Appendix F Export Coefficient Model

Nutrient Export Coefficients

The Export Coefficient Model (ECM) (Reckhow et al., 1980) is a scoping model regularly used to compute lumped annual basin nitrogen or phosphorous loads based on summing nonpoint and point source estimated loads. The ECM requires the use of nutrient export coefficients. Nutrient export coefficients are the amounts of nitrogen or phosphorus exported from an area over a specific time period and are generally applied to a specific land use. They are typically expressed as kilograms of phosphorus per hectare per year, or pounds of nitrogen per acre per year, or some other mass-area-time unit.

The general form of the ECM is:

$$L_N = \sum_{i=1}^{n} [Ei * Ai] + S + W + P$$

L_N is the catchment nutrient load (kg/year);
E_i is the export coefficient (kg/ha/yr) for a land class i;
A_i is the area of the catchment occupied by land class i;
W is the waste water load from point sources (kg/yr);
S is the septic load (kg/yr);
P is the precipitation/atmospheric load (kg/yr)

In the absence of significant loads from point sources or septic, the nonpoint source land use load is the watershed summation of the *Ei* and *Ai* product alone, plus the atmospheric load.

Pollutant loads from various land uses can be calculated by applying appropriate export coefficients from published literature to the corresponding land use areas. Unfortunately, peer-reviewed nutrient export coefficients have not been reported for the Project Area or in Monterey County. However, numerous studies have derived land use based export coefficients characteristic of various watershed conditions for estimating nonpoint source pollutant yields.

Despite the existence of scientifically peer-reviewed literature values, it is important to recognize that selection of nutrient export coefficients remains, to a degree, an unavoidably subjective task. Nutrient loading to streams is dependent on climate, catchment geology, vegetation, soil type, human activities and land use practices (Sharpley et al., 1994; Mulholland and Hill, 1997; Coulter et al., 2004). As a result, there is a wide range of reported nutrient export coefficients for various land uses. Therefore, it is important to apply best professional judgment and knowledge of local watershed conditions in choosing appropriate export coefficients.

Some researchers (Shaver et al., 2007; Joubert et al, 2003) indicated that the export coefficient model can be improved by establishing a range of areal loading rates (in contrast to a single export coefficient per land use category) from published literature sources to account for uncertainty or error. It is important to note that although there are a substantial amount of studies on the linkage between land use and nutrient export coefficients, comparable studies conducted in Mediterranean-like climates are rare. Mediterranean-like climates are characterized by high variability in precipitation and extended dry periods for which few nutrient export studies have been conducted. Consequently, staff identified a range of reasonable land use export coefficients from regions that have similar watershed characteristics to the Project Area of northern Monterey County; or alternatively by identifying "averaged" median national export coefficient values.

Accordingly, staff used a hierarchical approach to obtain a reasonable range of values for nutrient export coefficients by taking the following steps:

i. First, coefficients from a variety of studies and publications were obtained.
ii. From these literature-reported values, nutrient export coefficients from Level III Nutrient Ecoregion, Zone 6 (i.e., Southern and Central California Chaparral and Oak Woodlands ecogregion) were selected. Note that nutrient ecoregions are USEPA designations for subregions of the United States that denote areas with ecosystems that are generally similar (e.g., physiography, climate, geology, soils, land use, hydrology).
iii. Next, export coefficients from other nutrient ecoregions located in the State of California were selected.
iv. In the absence of Level III Zone 6 ecoregion data, or California-specific export coefficients, median national values, or regional values applicable to the western United States were selected.
v. Finally, local watershed conditions were considered in screening and culling the literature export coefficients. For example, reported national median export coefficient values for agricultural land uses that are not representative of the Project Area (e.g., corn, soybean, cotton) were not selected for consideration. Where possible, export coefficients were selected that could reasonably be associated with Project Area-specific land uses.

Figure 1 illustrates the nutrient ecoregions of California and the locations of nutrient export coefficients used in this report.

Figure 1. Map of Nutrient Ecoregions of California and Locations of Literature Nutrient Coefficients Selected for Use in the TMDL Project.

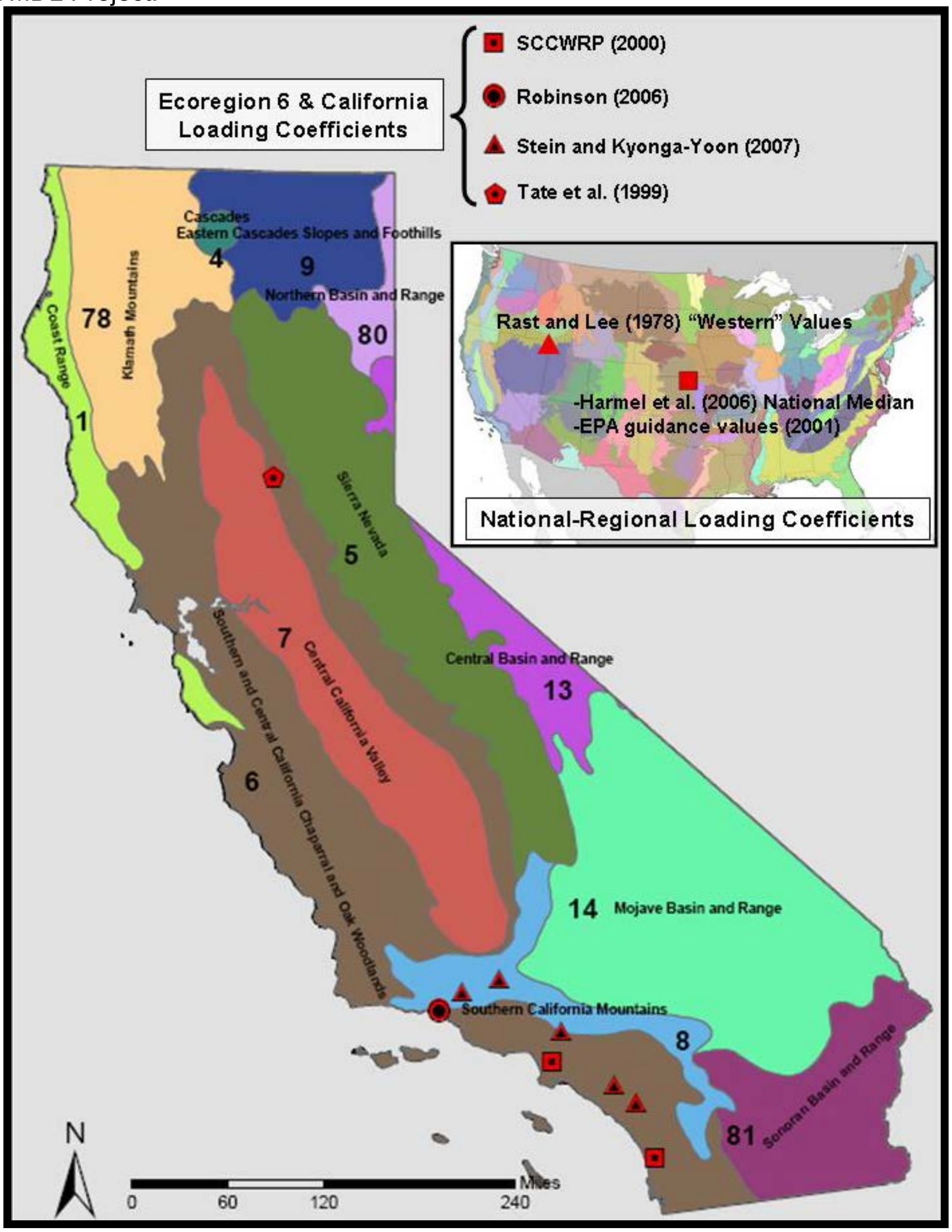


Table 1 compiles the values and ranges of nitrogen export coefficients used in this report.

Table 1. Selected Literature Nitrogen Export Coefficients (Units = kg/ha/year).

		Literature Source / Study Area							
Land Use	***Land Treatment or Subcategory***	**Rast and Lee (1983)**	**SCCWRP et al. (2000)**	**Harmel et al. (2006)**	**Robinson (2006)**	**USDA MANAGE Database**	**Stein and Kyonga-Yoon (2007)**	**Tate et al. (1999)**	**USEPA Nutrient TMDL Guidance (from Table 5-3, 2001)**
		"Western" Regional U.S. value	Coastal Southern California	Median National Values	Santa Barbara County Calif. (mean of dry and wet years)	Median National Values	Coastal Southern Calif. (Median Value for Four Watersheds)	Yuba County, Calif.- mean Value	Median Values
Agriculture -Cropland	Various Rotations	2.0 for all "ag"	4.4 for all "ag"	3.68	-	-	-	-	-
	Fallow Cultivated			3.0	-				
	Oats-wheat			6.61	-				
	Avocado			-	5.18				
Urban	Commercial-High Density	2.5 for all "urban"	4.7	-	12.93	-	-	-	5.8
	Residential		3.1		3.19	-			4
Pasture	Dryland alfalfa, barley, oats, etc.; No grazing to rotational grazing	-	-	0.97	-	0.8		-	4.2
	Pasture (grazed)					2.4			
Range/ Grassland	Native grass; No grazing to light grazing to moderate grazing	-	-	0.97	-	1.3	-	1.6	4.2
Forest/ Shrubland	Forest, Undeveloped Shrub Land	1	-	-	0.68		2.3	-	2
	"Open", undeveloped		0.9						
Wetland[A]		0	-	-	-	-	-	-	-

[A] Wetlands or marshes can act as sinks or sources of nutrients, depending upon the specific season of the year. It has been found, however, that the quantities of phosphorus that enter and leave wetlands over an annual cycle are essentially equal (as reported in Rast and Lee, 1983). On this basis, the net contribution of nutrients from wetlands is zero over the annual cycle

The Manage Method of Estimating Export Coefficients

Modifying Export Coefficients to Account for Variations in Runoff Potential: The MANAGE Method of Estimate Export Coefficients

In its traditional form the ECM assumes that export coefficient values are uniform for each land cover type or nutrient source within a catchment, regardless of proximity to water or hydrologic pathways. It is important to recognize that over large watershed areas, nutrient export may not be proportional to watershed area and some attenuation of nutrients occur due to variations in runoff rates, plant cover and retention, and travel distance to streams (Heathwaite and Burt, 1991; Minnesota Pollution Control Agency, 2003; Endreny and Wood, 2003; Theodore Endreny, personal communication, Nov. 2009). While the ECM is capable of generating reasonable estimates of nutrient loads simply from a watershed land cover data and associated homogeneous export coefficient values, research findings and professional literature suggest that the export coefficients approach can be slightly modified to account for field characteristics such as soil drainage, attenuation along hill slope runoff flow paths, and distance to streams from the contributing source area (Johnes and Heathwaite, 1997; McMahon and Roessler. 2002; Endreny and Wood, 2003; Mitsova-Boneva and Wang, 2008). Consequently, staff evaluated whether uniform land use export coefficients were appropriate, or whether modified export coefficients – taking into account watershed physical/spatial field characteristics – should be developed, as outlined below.

The Project Area is over 1,009 square kilometers, and has substantial variation in land cover, soils, and elevation. In addition, it is important to consider a watershed's drainage density, and how it qualitatively relates to the probability of material (e.g., nutrients) entering along a stream reach. Drainage density is simply a measure of how well or poorly a watershed is drained by stream channels, as is mathematically expressed as:

Drainage Density = Stream Length / Basin Area

Drainage density is dependent on climate, topography, vegetative cover, geology, and other conditions. The measurement of drainage density can provide a useful measure of runoff potential. On a highly permeable landscape, with low potential for runoff discharging directly to streams, drainage densities are sometimes less than 1 kilometer per square kilometer. Highly dissected watershed surface drainage densities can be tens or even hundreds of kilometers per square kilometer.

Staff calculated a drainage density of 1.01 kilometers per square kilometer for the Project Area, using a digital clipped river reach file, and a digital Project Area polygon.

Cumulative Stream Reach Length in Project Area	Project Area Size	**Drainage Density** (stream length / basin area)
1023 kilometers	**1010 km^2**	**1.01**

This drainage density qualitatively suggests that the Project Area, broadly speaking, has a relatively low potential for runoff discharging directly to a stream, compared to basins that are highly dissected by streams and have higher drainage densities. It is important to recognize however, that digital river reach files may not include field scale ditches, canals, and other unmapped water conveyance structures in the Project Area. Therefore the Project Area drainage density could be higher than the one calculated by Staff.

Based on the aforementioned information, Staff did not choose to apply uniform nutrient export coefficients for each land classification throughout the Project Area, as is often the case with the traditional Export Coefficient Model. Staff took into consideration in ruling out the use of uniform land use export coefficients:

- the large geographic scale of the project area;
- the heterogeneity of land cover and soils; and
- the relatively low drainage density of the project area.

Instead, Staff employed recognized-approaches that allow for modification of the Export Coefficient Model, accounting for field characteristics such as soil drainage, and distance-decay factors related to the physical proximity (distance) of source areas to surface waterbodies.

One such method for employing a GIS-based pollution risk assessment to derive modified export coefficients is the "Method for Assessment, Nutrient-loading, And Geographic Evaluation of Nonpoint Pollution" (MANAGE). In the MANAGE method a mass balance approach is used to estimate nutrient (nitrogen and phosphorus) loading to surface water (Adamus and Bergman, 1993). Upper and lower limits are assigned for nitrogen and phosphorus delivery to surface water from each land use category in lb/acre/yr or kg/ha/yr. Then the hydrologic soil group (HSG) is used to determine a "most likely" nitrogen or phosphorus export coefficient for a particular land use is calculated for each SOIL / LAND USE combination as:

$$PC = LPC + (HPC - LPC) \times X$$
$$NC = LNC + (HNC - LNC) \times X$$

where
PC or NC = Most likely export coefficient for phosphorus (P) or nitrogen (N)
LPC or LNC = Lower limit export coefficient for P or N
HPC or HNC = Upper limit export coefficient for P or N
X = Value associated with each HSG (see Table 2)

Table 2. Weighting Factors (X) Used for Different Hydrologic Soil Groups in Equation X.

Hydrologic Soil Group (HSG)	Value of X
A	0
B	1/3 (0.33)
C	2/3 (0.67)
D	1

Essentially this formula divides the range of export coefficients evenly into quarters, with the high end assigned to hydrologic soil group A (high infiltration/low runoff rate) and the low end assigned to hydrologic soil group D (very slow infiltration/high runoff rate). The MANAGE model indicates that this based on the approach developed by Adamus and Bergman (1993).

Using the range of literature nitrogen export coefficients from Table 1 and the MANAGE Model equation, Table 3 shows the calculated most likely nitrogen export coefficients for each Land Use/Soil combination.

Table 3. Total Nitrogen Export Coefficients (kg/ha/year) for Each Soil/Land Use Combination in Project Area.

Land Use Category	Export Coefficient Reference Values		Calculated Most Likely Export Coefficient Based on Hydrologic Soil Group			
	LNC	HNC	A	B	C	D
Agriculture/Cropland	2	6.61	2	3.52	5.09	6.61
Urban Commercial	2.5	12.93	2.5	5.94	9.49	12.93
Urban Residential	2.5	4	2.5	3.0	3.5	4
Pasture	0.8	4.2	0.8	1.92	3.08	4.2
Range/Grazing Land	0.97	4.2	0.97	2.04	3.13	4.2
Forest	0.68	2.3	0.68	1.21	1.77	2.3
Wetland	0	0	0	0	0	0

A compilation of literature-reported nutrient export coefficients was compiled in an Excel spreadsheet.

Distance Attenuation of Export Coefficients

Modifying Export Coefficients to Account for Distance Attenuation of Export Coefficients:

As noted earlier, in addition to using soil data to account for spatial variations in runoff potential (as in the MANAGE method above), researchers have also identified that there is some attenuation of nutrients occur due to travel distance to streams. Clearly, pollutants generated at a certain location are subject to degradation and transformation processes. One such process is the travel distance or travel time to the nearest stream discharge point.

Over large watershed areas, some researchers have noted that nutrient export is not proportional to watershed area and some attenuation of nutrients occurs, especially in natural vegetation that have low runoff rates. Recently, researchers who have examined the nutrient export issue on landscape level scales (large watersheds and higher order streams) have raised concerns over the applicability of uniform export coefficients across large watershed areas (Birr and Mulla, 2001; Cammermeyer, et al, 1999; Johnson and gage, 1997; Jones, et al, 2001; Mattson and Isaac, 1999; McFarland and Hauck, 1998; Richards, et al, 2001;Sharpley, et al, 1993; Soranno, et al, 1996; Worrall and Burt, 1999). The underlying issue related to this concern is that not all areas in a large watershed contribute nutrients equally. In its traditional form the ECM assumes that nutrient export coefficients are homogeneous within each land cover type, yet basic nutrient runoff and hydrological theory suggests that runoff rates have spatial patterns controlled by filtering and attenuation along the flow paths from the upslope contributing area to the downslope stream discharge point (Endreny and Woods, 2003).

Johnes and Heathwaite (1997) suggested that greater rates of nutrient export occur for sources located within the riparian zones than for those at distance from the stream. Accordingly, Johnes and Heathwaite (1997) used a distance decay function to model the impact of land use change on nitrogen and phosphorus concentrations in streams. They argued that nutrient-contributing areas greater than 50 meters from the drainage network were less important than near-stream zones due to attenuation and uptake of nutrients during downslope transit and that export coefficients for each land use can be adjusted for each field in a catchment with respect to their proximity to surface waterbodies. In other words, areas within the 50 m wide riparian zone, were defined as high risk areas, with a higher index of nutrient export than similar land use types outside this zone. Jones and Heathwaite concluded that nutrient contributing areas outside the 50 meter riparian zone is subject to at least a 50% attenuation rate.

Based on the aforementioned research, distance-decay weighting of export coefficients has been utilized in nutrient TMDL development. For example, in the USEPA-approved State of New Mexico Rio Hondo TMDL (2005), the Export Coefficient Model (Reckhow, et al., 1980) was modified by weighting the nitrogen export based on distance from the stream with 50 meter, 500 meter, and 5000 meter buffer zones. The largest unit load was assigned to the 50 meter zone and the smallest unit-area load was assigned to the 5000 meter zone. In other words, the approach assumed that the export coefficient values undergo a step-wise decay when originating beyond the 50 meter distance cutoff and that nutrient loading is buffered beyond this distance.

Table 4 tabulates the distance decay attenuation coefficients derived from the aforementioned research and TMDL studies, and presents provisional distance decay attenuation coefficients for use in the Lower Salinas River watershed nutrient TMDL. As shown in the table, export coefficients associated with a particular land use category are attenuated by 50 % outside the 50 meter riparian buffer, and by 90% outside a 500 meter buffer. It is important to note that for the lower Salinas River nutrient project it may be prudent to use a 60 meter riparian buffer, rather than a 50 meter buffer. This is due to the fact that land use raster grid data available for use in GIS have a grid increment of 30 m. A 60 meter spatial buffer would be an increment of measurement exactly 2 times the raster grid sampling density.

Table 4. Weighting Coefficients for Modified Nutrient Export Coefficients based on Distance Attenuation.

	Relative Nutrient Loading Risk		
	Higher	***Moderate***	***Lower***
Source/Study	**50 m Buffer**	**> 50 m to < 500 m Buffer**	**> 500 m Buffer**
Johnes and Heathwaite (1997)	1.0	0.5	N.A.
New Mexico Rio Hondo Nutrient TMDL	1.0	0.5	0.1
Lower Salinas Nutrient TMDL (provisional)	1.0	0.5	0.1

Conceptually, the modification of land use-based export coefficients using the MANAGE method and distance-to-stream attenuation as detailed above, can be illustrated as shown in Figure 2:

Figure 2. Modifying Export Coefficients.

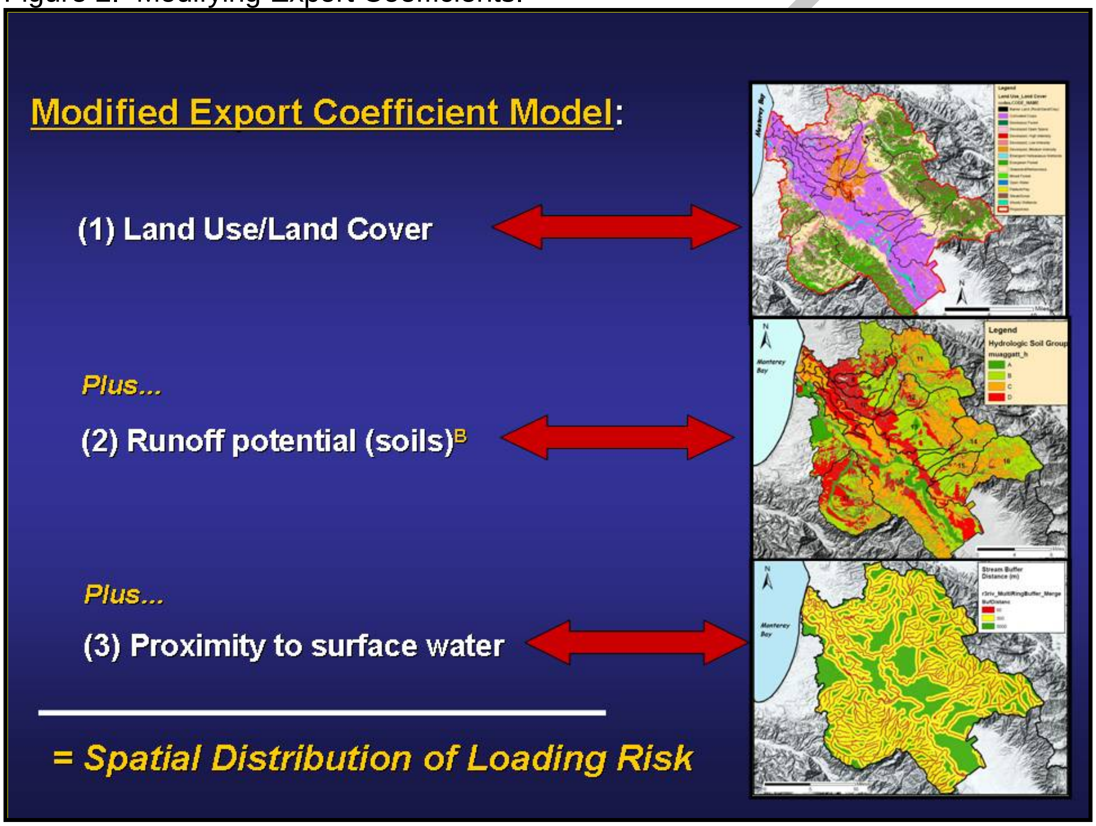
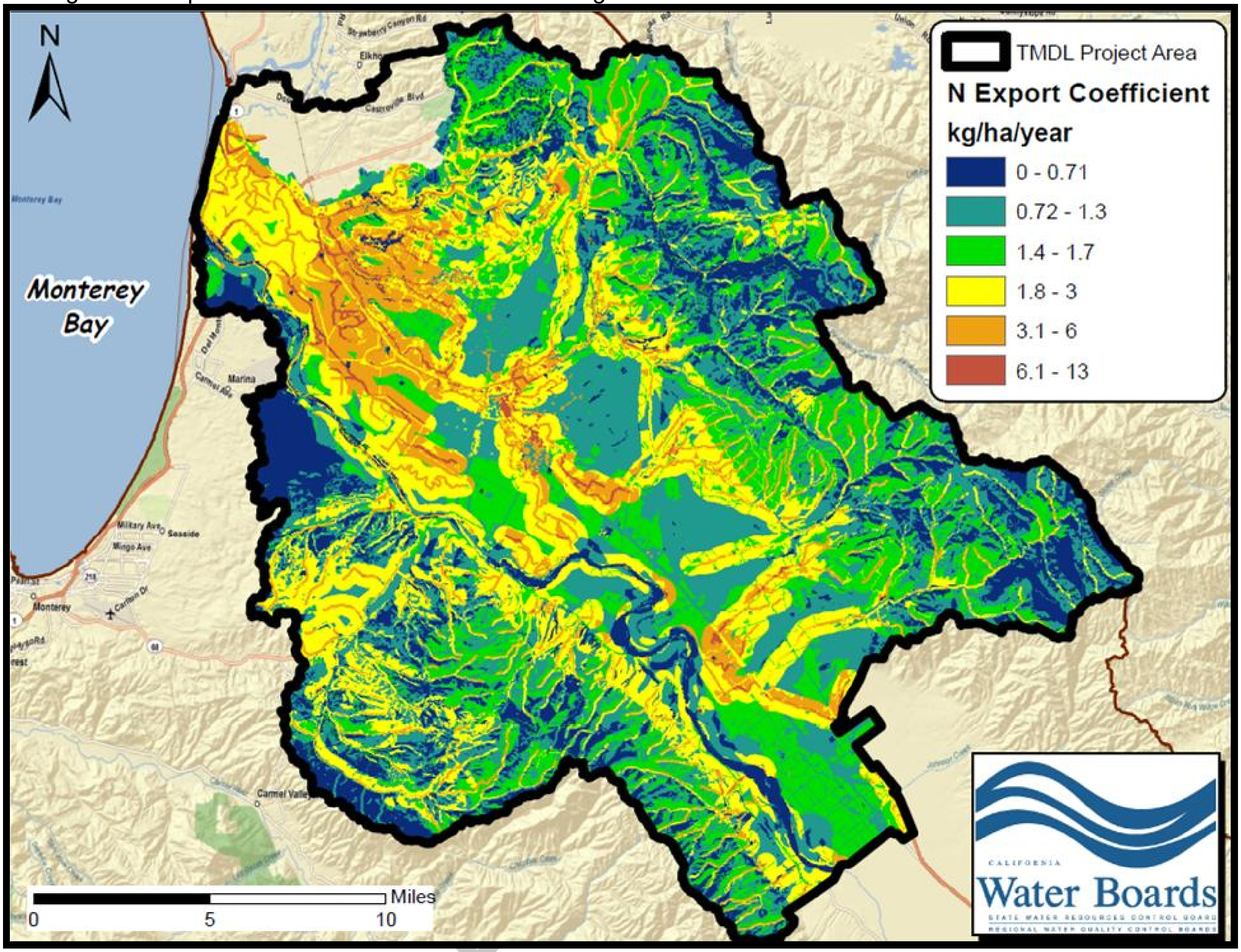


Figure 3 illustrates a preliminary and provisional export coefficient model for total nitrogen which incorporates weighting factors to standard export coefficients based on the land use / hydrologic soil group/ and distance to stream combinations, as outlined above.

Figure 3. Export Coefficient Model for Total Nitrogen in Lower Salinas River Watershed.



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