Irrigation District areas, about 90 percent of the irrigation water is surface water, while almost all of the irrigation water in Eastside Water District (EWD), Ballico-Cortez Water District, and other non-district areas is groundwater. The components of the water budget, including average inflows and outflows from 1997 to 2006, are summarized on Figure 19 of the GWMP.

SOIL AND SURFICIAL GEOLOGY IMPACT ON RECHARGE

The potential for groundwater recharge in any given area of the basin is controlled, in part, by natural physical conditions including soil characteristics, surficial geology, and topographic slope. Permeable soils and geologic units allow infiltration of precipitation, irrigation in excess of evapotranspiration (referred to as return flows), and surface water in rivers, canals, and lakes. Conversely, vertical movement of water is limited by low permeability soils and geologic units (such as duripan and shallow cemented layers, referred to herein as restrictive layers). The topography over much of the basin is relatively uniform and flat. As such, slope is not as significant as soil and geologic conditions in controlling recharge potential.

Soil permeability and restrictive layers within the basin are illustrated on Figure A-2. The brighter colors (i.e., yellow, orange, and red) represent soils ranging from “moderately high” to “very high” soil permeability as described by the U. S. Department of Agriculture (USDA). The shades of green represent soils ranging from “very low” to “moderately low to moderately high” permeability. This figure is based on an analysis of digital soil coverages obtained from Turlock Irrigation District (TID) and combined with soil type descriptions from the Soil Data Mart website of the USDA National Resources Conservation Service (NRCS, 2011). The physical properties were classified up to a depth of 6 feet below ground surface. The soil permeability is based on the saturated vertical hydraulic conductivity (KV_{sat}) of the layer that most limits percolation. The restrictive layers are based on the presence and depth to duripan (silicic clays), paralithic bedrock (cemented sediments) and lithic bedrock (lithified rock) provided in the soil survey. The thickness of the duripan is not provided in the soil survey. However, based on soil borings drilled by Eastside Water District (east of Turlock, see Figure A-1) in 2003 and 2005, the duripan extends to approximately 15 feet below ground surface.

A more simplified representation of relative recharge was developed by assigning a soil permeability recharge potential to the different soil types. Soil permeability recharge potential, based on relative permeability and the presence/absence of restrictive layers, is based on the following criteria:

Table A-1 Soil Permeability Recharge Potential

Ksat (in/hr)	Ksat (feet/day)	Description (USDA)
1.98 to 19.98	3.96 to 39.96	High to very high
0.57 to 1.98	1.04 to 3.96	Moderately high to high
0.20 to 0.57	0.40 to 1.04	Moderately high
0.06 to 0.20	0.12 to 0.40	Moderately low to moderately high
0.00 to 0.06	0.00 to 0.12	Very low to moderately low

In addition, restrictive layers (duripan, paralithic bedrock, lithic bedrock, or bedrock) are assumed to decrease the soil recharge potential to zero.

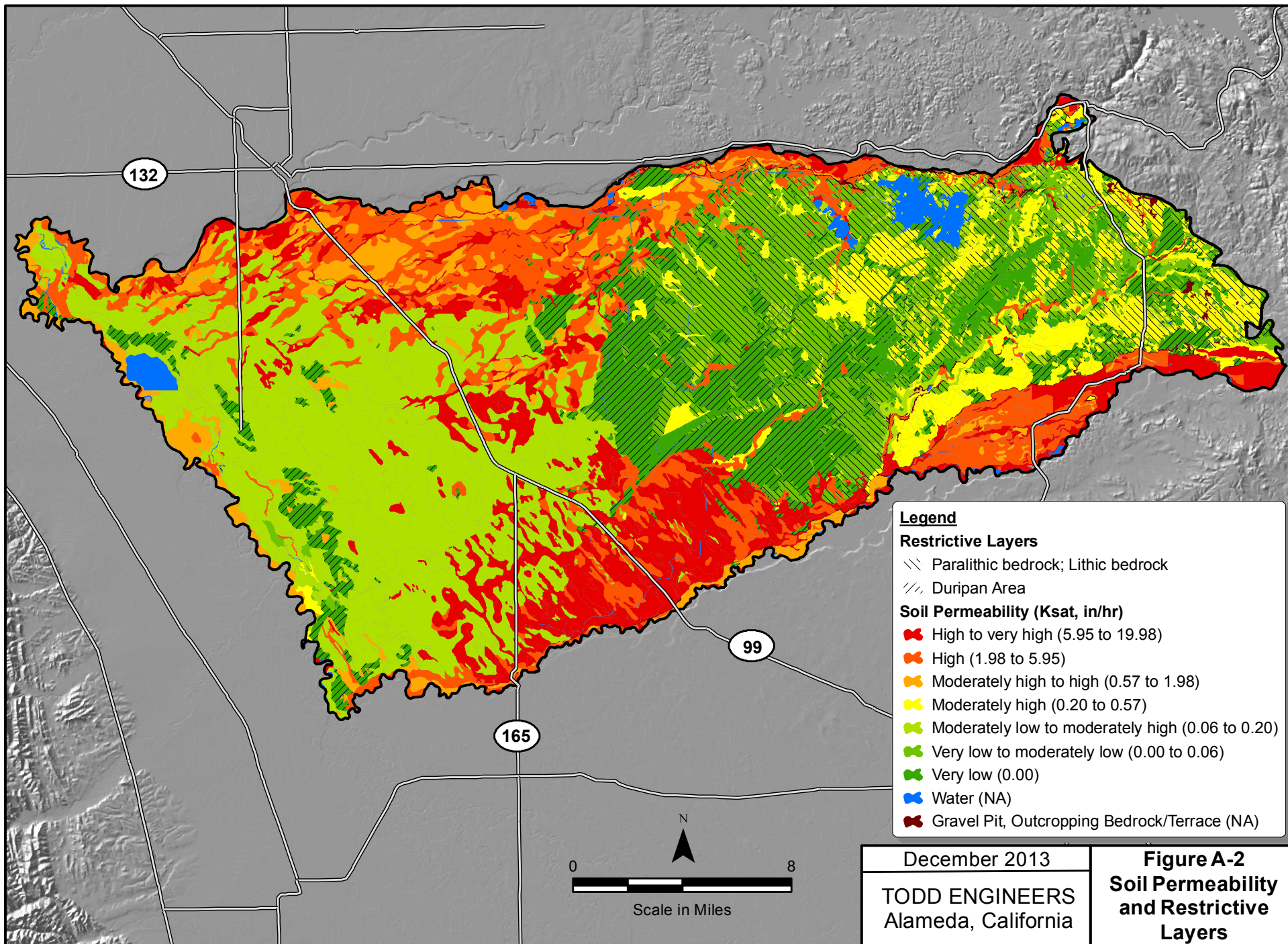


Figure A-3 shows the distribution of soil types with a soil recharge potential greater than zero. For soils in which a restrictive layer is present, a soil recharge potential of zero was assigned and the soil is not shown. In addition, soils with a “very low to moderately low” recharge potential are not shown on Figure A-3. As shown on Figures A-2 and A-3, relatively high permeability soils occur along the northern and southern margins of the basin and in the central region of TID, in the vicinity of Highway 99. Lower permeability soils generally occur within the central axis of the basin. In general, the restrictive features are associated with low soil permeability. Duripan occurs in soils classified as “very low” soil permeability while paralithic bedrock and lithic bedrock occur in soils ranging from “very low” to “moderately low to moderately high.” The low recharge in the eastern region of the basin is primarily due to these geologic restrictive layers.

LAND USE IMPACTS ON RECHARGE

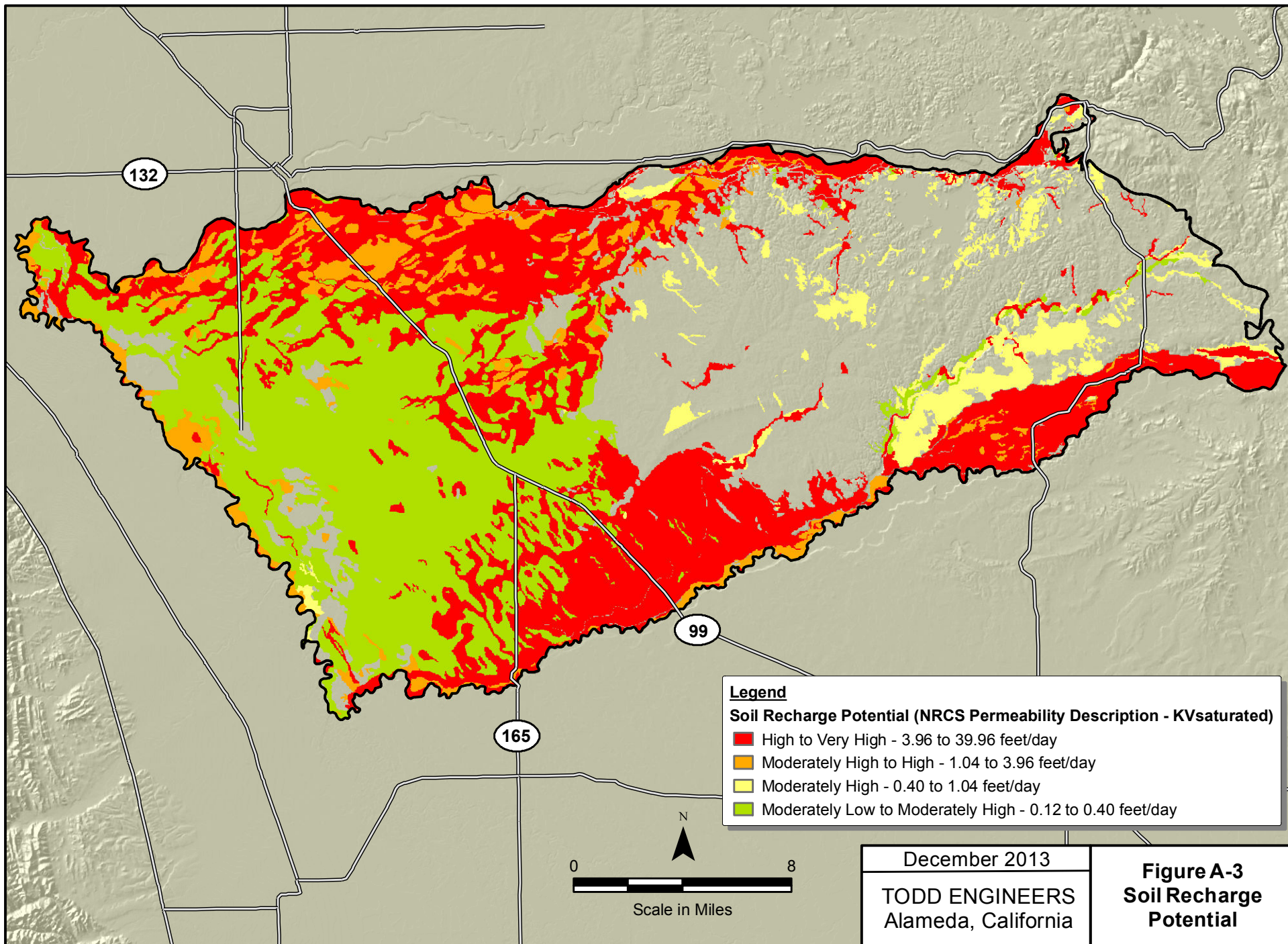
Actual recharge is not only affected by natural surface characteristics, but also by land and water use across the basin. Both surface water and groundwater are used for irrigation. In areas where surface water is available (e.g., TID and Merced ID), irrigation return flows represent recharge that replenishes the groundwater system. In areas where groundwater is the only current water supply (e.g., EWD and other areas east of TID), irrigation return flows also recharge groundwater but serve only to decrease the amount of groundwater removed by pumping. River recharge is controlled by channel permeability but also by annual hydrologic cycles and releases from upstream reservoirs.

Urban areas represent areas of increased paving, buildings, and hard surfaces that can reduce natural recharge. Urban irrigation and managed recharge of stormwater focus urban recharge into relatively small areas.

DISTRIBUTION OF RECHARGE ACROSS THE BASIN

Estimates of annual groundwater recharge volumes in the basin from 1991 to 2002, as modeled by Durbin (2008), are illustrated on Figure A-4. This figure shows that the largest recharge amounts occur in the western portion of the basin within TID. Relatively low recharge amounts occur in the urban areas, such as the City of Turlock, and in areas with low soil permeability. The lowest recharge volumes occur in the eastern foothills and areas outside of TID and Merced ID. Although not shown on Figure A-4, relatively high recharge amounts also occur along the upper reaches of the rivers. Based on water level information, the Tuolumne and Merced rivers are losing in the upper reaches and gaining in their lower reaches (Phillips et al., 2007). The San Joaquin River is gaining within the basin (Phillips et al., 1991). The gaining river reaches represent areas where groundwater is discharging to the river as base flow rather than receiving recharge.

The estimated recharge volumes and percentages from Durbin’s model between 1991 and 2002 (Durbin, 2008) are summarized in Table A-2.



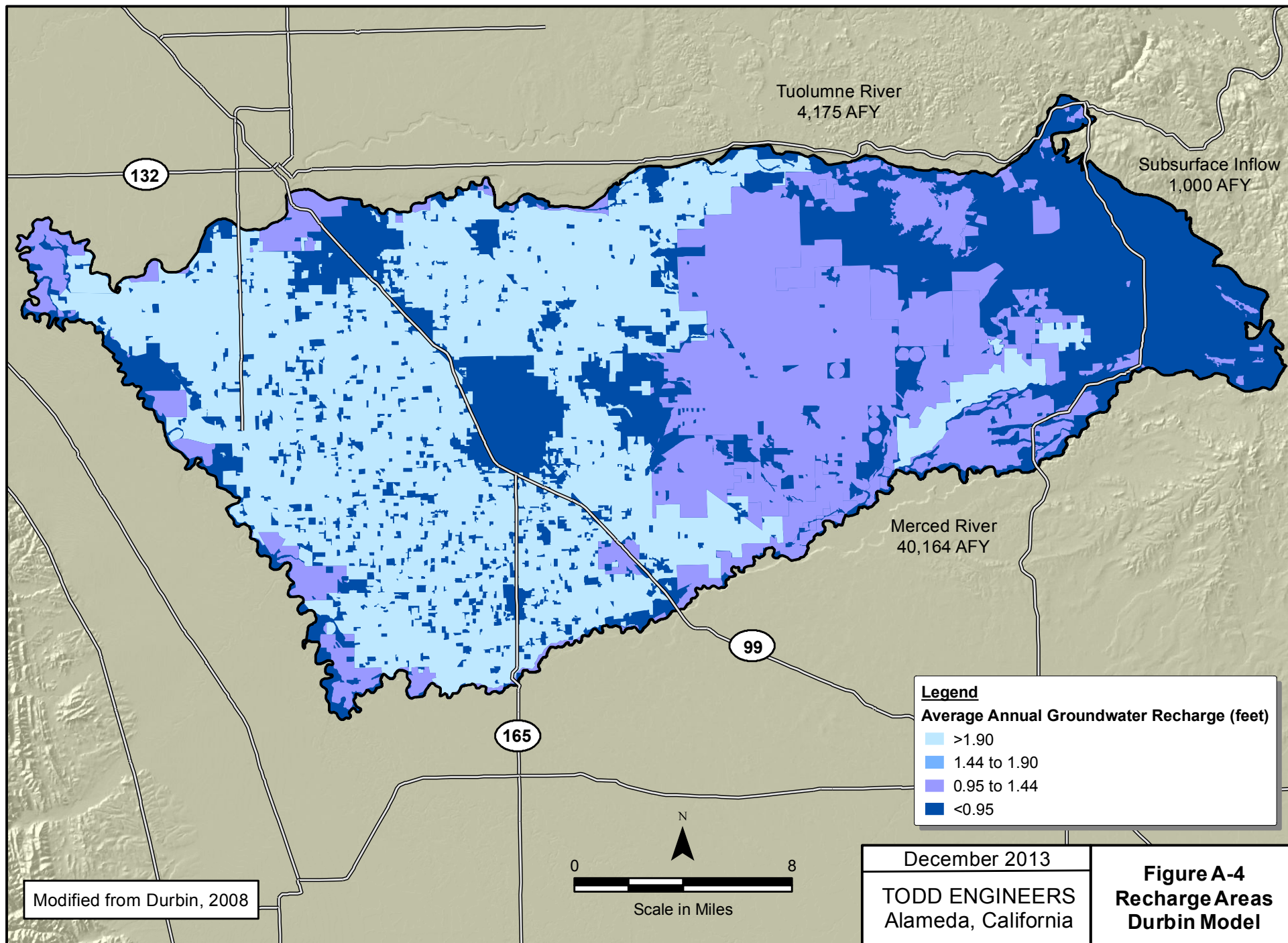


Table A-2 Estimated Steady-State Recharge

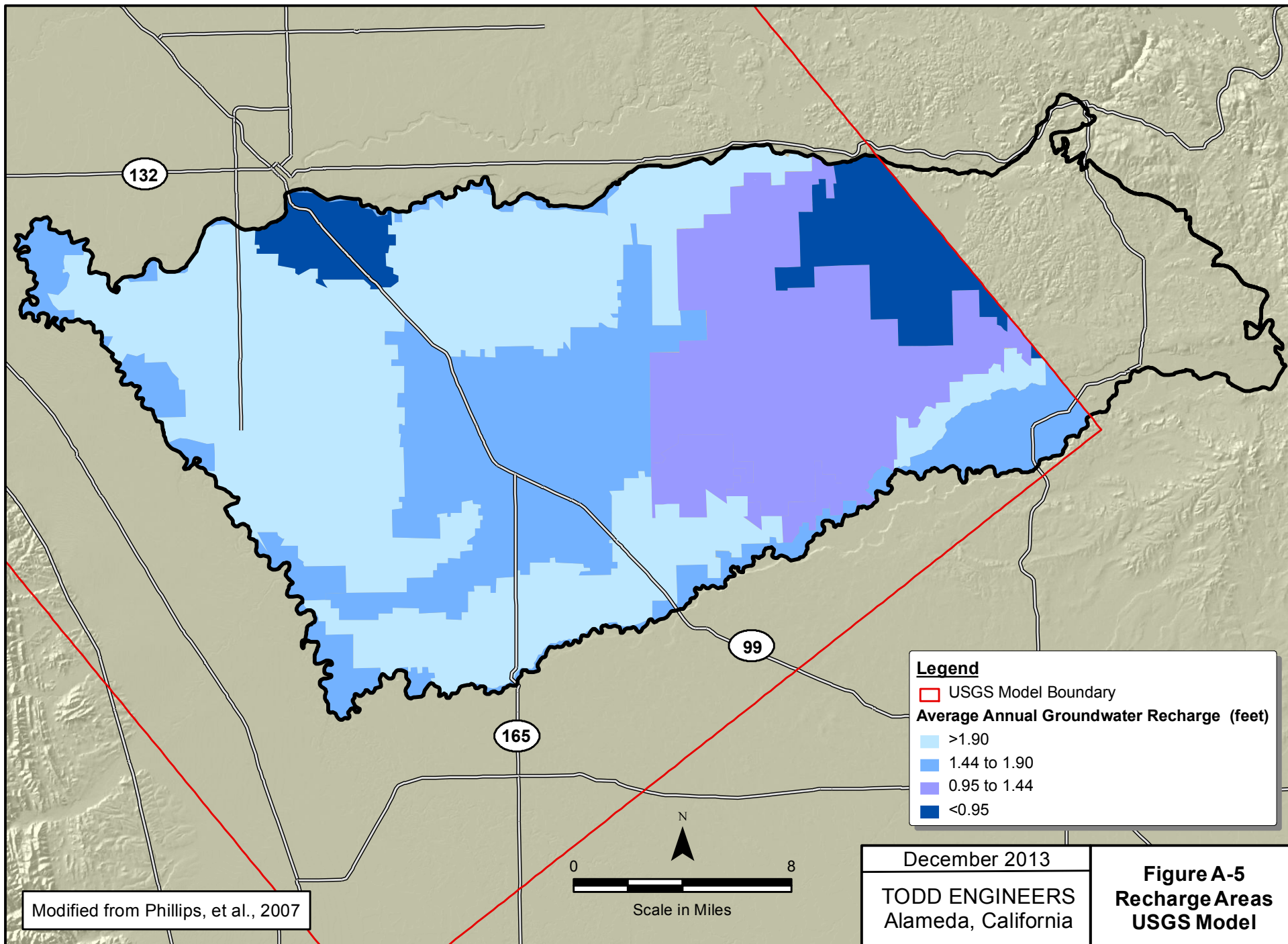
1991 to 2002		
Recharge Components	Acre-Feet per Year	Percentage of Total
Precipitation infiltration (non-irrigated lands)	633	0.1
Tuolumne River	5,933	1
Merced River	46,840	9
San Joaquin River	2,472	0.5
Turlock Lake recharge	69,799	13
Eastside, Ballico-Cortez, and non-district agricultural return flows (from groundwater pumping)	112,564	21
TID (irrigated lands)	264,958	50
Merced ID (irrigated lands)	11,723	2
Municipal and rural residential return flows (from groundwater pumping)	12,378	2
Foothills underflow	1,000	0.2
Deep formation inflow	2,000	0.4
Total	530,300	

Source: Durbin, 2008

The USGS also estimated annual recharge rates based on a water budget to support a regional groundwater flow model for Water Year 2000 (Phillips et al., 2007). This groundwater flow model is in progress, but initial recharge rates are presented on Figure A-5 for a comparison to the Durbin analysis on Figure A-4.

In general, Figures A-4 and A-5 indicate similar regional recharge patterns, although recharge rates vary locally between the two analyses. The differences in recharge rates are a result of the different areas over which recharge is calculated and the hydrologic average conditions represented by on Durbin map. Also, the recharge rates developed by the USGS (Figure A-5) have a more simplified spatial distribution than Durbin's detailed model (Figure A-4). Nonetheless, areas of higher and lower recharge are similar, and are consistent with the hydrogeologic conceptual model of the basin including land use and water use conditions.

Figures A-4 and A-5 present a reasonable distribution of recharge in the basin based on recent and current land and water use practices. However, as land use and water use vary over time, the amounts and locations of recharge will vary accordingly.



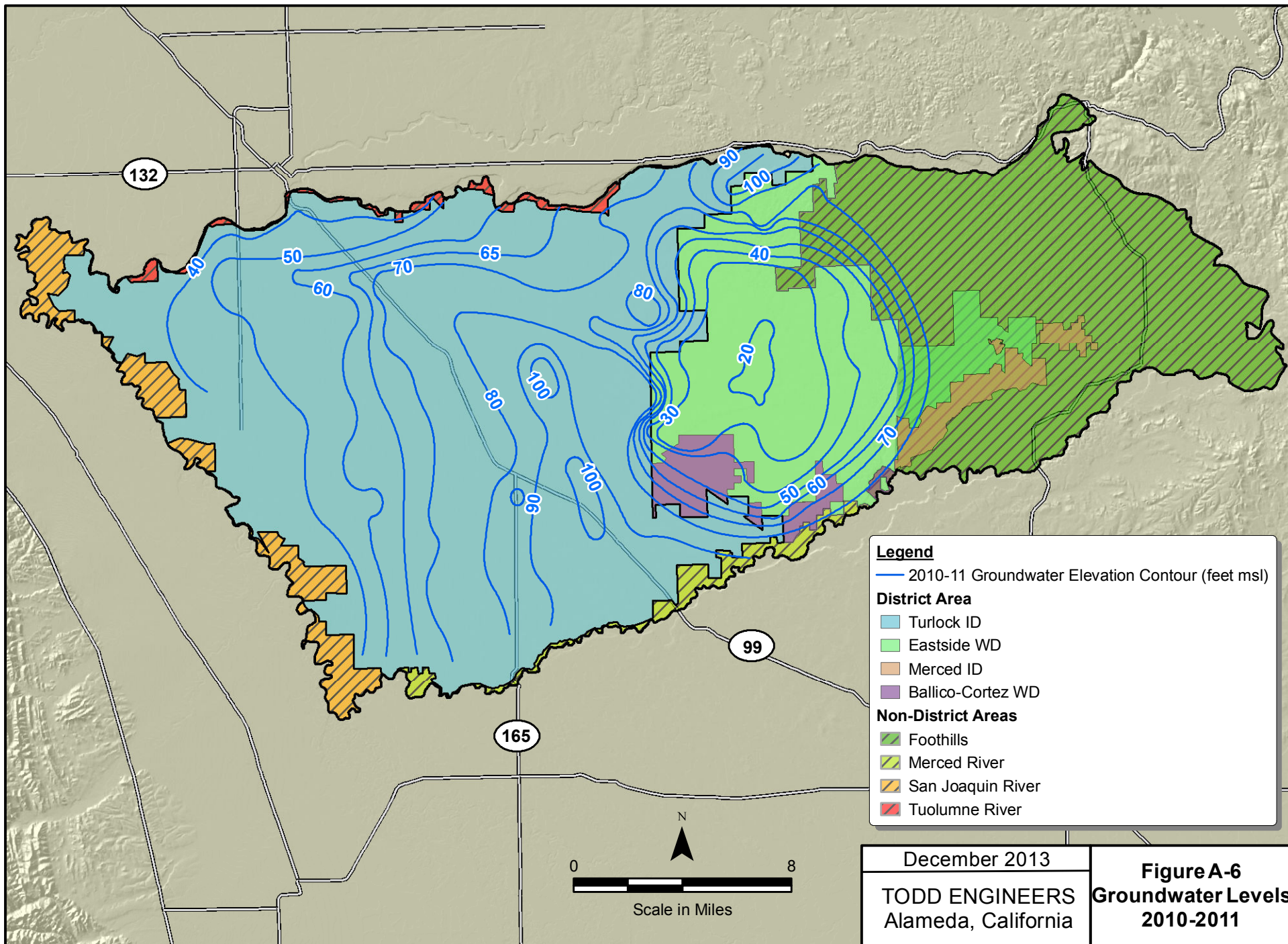
FAVORABLE AREAS FOR ENHANCING GROUNDWATER RECHARGE

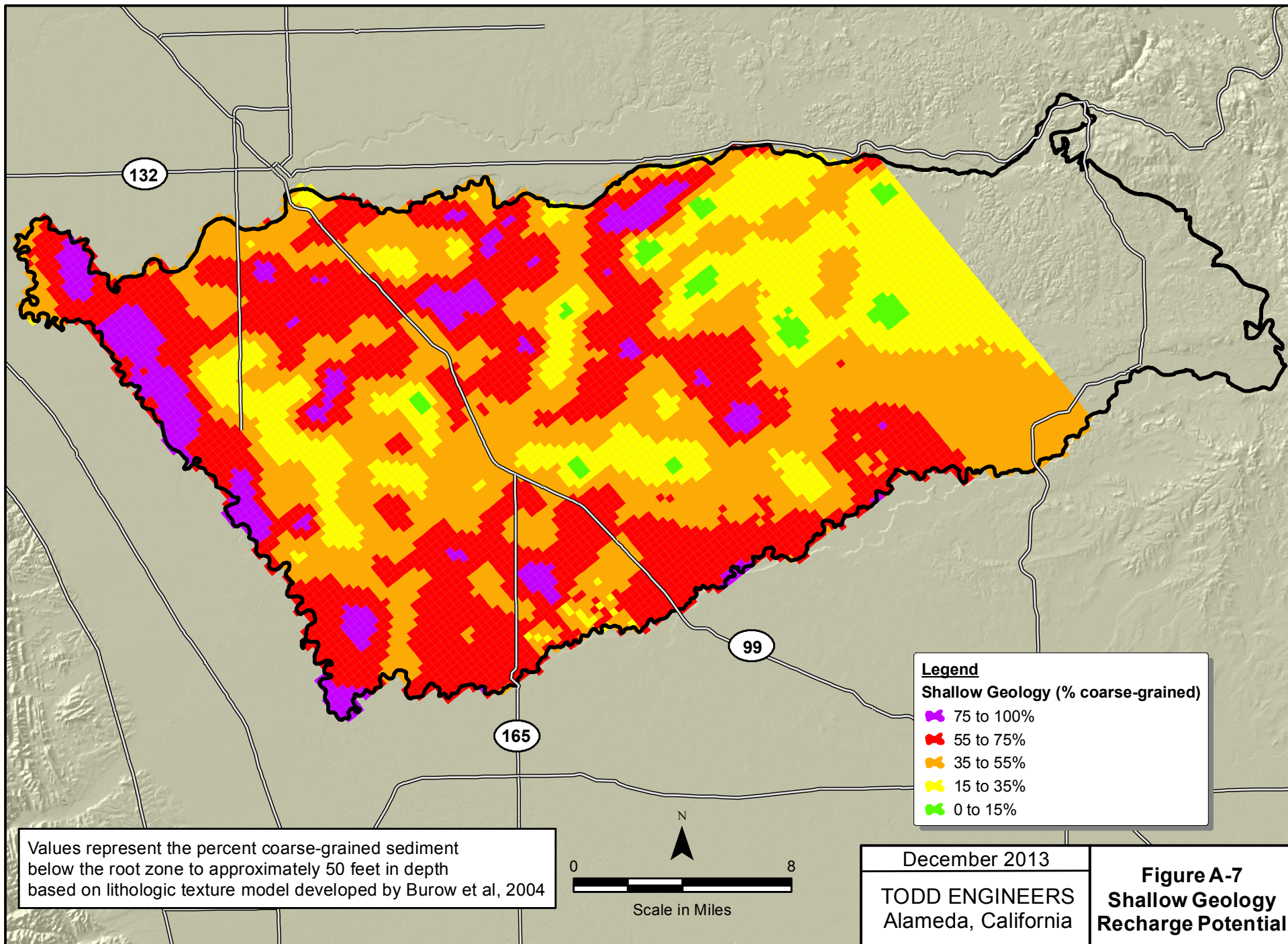
Two additional datasets, depth to water and shallow geology, are evaluated to identify favorable areas for enhancing groundwater recharge based on current groundwater conditions and potential future conditions. For current groundwater conditions, depth to water, based on groundwater elevation contours within the Turlock Basin for 2010-2011, is used to identify areas with sufficient vadose zone storage under current conditions. Shallow geology, based on the percentage of coarse-grained sediment below the root zone and to approximately 50 feet in depth, is used to identify areas where recharge water can sufficiently percolate through the vadose zone to the underlying water table.

Figure A-6 shows groundwater elevation contours within the Turlock Basin for 2010-2011. As indicated by the contours, the general direction of groundwater flow is westward from the foothills to the San Joaquin River. Groundwater elevations range from approximately 40 feet msl in the northwest to approximately 100 feet msl in the central region of the Study Area. Locally, there is a large pumping depression in the vicinity of EWD and Ballico-Cortez Water District with groundwater levels as low as 20 feet msl. Figure A-6 shows a groundwater divide in the central portion of the basin with groundwater flowing from the divide west toward the San Joaquin River and east into the eastern pumping depression.

The 2010-2011 groundwater elevations (Figure A-6) were subtracted from the ground surface elevation, as represented by the Digital Elevation Model (DEM) provided by TID, to estimate depth to water. Areas where the water table was less than 20 feet below ground surface were removed from the analysis due to lack of sufficient available storage.

Figure A-7 shows the shallow geology recharge potential based on the percent of coarse-grained material within the Study Area. The USGS, in cooperation with the Modesto Irrigation District, developed a three-dimensional lithologic texture model for a regional study that includes most of the Turlock Subbasin (Burow et al., 2004). Using a rating scheme to address ambiguity and variability in lithologic descriptions, a subset of 3,504 driller's logs (out of an original 10,000 driller's logs) was incorporated into the texture model. The well dataset includes primarily domestic (61%) and irrigation wells (27%) with a relatively small number of municipal, test, stock, industrial, and undesignated wells (2%). Lithologic descriptions were expressed as a percentage of coarse-grained sediment for one-meter depth intervals starting at 5 meters-bgs (16 feet-bgs), which removes any influence from near-surface soils. A binary classification system of either "coarse-grained" or "fine-grained" was used to assign a texture parameter to each interval noted in the well logs. A texture value of 100 percent was assigned to all intervals classified as coarse-grained, which was defined as consisting principally of sand or gravel including sand; clayey and silty sand; gravel; and clayey, silty, and sandy gravel. A texture value of 0 percent was assigned to all intervals classified as fine grained, which was defined as consisting principally of silt or clay, including silt, clayey silt, clay, and silty or sandy clay. Coarse-grained percentages were then interpolated using three-dimensional kriging over a grid equivalent to the regional model in the horizontal dimension for successive 10-m thick intervals in the vertical direction. A complete explanation of the development of the primary and derivative texture datasets is provided in Burow et al. (2004).





The three-dimensional texture model (which was incorporated into the 16-layer variable thickness regional model) was obtained directly from the USGS. Model layer thicknesses were used to determine the weighted-average, percent coarse-grained sediments from below the soil root zone to approximately 50 feet-bgs. It is assumed that this portion of the vadose zone would most directly influence the ability of recharge water to reach groundwater. It is recognized that the unsaturated zone thickness across much of the study area is less than 50 feet; however, the recharge mapping approach takes this into account by assigning a poor recharge potential for areas characterized by shallow groundwater.

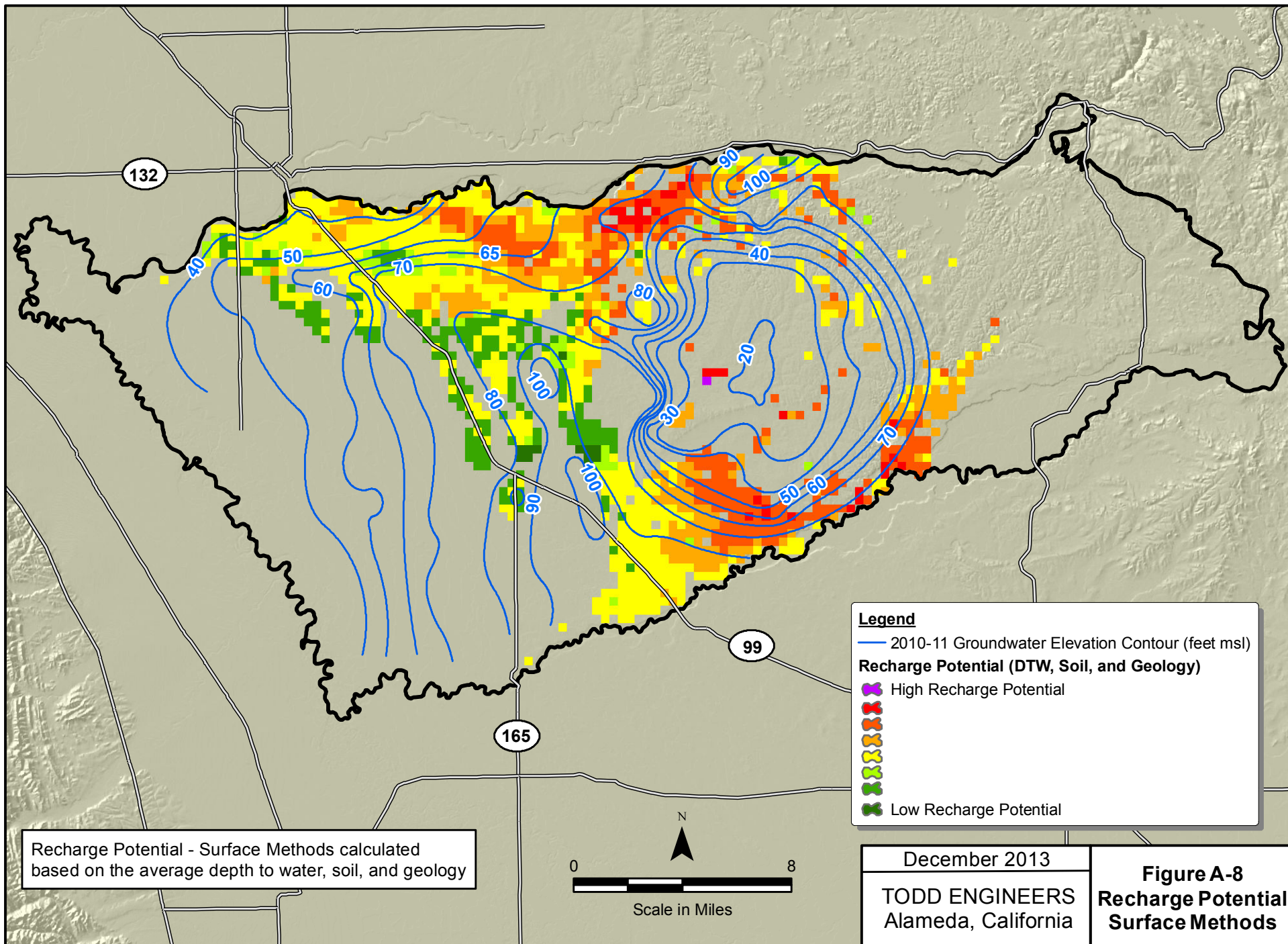
The average percentage of coarse grained sediments identified from below the root zone to approximately 50 feet-bgs was assigned a shallow geology recharge potential. As shown on Figure A-7, there is a high degree of variability in lithology across the Study Area with relatively large areas having 55% or greater coarse-gained sediments. The high degree of variability is not unexpected given the large area covered and the varying geologic deposits represented at the surface and at shallow depths.

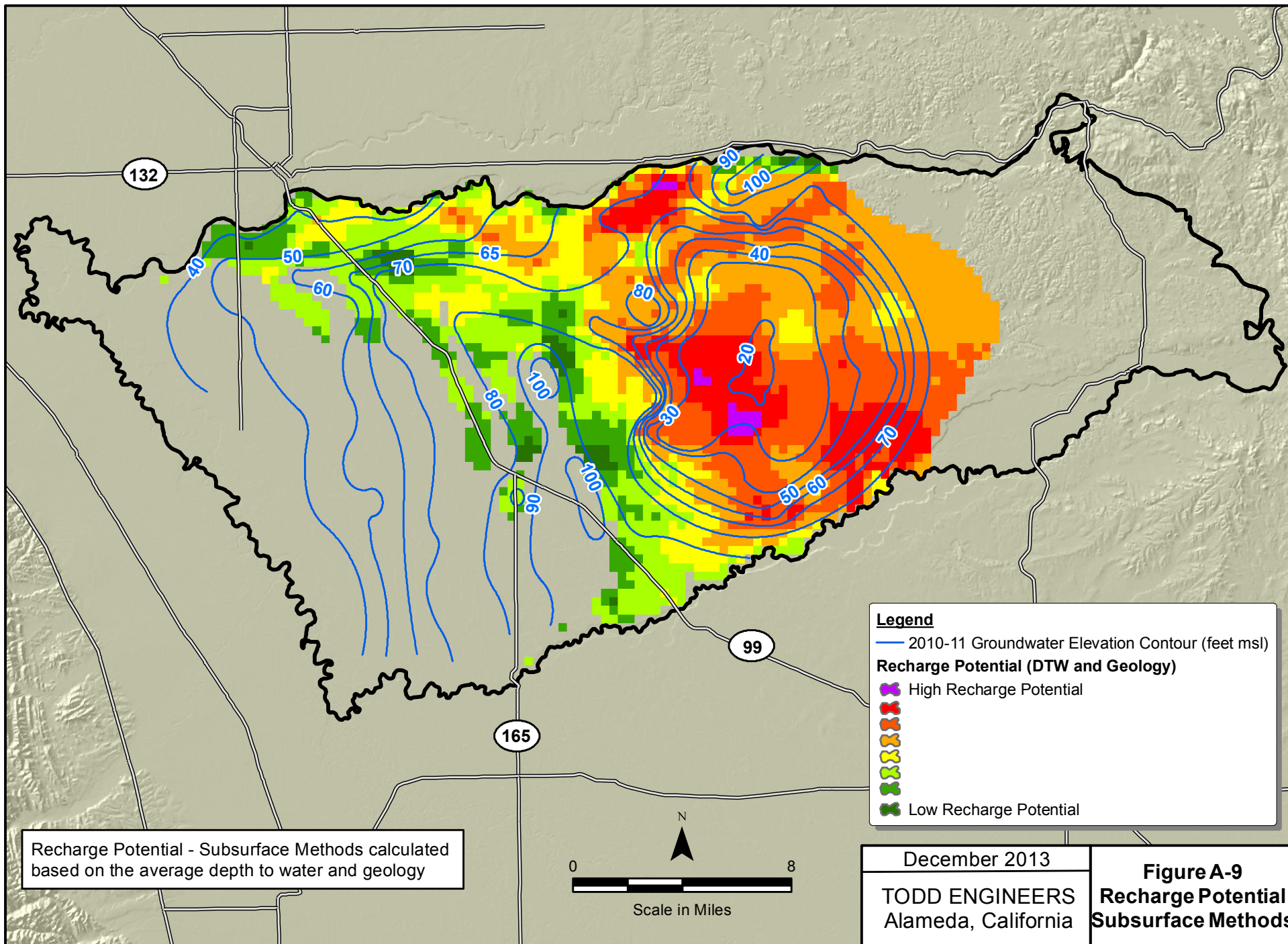
Recharge potential maps were developed based on 2010-2011 groundwater levels (Figure A-6), shallow geology recharge potential (Figure A-7), and soil recharge potential (Figure A-3) for both surface and subsurface groundwater recharge methods. Surface groundwater recharge methods include in-stream check dams in perennial and ephemeral rivers and creeks and off-stream infiltration basins, pits, trenches, and open fields. Subsurface groundwater recharge methods include deep infiltration basins/trenches/pits, vadose zone wells, and direct injection wells.

Recharge potential for surface methods is illustrated on Figure A-8. This map was created by averaging the depth to water, soil recharge potential, and shallow geology recharge potential. Because surface methods are sensitive to soil permeability, areas containing a restrictive layer (see Figure A-2) or a zero or undefined hydraulic conductivity were removed from consideration in this map. As shown on Figure A-8, much of the area overlying the EWD pumping depression is unfavorable for recharge using surface methods due to the presence of duripan, although there are some localized areas (e.g., between the 20 and 30 feet-msl contours) where recharge may be feasible. The map shows that there are areas favorable for recharge using surface methods to the southwest and northwest of the EWD pumping depression.

Recharge potential through subsurface methods is illustrated on Figure A-9. This map was created by averaging depth to water and shallow geology recharge potential. Soil permeability was not considered because it is assumed that surface soils can be bypassed using subsurface recharge methods. This map shows that a more extensive area for recharge is available using subsurface methods. In fact, large areas overlying the EWD pumping depression that are considered unfavorable for recharge using surface methods are favorable using subsurface methods.

Figures A-8 and A-9 illustrate areas favorable for enhancing future groundwater recharge based on 2010-2011 groundwater levels. As groundwater levels change in the future, the areas favorable for recharge will vary accordingly. Changes in groundwater levels and recharge areas are analyzed further in the following section.





AREAS FOR ENHANCING RECHARGE UNDER POTENTIAL FUTURE GROUNDWATER CONDITIONS

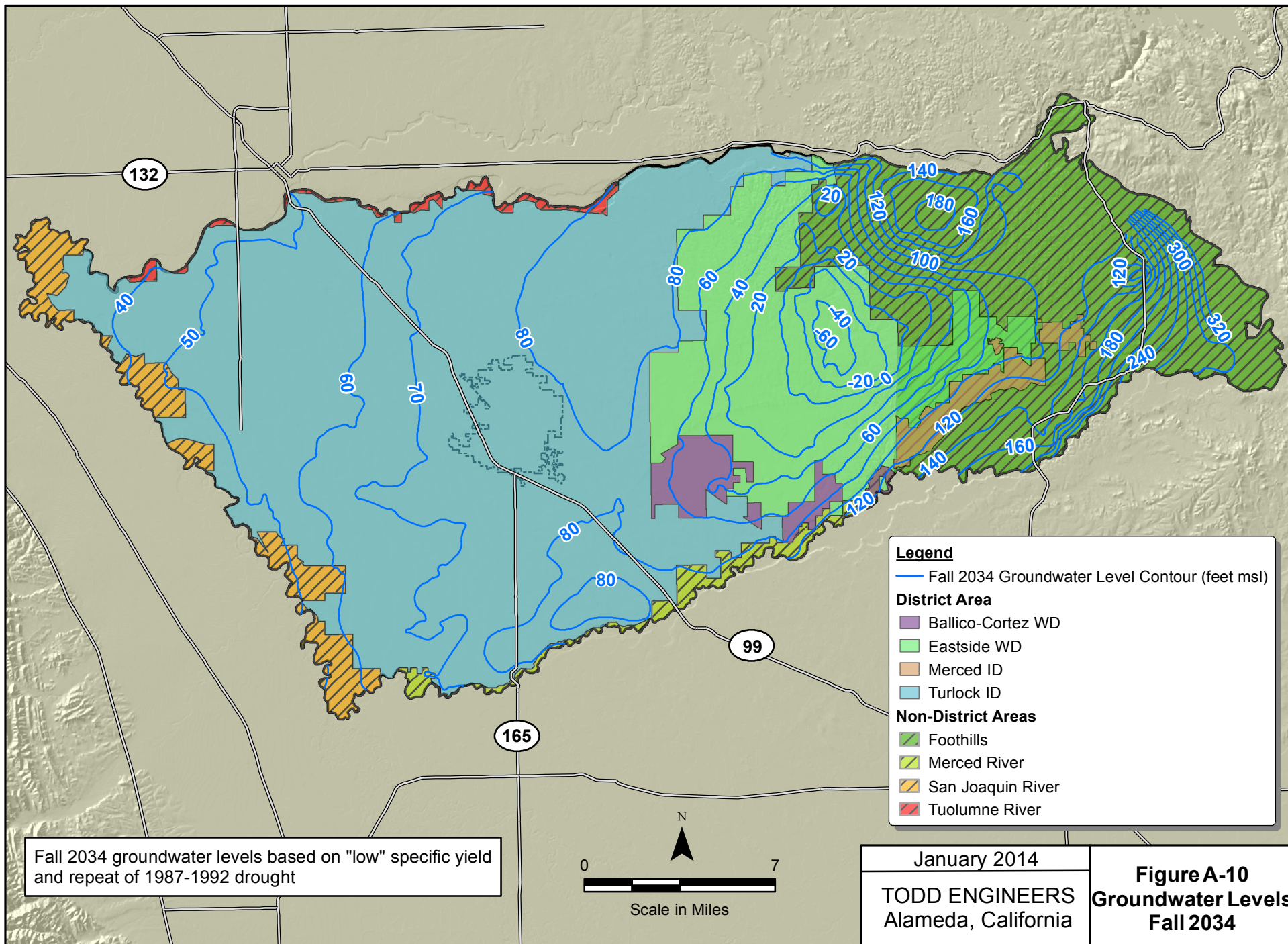
Areas of current and potential recharge have been analyzed herein based on three factors: soil conditions, shallow subsurface geologic conditions, and depth to water. Of these factors, soil and shallow geologic conditions are unlikely to vary substantially in the future. Although soils could potentially be altered with changing land use (e.g., urbanization in certain areas), the depth to water is the factor that will likely change the most on a basin-wide basis. Substantial water level changes can affect recharge potential, as areas currently defined as having a “low recharge potential” because of shallow groundwater may become more favorable if groundwater levels decline.

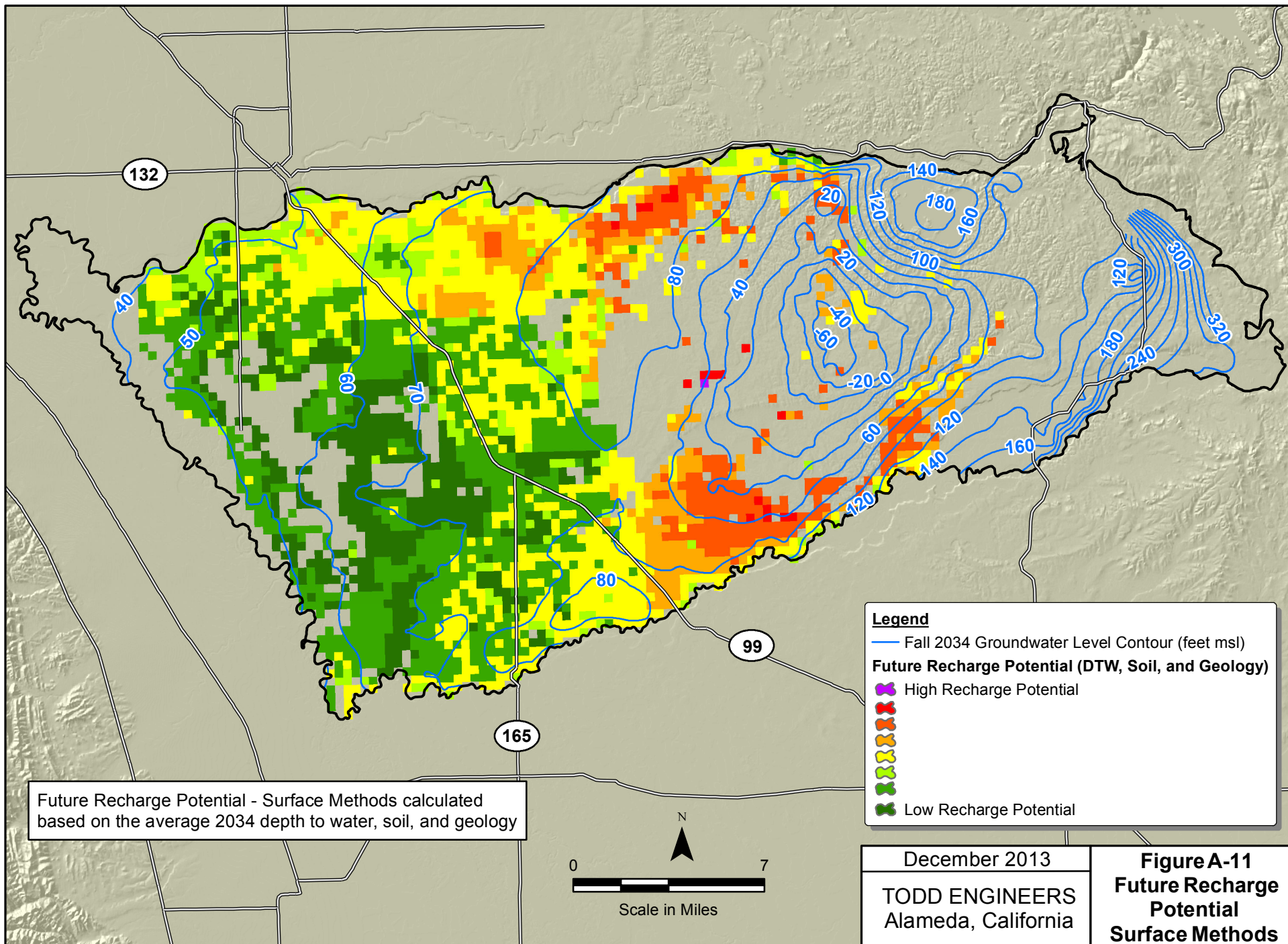
To identify areas where this may occur, simulated Fall 2034 groundwater levels modeled by Durbin (2008) were incorporated into the analysis. The Fall 2034 groundwater levels are shown on Figure A-10. The analysis contains the following assumptions: (1) a “low” (2.2 percent) specific yield for the geologic formations occurring within the eastern part of the Turlock Basin and (2) a repeat of 1987-92 drought conditions. These assumptions provide a reasonable estimate of how water levels might decline under future drought conditions.

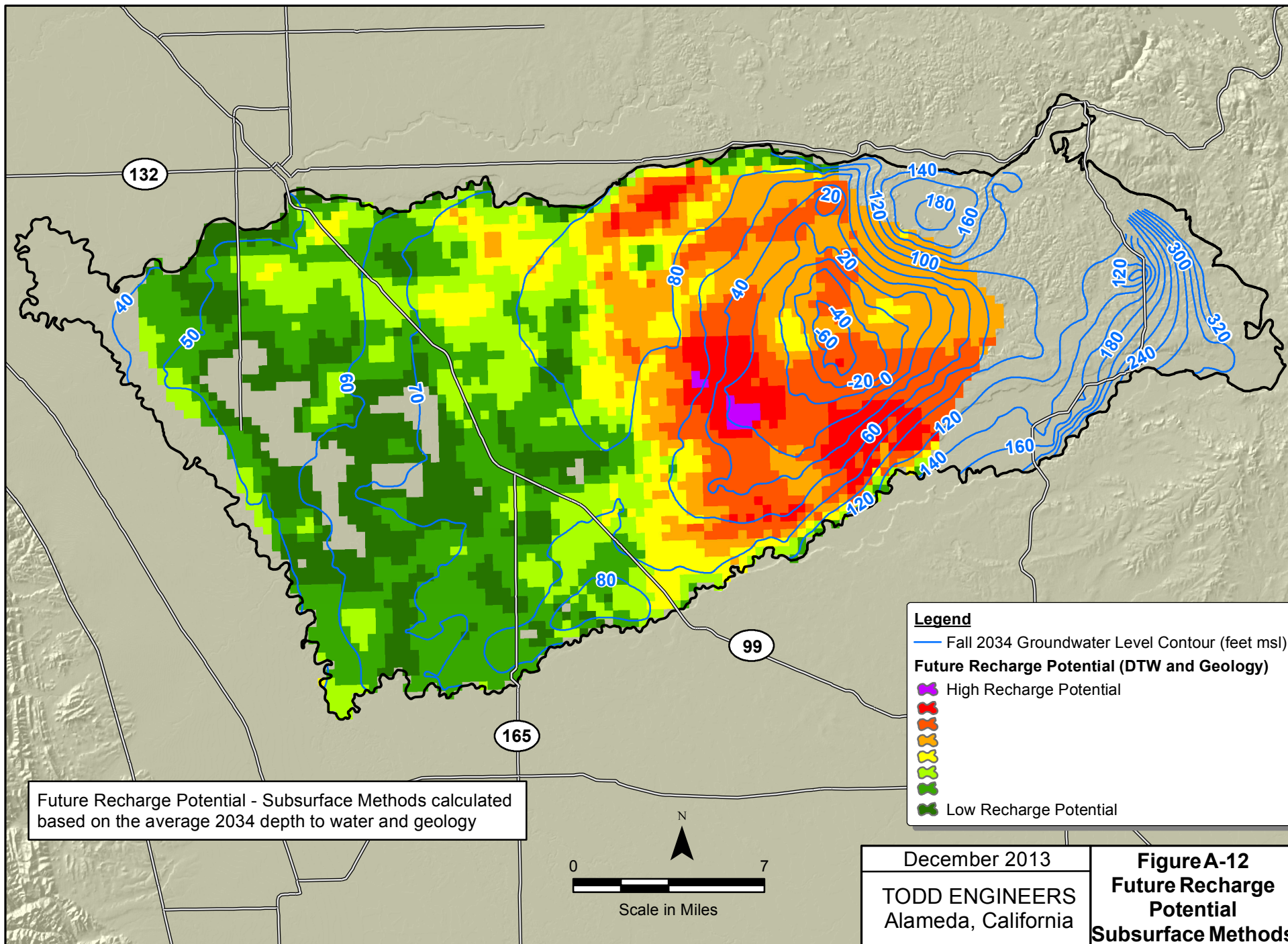
A comparison of Figure A-10 with Figure A-6 indicates that water levels may decline significantly over time. Water level declines of about 10 to 20 feet are predicted for most of the TID area, while declines of more than 60 feet are predicted in areas within EWD.

The 2034 groundwater level contour map was used to develop a “future condition” depth to water to be incorporated with the existing soil permeability and shallow geology data sets. This analysis was used to develop surface and subsurface recharge potential maps for future groundwater conditions. Future (2034) recharge potential maps are based on reasonable assumptions for urban growth, irrigated acreage, surface water deliveries, groundwater pumping, and other factors incorporated in the numerical groundwater model.

Figure A-11 identifies areas favorable for enhanced recharge using surface methods based on simulated Fall 2034 groundwater level conditions. Figure A-12 identifies areas favorable for enhanced recharge using subsurface methods, which are insensitive to soil permeability. As shown on both figures, predicted future groundwater level declines in the central and eastern portions of TID may provide additional recharge opportunities in the future. A comparison of Figure A-8 with Figure A-11 and Figure A-9 with Figure A-12 indicate that favorable areas based on current water levels also remain favorable under future conditions.







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