5 RESULTS

The nonpoint source pollution methodology outlined in sections 4.1 through 4.5 has been performed for four of the pollutant constituents included in Table 3.6. Results of these analyses are discussed in this section. In addition, the point source simulation discussed in section 4.6 is performed for both phosphorus and nitrogen. Finally, results of the optimization runs for estimation of phosphorus expected mean concentration values are analyzed.

5.1 Nonpoint Source Pollution Assessment

The original intent of this research was to provide an assessment of nonpoint source pollution in the San Antonio-Nueces Coastal Basin, using GIS. The method of associating pollutant expected mean concentrations with land use and accumulating pollutant loads along flow direction paths in the basin shows that, for subbasins where few or no point sources are suspected, predicted pollutant concentrations match well with average measured concentrations. The results of the nonpoint source pollution assessment for total phosphorus, total nitrogen, total cadmium, and fecal coliform are included below.

Total Phosphorus

The aerial distribution of total phosphorus expected mean concentrations in the San Antonio-Nueces basin is shown in Figure 4.14. This map shows that most of the total phosphorus contribution comes from the southern and western portions of the basin, where agricultural land uses are prevalent. The expected mean concentration value for range land uses (from Table 3.6) is <0.01 mg/L, which indicates that all or most of the concentrations observed during the establishment of expected mean concentrations were below the reporting limit for total phosphorus (Baird, et al.. 1996). This entry is interpreted as 0 mg/L for assignment to the range land use polygons. Also, since no expected mean concentration values for forest land uses exist in Table 3.6, the values for range land uses are assigned as approximations. As a result of these two interpretations, a value of 0 mg/L is assigned to all of the range and forest land use polygons, which occupy a significant portion of the north and central portions of the basin.

The geographic differential between assigned expected mean concentration values also reveals itself through the assessment of annual cumulative loads in the basin, as seen in Figure 4.15. As one might anticipate from the expected mean concentration map, total loads to Copano Bay from stream networks in the southern agricultural part of the basin (Aransas River, Chiltipin Creek, Taft drainage ditch) are significantly greater than loads from the Mission River or Copano Creek. When loads from the three major streams in the southern basin are combined, the total annual phosphorus load is estimated in excess of 138,000 kilograms, more than twice the predicted load from the Mission subbasin. Table 5.1 summarizes the predicted annual loads to Copano Bay for each of the five major stream network outlet points.

Total phosphorus concentrations predicted for the stream networks of the San Antonio-Nueces basin also indicate a heavier contribution of phosphorus from the southern agricultural region, as seen in Figure 4.23. Concentrations throughout the length of Chiltipin Creek, which drains an almost exclusively agricultural area near Sinton, TX, are predicted to be between 1.0 and 1.3 mg/L. For the main stem of the Aransas River, phosphorus concentrations expected from nonpoint sources fall in the range between 0.5 and 1.0 mg/L, and a general dilution effect is expected as tributaries of higher phosphorus concentration mix with the increased flows of the larger stream.

Observed concentrations along the Aransas River are consistently higher than the predicted values but, as is discussed in section 5.2, this is attributed to the additional phosphorus contribution from point sources. The average measured concentrations at two locations along the Mission River (in the 0 - 0.2 mg/L range) are actually lower than the predicted values (between 0.2 and 0.5 mg/L). As most of the upstream phosphorus contributing land uses in this subbasin are also agricultural, this trend indicates that either (a) the expected mean concentration assigned to those specific land use polygons is too high or (b) there is some loss of phosphorus that occurs along the length of the Mission River, possibly as the result of sedimentation or decay.

Stream Outlet Point	Total Phosphorus (kg/yr)	Total Nitrogen (kg/yr)	Total Cadmium (kg/yr)	Fecal Coliform (trillion col./yr)
Copano Creek	9320	67,152	45.4	941
Mission River	60,594	369,122	173.5	1469
Aransas River	57,781	239,843	76.8	550
Chiltipin Creek	60,900	213,314	56.1	506
Taft Drainage	19,524	66,252	15.3	43
Aransas Subbasin	138,205	519,409	148.2	1099
Copano Bay	208,119	955,683	367	3509

Table 5.1 : Predicted Annual Pollutant Loads to Copano Bay

Total Nitrogen

Figure 5.1 shows the expected mean concentration values for total nitrogen assigned to land use polygons in the San Antonio-Nueces basin. As for phosphorus, the highest nonpoint source derived concentrations of total nitrogen (4.4 mg/L) are expected from agricultural land uses. However, the contributions of total nitrogen from range and forest land uses are not negligible (0.7 mg/L).

The average annual cumulative loads of total nitrogen are shown in Figure 5.2. In contrast to the loadings of total phosphorus, the largest single cumulative load of nitrogen in the basin is predicted at the outlet of the Mission River. This is due to the non-zero value of concentration associated with the range and forest land uses in the drainage area and the larger runoff from the subbasin. When the loads from the three major streams in the southern basin are combined, however, the total annual estimated nitrogen load exceeds 519,000 kilograms, which is 41% more than the load estimated from the Mission River subbasin.

In general, annual nonpoint source nutrient loads in the San Antonio-Nueces coastal basin are seen to be predominantly from the agricultural areas there. Even at the Mission River outlet, the predicted loads of phosphorus and nitrogen are strongly influenced by agricultural land uses in that subbasin. Table 5.1 includes the predicted

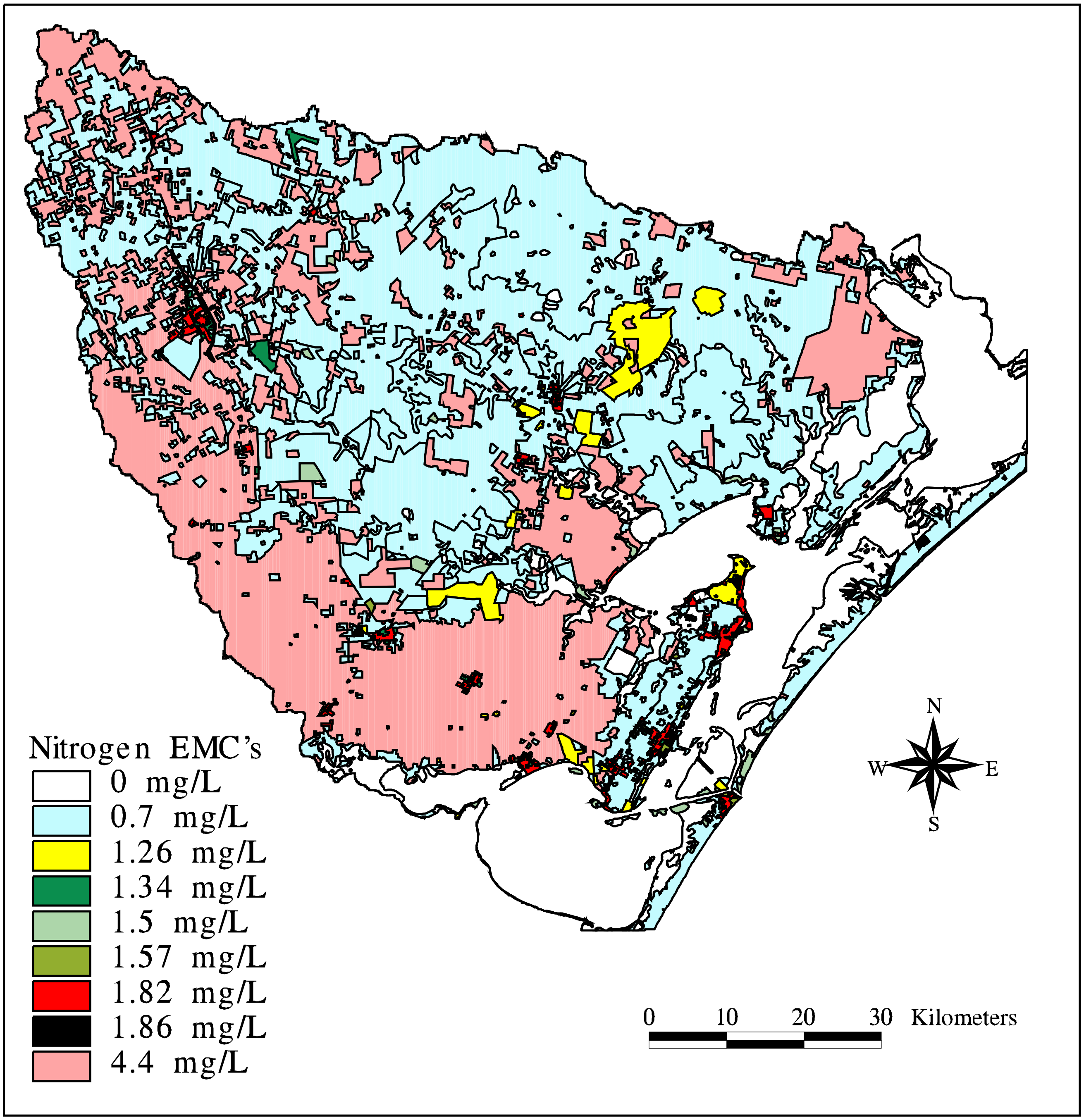

Figure 5.1 : Total Nitrogen Estimated Mean Concentrations in the San Antonio-Nueces Coastal Basin

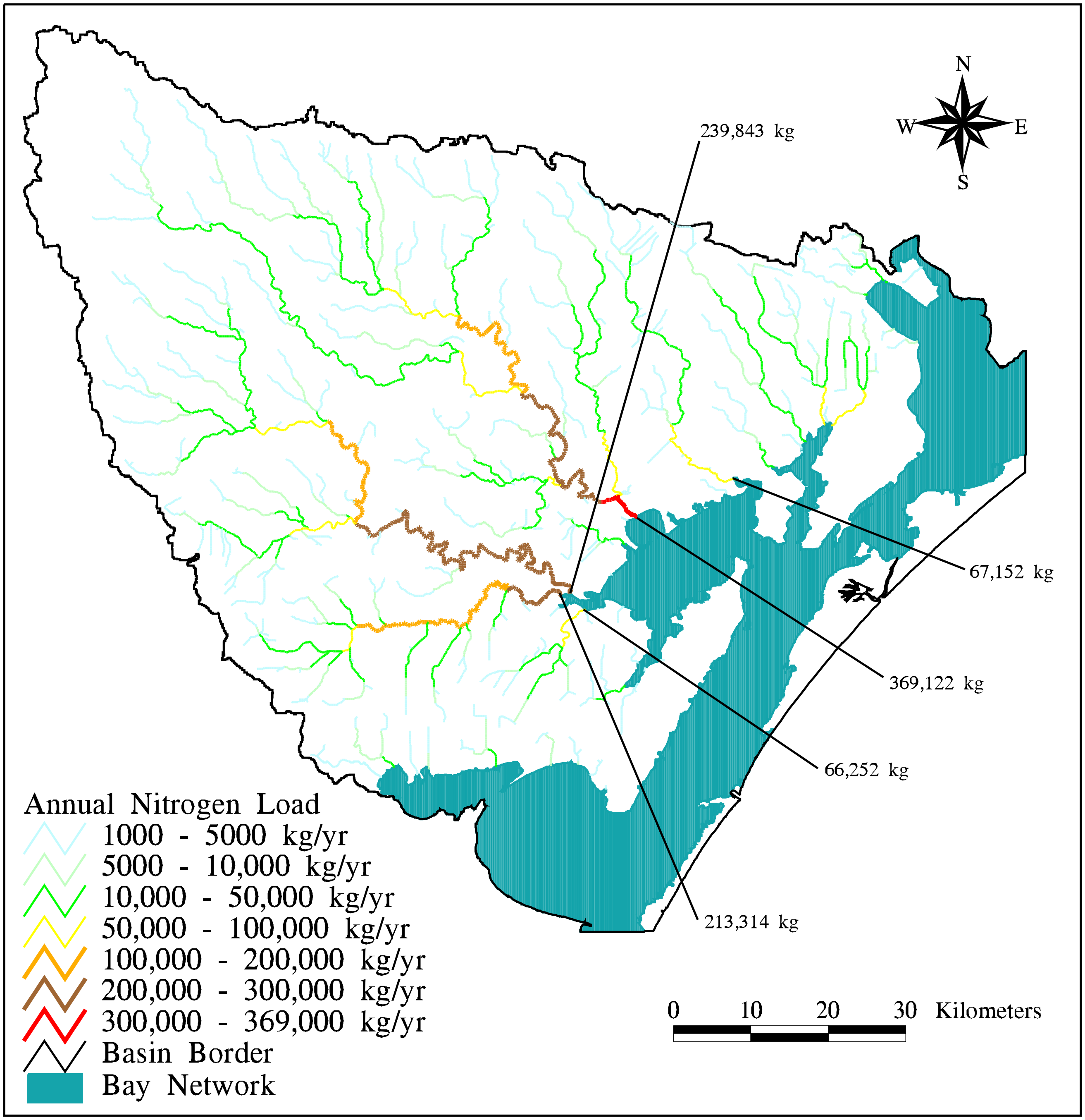

Figure 5.2 : Average Annual Total Nitrogen Loads in the San Antonio-Nueces Coastal Basin

annual nitrogen loads to Copano Bay for each of the five major stream network outlet points.

Figure 5.3 shows the total nitrogen concentrations predicted for the stream networks of the San Antonio-Nueces basin. As for the phosphorus concentrations in Figure 4.23, the highest concentrations of nitrogen are expected from the southern agricultural region of the basin. Concentrations along the main stem of the Aransas River are predicted to be between 2.0 and 4.0 mg/L. Observed concentrations along the river are consistently higher than predicted values. As with the phosphorus concentrations, this is attributed to additional nitrogen loads from point sources along the river.

The average measured nitrogen concentrations at two locations along the Mission River (in the 0 - 1.0 mg/L range) are lower than the predicted values (between 1.0 and 2.0 mg/L). This trend was also observed for phosphorus, but no load contributions from range and forest land uses exist for that nutrient. The lower observed nitrogen concentrations may be due to elevated expected mean concentration values assigned to either the range, forest, or agriculture land uses in the basin. Alternatively, the fact that no loss of pollutant is included in the assessment may account for the elevated predicted concentrations in this subbasin.

Total Cadmium

Table 3.6 includes expected mean concentration data for six heavy metal pollutants. Cadmium is chosen as a representative metal with which to perform the nonpoint source pollution assessment. Figure 5.4 shows the aerial distribution of total cadmium expected mean concentrations in the San Antonio-Nueces coastal basin. Expected mean metal concentrations are three orders of magnitude lower than for the nutrients, and are measured in micrograms per liter (μg/L). Unlike for the nutrient concentrations, the highest levels of cadmium (2.0 μg/L) are expected from urban industrial land uses, rather than agricultural land uses (1.0 μg/L). Cadmium concentrations from range and forest land uses are expected to be 0.5 μg/L. Actual metal contributions from urban industrial land uses are expected to vary with the particular industries that occupy each specific land use area. Closer review of Figure 5.4

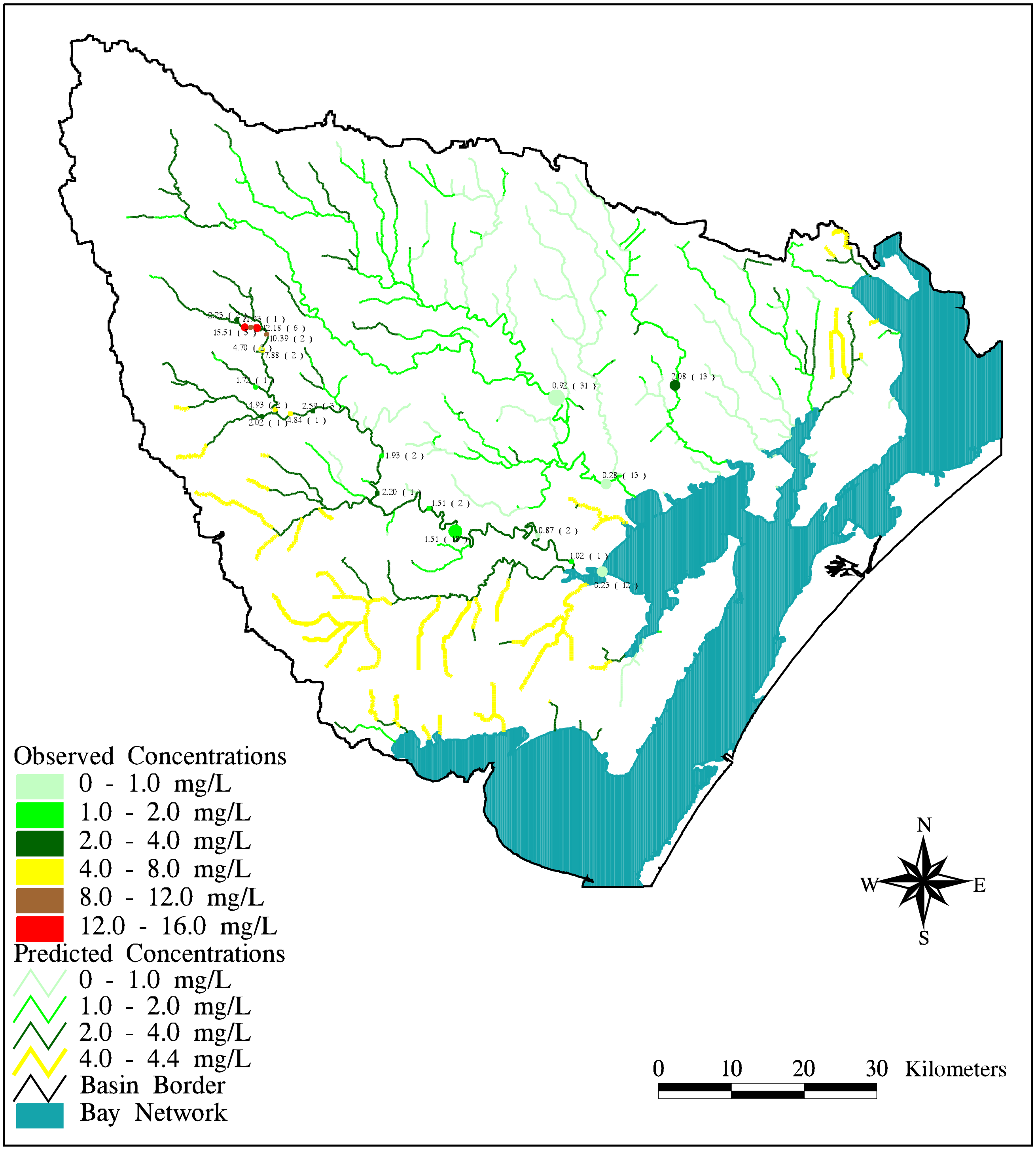

Figure 5.3 : Comparison of Estimated and Average Observed Total Nitrogen Concentrations in the San Antonio-Nueces Coastal Basin

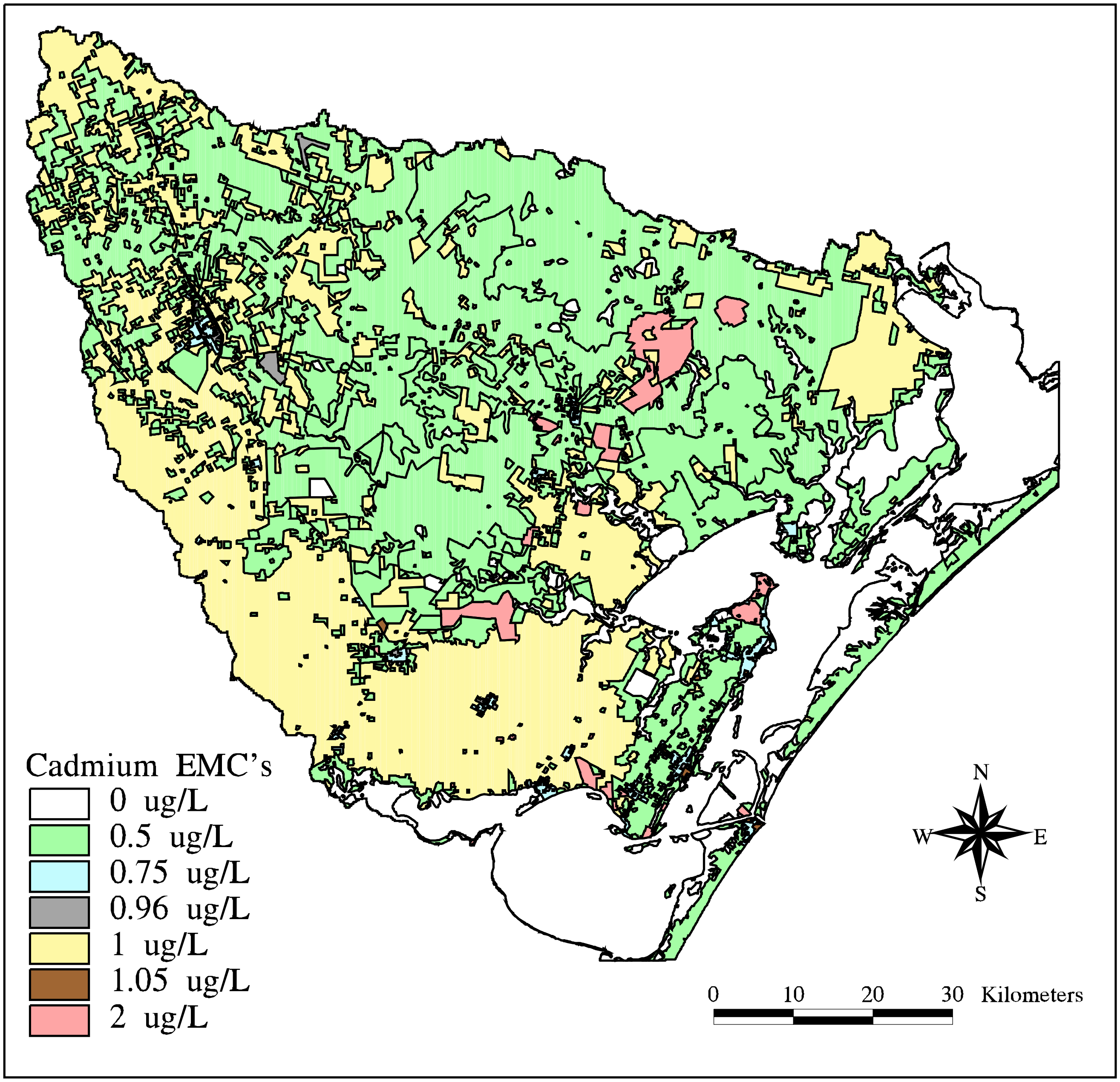

Figure 5.4 : Total Cadmium Estimated Mean Concentrations in the San Antonio-Nueces Coastal Basin

shows the largest patch of urban industrial land uses exists in the northern central part of the basin. These areas depict the boundaries of existing oil fields in the region.

Figure 5.5 shows the predicted annual cumulative cadmium loadings to stream networks in the San Antonio-Nueces basin. The largest cumulative cadmium load (173.5 kg/yr) is expected at the outlet of the Mission River subbasin, which drains the largest area in the coastal basin and includes part of the oil field land use area discussed above. The magnitudes of the cumulative loads are significantly smaller than those for the nutrients, as a result of the smaller expected mean concentrations assigned to the land use polygons. Table 5.1 shows that, unlike for the nutrient loads, total annual cumulative cadmium load from the Mission River subbasin exceeds the sum of the loads from the three major streams in the Aransas River subbasin (148.2 kg/yr). This corresponds to a lower relative level of cadmium contribution from agricultural land uses.

A review of the predicted cadmium concentrations from Figure 5.6 shows that concentrations in the San Antonio-Nueces coastal basin are almost universally expected to be in the 0.5 - 1.0 μg/L range. There are a few small tributaries in the Copano and Mission subbasins where concentrations are expected to exceed 1.0 μg/L. These are the tributaries draining the oil fields in the north central part of the basin. One small tributary to Chiltipin Creek that passes through an urban industrial area also includes a reach where concentrations are expected to be higher than 1.0 μg/L. Finally, there are some small reaches in the southern part of the basin that drain agricultural land use regions, only. Concentrations along these reaches are expected to be exactly 1.0 μg/L, but are identified as being in the 1.0 - 2.0 μg/L range. Due to the rounding associated with the division of cumulative load by the integer values of cumulative runoff, the calculated values for predicted cadmium concentration are slightly higher than the expected 1.0 μg/L.

Figure 5.6 also includes four measurement locations where values for observed cadmium concentrations were recorded. A review of the TNRCC Surface Water Quality Monitoring (SWQM) data for these locations shows only one location (Mission River) where more than a single measurement exists. A comparison of the TNRCC recorded concentrations for other heavy metal pollutants with the measurements for cadmium shows that the exact same values are recorded for all heavy metal measurements at each location. This fact leads to the conclusion that the

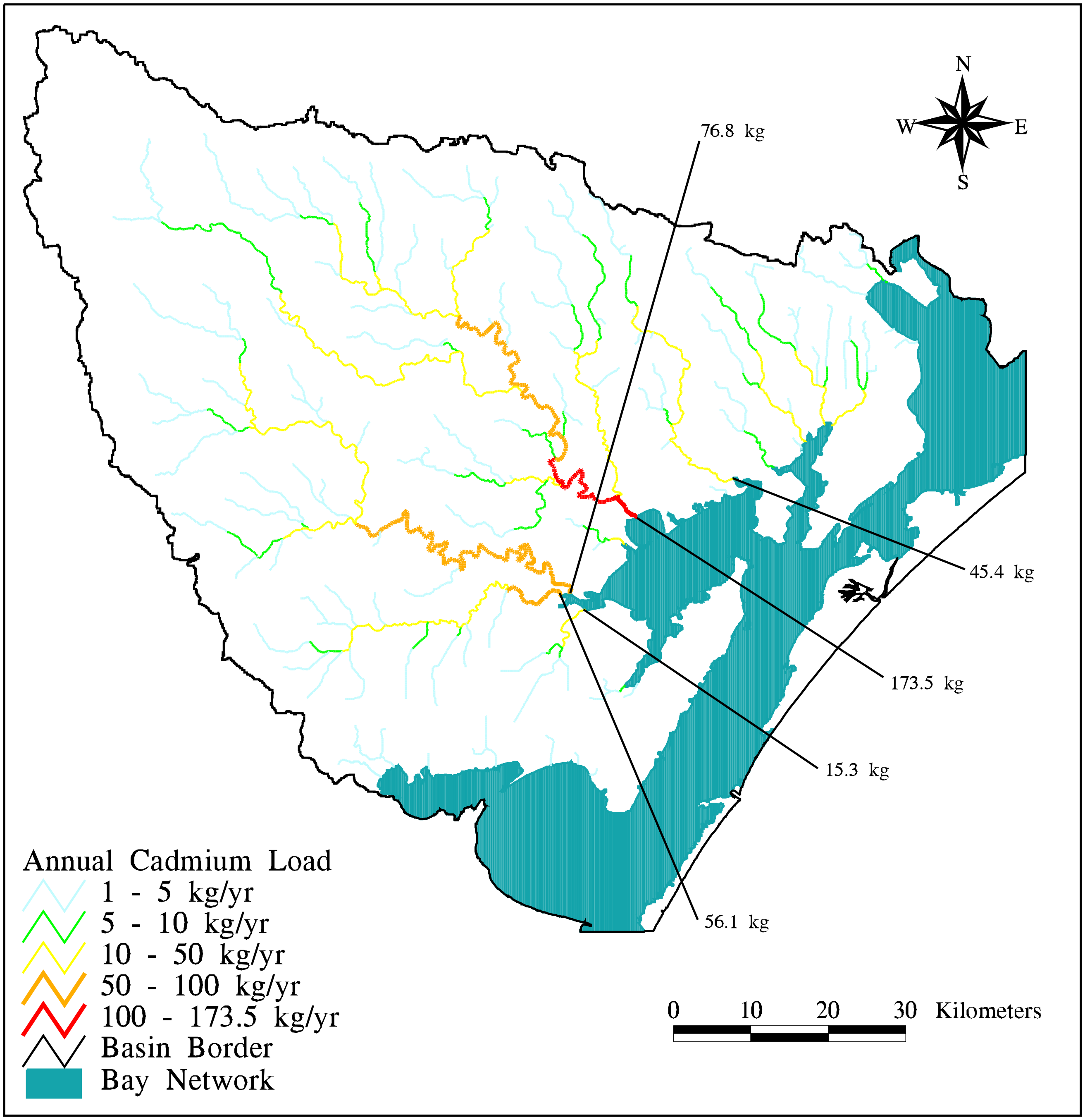

Figure 5.5 : Average Annual Total Cadmium Loads in the San Antonio-Nueces Coastal Basin

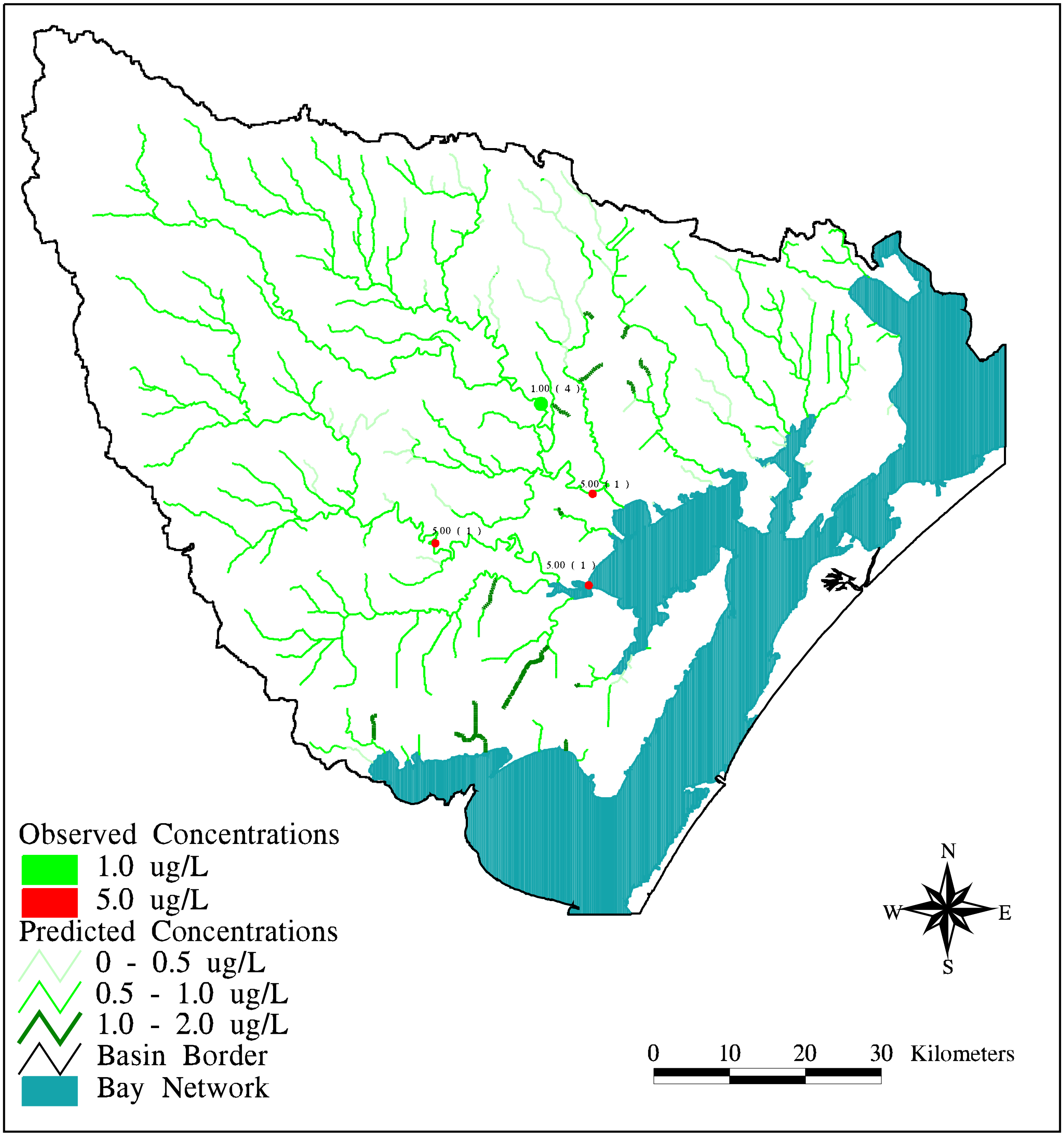

Figure 5.6 : Comparison of Estimated and Average Observed Total Cadmium Concentrations in the San Antonio-Nueces Coastal Basin

TNRCC SWQM data for heavy metals is questionable and more data are needed to judge the accuracy of the nonpoint source pollution assessment.

Fecal Coliform

Fecal coliform bacteria are present in the feces of warm blooded animals and are indicators of bacteriological water quality. Concentrations of fecal coliform are measured in number of bacteria colonies per 100 milliliter sample. The fecal coliform expected mean concentration data from Table 3.6 only includes values for urban land uses and range/forest land uses. The urban land use concentrations are established from concentrations measured as part of the Dallas-Ft. Worth National Pollutant Discharge Elimination System (NPDES) study and the range land expected mean concentrations are established from measured concentrations at the USGS stream gauge #08201500 on Seco Creek near Utopia, TX (Baird, et al., 1996). No expected mean concentration value for agricultural lands is provided in Table 3.6. Preliminary copies of this table actually included agricultural expected mean concentration values in the range of 20,000 - 30,000 colonies per 100 milliliters but, ultimately, the variability observed in the unpublished editions of the table persuaded the authors to exclude any official value for agricultural lands. In accordance with this lack of actual published data, no fecal coliform concentration is assumed from agricultural land uses.

Figure 5.7 shows the aerial distribution of the available expected mean concentration data in the San Antonio-Nueces coastal basin. As is the case with Table 3.6, the most significant concentration values are associated with urban land uses in the basin. A value of 200 colonies per 100 milliliters is assigned to the range and forest land use regions in the basin.

Average annual fecal coliform loads in the San Antonio-Nueces coastal basin are calculated using the procedure outlined in section 4.5. However, due to the uncommon units of the fecal coliform expected mean concentrations and the magnitude of the cumulative loads, the cumulative load equation for this calculation is modified to

$$L = Q\ (\text{mm/yr}) * EMC\ (\text{colonies/100 mL}) * A\ (10{,}000\ \text{m}^2/\text{cell}) * 10^{-9}\ \text{trillion mL-m/mm-m}^3, \quad (5\text{-}1)$$

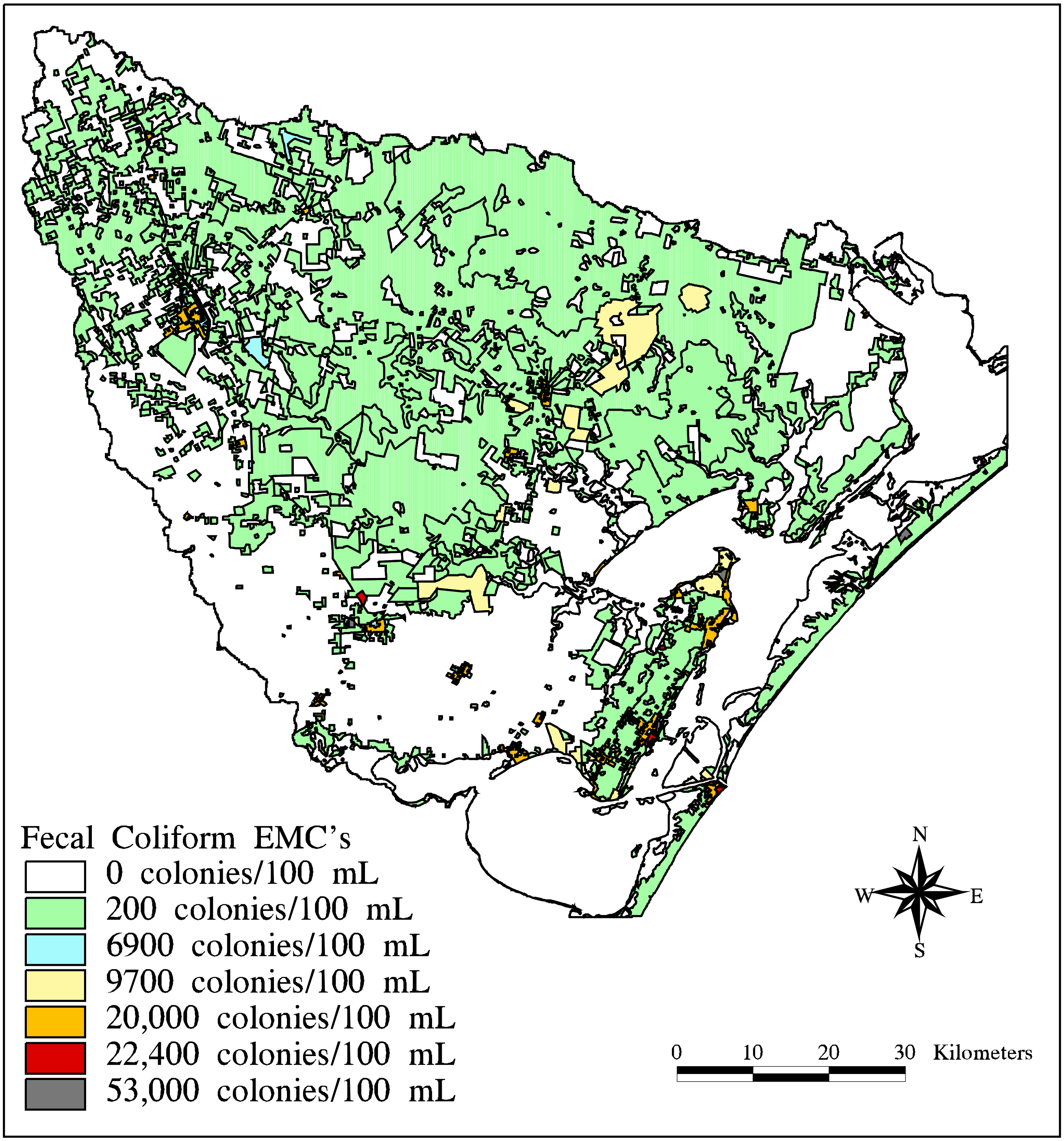

Figure 5.7 : Fecal Coliform Estimated Mean Concentrations in the San Antonio-Nueces Coastal Basin

where load (L) is determined in units of trillion colonies per year. Figure 5.8 shows the average annual cumulative loadings in the San Antonio-Nueces coastal basin. Due to the zero value of expected mean concentration assigned to the agricultural land use areas, streams that exclusively drain agricultural regions accumulate no loads and, hence, are absent from this figure.

The largest predicted cumulative load in the San Antonio-Nueces basin occurs at the outlet of the Mission River subbasin and is almost 1.47 x 10^{15} colonies per year. As can be seen from Table 5.1, this value exceeds the sum of the loads from the three major streams of the Aransas River subbasin (1.1 x 10^{15} colonies per year) and the fecal coliform average annual load from Copano Creek (941 x 10^{12} colonies).

Figure 5.9 shows predicted fecal coliform concentrations in the San Antonio-Nueces coastal basin stream network. These values range up to almost 9000 colonies/ 100 milliliter sample. The largest concentrations occur immediately downstream of the locations of various urban land uses in the basin. Average observed fecal coliform concentrations throughout the basin are consistently lower than the predicted values, although, for most of the sampling locations, only one measurement specifies the average observed value. The trend of predicted concentration values exceeding average measured values indicates that the fecal coliform expected mean concentration values assigned to urban land uses are probably too high. Given the magnitudes of these expected mean concentration values and the large degree of variability between measurements, the nonpoint source pollution assessment for this constituent (and fecal streptococci) needs further investigation and data collection to be reliable.

5.2 Assessment of Basin Pollution Including Point Sources

Section 4.6 describes a method of estimating point source loads by considering the difference between calculated nonpoint source pollution concentration levels and observed concentration levels at a specific location, and then accounting for that difference with a single point load at the location. This method is employed for both total phosphorus and total nitrogen, since nutrients are of particular interest to the TNRCC. Also, since there are significant numbers of TNRCC Surface Water Quality Monitoring data measurements for phosphorus and nitrogen, the average of the

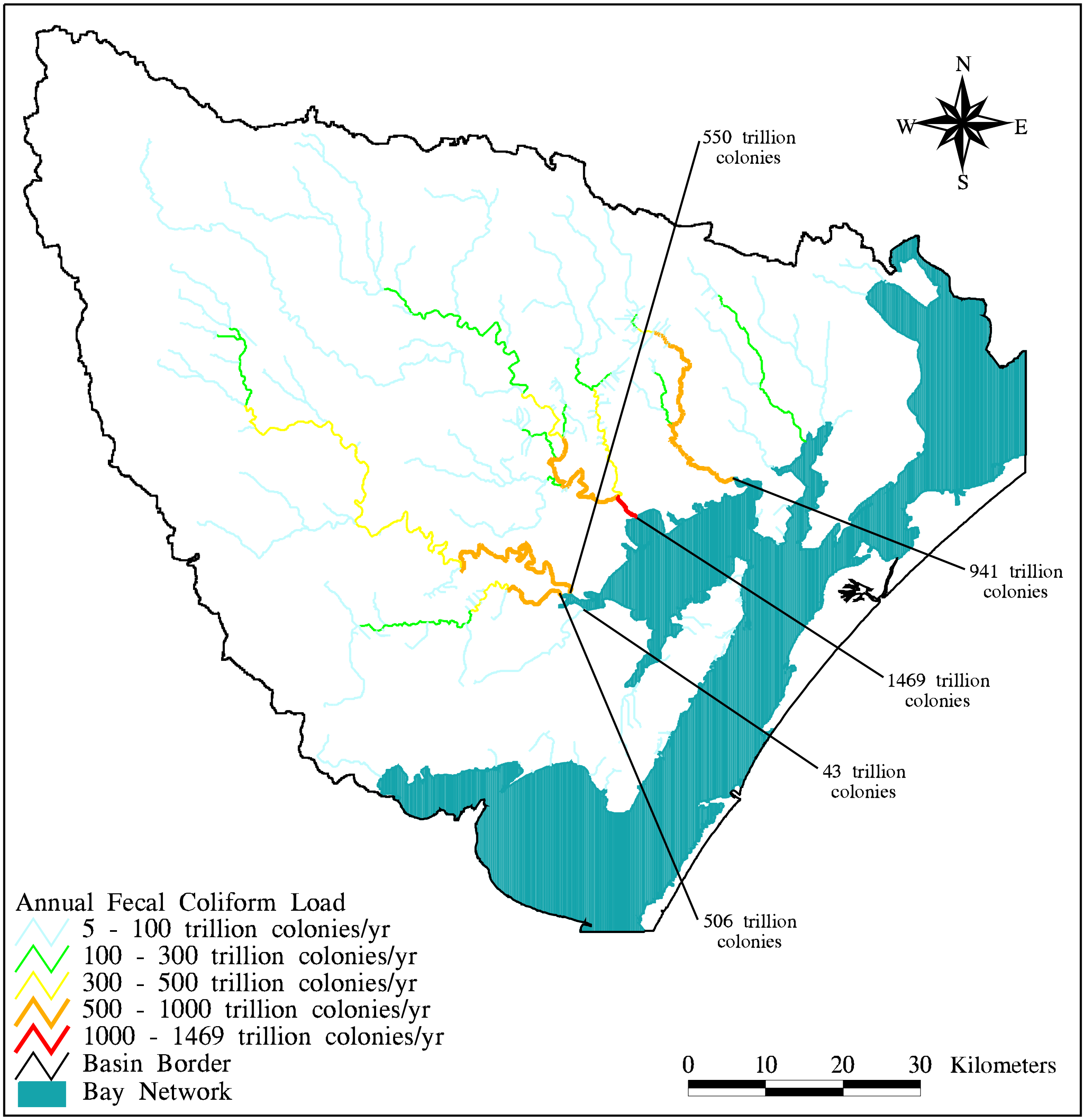

Figure 5.8 : Average Annual Fecal Coliform Loads in the San Antonio-Nueces Coastal Basin

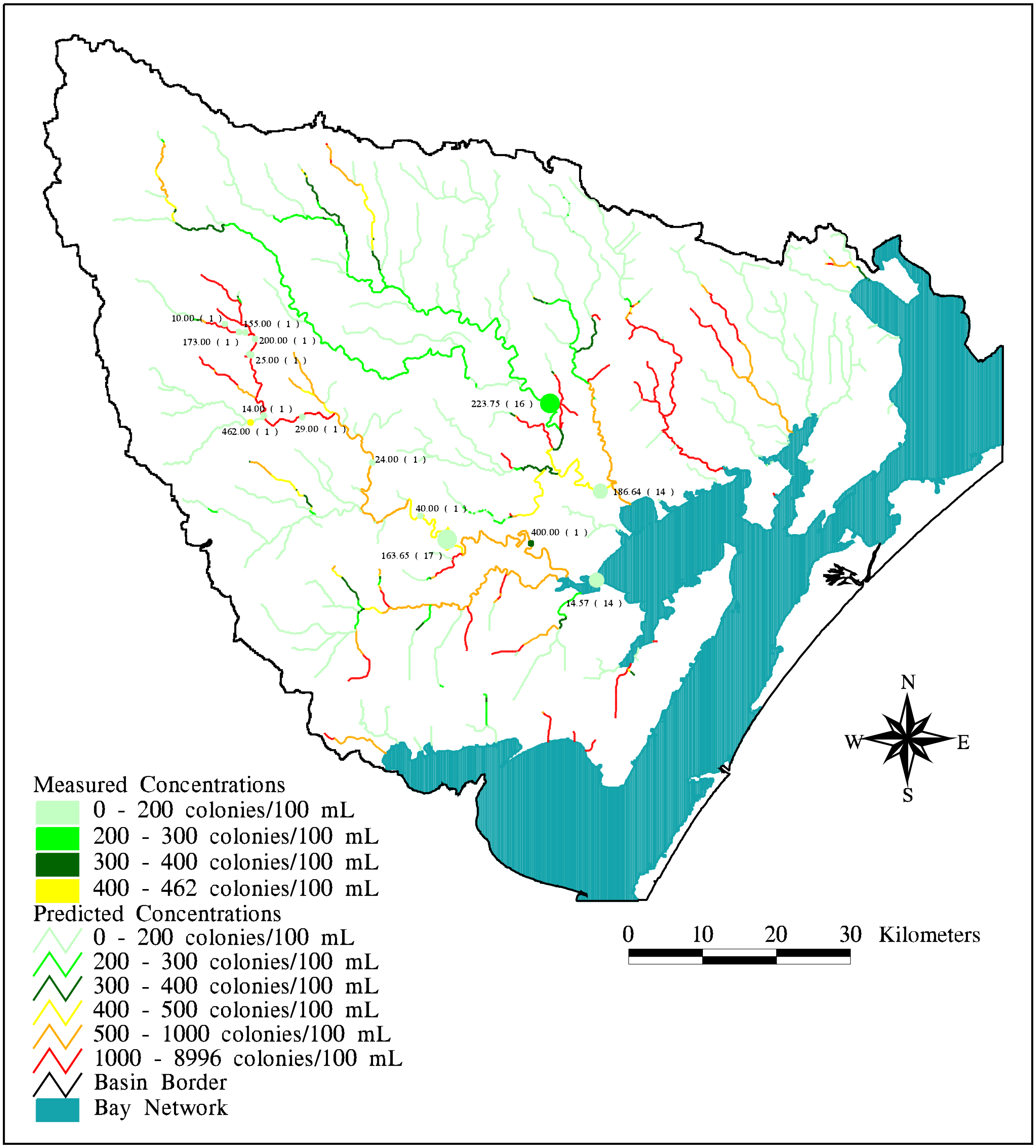

Figure 5.9 : Comparison of Estimated and Average Observed Fecal Coliform Concentrations in the San Antonio-Nueces Coastal Basin

observed concentrations for these pollutants is considered more representative of actual conditions within the stream networks. Hence, comparison of predicted and average observed concentrations is considered more significant for these constituents.

Total Phosphorus

As discussed in section 4.6, the phosphorus point load established by this method, estimated at the furthest upstream location where a significant concentration discrepancy exists, is approximately 100% higher than an equivalent load estimated using the methods of Thomann and Mueller (1987) and approximately 69% higher than a load estimated using the current average daily flow reported by the Beeville wastewater treatment plant (Barrera, 1996).

The discrepancy between the point load estimation and these other methods of calculating point loads could be explained by the existence of additional point sources in close proximity to or somewhere upstream from the location of the Beeville wastewater treatment plant. Alternatively, the effluent phosphorus concentration from the plant may have been higher than Thomann and Mueller's typical estimate of seven mg/L during the period when phosphorus measurements were recorded at the location. Regardless of whether this method accurately represents the phosphorus point load from the Beeville wastewater treatment plant, the method does illustrate a method of simulating a conservative point load and applying the corresponding increase in mass load to all downstream locations.

Figure 4.25 (a-c) shows the modified in-stream phosphorus concentrations compared with the average observed phosphorus concentrations at measurement locations along the Aransas River. As a result of the point source addition at Beeville, the dilution effect of the higher concentration tributaries mixing with the larger flows of the Aransas main stem is more pronounced. Also, while the chosen predicted and observed concentration ranges still do not match up exactly at all downstream locations, the differential at each location is made smaller and, in fact, predicted concentration ranges do match the observed ranges in the lower reaches of the Aransas River (Figure 4.25c).

Total Nitrogen

For total nitrogen, a nonpoint source pollution concentration grid, nitconc, is created as per the procedure outlined in section 4.5. The predicted nonpoint source nitrogen concentration at the point where the Beeville wastewater treatment plant effluent is estimated (from the total phosphorus analysis) is queried, using the Gridpaint and Cellvalue commands, as in section 4.6.

Grid: **gridpaint nitconc value linear nowrap gray**
Grid: **polygonshades nitpts 2**
Grid: **cellvalue nitconc ***
The cell containing point (1223830.414,693729.621) has value 2.434

Noting that the average observed total nitrogen concentration at the point source location is 15.51 mg/L, the amount of this concentration attributed to the point source effluent is calculated as 15.51 mg/L - 2.434 mg/L = 13.076 mg/L. By multiplying this value by the cumulative runoff at the point source established from the total phosphorus analysis in section 4.6, the total annual estimated cumulative nitrogen point load is determined as

$$13.076 \text{ mg/L} * 5{,}467{,}914 \text{ m}^3\text{/yr} * 1000 \text{ L/m}^3 * 10^{-6} \text{ kg/mg} = 71{,}498 \text{ kg/yr.} \quad (5\text{-}2)$$

Thomann and Mueller's estimate for a typical mean value of total nitrogen concentration in the effluent of a conventional secondary treatment facility is 18 mg/L (Thomann and Mueller, 1987). Using this value, along with the other parameters from equation 4-13, an alternative value for total nitrogen load is estimated as

$$125 \text{ gcd} * 13547 \text{ pop.} * 365 \text{ d/yr} * 3.785 \text{ L/gal} * 18 \text{ mg/L} * 10^{-6} \text{ kg/mg} = 42{,}110 \text{ kg/yr.} \quad (5\text{-}3)$$

Finally, using the average daily flow from the Beeville wastewater treatment plant to replace the population-derived flow, a third estimate of annual total nitrogen load is calculated as

$$2{,}000{,}000 \text{ gal/d} * 365 \text{ d/yr} * 3.785 \text{ L/gal} * 18 \text{ mg/L} * 10^{-6} \text{ kg/mg} = 49{,}735 \text{ kg/yr.} \quad (5\text{-}4)$$

The total nitrogen point load calculated in equation 5-2, estimated by accounting for the complete difference in predicted nonpoint source concentration and average observed concentration with a single point source, exceeds the value estimated using Thomann and Mueller's method by approximately 70%. Alternatively, the load of equation 5-2 is only 44% greater than a load calculated using the current average daily flow at the Beeville wastewater treatment plant.

As for the estimate of annual total phosphorus point load, the fact that the estimate from equation 5-2 is within the same order of magnitude as the other estimates is encouraging, but also indicates that there may be additional point sources in close proximity to the location of the Beeville wastewater treatment plant. Alternatively, if the effluent nitrogen concentration from the plant was as high as 26 mg/L during the period when nitrogen measurements were recorded at the location, instead of Thomann and Mueller's typical estimate of 18 mg/L, then the difference between predicted and observed total nitrogen concentrations would be explained by the single point source.

Figure 5.10 (a-c) shows the in-stream predicted total nitrogen concentrations, determined with the point source at Beeville included and compared with the average observed total nitrogen concentrations at measurement locations along the Aransas River. As for the similar total phosphorus comparison in Figure 4.25 (a-c), the predicted and observed concentration ranges do not match exactly throughout the length of the river, but do agree quite well, particularly in the reaches immediately downstream of the suspected point source at Beeville. In the lower reaches of the Aransas River, where the defined concentration ranges are smaller, predicted concentrations typically fall within 1-2 mg/L of the average observed concentrations.

5.3 Expected Mean Concentration Values from the Optimization Routine

Table 4.7 shows the results from the Microsoft Excel Solver optimization program runs. As identified is section 4.7, the original intent of using this routine was to establish a method of estimating pollutant expected mean concentration values rather than having to rely on literature-based values. However, since there are only four useable Surface Water Quality Measurement stations with a significant number of

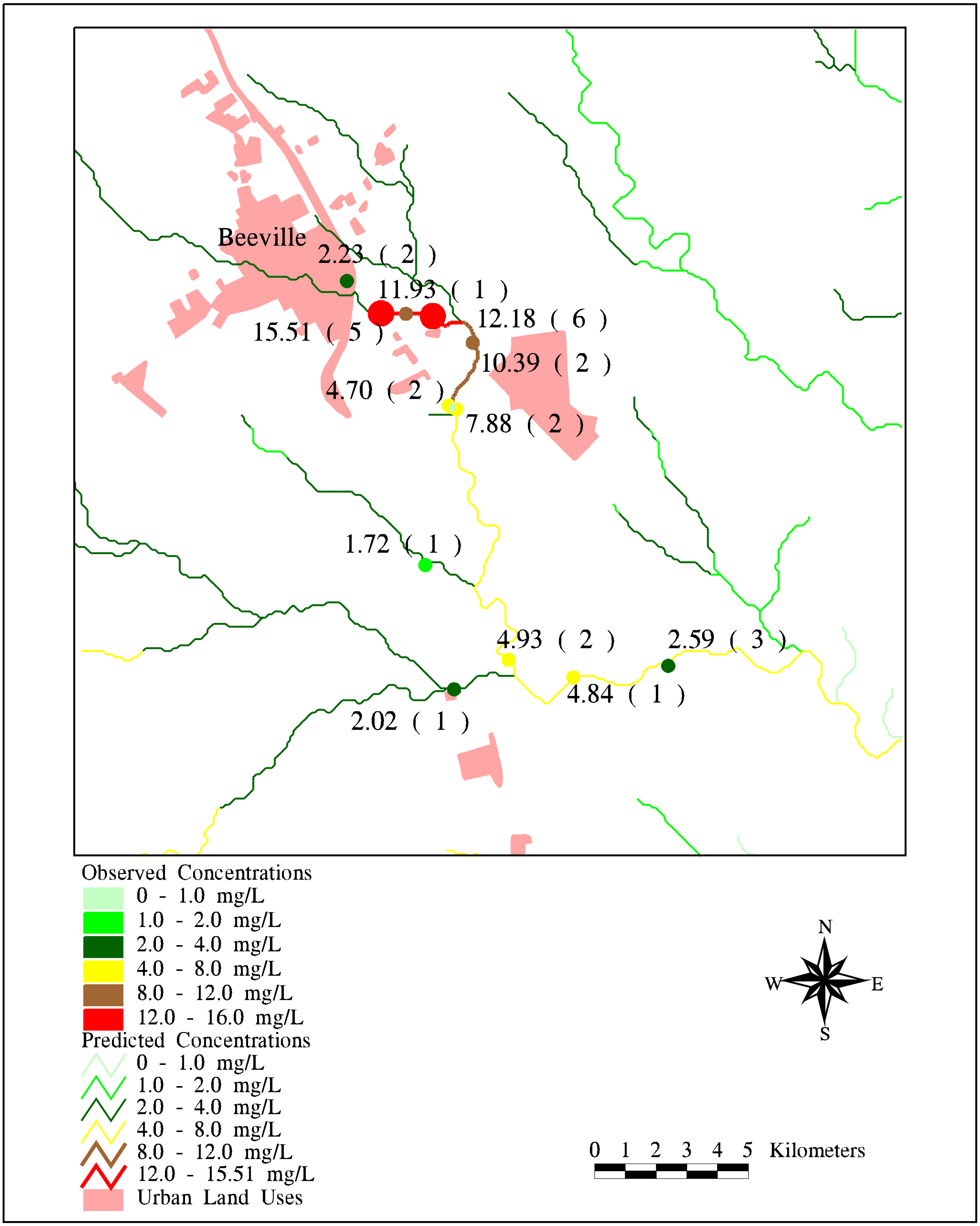

Figure 5.10a : Predicted vs. Observed Total Nitrogen Concentrations (Beeville Point Source Included) Just Downstream of Beeville, TX

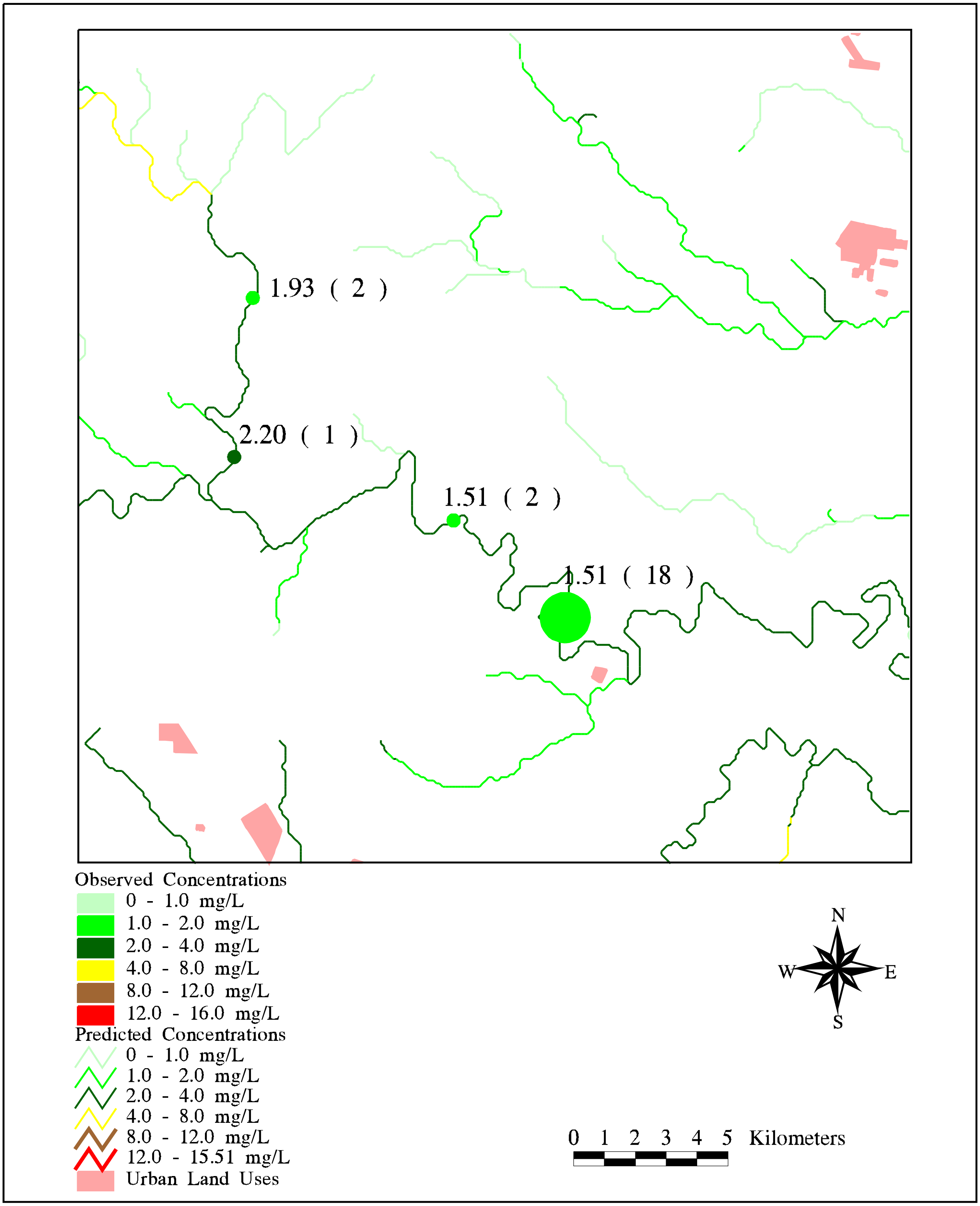

Figure 5.10b : Predicted vs. Observed Total Nitrogen Concentrations (Beeville Point Source Included) for Middle Aransas River

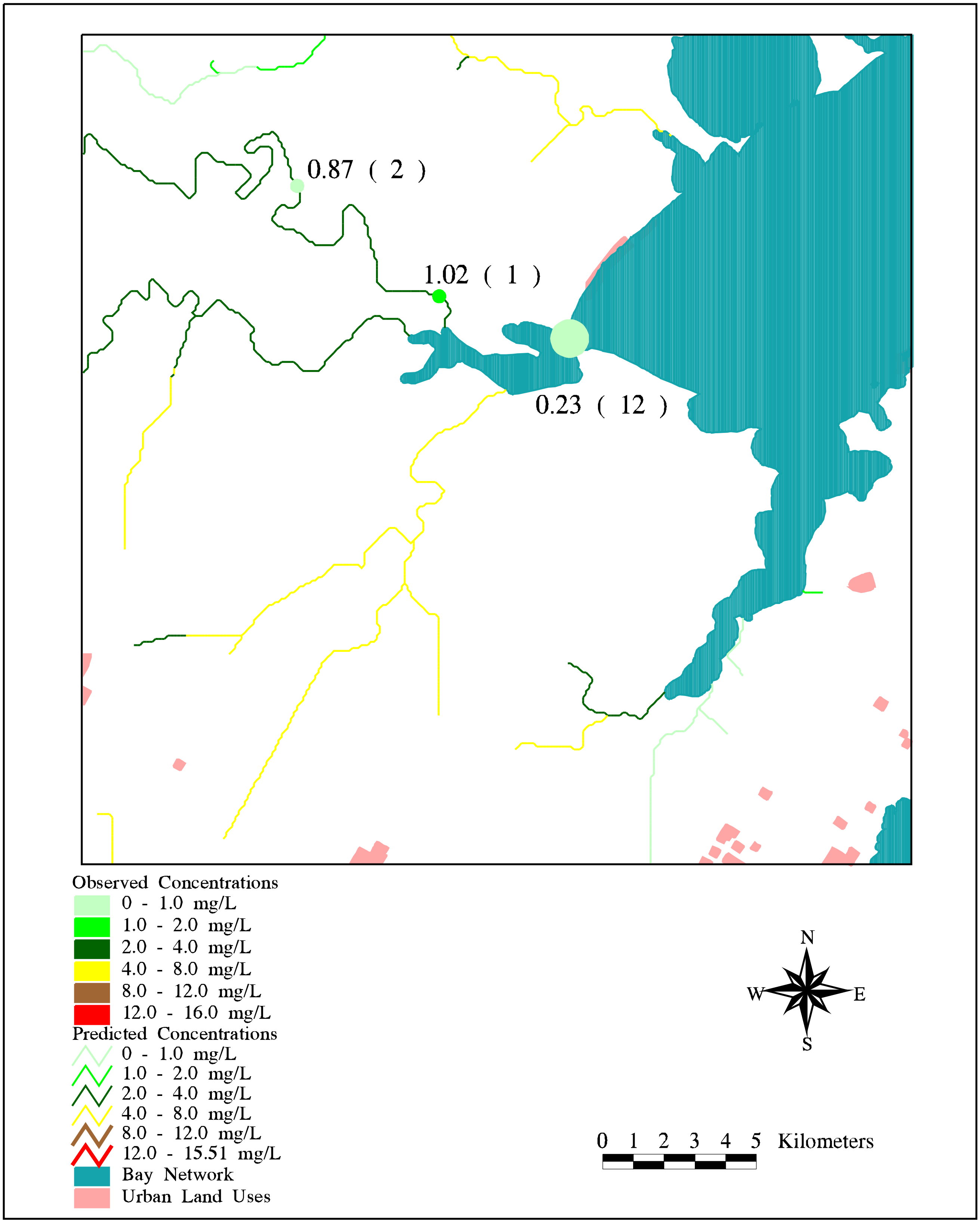

Figure 5.10c : Predicted vs. Observed Total Nitrogen Concentrations (Beeville Point Source Included) for Lower Aransas River

measurements (more than 15) for total phosphorus concentration, only four concentration balance equations are established for those sampling locations. The fact that there are 12 different land uses in the four subbasins draining to these sampling locations necessitates that 12 expected mean concentration variables are included in the four concentration balance equations.

With only four equations and 12 variables, additional constraints on the variables are required to limit the number of possible solutions. By constraining the water and wetland expected mean concentrations to a value of zero and by making the values of other urban and mixed urban expected mean concentrations dependent on the residential, commercial, industrial and transportation expected mean concentration values, the number of variables in the four equations is effectively reduced to eight. However, four equations with eight variables can still be solved with an infinite number of solutions. The initial values entered for each expected mean concentration value have a definite impact on the final values established by the optimization routine. Hence, for these runs, the optimization routine does not provide an independent method of determining expected mean concentration values. Rather, it provides a method of adjusting initial values until a more optimum solution is established.

The two methods used to establish optimum expected mean concentration values for the subbasin land uses are (1) minimization of the sum of the absolute values of each concentration balance and (2) minimization of the maximum concentration balance absolute value. With only four equations and eight effective variables, the concentration balance equations do not converge to zero for either method.

Using the first optimization method, the routine converges to a solution that includes a negative concentration balance of 0.184 mg/L at the Mission River station. This negative value of concentration balance represents an overestimation of the predicted concentration at that location. The same method underestimates the predicted concentration at the Aransas station by 0.117 mg/L. An additional observation with the use of this optimization method is that, for urban industrial, urban transportation, range, and barren land uses, the final optimized expected mean concentrations are equal to the +/- 50% constraint value imposed on each variable. This indicates that the optimization routine stops because it reaches the constraint values and doesn’t necessarily find the most optimum solution.

Minimization of the maximum concentration balance absolute value converges to a solution that overestimates the predicted concentration at the Mission River station by only 0.165 mg/L, but also underestimates the predicted concentration at the Aransas River station by 0.165 mg/L. Interestingly, no constraint value is reached when using this optimization method. In fact, only the optimized expected mean concentration value for forest land is more than 7% greater than the initial value entered from Table 3.6. Since this optimization method produces adjusted results that are closer to the empirically established expected mean concentration values of Table 3.6, and since the optimization converges to a solution without reaching any of the constraint values, this method is preferred to the minimization of the concentration balance sum as the means to adjust expected mean concentration values.

For future investigations, this optimization method may be used to independently establish land use-based expected mean concentration values by including additional measurement locations in or near the basin of interest. For this study, no additional measurement locations with more than six total phosphorus concentration measurements exist in the basin. However, by including additional measurement locations in close proximity to the basin, more concentration balance equations could be added to the optimization without adding more expected mean concentration variables. By simultaneously solving a number of concentration balance equations with the same number of expected mean concentration variables, an unique solution should be achievable.