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MEMORANDUM

To:	Walt Ward, MID Tom Lutterman, DWR	**CC:**	Eric Hong, DWR
From:	Matt Zidar Jim Blanke	**Date:**	May 2, 2007
Subject:	**Recharge Characterization for Stanislaus and Tuolumne Rivers Groundwater Basin Association**		
Project Reference:	317.T01.00		

INTRODUCTION AND PURPOSE

The Stanislaus and Tuolumne Rivers Groundwater Basin Association (STRGBA) was formed through a Memorandum of Understanding between the cities of Modesto, Oakdale, and Riverbank; Modesto Irrigation District (MID); Oakdale Irrigation District (OID); and Stanislaus County. The purpose of the STRGBA is to coordinate groundwater management activities between the local agencies. An important component of groundwater management is identification of groundwater recharge areas.

The purpose of this analysis was to define recharge areas by evaluating physical characteristics (e.g., soil type, depth to water, hydrogeology) and anthropogenic (human-influenced) conditions. The information may be used by STRGBA to identify potential locations for artificial recharge facilities, or to define where additional management practices should be considered as part of the overall groundwater management and protection program.

Understanding of recharge areas and mechanisms helps identify where recharge is occurring currently and where it has occurred in the past. Given that water can remain in the ground for tens, hundreds, or thousands of years, preserving historical recharge areas is an important groundwater management consideration. Identification of recharge areas and mechanisms can also assist in preserving and managing important natural features such as riparian areas or stream channels. Anthropogenic recharge, particularly deep percolation from agricultural irrigation, is a key source of recharge in the STRGBA area. Identifying where this and other human-influenced recharge is occurring can provide an assessment of current recharge and assist in the recognition of the effects of land use change.

This memorandum presents a detailed analysis of the various physical conditions and recharge processes to identify areas with high and low recharge potential.

BACKGROUND

The references listed in the back of this technical memorandum identify previous studies performed in the Modesto Groundwater Subbasin and in the greater San Joaquin Valley that were reviewed as part of this evaluation. R. W. Page performed studies for the United States Geological Survey (USGS) in the 1970s. These studies included data on geology, water quality, hydrology, wells, and groundwater modeling in the Modesto area. Recent USGS studies conducted as part of the National Water-Quality Assessment (NAWQA) and other programs, contain regional water quality information from the Modesto area (e.g., Kratzer, 1998, and Wright et al., 2004). In 2005, the *Integrated Regional Groundwater Management Plan for the Modesto Subbasin* was published by the STRGBA. Other reports by the California Department of Water Resources (DWR) and the USGS provided valuable information on regional geology and hydrogeology.

The most recent comprehensive, regional scientific investigation done in the area by the USGS is the *Hydrogeologic Characterization of the Modesto Area, San Joaquin Valley, California* (Burow et al., 2004). This USGS report builds on the previous work cited above and includes a substantial amount of new hydrologic data. The USGS report also describes the development of a MODFLOW groundwater model. One purpose of the MODFLOW model is to quantify the water budget and recharge in the area.

The analysis presented in this memorandum utilized the existing documents and data to further characterize groundwater conditions.

HYDROLOGIC SETTING

This section provides a brief summary of the hydrogeologic setting in the study area. For more detailed information, please see *Hydrogeologic Characterization of the Modesto Area, San Joaquin Valley, California*, which is available at http://pubs.usgs.gov/sir/2004/5232/ at the time of publication of this memorandum. Figure 1 shows the study area, which includes most of Stanislaus County.

SURFACE WATER

The two primary sources of surface water to the STRGBA area are the Tuolumne River and the Stanislaus River which flow toward the west-southwest through the study area to their respective confluence with the San Joaquin River. Both the Tuolumne and Stanislaus Rivers have large watersheds of 1,600 and 1,100 square miles, respectively (Burow et al., 2004), and originate in the Sierra Nevada where precipitation is typically more than 50 inches per year.

The study area itself receives between 11 and 15 inches of rain annually, increasing from west to east (DWR, 2003). The water in the Tuolumne and Stanislaus Rivers is the main source for irrigation in the STRGBA area.

HYDROGEOLOGY AND GROUNDWATER

The Modesto Groundwater Subbasin is a 385–square mile basin between the Stanislaus River to the north and Tuolumne River to the south and between the San Joaquin River to the west and the crystalline basement rock of the Sierra Nevada foothills to the east (DWR, 2003). The analysis also includes the Stanislaus County portion of the Turlock Groundwater Subbasin, immediately to the south and west of the Modesto Groundwater Subbasin, portions of the Delta-Mendota Groundwater Subbasin to the southwest, and portions of the Eastern San Joaquin Groundwater Subbasin to the north.

The groundwater basin is a complex sequence of overlapping sediments largely deposited and shaped from the Stanislaus and Tuolumne Rivers. A defining feature of the groundwater basin is the Corcoran Clay, which is located beneath the southwestern part of the basin at a varying depth of around 200 feet. The groundwater system in the Modesto Basin consists of an unconfined aquifer above and to the east of the Corcoran Clay and a confined aquifer below the Corcoran Clay. There are also many clay lenses in the basin that restrict the downward flow of groundwater and result in semi-confined conditions.

The unconfined aquifer system is made up of unconsolidated sediments from Quaternary deposits, including the Modesto, Riverbank, and Turlock Lake Formations. These formations generally have moderate to high yields. The general groundwater flow direction in the unconfined aquifer is to the west and southwest; however, well pumping and recharge affect the localized groundwater flow direction and levels. For example, groundwater levels are very high west of Highway 99 and along the Tuolumne and Stanislaus Rivers.

Generally, domestic wells are pumping at shallow depths in the unconfined aquifer while irrigation and municipal wells are pumping from the deeper zones (Burow et al., 2004).

ALTERNATIVE METHODS FOR ANALYSIS OF RECHARGE AREAS

Three general methods of recharge analysis that have been applied to other areas were evaluated for application to this investigation, including:

1. Remote sensing,
2. Hydrologic modeling, and

3. GIS overlay.

1. The remote sensing method uses an airborne platform to capture images from different bands of the electromagnetic (EM) spectrum. Analysis of the images can yield information on groundwater level and quality. At the simplest level, remote sensing can be an analysis of the visible spectrum (a standard aerial photograph), looking at factors such as plant distribution, appearance, and growth. For example the presence of green native vegetation in autumn when there has been no precipitation in several months often means that the groundwater levels are near the surface in that area. Also, the type of vegetation can be an indicator of the groundwater chemistry as some plants are more suited to grow in saline water.

   Other methods utilize the infrared (IR) spectrum. Analysis of remote sensing data often needs to be done in conjunction with existing geological maps and other available data. Remote sensing methods are more difficult to implement in developed agricultural or urban areas because the conditions on the ground as seen from the images are often a result of human activities. Results typically should be verified by detailed field analysis.

2. The hydrologic model method uses a computer simulation of the groundwater system and related processes to calculate the groundwater levels in the aquifer. This method can potentially produce the most accurate results. However, this method also requires large, complete volumes of high quality input data and significant time to develop, calibrate, and operate. The USGS model developed for the Modesto area was used by the USGS to evaluate the water budget for the area and to quantify recharge over variable hydrologic conditions.

3. The Geographic Information System (GIS) overlay method analyzes available spatial data and integrates the information to interpret physical conditions and produce a single, aggregate map. The process involves multiple steps which typically might include:

   - Obtaining or creating GIS datasets that influence groundwater recharge;
   - Applying ranking criteria and weights to each dataset;
   - Overlaying and analyzing the data layers and conducting calculations to aggregate data to produce a map showing preferred areas for groundwater recharge.

RECHARGE ANALYSIS APPROACH

Based on the available data, prior analysis for the area, and ability to produce an understandable work product, the GIS overlay method was selected as the preferred approach for the STRGBA recharge analysis. The investigation described in this technical memorandum used some of the USGS modeling results and related data, and is intended to compliment the modeling work by providing an independent, map based analysis of the recharge areas in the STRGBA region. The remainder of the memorandum covers the procedure and results of the analysis.

Digital data were collected and used to identify suitable recharge areas in the STRGBA area. These data, available in GIS compatible digital files, were used to evaluate the three recharge conditions presented in Table 1.

Table 1. Types of Data Used to Evaluate Recharge Conditions

	Natural	Anthropogenic	Project Siting
Hydrologic soils group	√	√	√
Soil texture at 5 meters (16 feet)	√	√	√
Soil texture at 10 meters (33 feet)	√	√	√
Soil texture at 25 meters (82 feet)	√	√	√
Slope	√	√	√
Corcoran clay	√	√	√
Land use		√	√
Depth to groundwater			√

An index ranking system was developed and applied using GIS. The features on each dataset were ranked on a scale from 1 to 5 with 1 being least favorable conditions and 5 being most favorable conditions. An index value of zero was given for situations that would preclude recharge or location of a successful project. Additionally, each dataset was weighted based on its importance in determining recharge. The ranking factors and quantification methods are shown in Table 2. Weighting factors are shown in Table 3.

Table 2. Ranking Factors and Quantification Methods

Factor	Quantification Method	Attribute	Ranking Index		
			Natural Recharge	Anthropogenic Recharge	Facility Siting
Appropriate land uses	Land use is quantified by land use maps	Land Use			
		Idle		3	5
		Vacant		3	4
		Field Crops		5	3
		Pasture	N/A	5	3
		Other Crops		5	2
		Urban, Semi Ag		1	1
		Riparian, Water		5	0
		Native		3	0
Surface and Subsurface Conditions	Soil permeability is quantified using soils data from USDA-NRCS soil surveys in combination with slope and the presence of the Corcoran clay.	Hydrologic Soils Group			
		Type A	5	5	5
		Type B	3.75	3.75	3.75
		Type C	2.5	2.5	2.5
		Type D	1.25	1.25	1.25
		Water/Dumps	0	0	0
		Slope (degrees)			
		0–2	5	5	5
		3–5	4	4	4
		6–8	3	3	3
		9–15	2	2	2
		16+	1	1	1
		Corcoran Clay			
		Absent	5	5	5
		Present	1	1	1
Available storage	Available storage is quantified by soil texture and depth to water	Soil texture			
		(% Coarse			
		Grained			
		Materials)	5	5	5
		80–100	4	4	4
		60–80	3	3	3
		40–60	2	2	2
		20–40	1	1	1
		0–20			
		Depth to Water			5
		(feet)			4
		>50	N/A	N/A	3
		40–50			2
		30–40			1
		20–30			0
		10–20			
		0–10			

Table 3. Weighting Factors

Attribute	Weighting Factor		
	Natural Recharge	Anthropogenic Recharge	Facility Siting
Land Use	N/A	5	3
Hydrologic Soils Group	5	5	5
Slope	1	1	2
Corcoran Clay	1	1	1
Depth to Water	N/A	N/A	5
Soil Texture	5	5	5

Hydrologic soils group shows the capability of near-surface soils to infiltrate water. The classification of the hydrologic soil groups is provided by the United States Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS); the soils groups are shown on the USDA-NRCS soils maps. Areas identified as having smallest runoff potential (i.e., the highest capacity for infiltration) (Type A) are ranked highest, and areas identified as having greatest runoff potential (Type D) are ranked lowest. A map of the Hydrologic Soil Groups is shown in Figure 2A. A map of the ranking index for Hydrologic Soil Groups used in the recharge analysis is shown in Figure 2B. Unmapped areas, such as in central Modesto, were estimated using nearby hydrologic soils group classifications.

Soil texture at depth identifies areas that have both an ability to store water and to transmit water due to large grain sizes, such as sands and gravels. Three depth intervals were selected to focus on the shallow subsurface environment: 5 meter, 10 meter, and 25 meter. These three layers were averaged into one layer of the average soil texture found in the shallow subsurface. Figure 3A shows this averaged soil texture layer measured by percent of coarse-grained materials. Figure 3B shows the ranking index for soil texture.

Areas with significant slope result in more rainfall running off to streams and rivers rather than infiltrating to groundwater. As slope is not considered in the USDA classification of hydrologic soils group, this dataset can show where slope can decrease the natural infiltration. A map of the slope of the land measured in degrees is shown in Figure 4A. A map of the ranking index for slope is shown in Figure 4B.

The Corcoran Clay limits the vertical migration of water in the western portion of the study area and is typically observed 200 feet below ground surface. The Corcoran Clay would not greatly inhibit surface recharge or preclude the development of recharge projects—unless the Clay results in local high water levels—or the recharged water quality could be degraded. Site-specific investigation should be conducted prior to locating recharge facilities. Figure 5A shows the extent of the Corcoran Clay and Figure 5B shows the Corcoran Clay ranking index.

Human development, as shown through land use patterns, has a significant impact on the recharge of the groundwater system. Increased impervious surfaces, such as asphalt, concrete, or structures, increase runoff and decrease recharge. Other land uses, such as irrigated agriculture where significant amounts of surface water are applied, result in deep percolation of applied water and increased groundwater recharge. A detailed land use map for the study area is shown in Figure 6A. The ranking index map of land use that is used for the anthropogenic recharge analysis is shown in Figure 6B. The ranking index map of land use that is used for the facility siting analysis is shown in Figure 6C.

Depth to groundwater can limit recharge if groundwater is too close to the ground surface. Recharge resulting in high water tables may damage crops, particularly deep-rooted crops such as tree crops. Depth to groundwater is calculated by taking the difference of land surface elevations on groundwater elevation. The groundwater elevation, calculated depth to water, and depth to water ranking index are shown in Figures 7A, 7B, and 7C respectively.

RESULTS

NATURAL RECHARGE

Figure 8 shows the results of the Natural Recharge Index. The results show that most natural recharge from rainfall and stream flow sources occurs in the flat areas with highly permeable soil to the east of Highway 99 and along the Stanislaus and Tuolumne Rivers.

ANTHROPOGENIC RECHARGE

Figure 9 show the results of the Anthropogenic Recharge Index. The results are somewhat similar to Figure 8 except that recharge is less in urbanized areas, such as the cities of Modesto, Oakdale, and Turlock, and higher on the surrounding irrigated agricultural lands.

POTENTIAL FOR ARTIFICIAL RECHARGE

Figure 10 shows the results of the Facility Siting Index. The results show that the most promising locations for recharge facilities are generally from Highway 99 to about 10 miles to the northeast. Areas to the southwest of Highway 99 and along the rivers generally rank lower because of high groundwater.

DATA GAPS

Sufficient data was available to characterize recharge in the study area. As with most studies, additional data could improve or expand the analysis. Data that would contribute the most toward improving the results are canal and water quality data. The GIS analysis has been developed in a flexible form such that additional data can be incorporated into the analysis as it becomes available.

CANAL ATTRIBUTES

Canal capacity and lining information was not readily available for the study area in a format suitable for inclusion in the GIS analysis. Figure 11 shows the location of the canals as provided by Stanislaus County; however, the dataset does not contain attributes to determine where the canals are lined or unlined. With the exception of the MID Upper Main Canal, MID canals are generally unlined upstream of the Modesto Reservoir and concrete lined below the Reservoir, while OID's canals are unlined. The presence of unlined canals would affect the anthropogenic recharge since the percolation of irrigation water lost in canals could be an important source of present-day groundwater recharge. Canal capacity data would also help identify which canal facilities could be used to cost-effectively convey water to potential recharge locations. Capacity data (shown for MID canals in Figure 12) is not available in GIS format and was not included in the analysis.

WATER QUALITY

Regional water quality and point source water quality data was not readily available for the study area in a format suitable for inclusion in the GIS analysis. Local groundwater quality should be investigated when siting recharge facilities. If clean water is percolated into the aquifer in areas where the water quality is poor, such a condition could degrade the recharged water such that the water could not be pumped out later and put to beneficial uses. Recharging water can also change the localized groundwater flow patterns, which could potentially move plumes of contaminated water in undesirable directions.

GROUNDWATER ELEVATION

Current groundwater level data were available for the study area from the 2004 USGS study. However, the contours in this study did not cover the entire western portion of the study area and did not provide good detail near the rivers. For this reason, the Facility Siting Index in Figure 10 could not be calculated past the western extent of the groundwater level data and a portion of the western part of the study area is blank. Also, water levels near the rivers were interpolated using the closest contours. It should be noted that the area in the western portion of the study area not covered by the groundwater elevation dataset typically has groundwater close to the surface, making surface recharge more limited than for other areas.

CONCLUSIONS

Understanding recharge is important for effective management of groundwater. This analysis characterized recharge in three ways: natural, anthropogenic, and for purposes of locating recharge facilities.

The analysis method selected is relatively straightforward, transparent, and repeatable. The details of the analysis, the ranking and weighting of the datasets, should help improve the awareness of the STRGBA stakeholders of the importance of the recharge areas to the overall management and operation of the groundwater basin. This awareness is intended to facilitate further discussion regarding how to best manage the local resources.

The results from the analysis presented herein show the relative capability for recharge or suitability for recharge projects. Based on these results, location of historical and current recharge areas, impacts of current and future land use changes, and where to concentrate efforts at purchasing land for recharge facilities can be better understood and put to use for future groundwater management activities.

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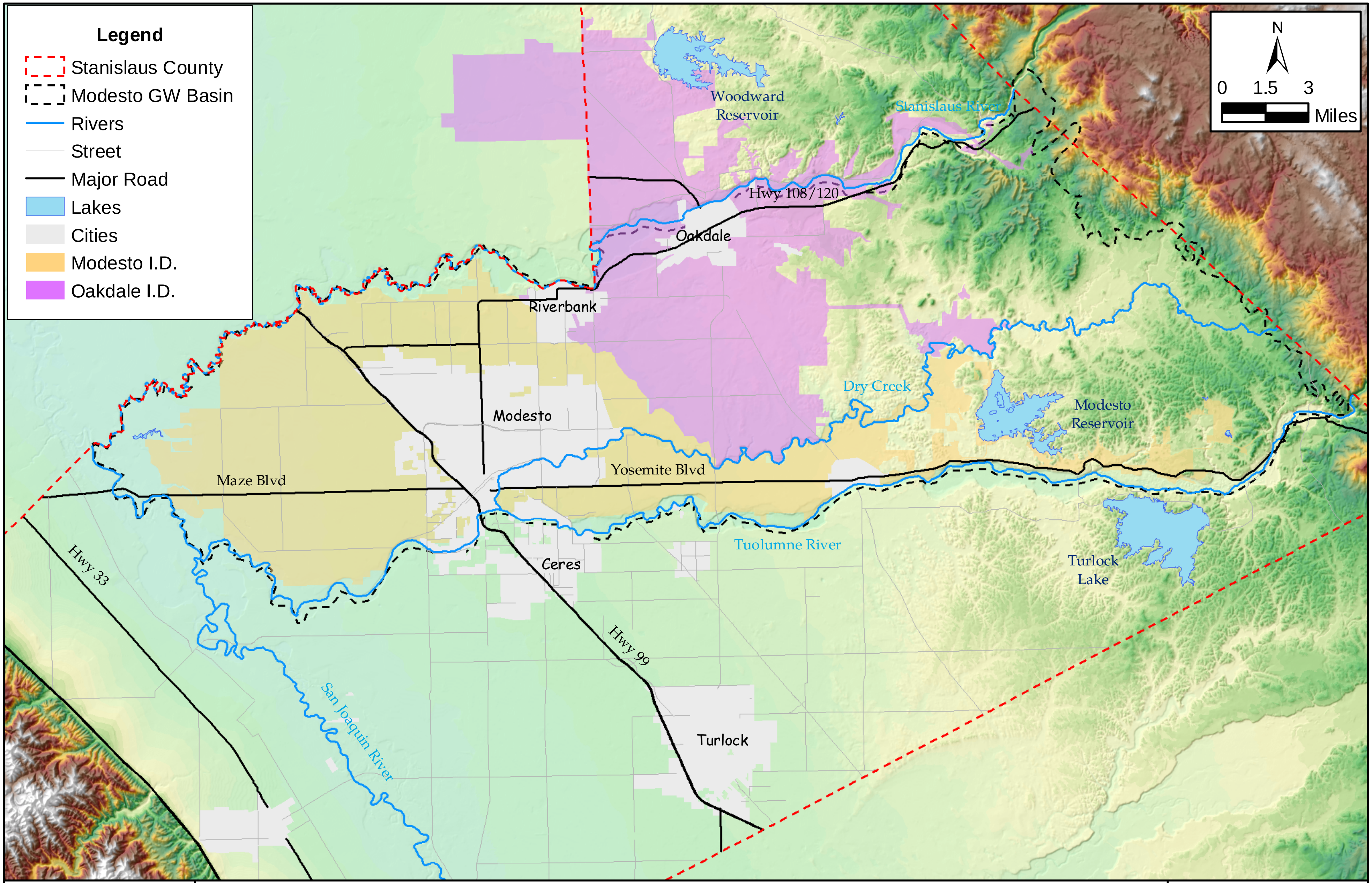

Study Area

STRGBA Recharge Analysis

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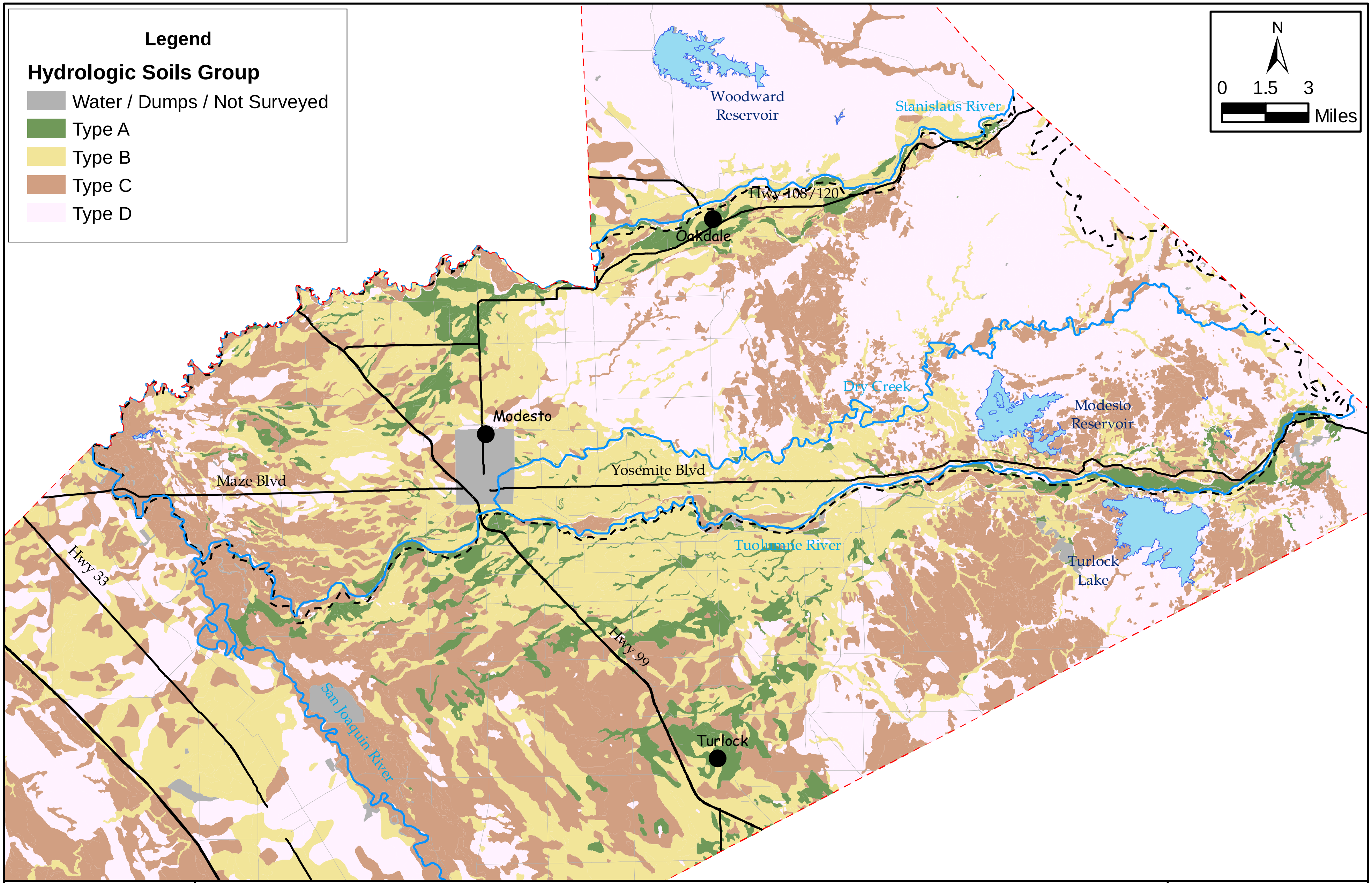
Figure 1



Source: USDA NRCS, 2006

Hydrologic Soils Group

STRGBA Recharge Analysis

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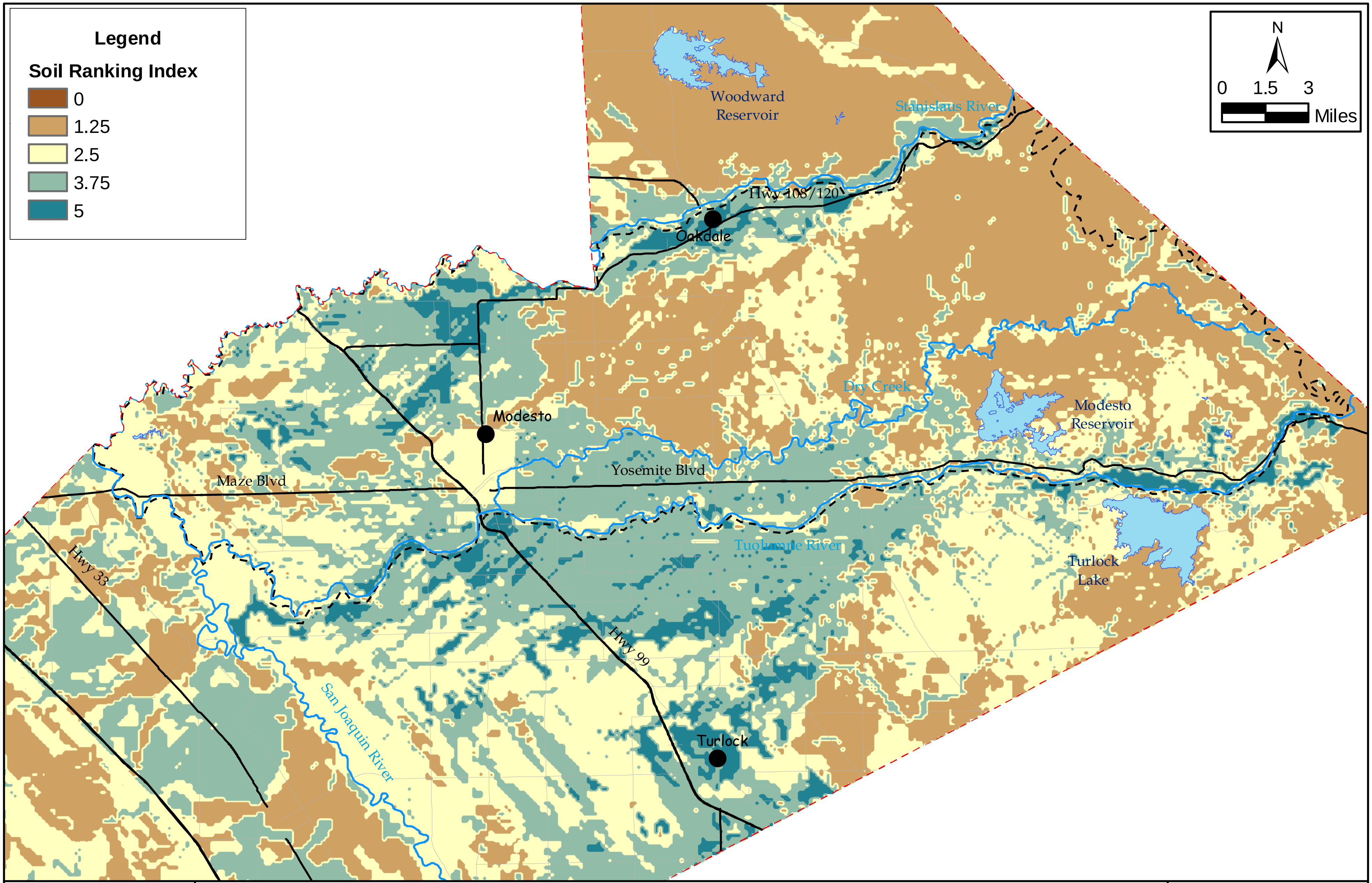
Figure 2A



Hydrologic Soils Group - Ranking Index

STRGBA Recharge Analysis

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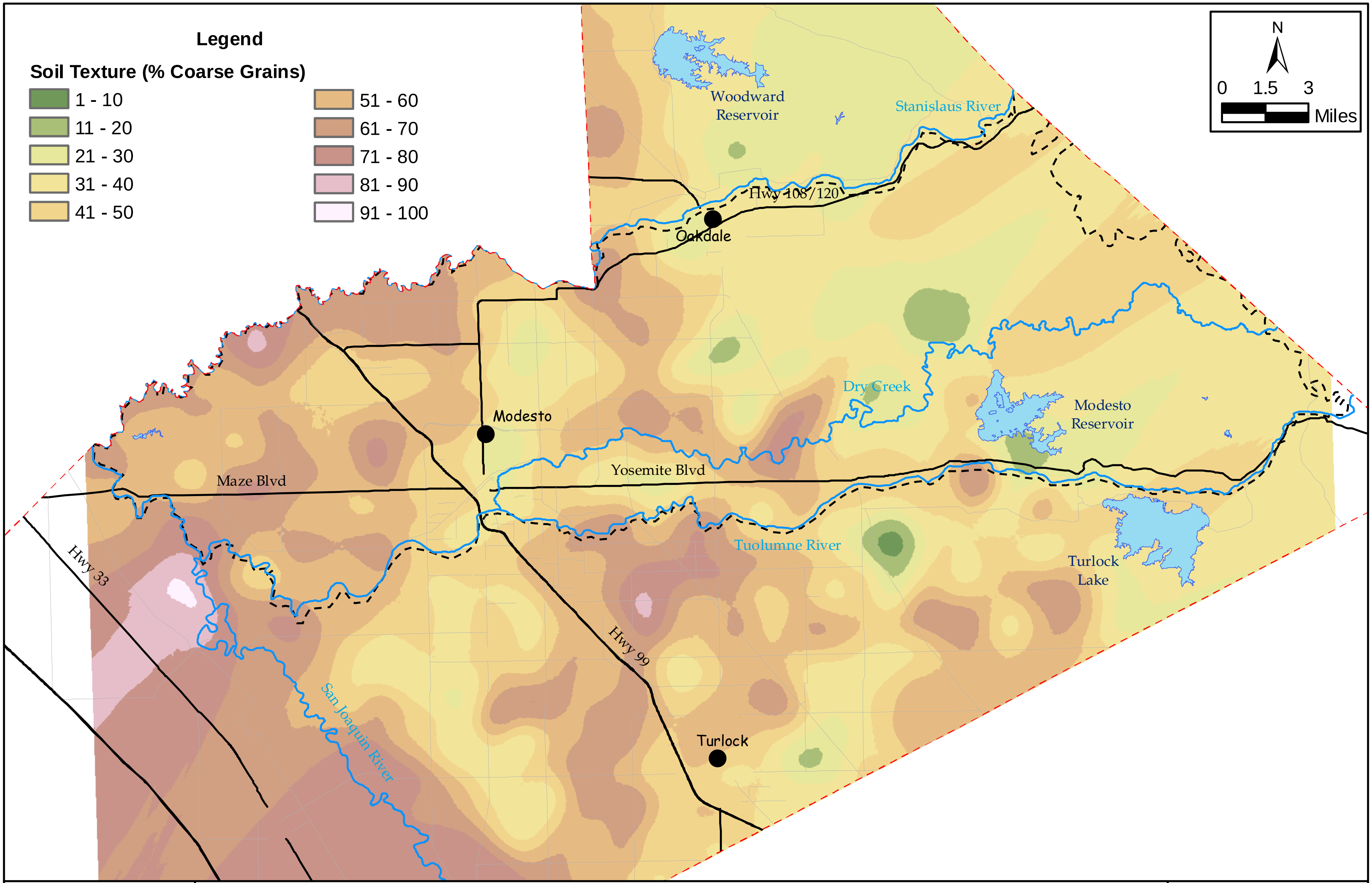
Figure 2B



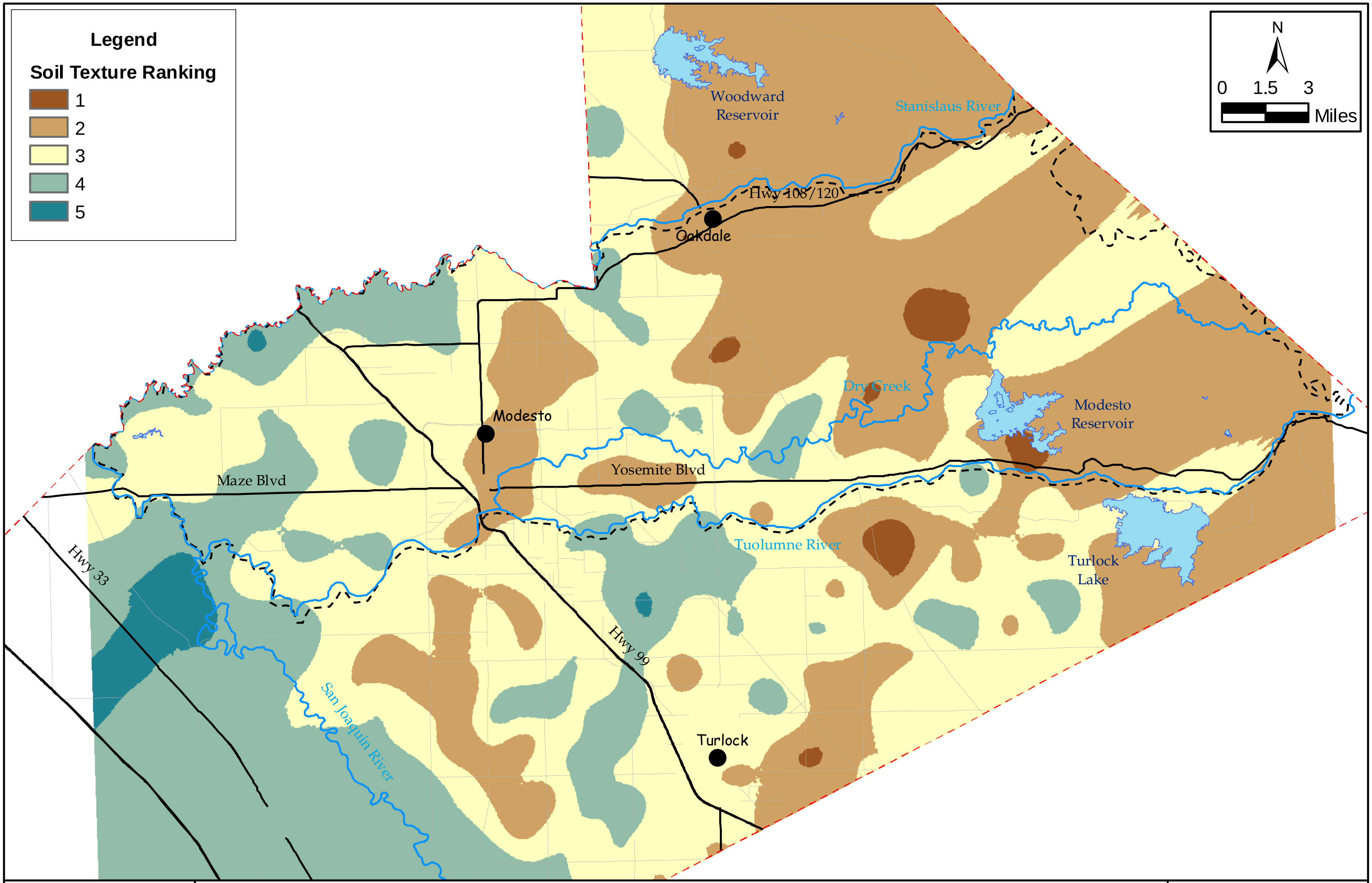
Source: Burow et al., 2004

Soil Texture

STRGBA Recharge Analysis

February 2007

Figure 3A



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Soil Texture - Ranking

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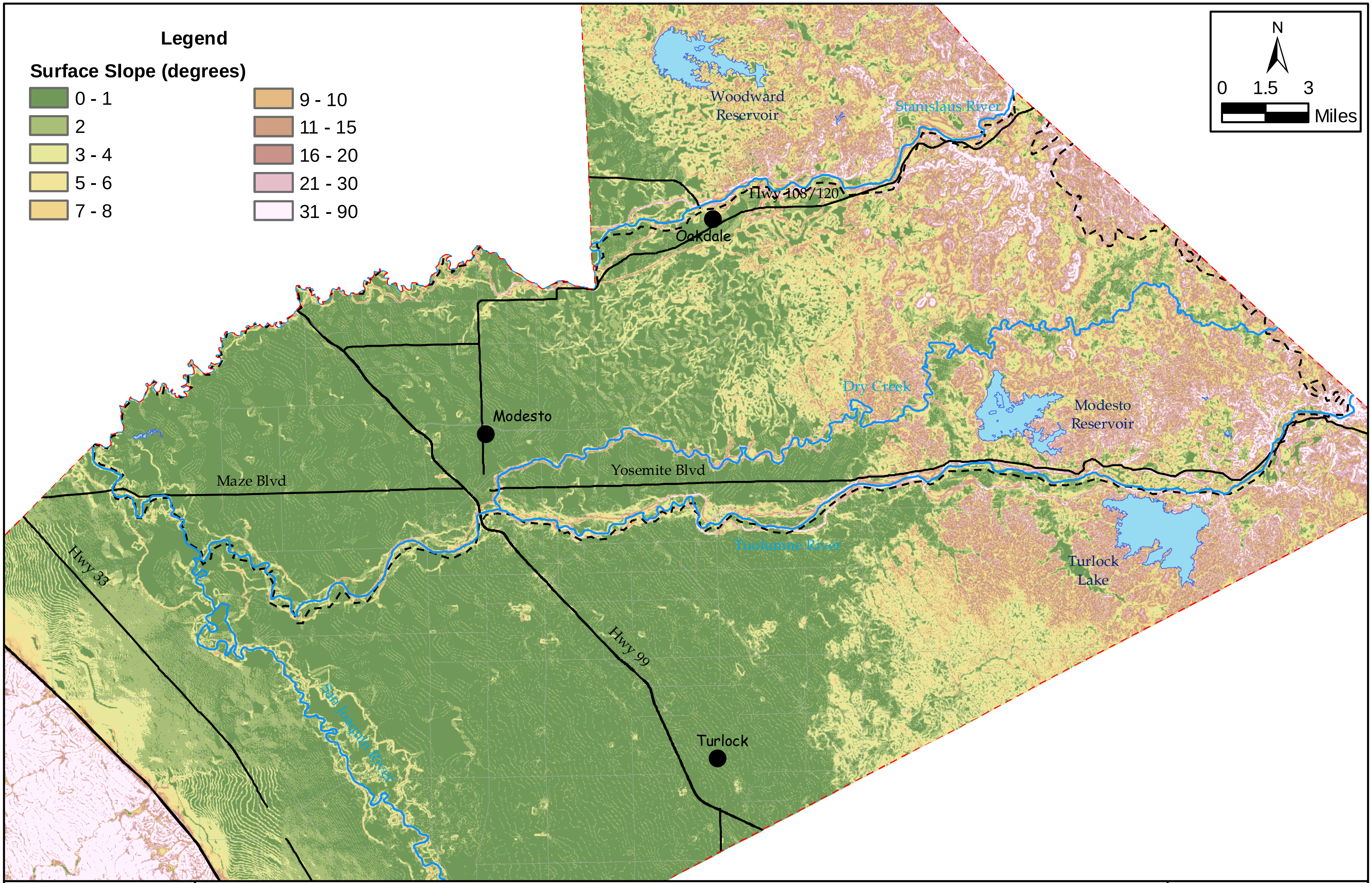
Figure 3B



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Calculated from 30-Meter DEM
Obtained from CaSIL, 2006

Surface Slope

STRGBA Recharge Analysis

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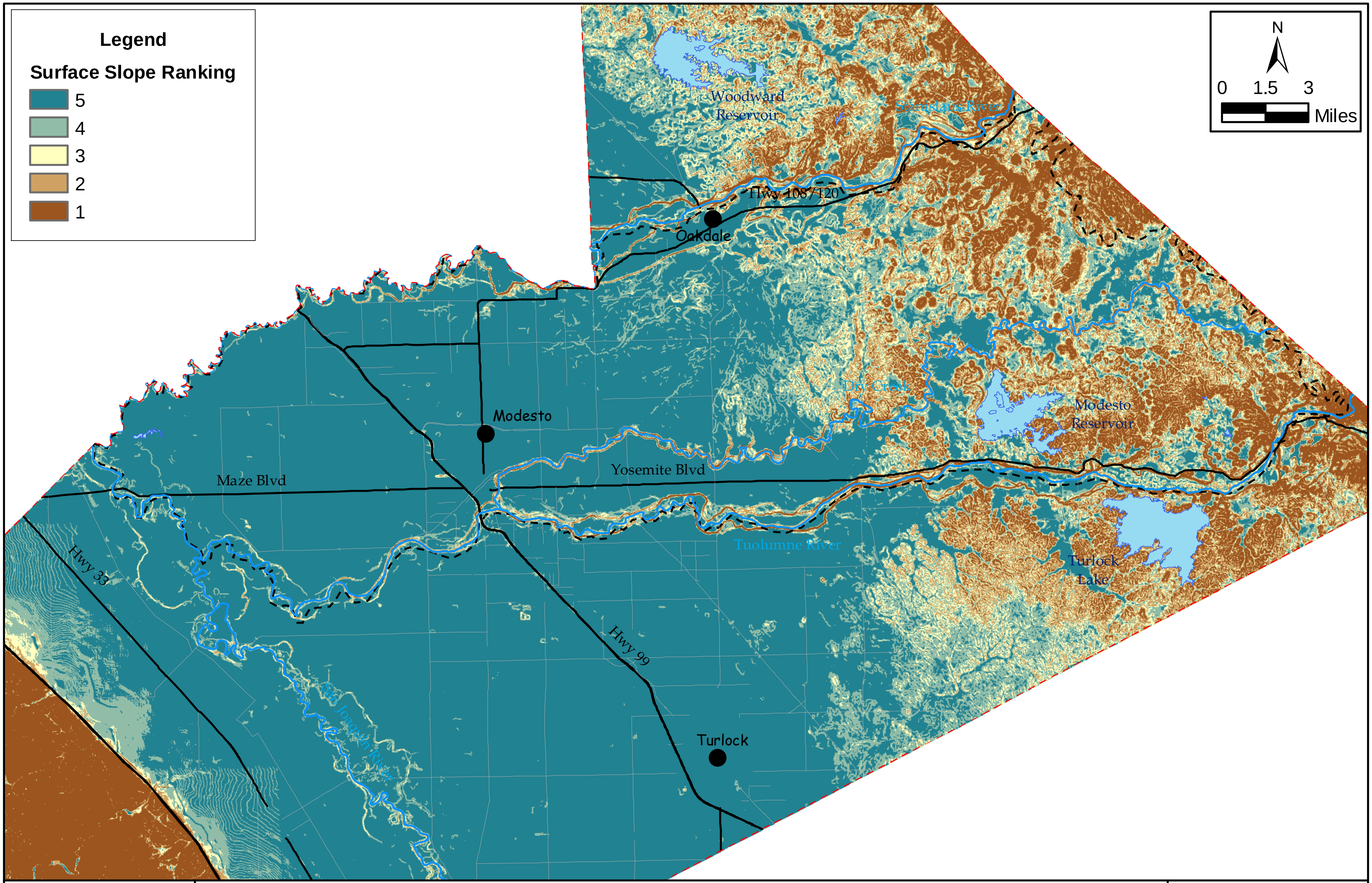
Figure 4A



Surface Slope - Ranking

STRGBA Recharge Analysis

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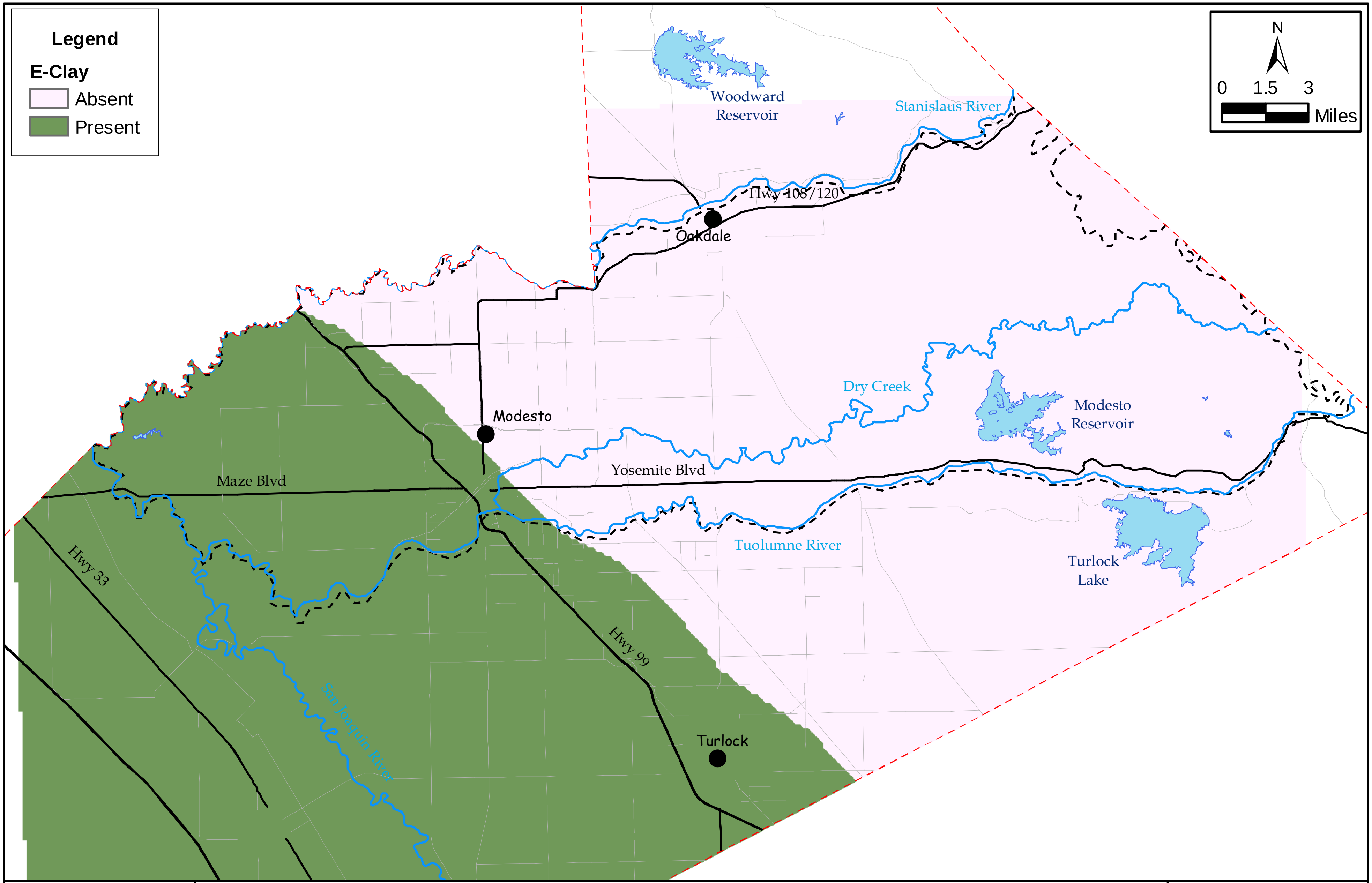
Figure 4B



Source: Burow et al., 2004

E-Clay

STRGBA Recharge Analysis

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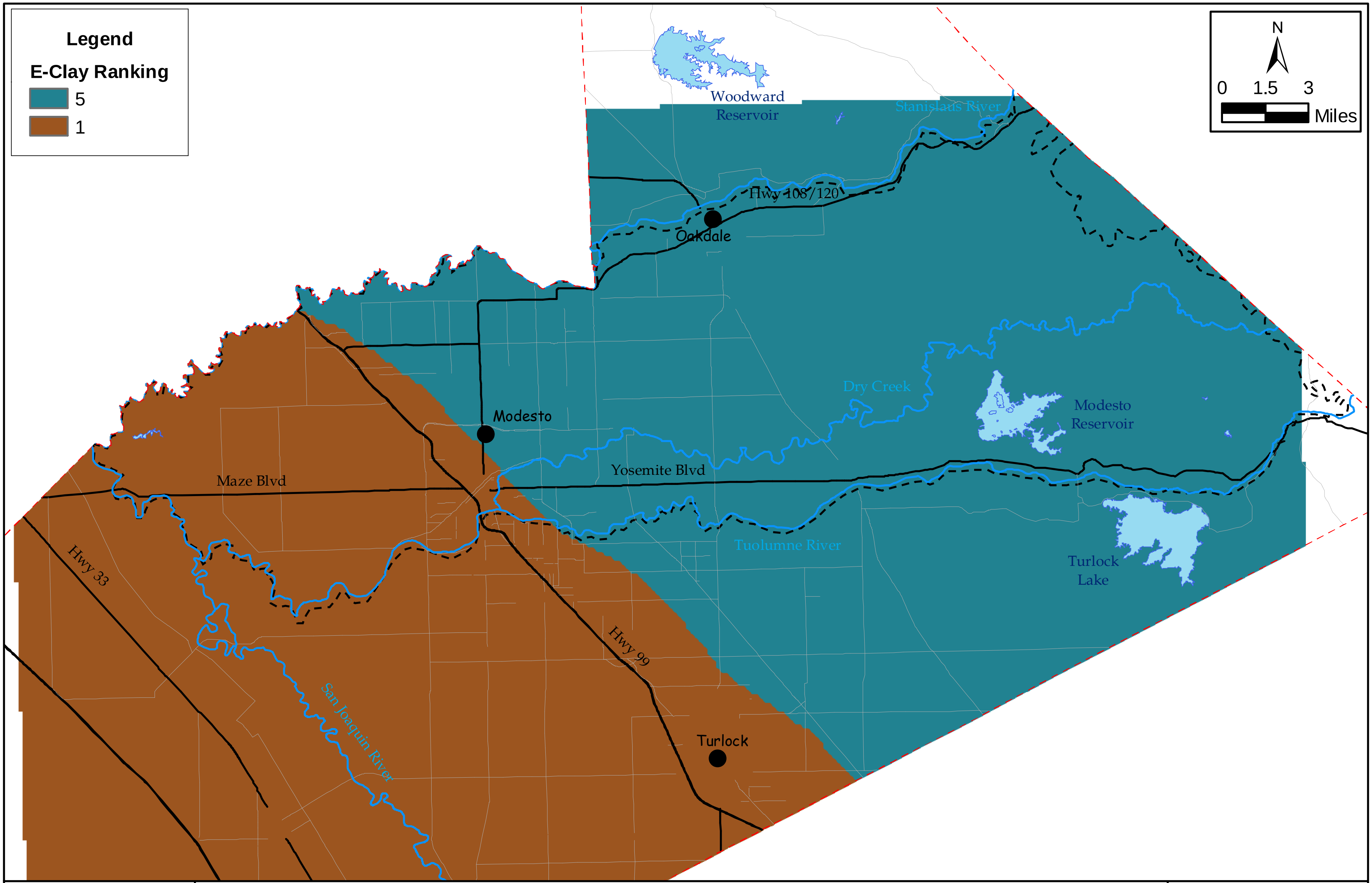
Figure 5A



E-Clay Ranking Index

STRGBA Recharge Analysis

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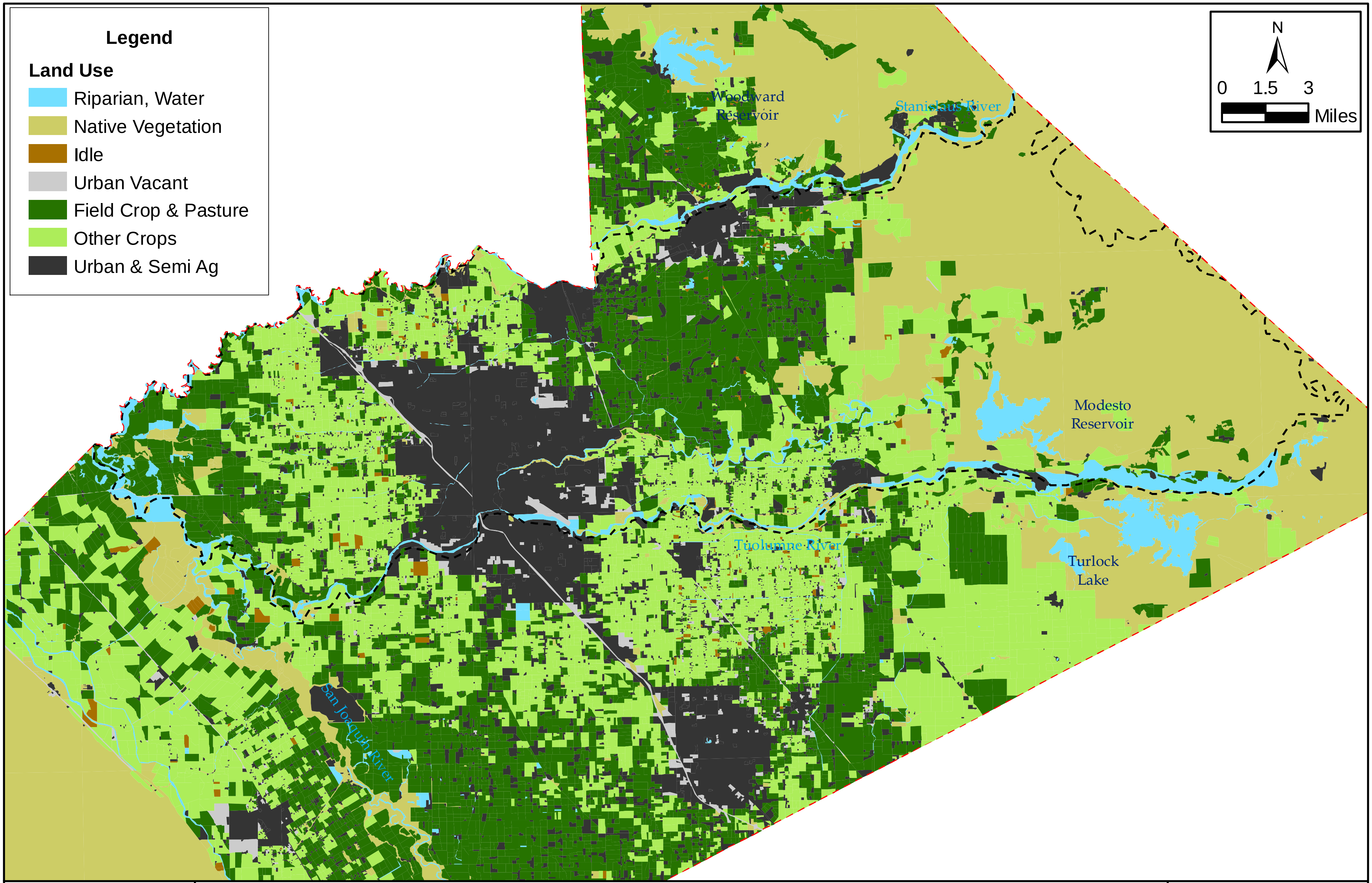
Figure 5B



Source: DWR
Stanislaus County Land Use Survey, 2004

Land Use

STRGBA Recharge Analysis

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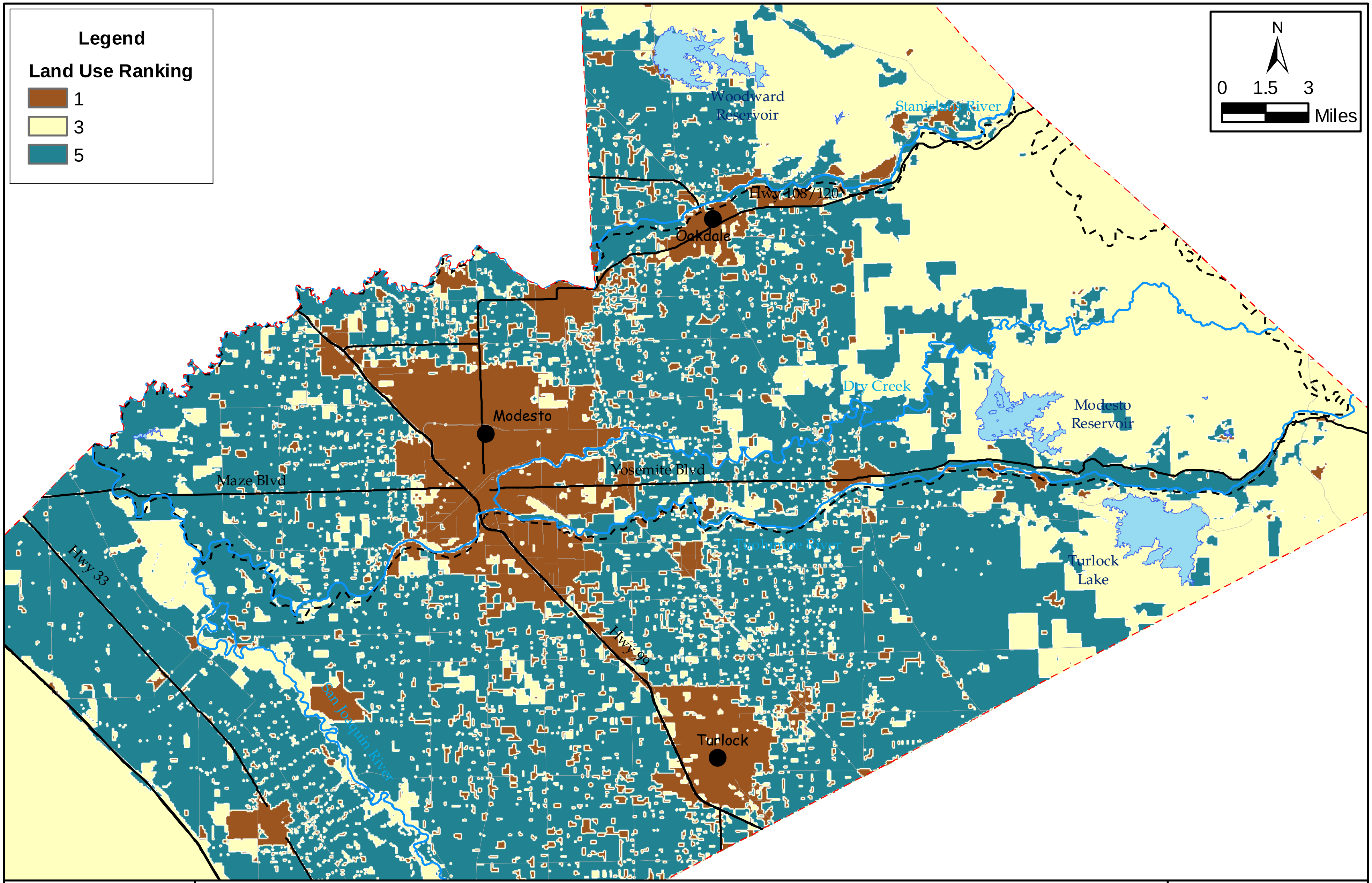
Figure 6A



Land Use Ranking for Anthropogenic Recharge

STRGBA Recharge Analysis

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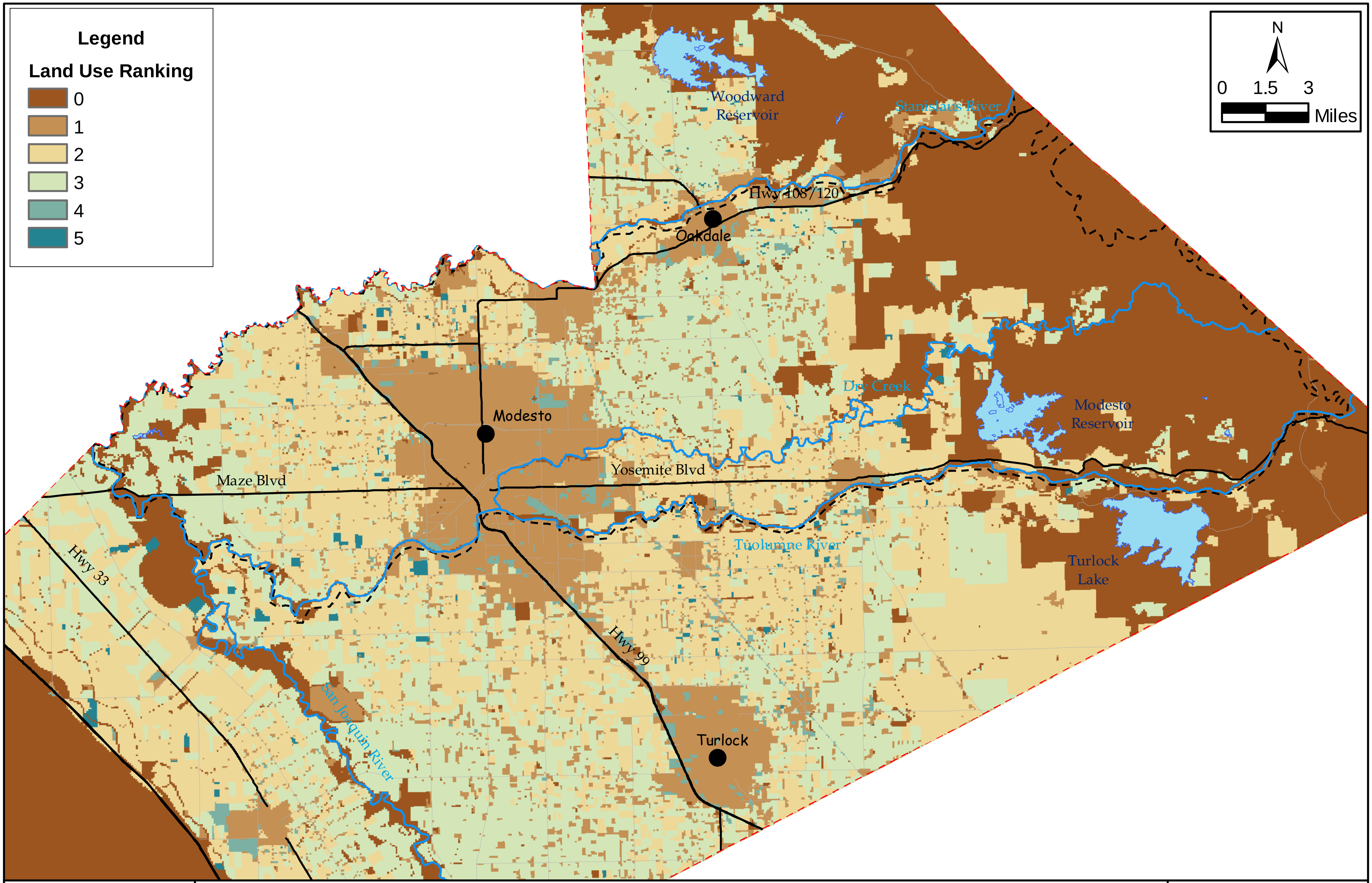
Figure 6B



Land Use Ranking for Artificial Recharge

STRGBA Recharge Analysis

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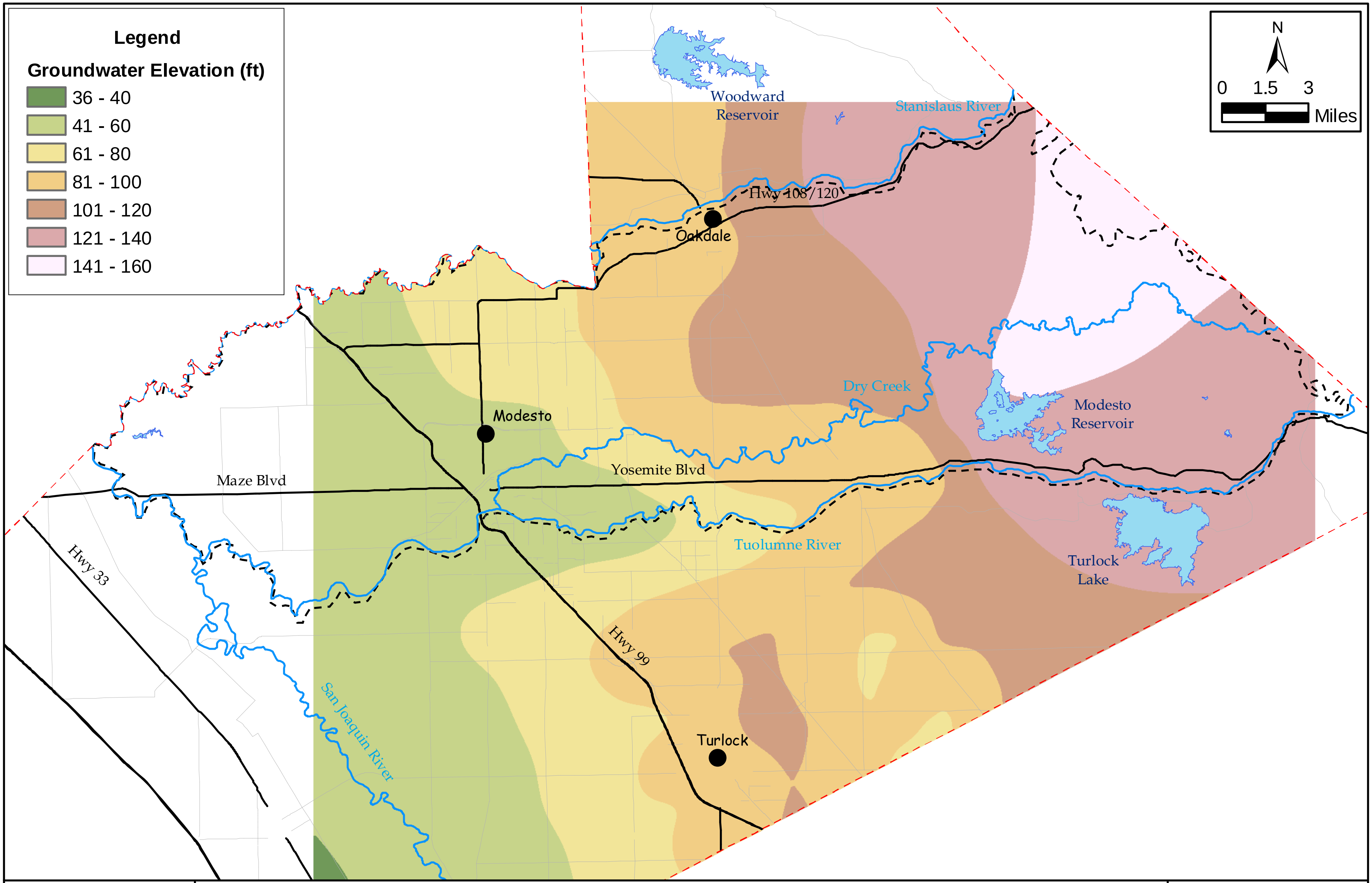
Figure 6C



Source: Burow et al., 2004

Groundwater Elevation

STRGBA Recharge Analysis

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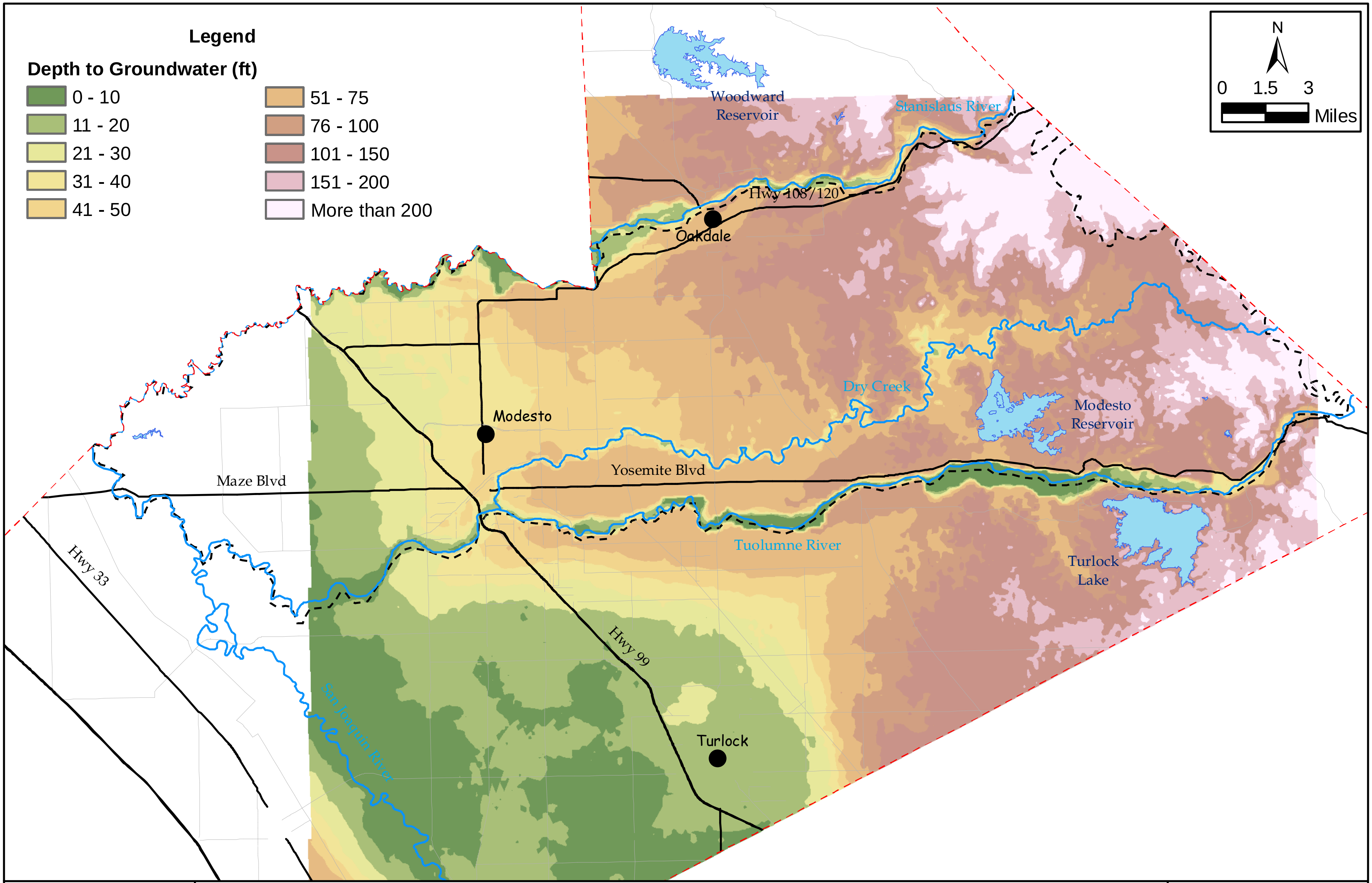
Figure 7A



Calculated as
(30 meter-DEM) - (GW Elevation)

Depth to Groundwater

STRGBA Recharge Analysis

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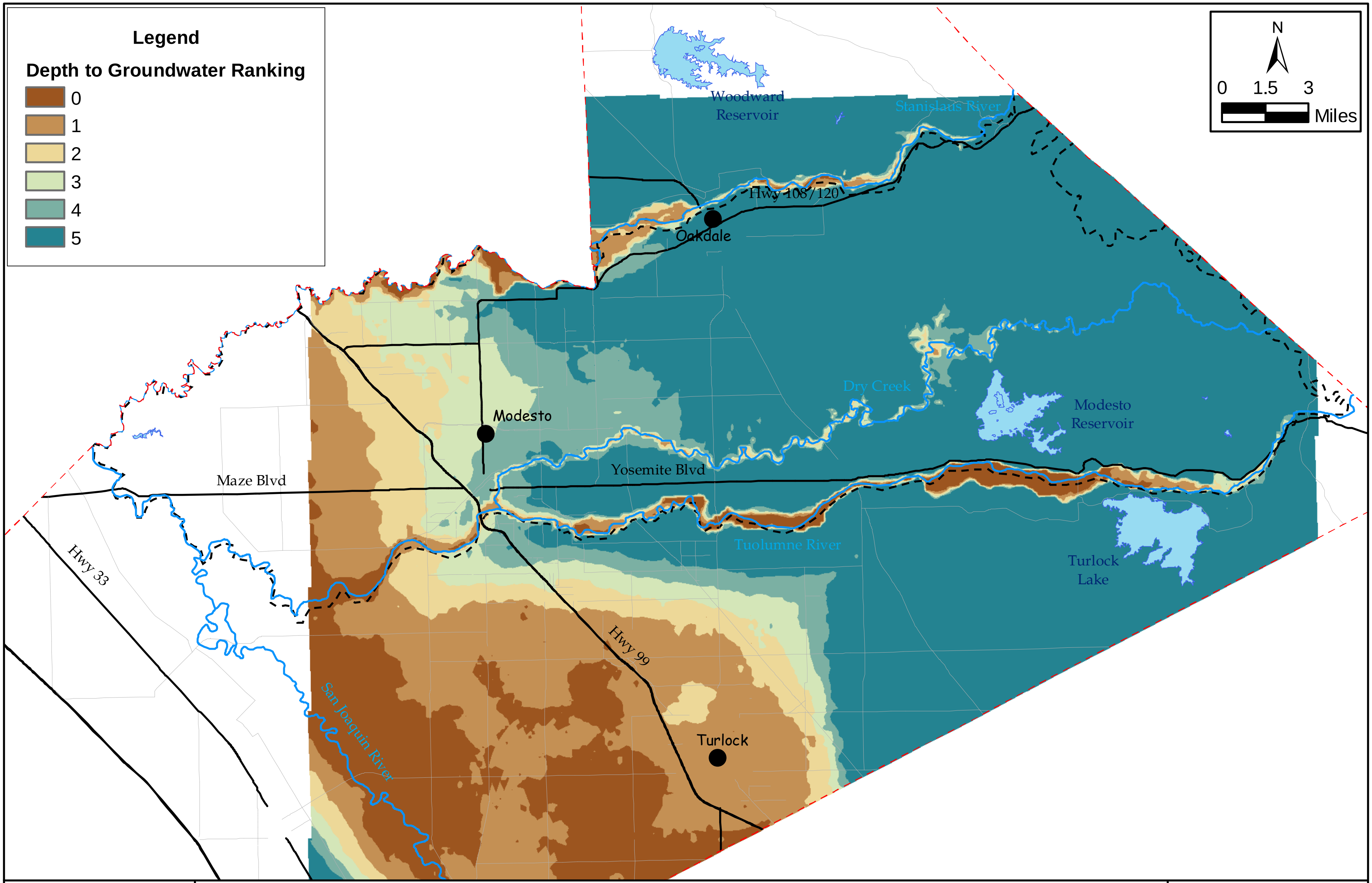
Figure 7B



Depth to Groundwater Ranking

STRGBA Recharge Analysis

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Figure 7C

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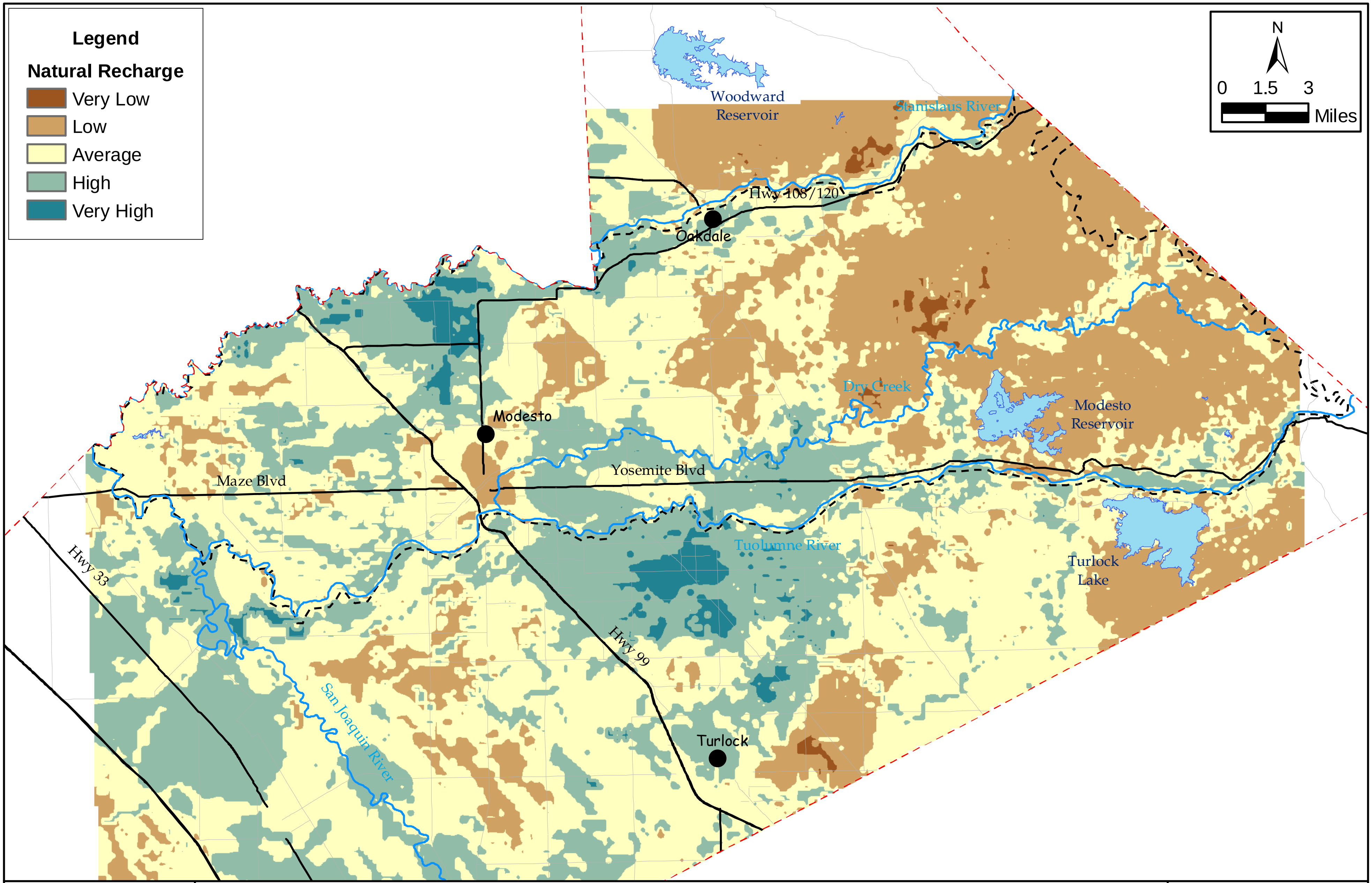

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Natural Recharge

STRGBA Recharge Analysis

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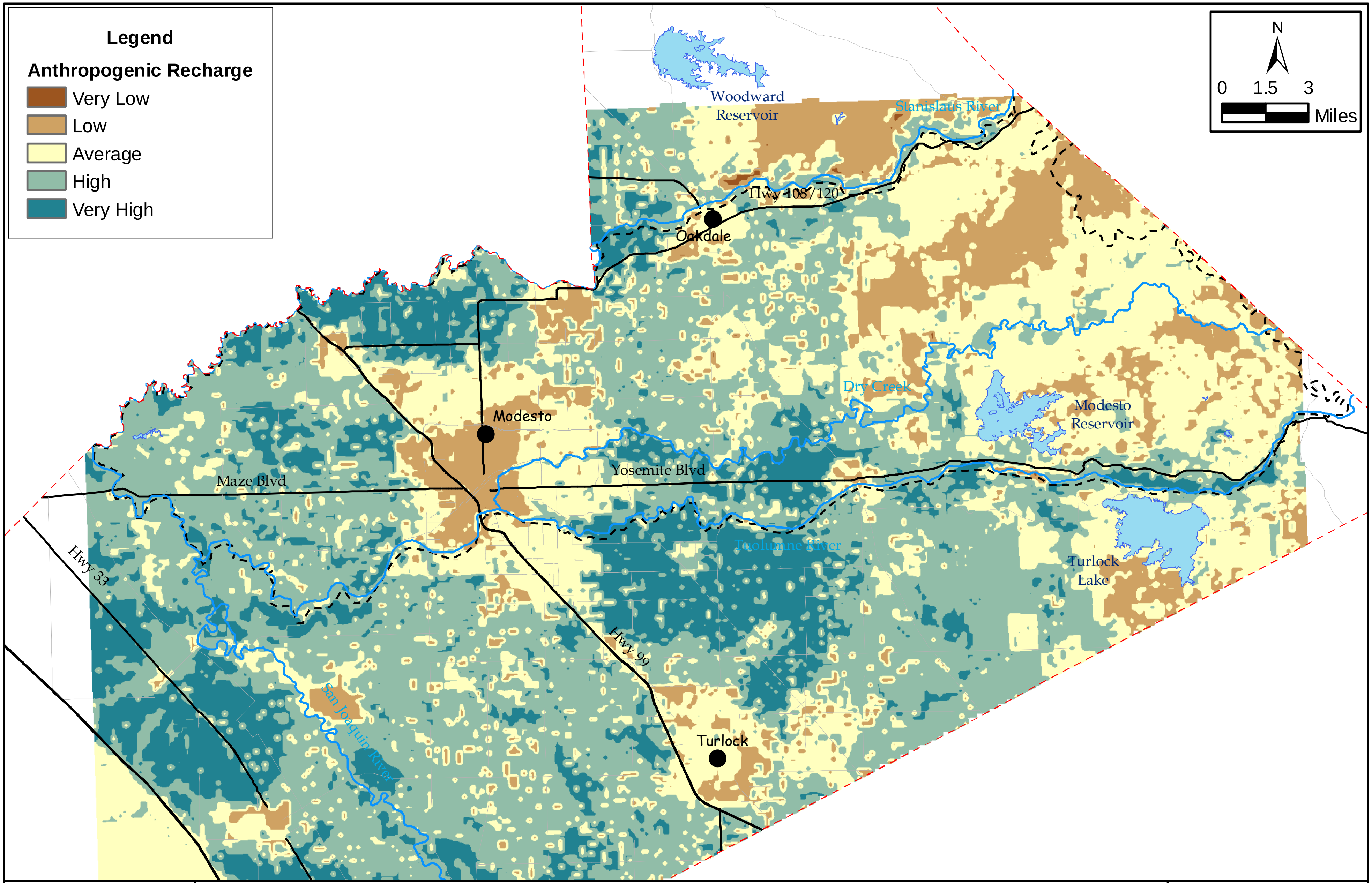
Figure 8



Anthropogenic Recharge

STRGBA Recharge Analysis

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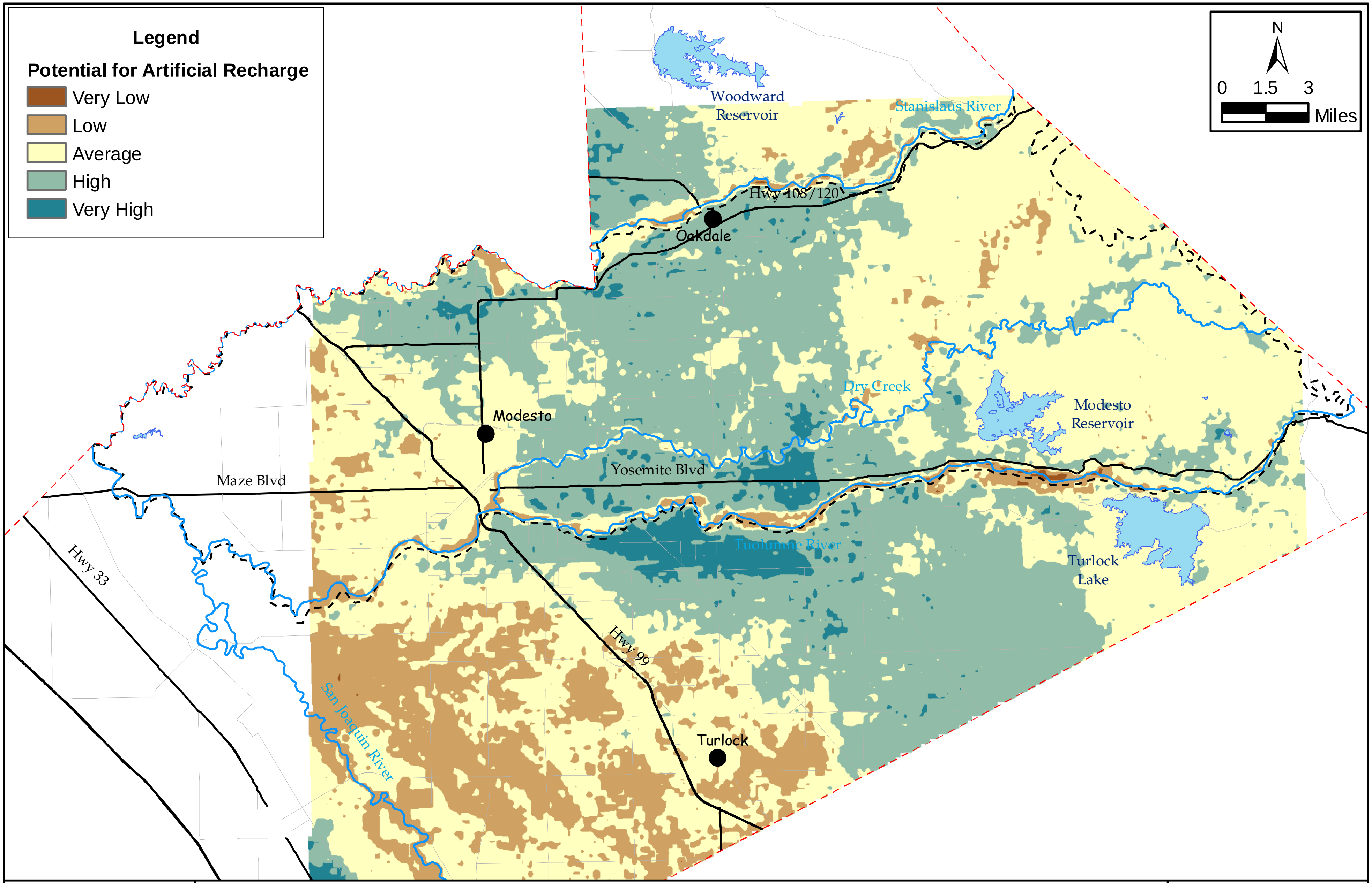
Figure 9



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Potential for Artificial Recharge

STRGBA Recharge Analysis

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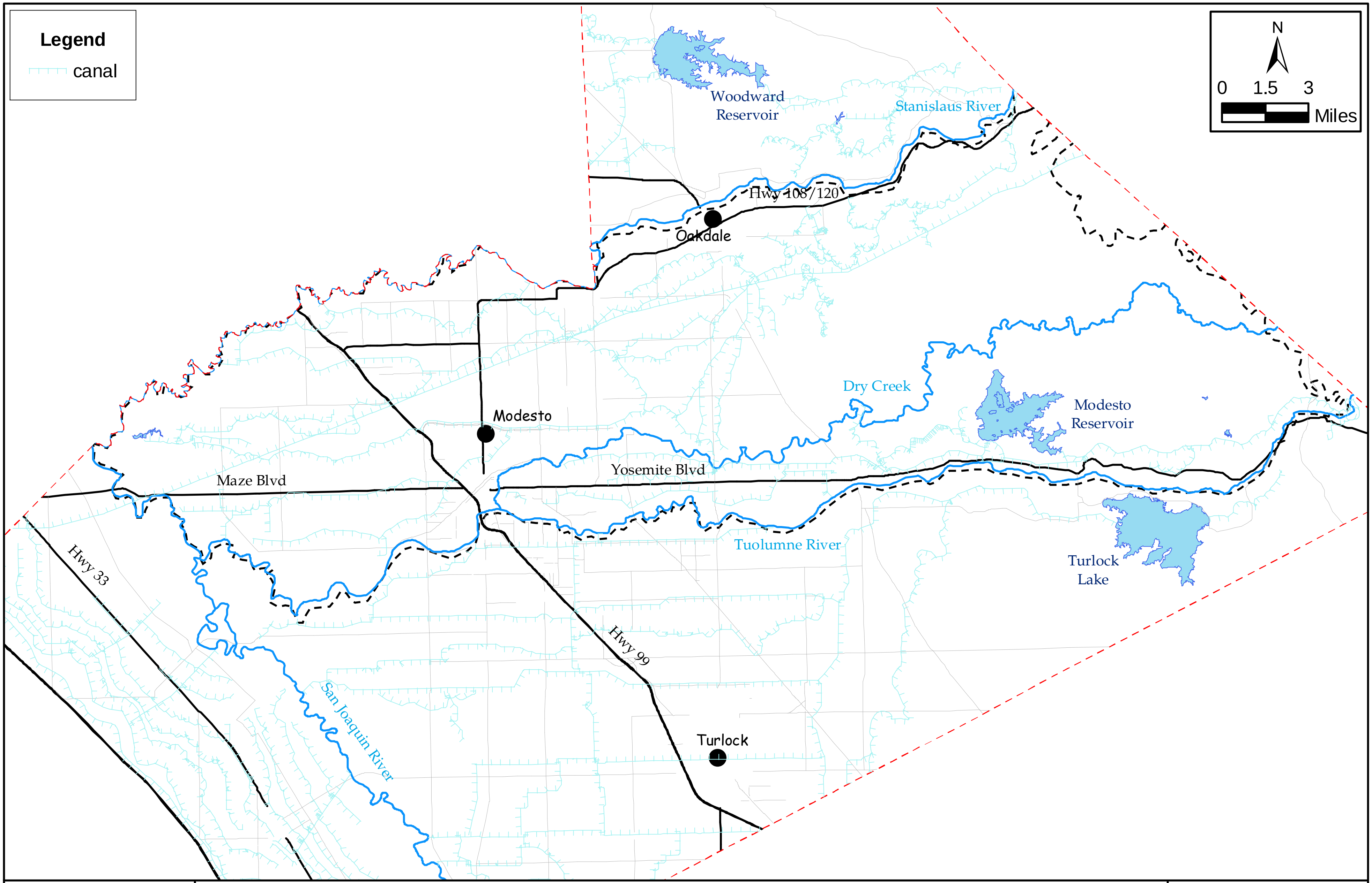
Figure 10



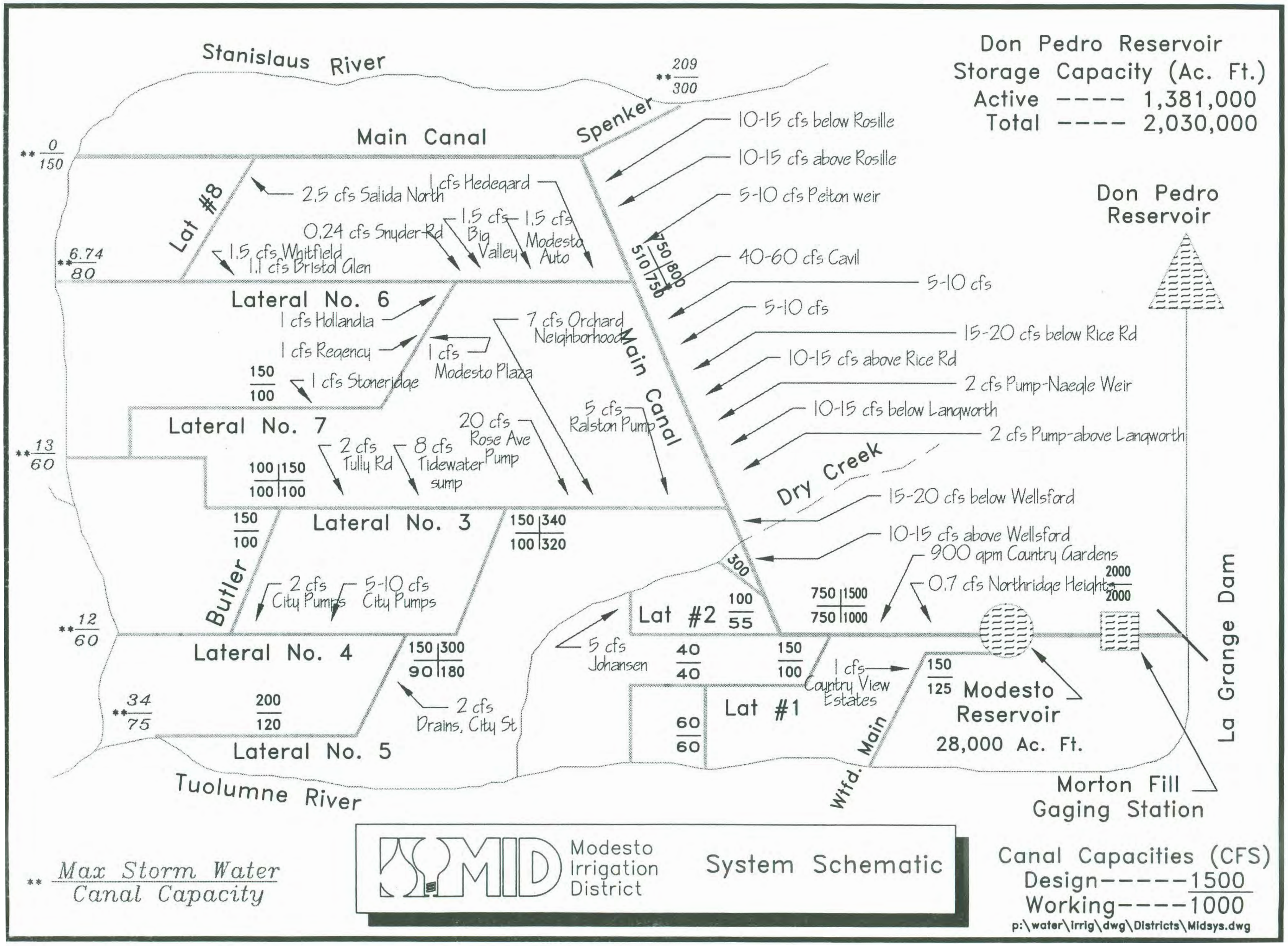
Source: Stanislaus County

Canal Locations

STRGBA Recharge Analysis

February 2007

Figure 11



Source: MID

MID Canal Capacity

STRGBA Recharge Analysis

February 2007

Figure 12