Corpus Christi Bay, Galveston Bay, Mission-Aransas Bay, San Antonio Bay, and Sabine Lake Lower-Watershed Multi-year Land-Use and Land Cover Classifications and Curve Numbers

TWDB Contract #0804830788

by

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Submitted to Texas Water Development Board

Introduction

Land use along the Texas coast has changed significantly in the past two decades. Land Cover and land use have a major impact on the amount of water that is absorbed by the soil, and ultimately on the amount of runoff that reaches the rivers and estuaries. This project aims to determine where land-use/Land Cover change has taken place in the lower drainage basins for Corpus Christi Bay (Corpus), Mission-Aransas Bay (Mission), San Antonio bay (Guadalupe), Galveston Bay (Galveston), and Sabine Lake (Sabine). It also determines the types of changes that have occurred. Of note, in the previous report, *Galveston and Lavaca Watershed Multi-year Land Use and Land Cover Classifications and Curve Numbers*, the Galveston watershed contained both the Galveston and Sabine watersheds. This report separates the two watersheds and provides the statistics for each individually. Below, the table shows the area of each watershed, including 150 meter buffer, and a reference map for the watersheds. Figure 1, on the next page, shows the study area.

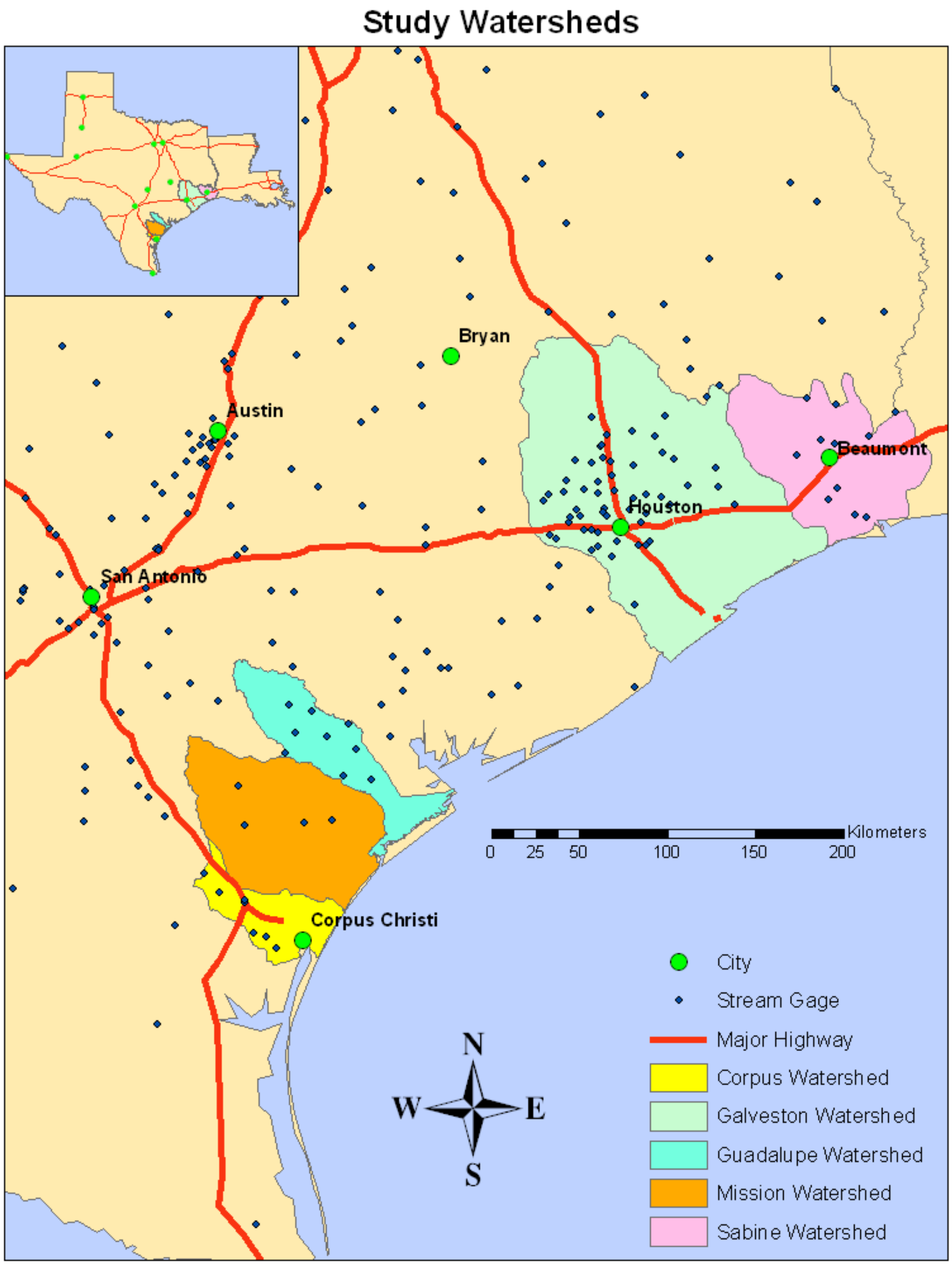


Figure 1. Overview map of the study area.

Methods

The first step in creating the Anderson Level I classification was securing images that covered the required area during the given time periods. The National Aeronautics and Space Administration's (NASA) satellite, LandSat Thematic Mapper (TM) images on the United States Geological Survey (USGS) website's Global Visualization Viewer (GLOVIS) met these requirements. The area being studied required seven LandSat TM scenes. The path/row for the scenes being used are 24/39, 25/39, 25/40, 26/40, 26/41, 27/40, and 27/41. Having two time periods to classify this required fourteen LandSat TM scenes, seven scenes with two images per path/row. The dates for each scene are in the table below.

Path	Row	Early Date	Late Date
24	39	03/10/1998	04/27/2004
25	39	03/17/1998	05/04/2004
25	40	03/17/1998	05/04/2004
26	40	04/09/1998	04/09/2004
26	41	03/08/1998	03/08/2004
27	40	03/31/2004	03/31/2004
27	41	03/31/2004	03/31/2004

Table 1. List of LandSat images used.

For the purposes of this project, only an Anderson Level I classification was needed. An Anderson Level I classification consists of generalized classes, including: 1) Urban, 2) Agriculture, 3) Rangeland, 4) Forest, 5) Water, 6) Wetland, 7) Barren Land, 8) Tundra, and 9) Perennial Snow or Ice. An Anderson Level II classification would break these generalized classes down to more specific ones, having the Urban class split into: 1) Residential, 2) Commercial and Services, 3) Industrial, 4) Transportation, Communications, and Utilities, 5) Industrial and Commercial Complexes, 6) Mixed Urban or Built-up Land, and 7) Other Urban or Built-up Land classes. This project only required the use of the first seven Anderson Level I classes because Tundra and Perennial Snow or Ice do not exist in the study area. The National Land Cover Data (NLCD) 1992 and NLCD 2001 are more in depth, analogous to an Anderson Level II classification, necessitating consolidation of some classes. Using Leica Geosytem's image processing software, ERDAS Imagine, NLCD 1992 and NLCD 2001 were recoded to fit the parameters of an Anderson Level 1 classification. The classes being used are Agriculture, Barren Land, Forest, Rangeland, Urban, Water, and Wetland. Below are the class structures for NLCD 1992 and NLCD 2001 along with the class its Anderson Level I classification used in this study.

Class Number	1992 NLCD	2001 NLCD	Anderson Classification
11	Open Water	Open Water	5) Water
12	Perennial Ice/Snow	Perennial Ice/Snow	Not Needed
21	Low Intesity Residential	Developed, Open Space	1) Urban
22	Heavy Intensity Residential	Developed, Low Intensity	1) Urban
23	Commercial/Industrial/Transportation	Developed, Medium Intensity	1) Urban
24	N/A	Developed, High Intensity	1) Urban
31	Bare Rock/Sand/Clay	Barren Land (Rock/Sand/Clay)	7) Barren Land
32	Quarries/Strip Mines/Gravel Pits	Unconsolidated Shore	7) Barren Land
33	Transitional	N/A	7) Barren Land
41	Deciduous Forest	Deciduous Forest	4) Forest
42	Evergreen Forest	Evergreen Forest	4) Forest
43	Mixed Forest	Mixed Forest	4) Forest
51	Shrubland	Dwarf Scrub	3) Rangeland
52	N/A	Shrub/Scrub	3) Rangeland
61	Orchards/Vineyards/Other	N/A	2) Agriculture
71	Grasslands/Herbaceous	Grasslands/Herbaceous	3) Rangeland
72	N/A	Sedge/Herbaceous	3) Rangeland
73	N/A	Lichens	3) Rangeland
74	N/A	Moss	3) Rangeland
81	Pasture/Hay	Pasture/Hay	2) Agriculture
82	Row Crops	Cultivated Crops	2) Agriculture
83	Small Grains	N/A	2) Agriculture
84	Fallow	N/A	2) Agriculture
85	Urban/Recreational Grasses	N/A	1) Urban
90	N/A	Woody Wetlands	6) Wetland
91	Woody Wetlands	Palustrine Forested Wetland	6) Wetland
92	Emergent Herbaceous Wetlands	Palustrine Scrub/Shrub Wetland	6) Wetland
93	N/A	Estuarine Forested Wetland	6) Wetland
94	N/A	Estuarine Scrub/Shrub Wetland	6) Wetland
95	N/A	Emergent Herbaceous Wetlands	6) Wetland
96	N/A	Palustrine Emergent Wetland	6) Wetland
97	N/A	Estuarine Emergent Wetland	6) Wetland
98	N/A	Palustrine Aquatic Bed	6) Wetland
99	N/A	Estuarine Aquatic Bed	6) Wetland

Table 2. Comparison of Land Cover classes used in the 1992 and 2001 NLCD, and their classification in this study.

Sources: 1992 NLCD: http://Land Cover.usgs.gov/classes.php
2001 NLCD: http://www.mrlc.gov/nlcd_definitions.asp

To have a baseline of locations of the Land Use/Land Cover classes, a new dataset was created from the recoded NLCD 1992 and NLCD 2001. Using the modeler in Leica Geosystem's ERDAS Imagine 9.1, pixels that had the same class value kept their classification and pixels that did not have the same class value were masked out to 0. The resulting image will be referred to as the "Combined NLCD" image.

The Corpus, Guadalupe, and Mission watersheds are fairly small and border each other. They were treated as one watershed (referred to as CGM) to be split after classification. However, the watersheds fell on multiple scenes. Because of this, it was necessary to align all of the scenes. Even though all the images were in the same projection, Universal Transverse Mercator (UTM) World Geodetic System 1984 (WGS84) Zone 14 North, they did not match up perfectly. To align the images a Texas transportation vector file was brought in. The transportation file was obtained from the Texas Department of Transportation (TXDOT) and shows the major roads of Texas. First, the transportation file was overlaid on the LandSat 27/40 and 41 images for both 1998 and 2004. The 2004 image was aligned with the transportation file, but the 1998 image was a little off so it was manually moved by adjusting the upper left X and Y using ERDAS. Once both images corresponded with each other and the transportation data, the other images and the Combined NLCD were adjusted. Each was done in the same manner as the 27/40 and 41 image for 1998. When all the adjusting was done, the images were aligned with both the other images of the same year and the corresponding image of the other year.

Using ERDAS, the watersheds were overlaid onto the LandSat TM scenes and Areas of Interest (AOI) were drawn around the area of the watershed, including a significant buffer within each scene. An AOI is a user defined region to be further examined. The images were clipped to the AOI for the CGM area. Three clipped images were made from this process. The Combined NLCD and Digital Elevation Models (DEM) were also clipped to the same AOI as well.

After clipping the Combined NLCD images, a set of random points were generated using ERDAS Imagine 9.0. Two sets of points were created according to the Combined NLCD for CGM, one for calibration and one for validation, with the same parameters. Equalized random sampling, with a requirement of a threshold of 9 pixels of a 3x3 window must belong to the same class, was used for all scenes. Each class received 10 points, except the “Barren Land” class because of its miniscule area, giving a total of 60 points per dataset. The “Barren Land” class was still included in the classification but not in the accuracy assessment.

After the list of points was generated, they were put into an Excel worksheet and converted to a .dbf file to bring them into ArcView GIS 3.3 to convert them to a shapefile. The points were overlaid on the Combined NLCD and the corresponding watershed images in ArcView. Each point was inspected individually to make sure it matched the class it was given in the Combined NLCD and then to make sure the points matched in both images. If the point did not match the Land Cover in both images, was on the edge of Land Cover, or was hard to determine what the Land Cover was; the point was manually moved to a large, easily identifiable area of contiguous Land Cover that also registered on the Combined NLCD location.

To perform the classification, Definien’s eCognition software was used. eCognition is an object oriented classification algorithm. An object-oriented classification algorithm first creates clusters of homogenous pixels through segmentation and then a supervised classification can be performed on the segmented image. eCognition allows the use of many different types of data to be used to create a classification. The layers used included all 7 bands of the LandSat TM image, DEM, and Normalized Difference Vegetation Index (NDVI) derived from the LandSat TM image. A NDVI layer is the ratio of the Red (R) and Near Infrared bands (NIR), represented by the equation below:

$$NDVI = \frac{NIR - R}{NIR + R}$$

The NDVI responds to green biomass and helped to separate the difference between the Forest and Rangeland classes. Segmentation takes several factors into account: how much weight each layer has, scale parameter, color vs. shape, and compactness vs. smoothness. Layer weight determines how important each layer is in the segmentation process. Scale parameter is a variable that determines the size of the cluster; larger scale parameters create larger clusters. The color vs. shape variable is a scale the either puts more emphasis on the color (pixel value) or shape of the object (which is related to the next variable). Compactness vs. smoothness is the last variable, and is a sliding scale, like the color vs. shape variable. Compactness is a function of area to perimeter, with a more compact area having a higher area to perimeter ratio. Smoothness describes the similarity of the object to a square. The parameters used for the segmentation of all images in this project are provided below:

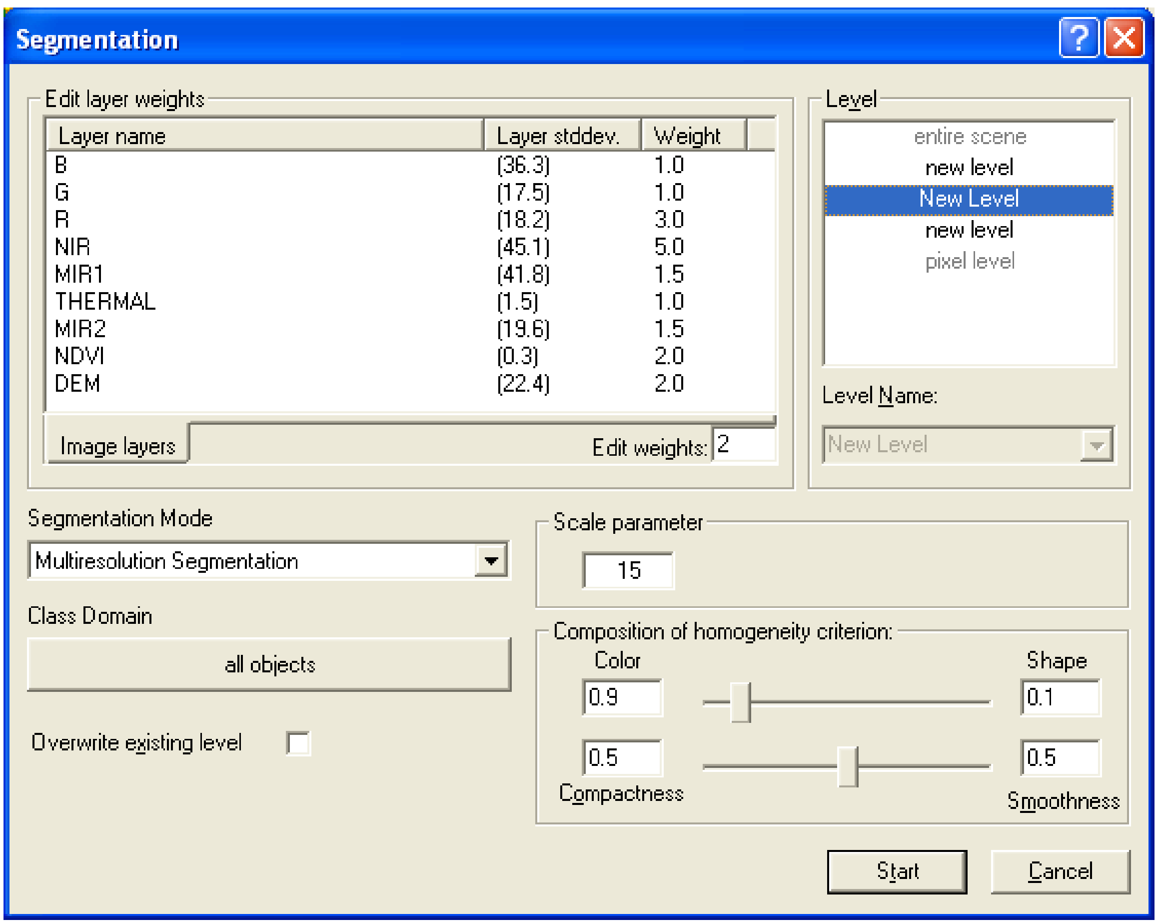


Figure 2. Segmentation dialogue in Definien's eCognition

These parameters were chosen by trial and error. The composition of homogeneity criterion is the default setting, while the scale parameter was increased from 10 to 15. A scale parameter of 10 increased the number of objects significantly, almost to the point of being the same as a pixel-based classification. Scale parameters greater than 15 tended to be too large and contained pixels of different classes in one object. Using a scale parameter of 15 provided a large enough object to be more than just a pixel-based classification while keeping the homogenous integrity of the object. Layers with greater variance were given greater weight.

To choose the training areas from the clusters created during segmentation, the Combined NLCD was overlaid on the corresponding image being classified and viewed in ERDAS. Training areas, in the object-based classification, are objects that are chosen because they are representative of a land use/land cover class. These chosen objects train the software package to know the spectral signature of the class so that it can make decisions to which class other objects belong. Objects were selected from areas that appeared in the Combined NLCD. After an adequate amount of training areas had been selected, a classification was performed. The accuracy assessment was done by exporting the classified image to ERDAS and using the accuracy assessment tool with the validation points created.

After classification, CGM's three parts needed to be mosaicked. When doing the classification, residential areas were extremely difficult to separate from the Agriculture, Forest, and Rangeland classes because of the vegetation. To keep the Urban class consistent, some post classification processing was performed. The first step was to remove any unwanted Urban classifications from the 1998 image. To do this, the 1998 image was compared to the 2001 NLCD image. When a pixel was classified as Urban in 1998 but not in 2001 it was changed to the 2001 classification. This process removed spurious Urban pixels. Next, the Urban class for the 1992 NLCD image and 1998 classified image with spurious Urban areas removed were merged to create a 1998 image that contained all of the Urban from 1992, no Urban that was not Urban in 2001, and the Urban areas that had developed since 1992. The resulting image, "1998_urban_merged", was used as the 1998 image. The Urban class from the newly created 1998 classification was then merged to the 2001 NLCD, with the resulting Urban class being merged with the 2004 classification. This made sure that anything that was classified as Urban in the previous classification was classified as Urban in the latter classification.

Soil data were downloaded from http://soildatamart.nrcs.usda.gov/ and then queried for the top layer of soil. The table below lists the curve numbers for each soil type (A, B, C, or D) for its corresponding Land Cover/ land use class.

	A	B	C	D
Urban	61	75	83	87
Agriculture	64	75	82	85
Rangeland	39	61	74	80
Forest	30	55	70	77
Water	98	98	98	98
Wetland	98	98	98	98
Barren	77	85	90	92

source:
http://www.ecn.purdue.edu/runoff/documentation/scs.htm
TR-55 model curve number

Table 3. Curve numbers used for each land-use/Land Cover with the possible soil type.

The curve numbers for the Water and Wetland classes were provided by Texas Water Development Board (TWDB). Once the curve numbers to be used were known, the classified images were combined with the soils data to generate a new image that used the curve numbers as the pixel values. The soil types are classified according to their drainage potential. Group A soils are deep and absorb water well, are well drained and composed of sand or gravel, therefore having lower curve numbers. Group D soils are at the other end of the continuum and do not absorb water well leading to higher curve numbers. They are thin layers of soil above bedrock or have a high percentage of clay near the surface.

Results

Several outputs were generated by this study: land-use classifications, land-use change detections, curve numbers, and statistics for each classification and change detection. First, accuracy assessments were needed for the classifications. Using eCognition with the parameters above the following accuracies were obtained and found to be adequate for this study:

Watershed	1998	2004
CGM Accuracy	86.67%	90.00%
CGM Kappa	0.8411	0.8800
Galveston-Sabine Accuracy	91.67%	86.67%
Galveston-Sabine Kappa	0.9000	0.8400

Table 4. Accuracy assessment

The accuracies reported for Galveston and Sabine are the same as the previous report. These accuracies were calculated using the validation points created earlier. Each point created was identified in the classified image and counted correct if it matched the validation point and incorrect if it did not correspond with the class given by the validation point. The Kappa is a statistic that quantifies agreement.

These classifications resulted in the following Land Cover percentages for the two Spatial Sciences Lab created classifications (1998 and 2004) and two NLCD classifications (1992 and 2001). (See Appendix A for larger charts and corresponding tables). The following table can be used to calculate the area for each land cover class, including 150 meter buffer.

Watershed	Area (sq. m.)	Area (sq. km.)	Area (acres)	Area (sq. mi.)
Corpus	2,330,938,831.40	2,330,938.83	575,987,528.02	899,980.52
Galveston	18,362,350,620.50	18,362,350.62	4,537,435,646.13	7,089,743.22
Guadalupe	3,717,056,311.51	3,717,056.31	918,504,616.05	1,435,163.47
Mission	7,249,508,662.76	7,249,508.66	1,791,392,600.17	2,799,050.95
Sabine	6,856,189,126.06	6,856,189.13	1,694,201,226.20	2,647,189.42

Table 5. Area calculation for each watershed in different units.

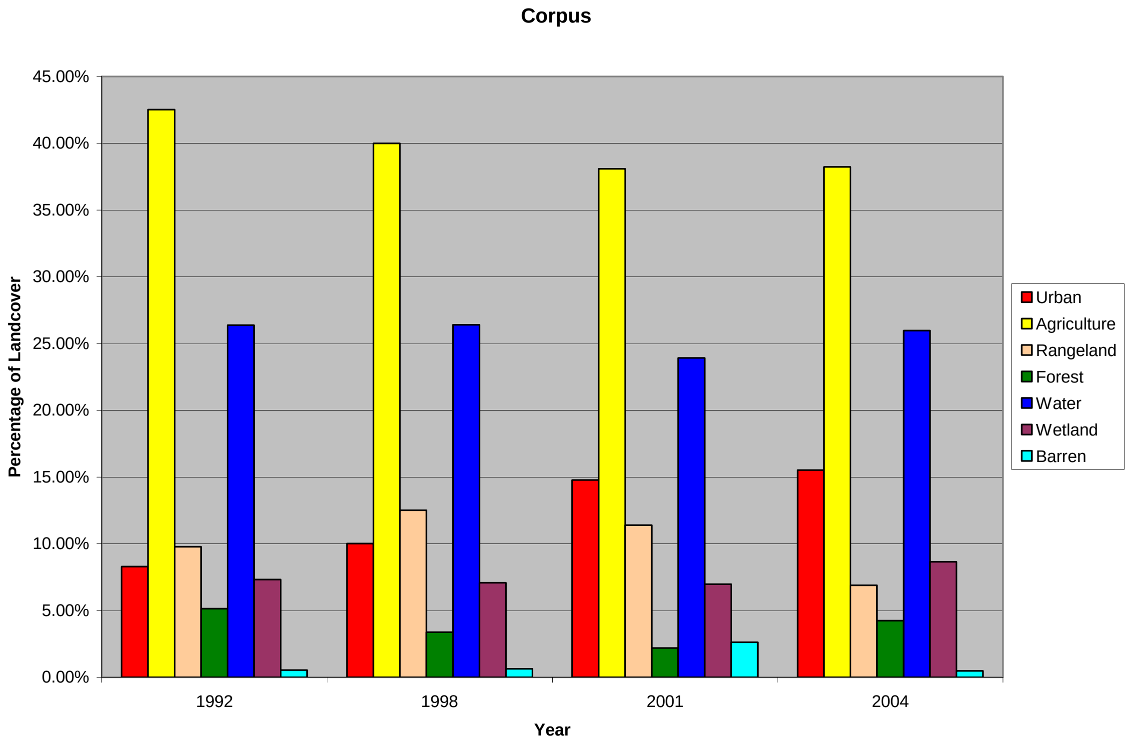


Figure 3. Percentage of land-use class per year for the Corpus watershed.

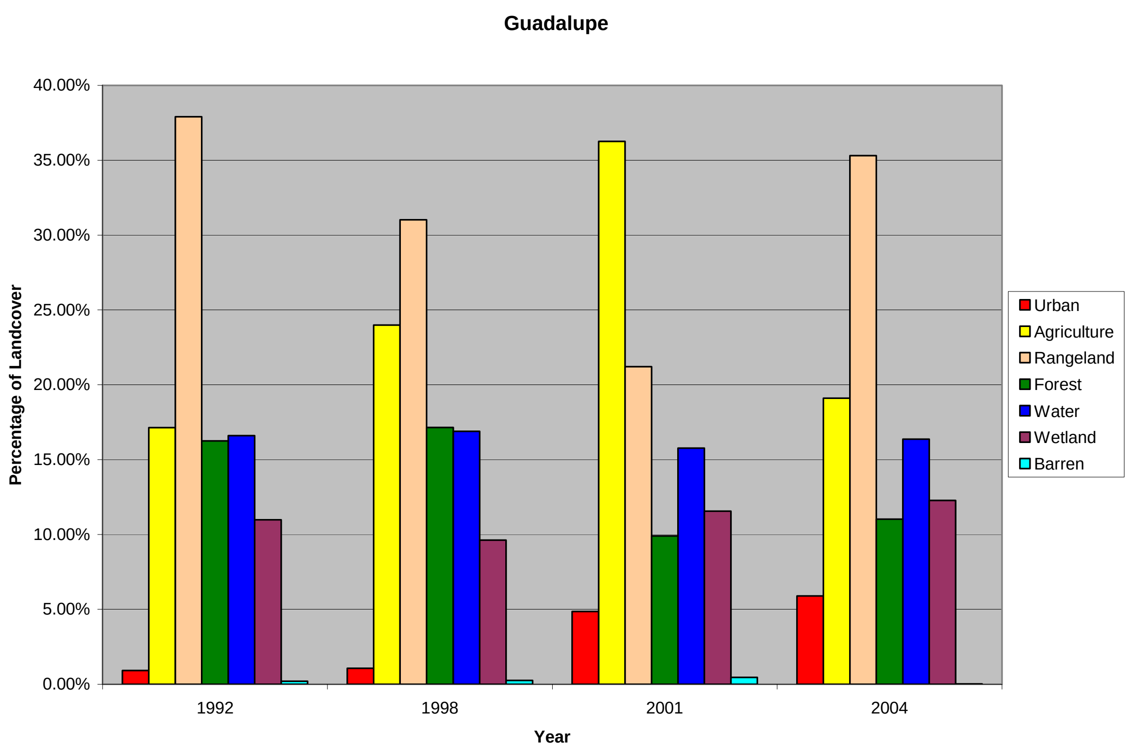


Figure 4. Percentage of land-use class per year for the Guadalupe watershed.

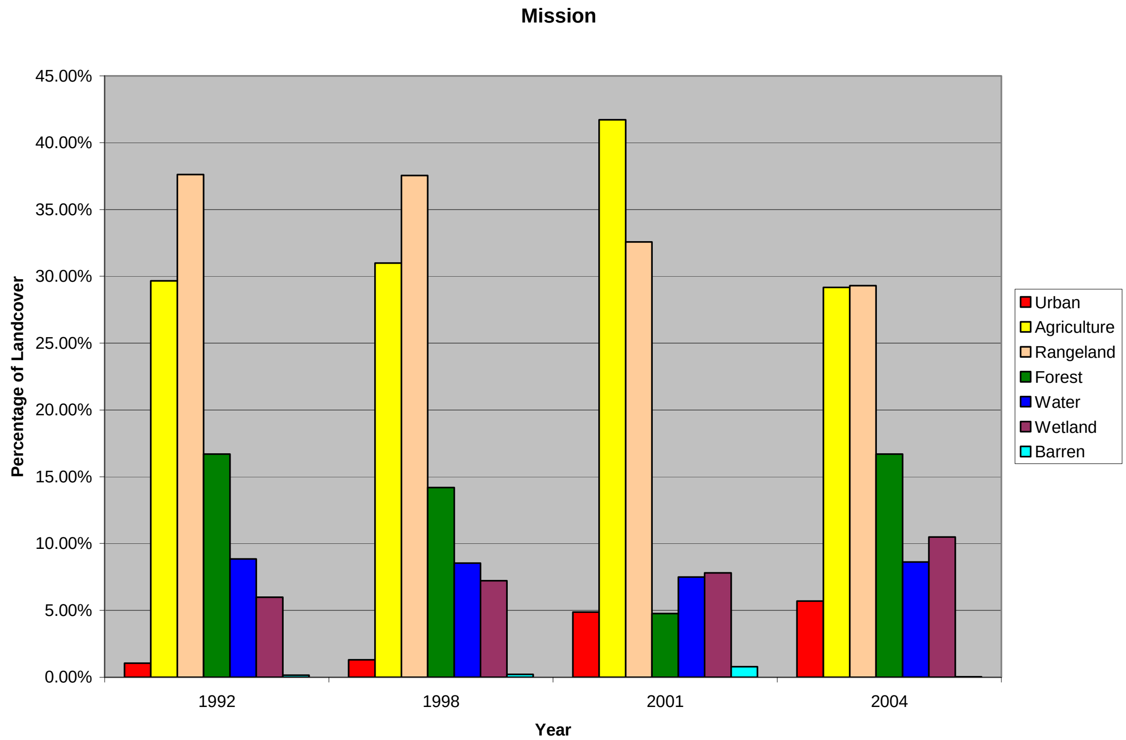


Figure 5. Percentage of land-use class per year for the Mission watershed.

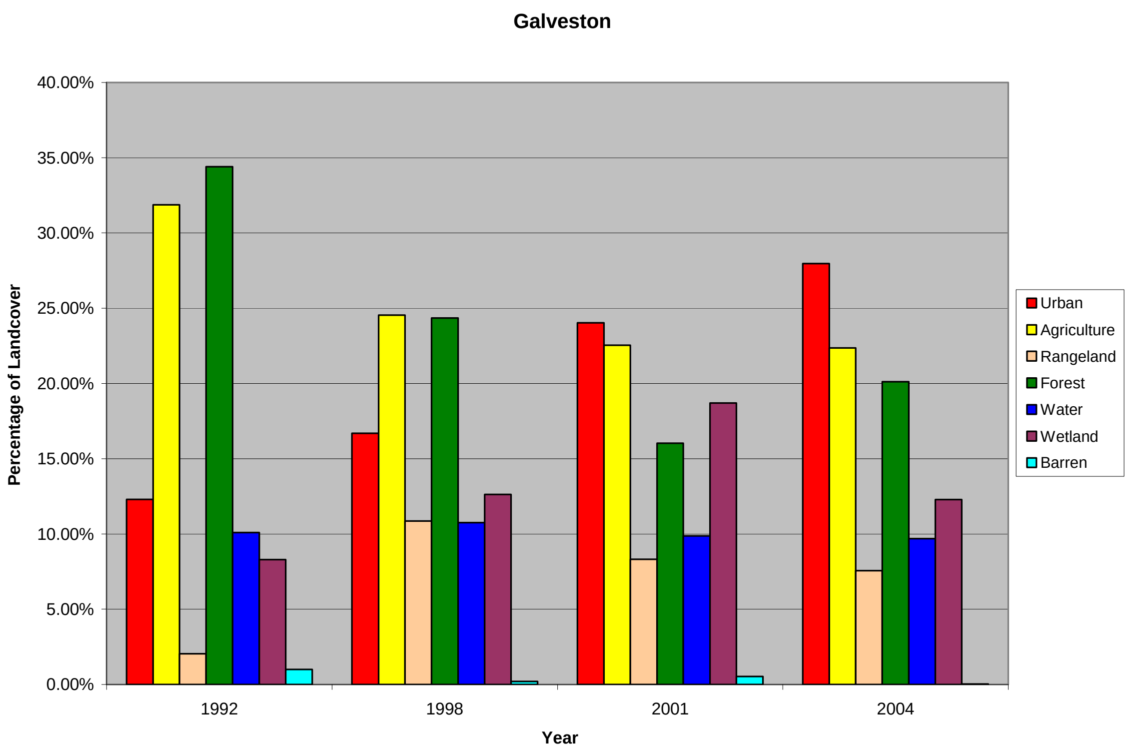


Figure 6. Percentage of land-use class per year for the Galveston watershed.

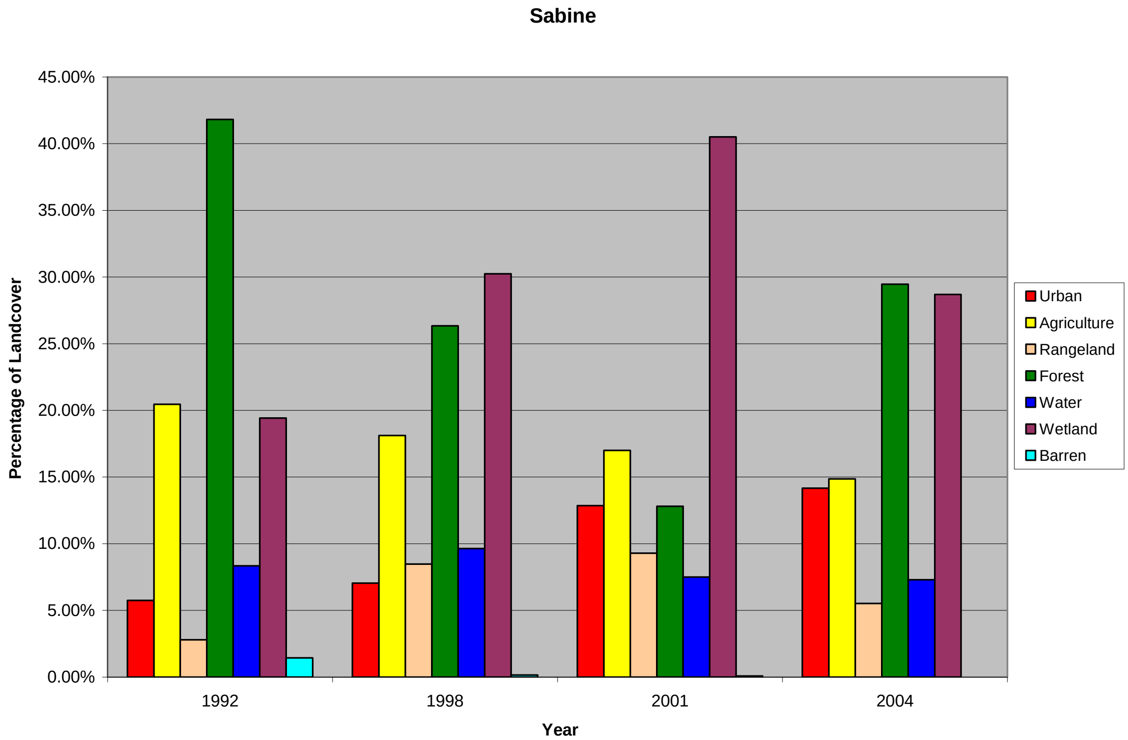


Figure 7. Percentage of land-use class per year for the Sabine watershed.

All of the watersheds have significant increase in Urban areas with reductions usually in Forest, Rangeland, and Agricultural areas. Corpus, Guadalupe, and Mission are all still dominated by Agriculture and Rangeland, but all have had a significant percentage increase in Urban areas.

The last step was creating curve number maps. Using the curve number table referred to earlier, the classifications were recoded to represent the curve number for the land use/Land Cover class and soil type. Maps for the classifications, curve number maps, and change statistics tables are attached in the appendices. The change statistics tend to show the largest change between classes is consistently between Agriculture and Rangeland for Corpus; and for Guadalupe and Mission, Rangeland, Agriculture, and Forest consistently have the largest percentage of change. Galveston still has the largest amount of change between Forest and Agriculture while Sabine has significant change between Forest and Wetland. This may be because these were the classes, for their respective watersheds, that were the hardest to separate in the classification. It may be difficult to understand the change statistics charts, so tables are also shown to help interpret the charts. To read them, the full bar is the early classification and the segments of that bar are what the previous classification changed to. In the table, columns represent the percentage of that class for the early year and rows represent the latter year. For example, in the chart below (Figure 8), the full bar would represent the percentage of the 1992 classification that was Agriculture and each segment inside that bar represents the class the pixels were classified as in the 1998 image and their percentage. Looking at the Agriculture bar, in 1992 about 43% of the image was classified as Agriculture. Of those 43% of the image, 1% changed to Urban, 35% stayed Agriculture, 6% changed to Rangeland, 1% changed to Forest, and 1% changed to Wetland in 1998. This is also shown in Table 6 by looking in the Agriculture column.

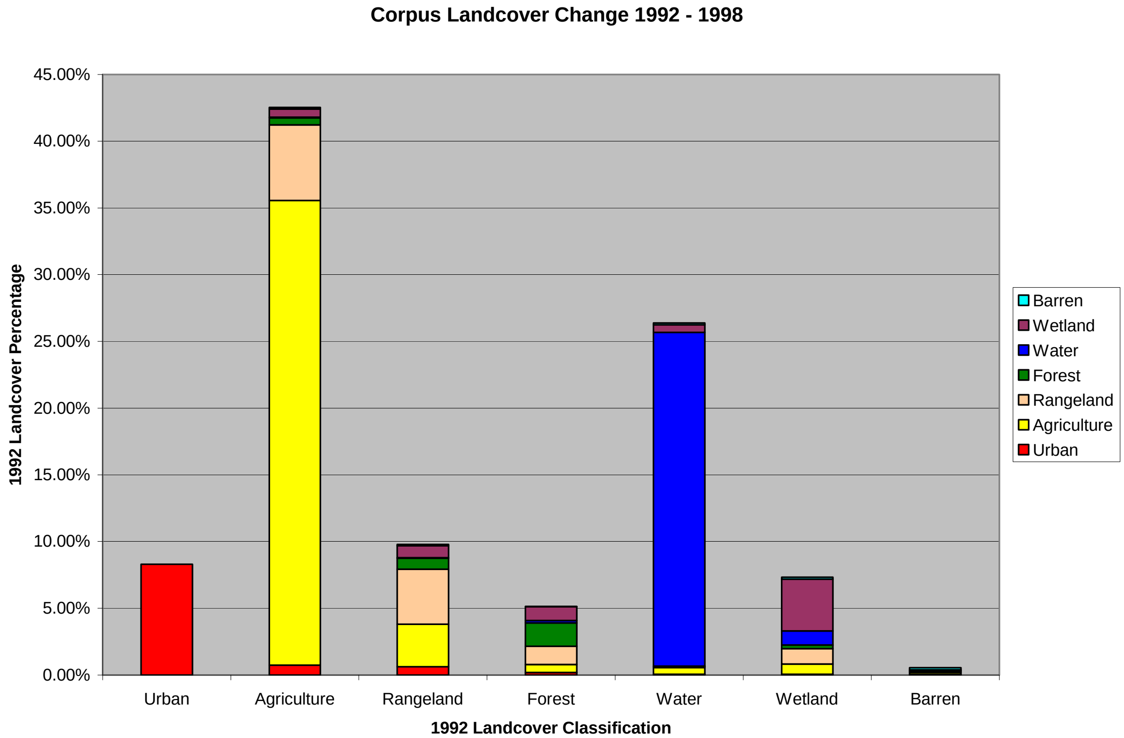


Figure 8. Land Cover change for the Corpus watershed from 1992 to 1998.

Corpus Land Cover Change 1992-1998

	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Barren	Total After
Urban	8.30%	0.75%	0.62%	0.19%	0.06%	0.07%	0.05%	10.03%
Agriculture	0.00%	34.81%	3.19%	0.60%	0.50%	0.75%	0.13%	39.98%
Rangeland	0.00%	5.66%	4.12%	1.36%	0.09%	1.16%	0.11%	12.50%
Forest	0.00%	0.53%	0.81%	1.75%	0.01%	0.27%	0.00%	3.38%
Water	0.00%	0.05%	0.04%	0.19%	25.01%	1.06%	0.04%	26.39%
Wetland	0.00%	0.61%	0.91%	1.04%	0.57%	3.88%	0.07%	7.08%
Barren	0.00%	0.12%	0.09%	0.02%	0.13%	0.13%	0.14%	0.64%
Total Before	8.30%	42.53%	9.79%	5.15%	26.38%	7.32%	0.54%	100.00%

Table 6. Land cover change for the Corpus watershed from 1992 to 1998.

Conclusion

There is significant land use and Land Cover change throughout the study period. Urban sprawl is evident by looking at the maps and statistics for each classification. Agriculture is also growing, while Forest, Rangeland, and Wetland areas are shrinking.

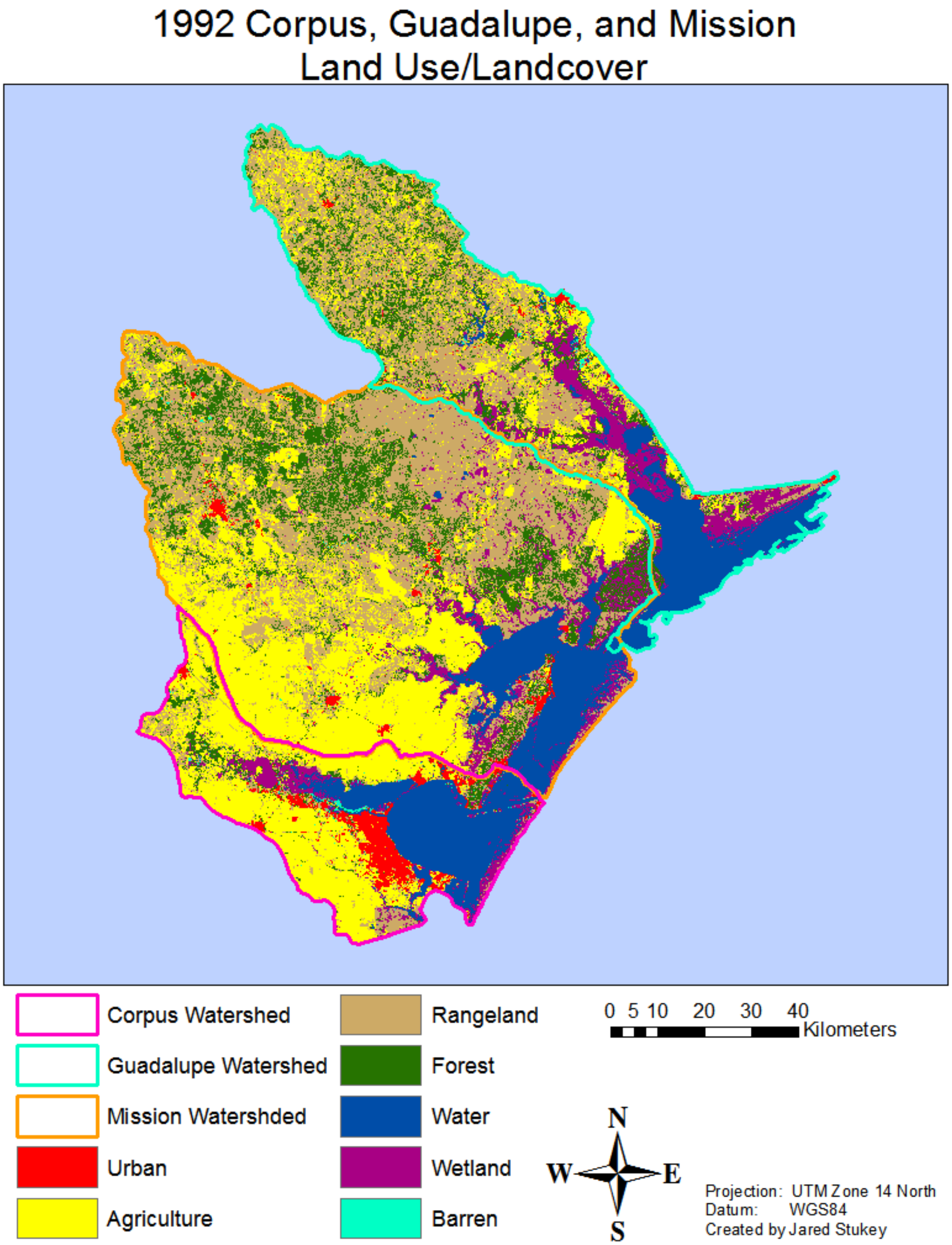
One difficulty of this project was the NLCD classifications. The 2001 NLCD, specifically, tended to over represent Agriculture and Wetland areas while under representing Forest areas. This may account for changes in classes between 1998 and 2001, and 2001 and 2004.

The 1992 and 2001 NLCD were created differently and had different classes, as shown in Figure 2, were. The use of the different class scheme may have led to more being classified as one class than they should have been. This is most evident in the 2001 Galveston classification. The Wetland class dominates the Forest class. This could be due to the multiple classes for Wetlands used in the 2001 NLCD. With the Wetlands class expanding its scope, what can be classified as Forest is reduced. This is especially true for woody wetlands.

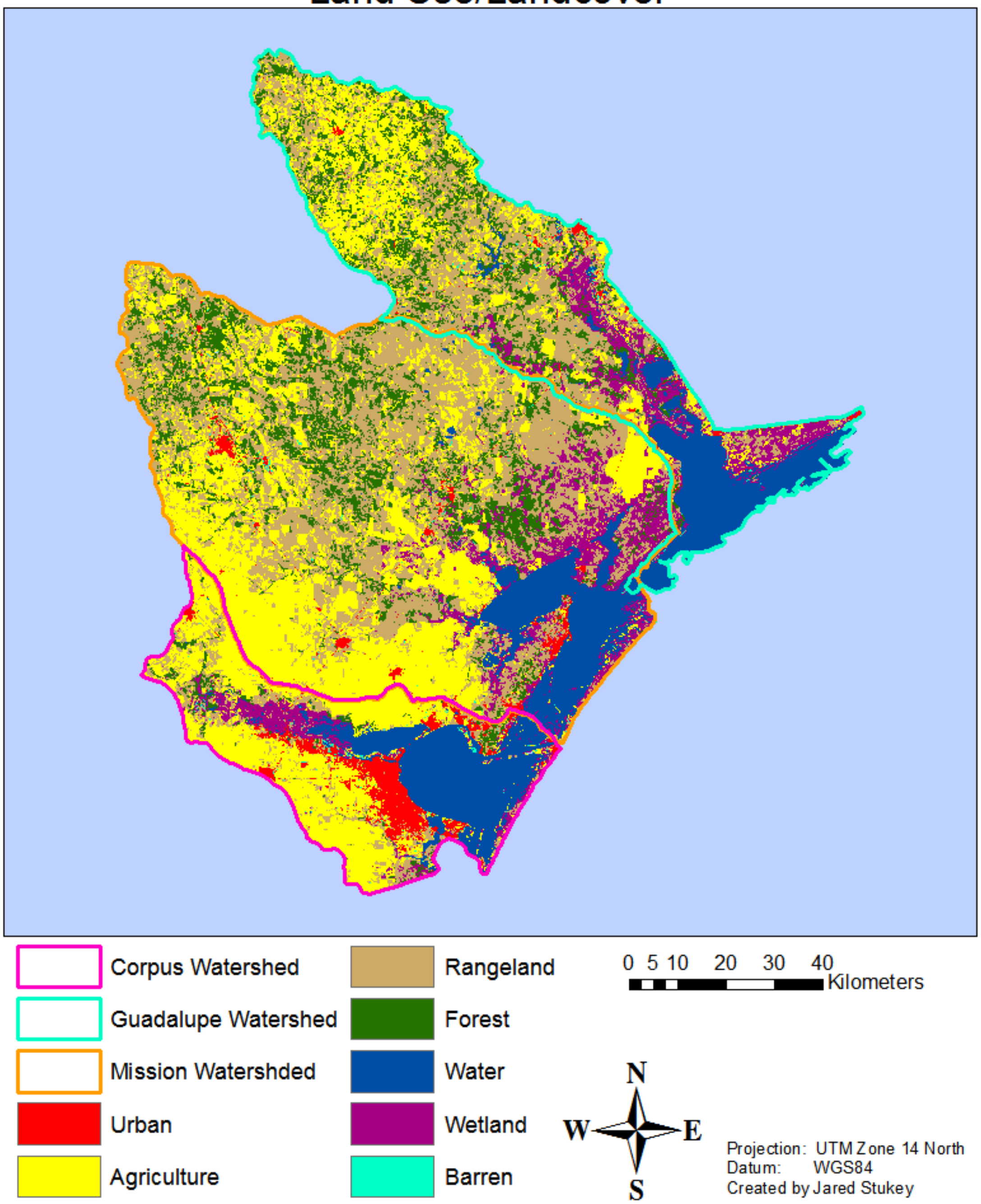
The statistics and maps for Galveston and Sabine used the previous report's classification and then split the two watersheds.

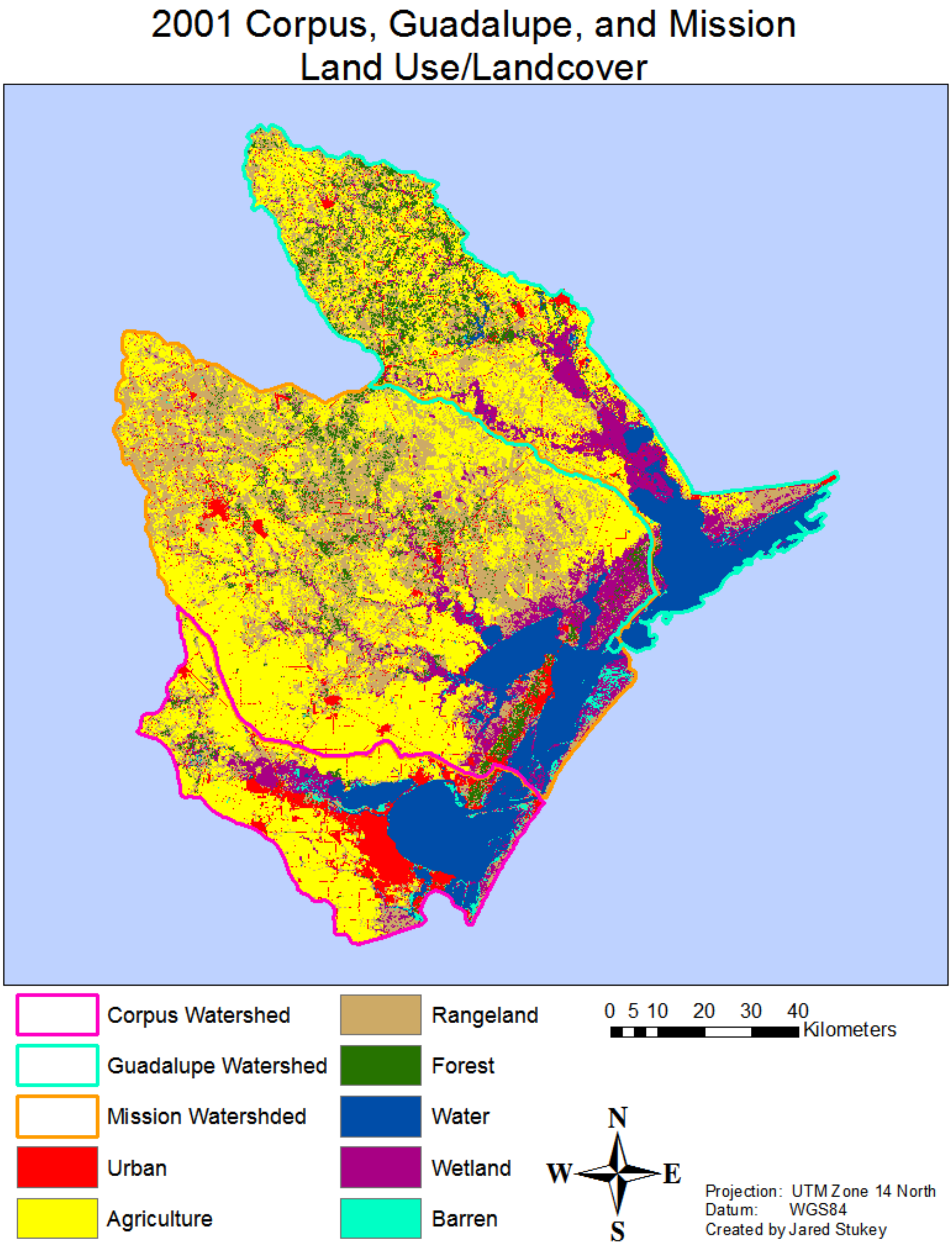
<u>Appendix A</u>

Classification

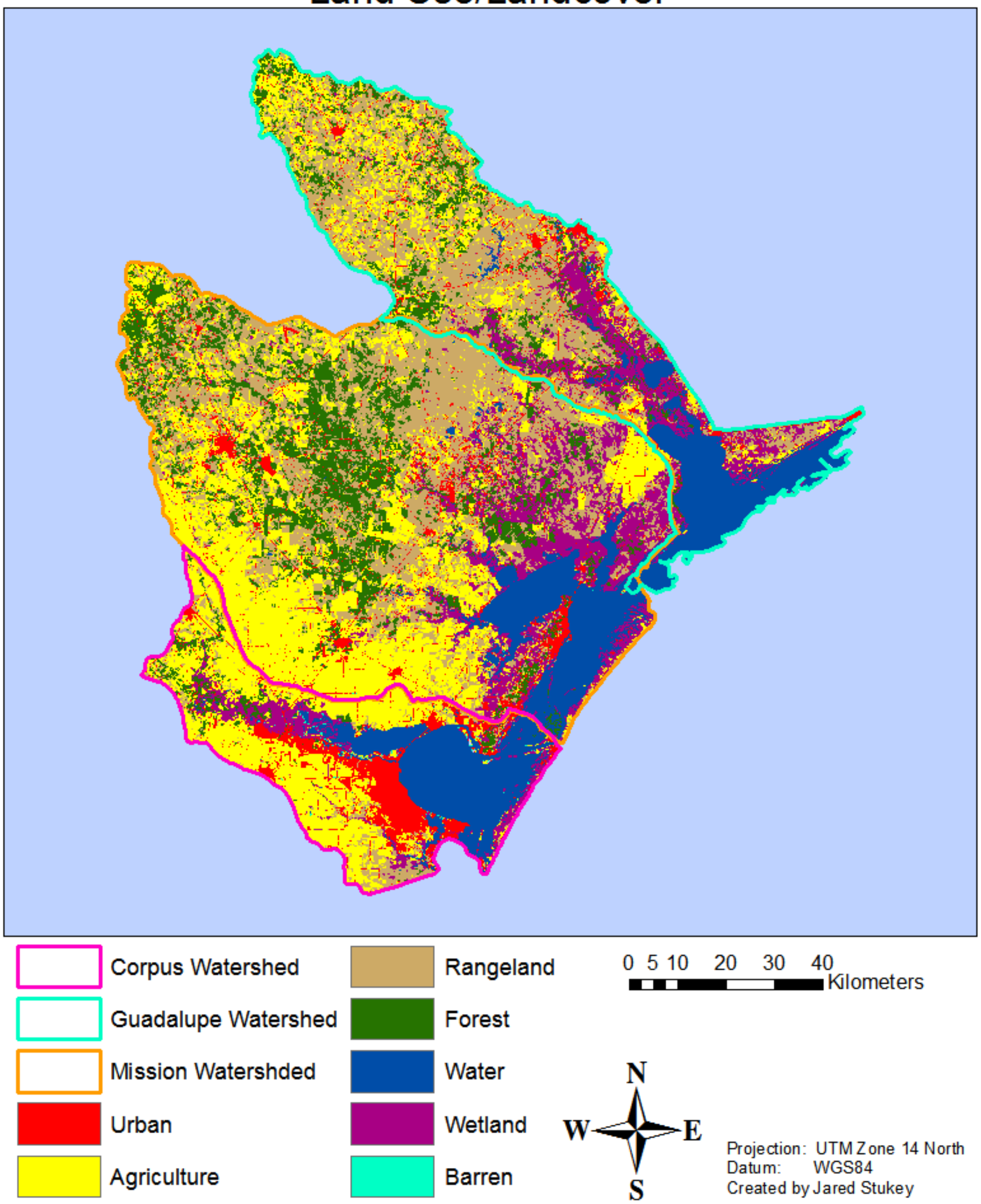

1992 Corpus, Guadalupe, and Mission
Land Use/Landcover
Corpus Watershed
Guadalupe Watershed
Mission Watershded
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
0 5 10 20 30 40
Kilometers
N
W
E
S
Projection: UTM Zone 14 North
Datum: WGS84
Created by Jared Stukey

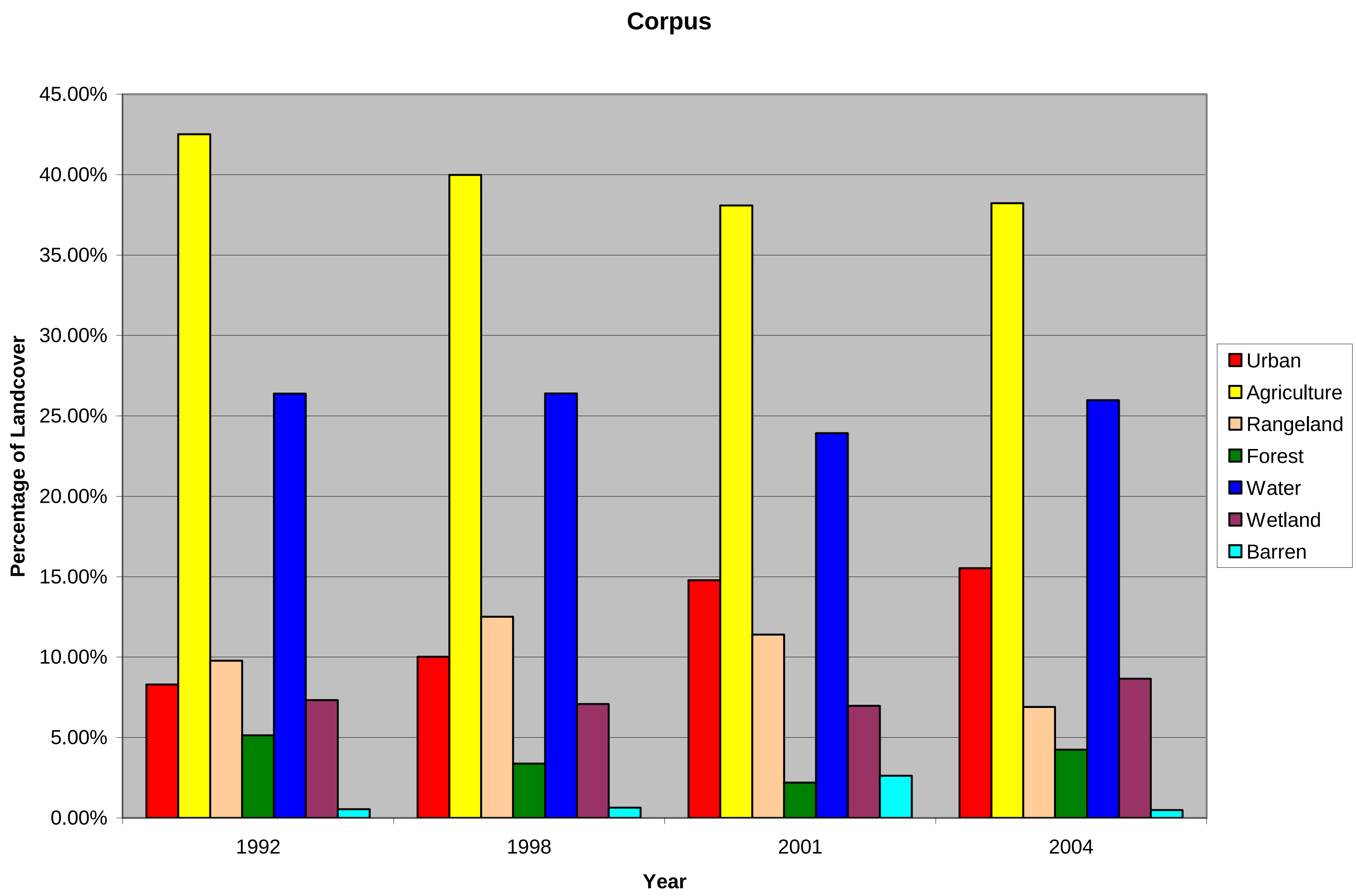
1998 Corpus, Guadalupe, and Mission
Land Use/Landcover



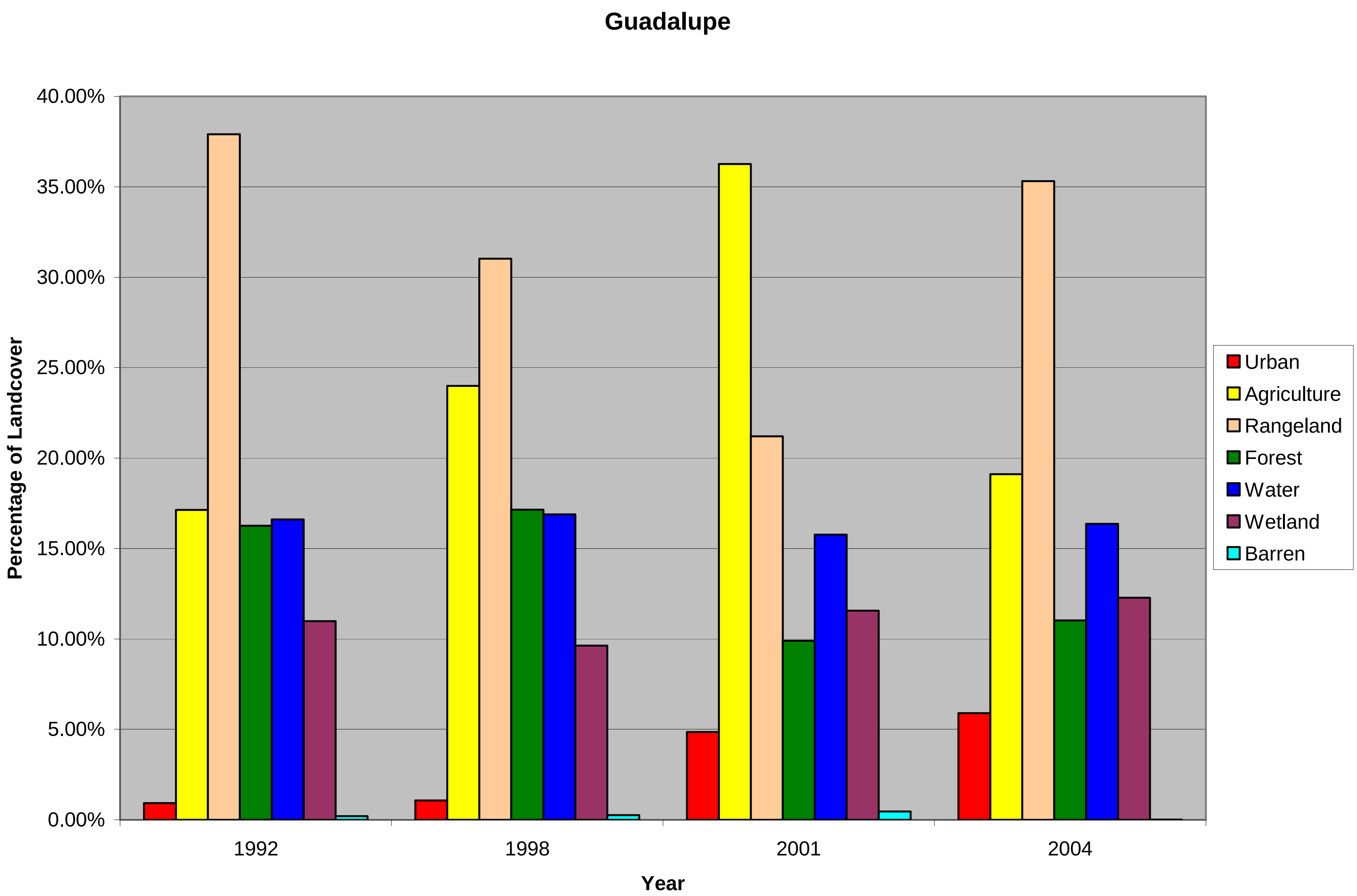

2001 Corpus, Guadalupe, and Mission
Land Use/Landcover
Corpus Watershed
Guadalupe Watershed
Mission Watershded
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
0 5 10 20 30 40
Kilometers
N
W
E
S
Projection: UTM Zone 14 North
Datum: WGS84
Created by Jared Stukey

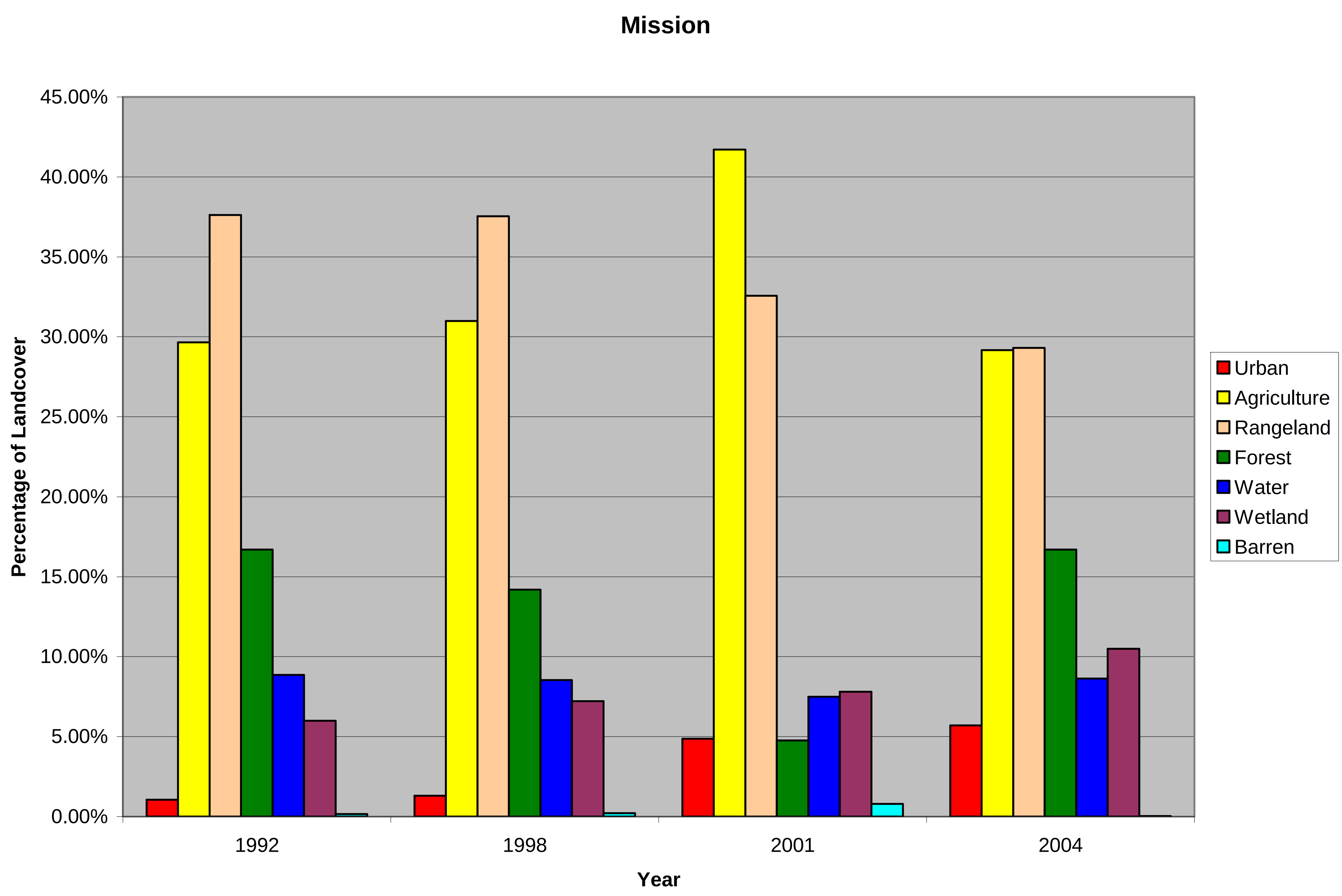
2004 Corpus, Guadalupe, and Mission Land Use/Landcover





Corpus
45.00%
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
Percentage of Landcover
1992
1998
2001
2004
Year
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren


Guadalupe
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
Percentage of Landcover
1992
1998
2001
2004
Year
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren


Mission
45.00%
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
Percentage of Landcover
1992
1998
2001
2004
Year
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren

Corpus Classification Statistics

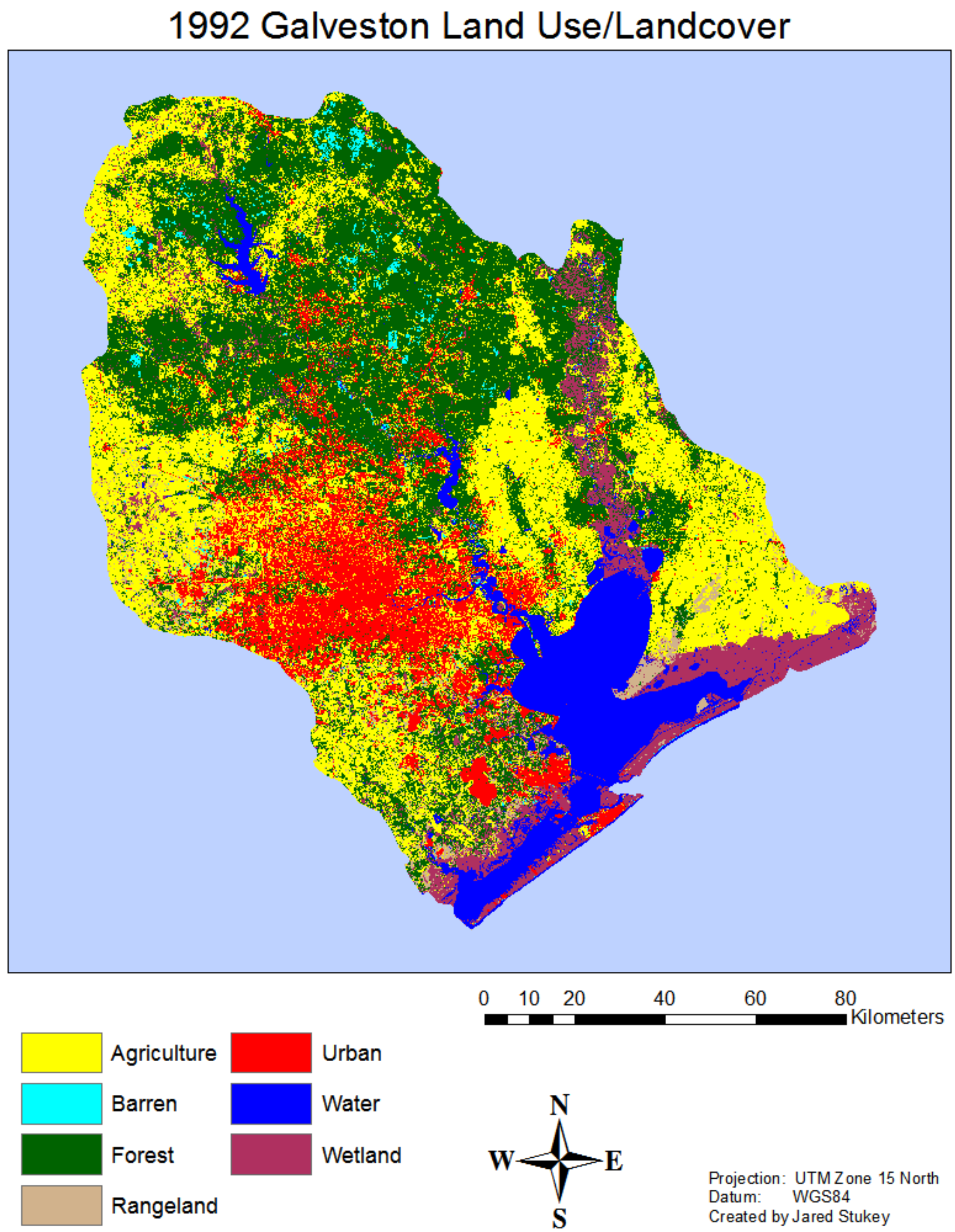
Class	1992	1998	2001	2004
Urban	8.30%	10.03%	14.79%	15.52%
Agriculture	42.52%	39.98%	38.09%	38.22%
Rangeland	9.79%	12.50%	11.40%	6.90%
Forest	5.15%	3.38%	2.20%	4.24%
Water	26.38%	26.39%	23.93%	25.97%
Wetland	7.33%	7.08%	6.98%	8.65%
Barren	0.54%	0.64%	2.62%	0.49%

Guadalupe Classification Statistics

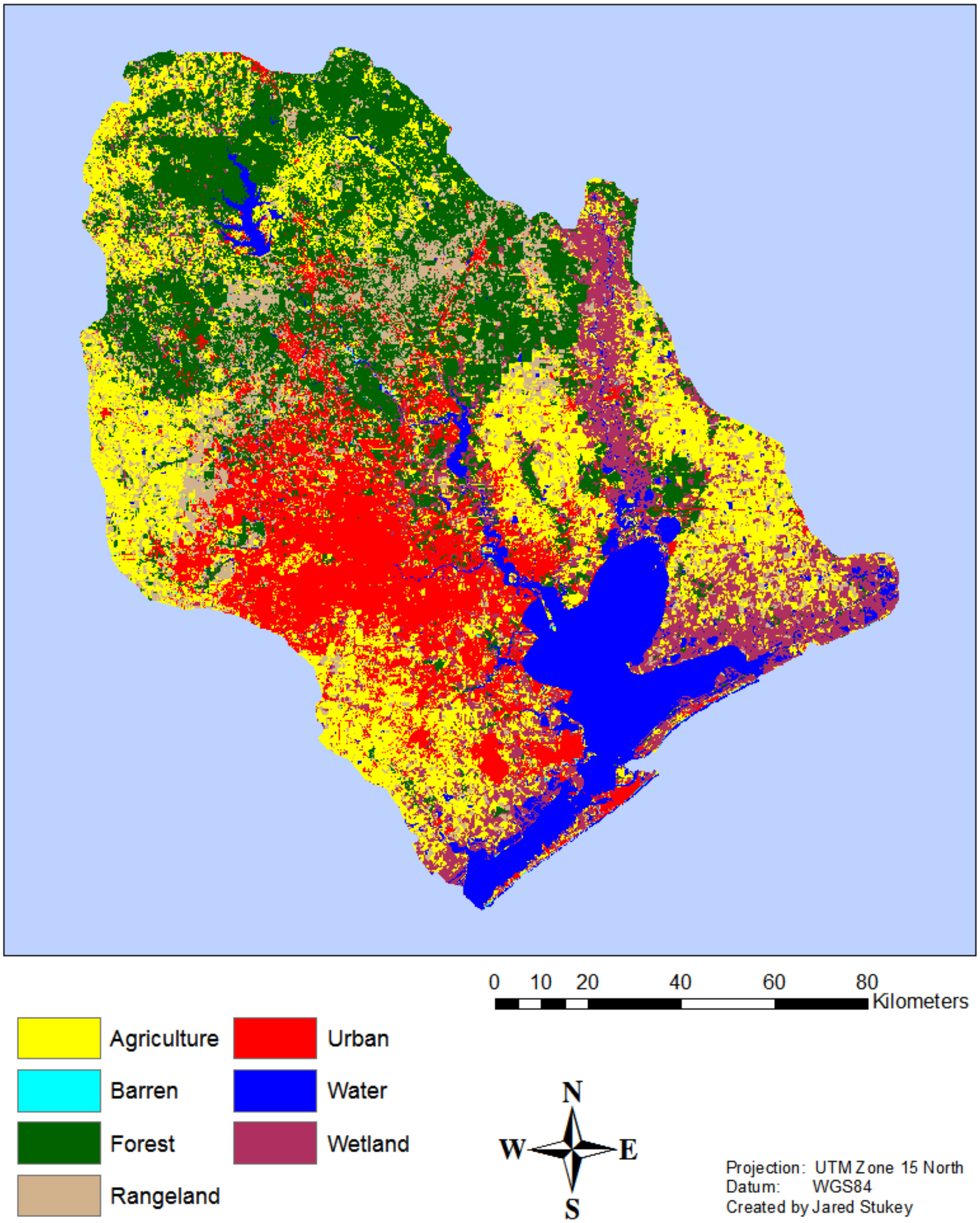
Class	1992	1998	2001	2004
Urban	0.91%	1.07%	4.86%	5.89%
Agriculture	17.13%	23.99%	36.25%	19.11%
Rangeland	37.91%	31.03%	21.20%	35.31%
Forest	16.26%	17.14%	9.90%	11.03%
Water	16.61%	16.89%	15.77%	16.37%
Wetland	10.98%	9.62%	11.56%	12.28%
Barren	0.21%	0.26%	0.46%	0.01%

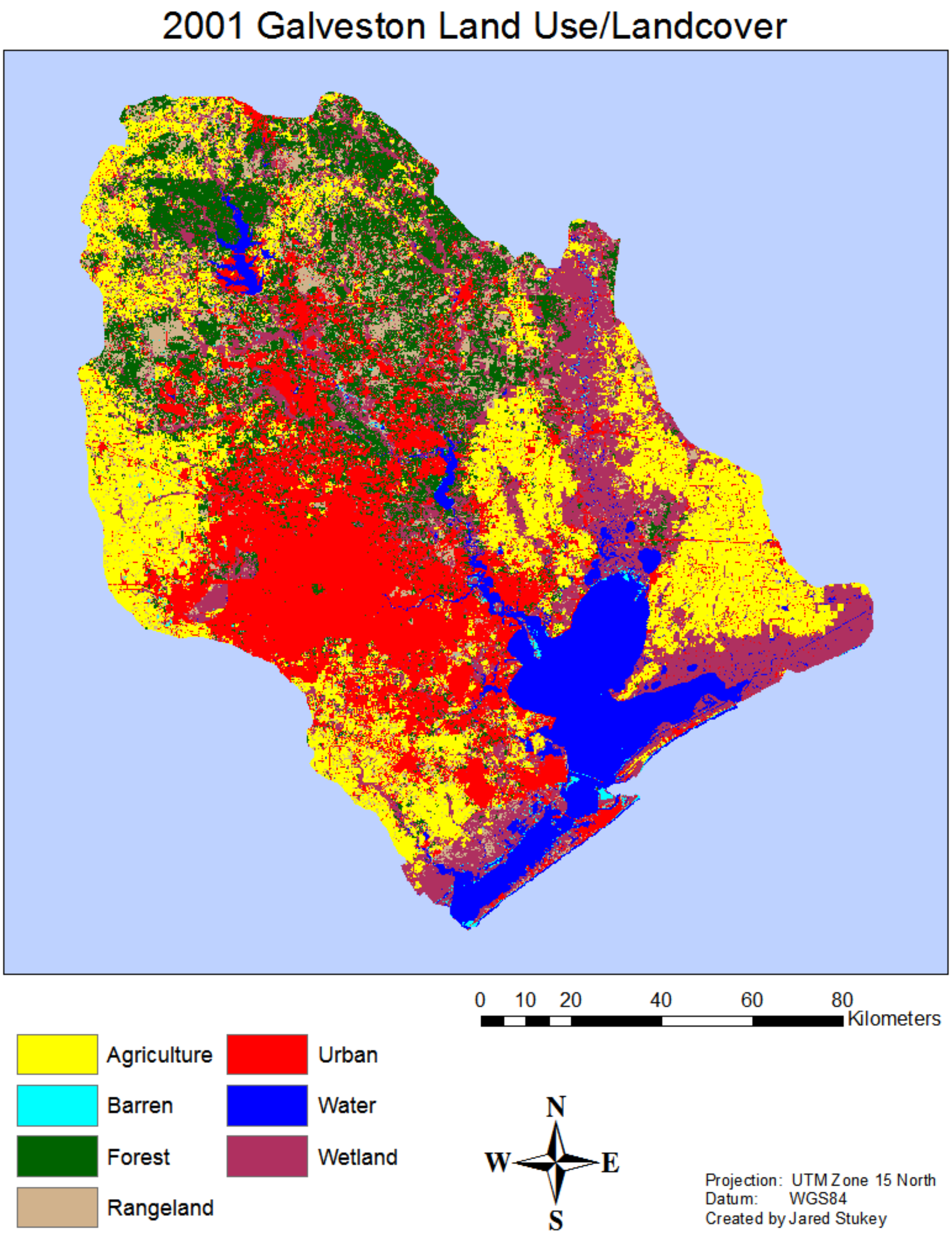
Mission Classification Statistics

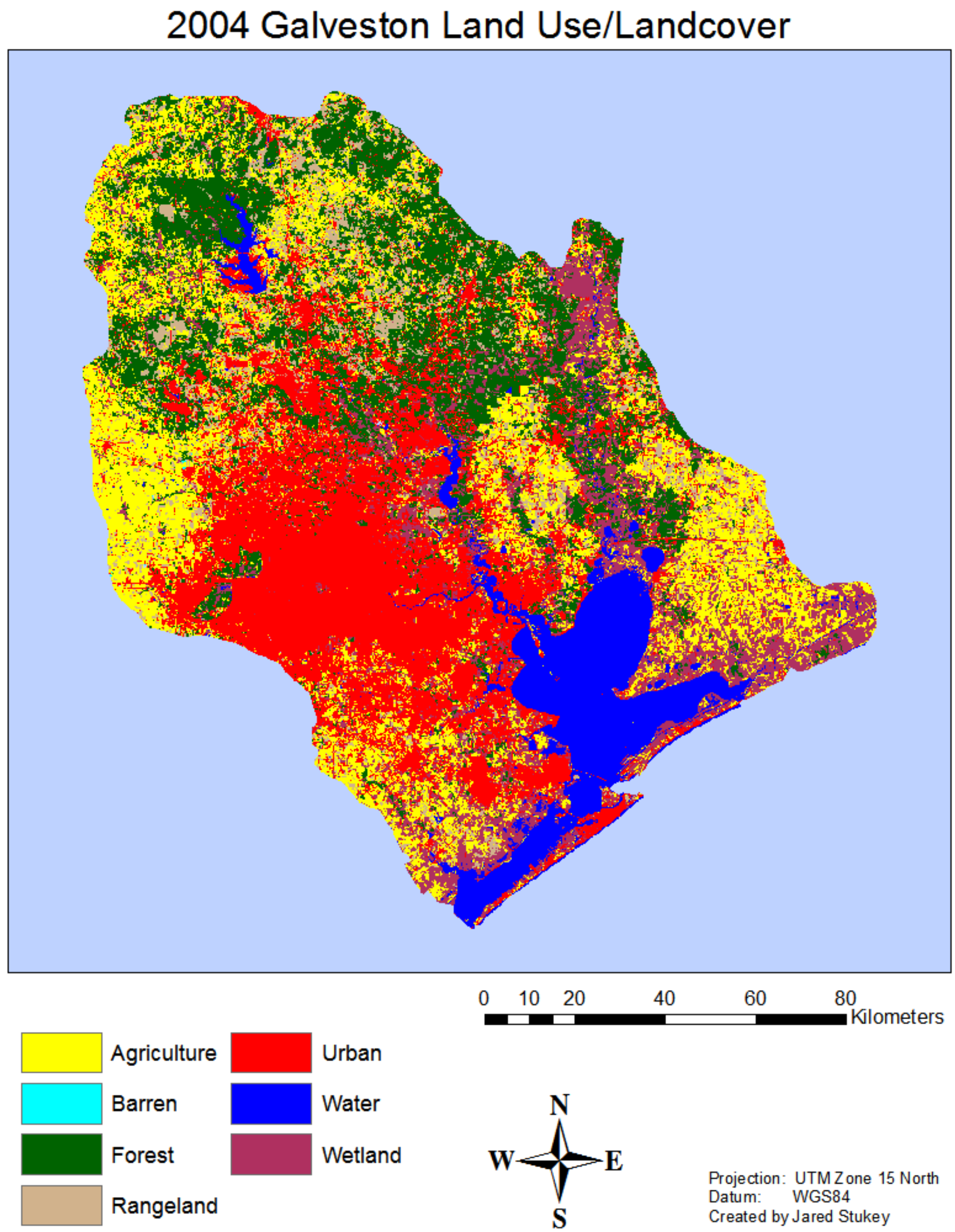
Class	1992	1998	2001	2004
Urban	1.04%	1.30%	4.86%	5.69%
Agriculture	29.65%	31.00%	41.71%	29.17%
Rangeland	37.61%	37.55%	32.57%	29.31%
Forest	16.70%	14.19%	4.76%	16.69%
Water	8.85%	8.54%	7.49%	8.62%
Wetland	5.99%	7.22%	7.81%	10.49%
Barren	0.15%	0.21%	0.79%	0.03%

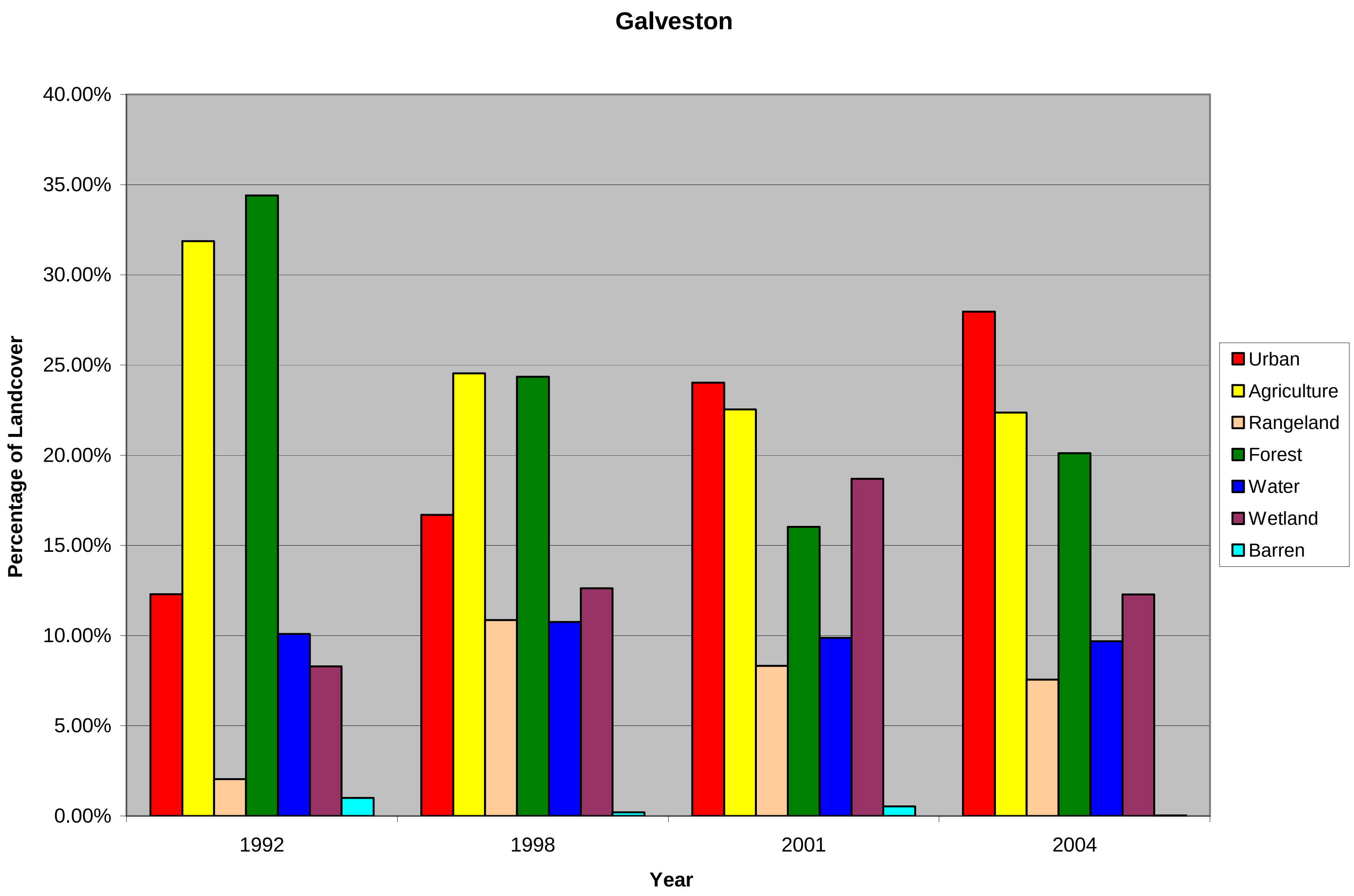

1992 Galveston Land Use/Landcover
0 10 20 40 60 80
Kilometers
Agriculture
Urban
Barren
Water
Forest
Wetland
Rangeland
N
W
E
S
Projection: UTM Zone 15 North
Datum: WGS84
Created by Jared Stukey

1998 Galveston Land Use/Landcover



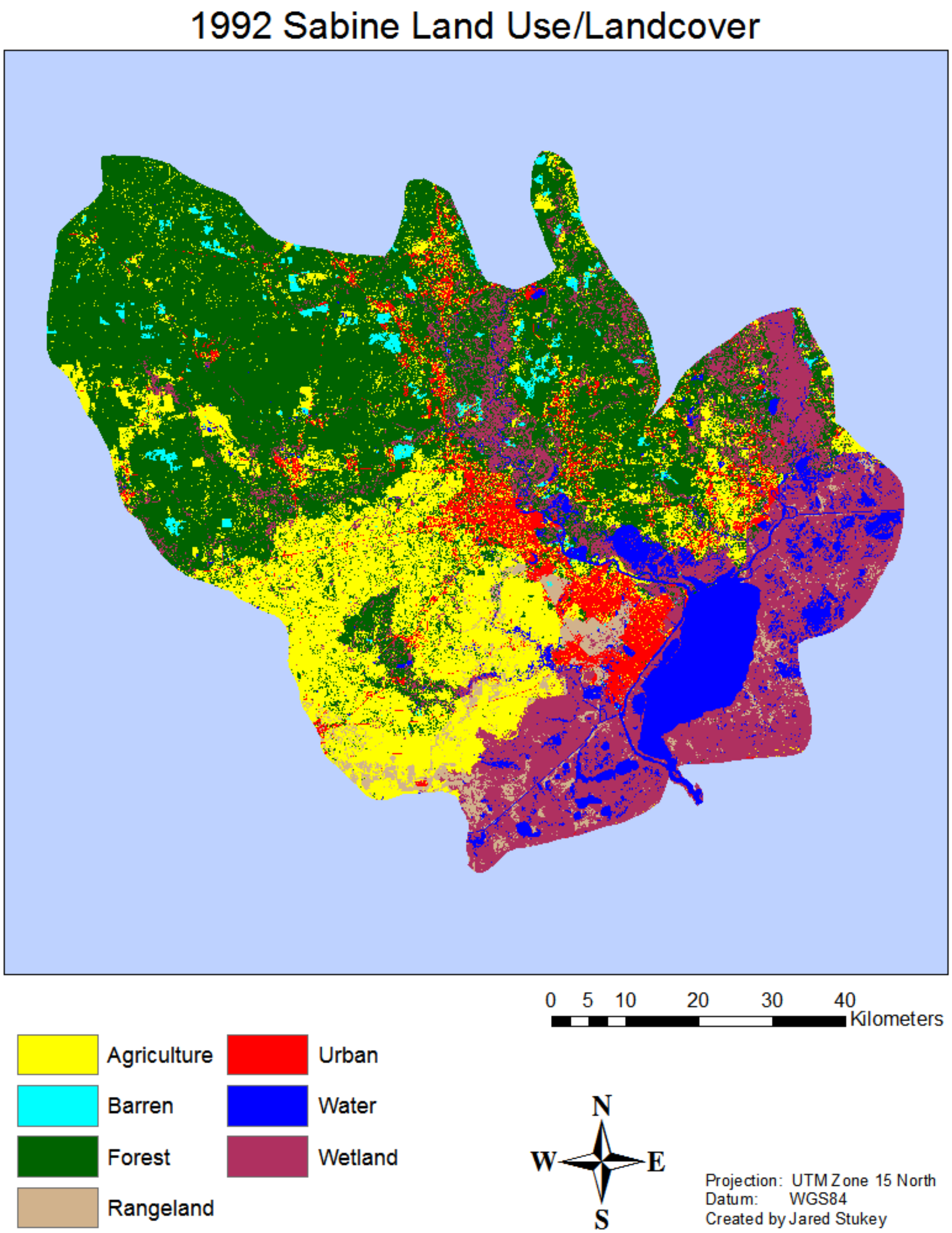

2001 Galveston Land Use/Landcover
0
10
20
40
60
80
Kilometers
Agriculture
Urban
Barren
Water
Forest
Wetland
Rangeland
N
W
E
S
Projection: UTM Zone 15 North
Datum: WGS84
Created by Jared Stukey


2004 Galveston Land Use/Landcover
0
10
20
40
60
80
Kilometers
Agriculture
Urban
Barren
Water
Forest
Wetland
Rangeland
N
W
E
S
Projection: UTM Zone 15 North
Datum: WGS84
Created by Jared Stukey

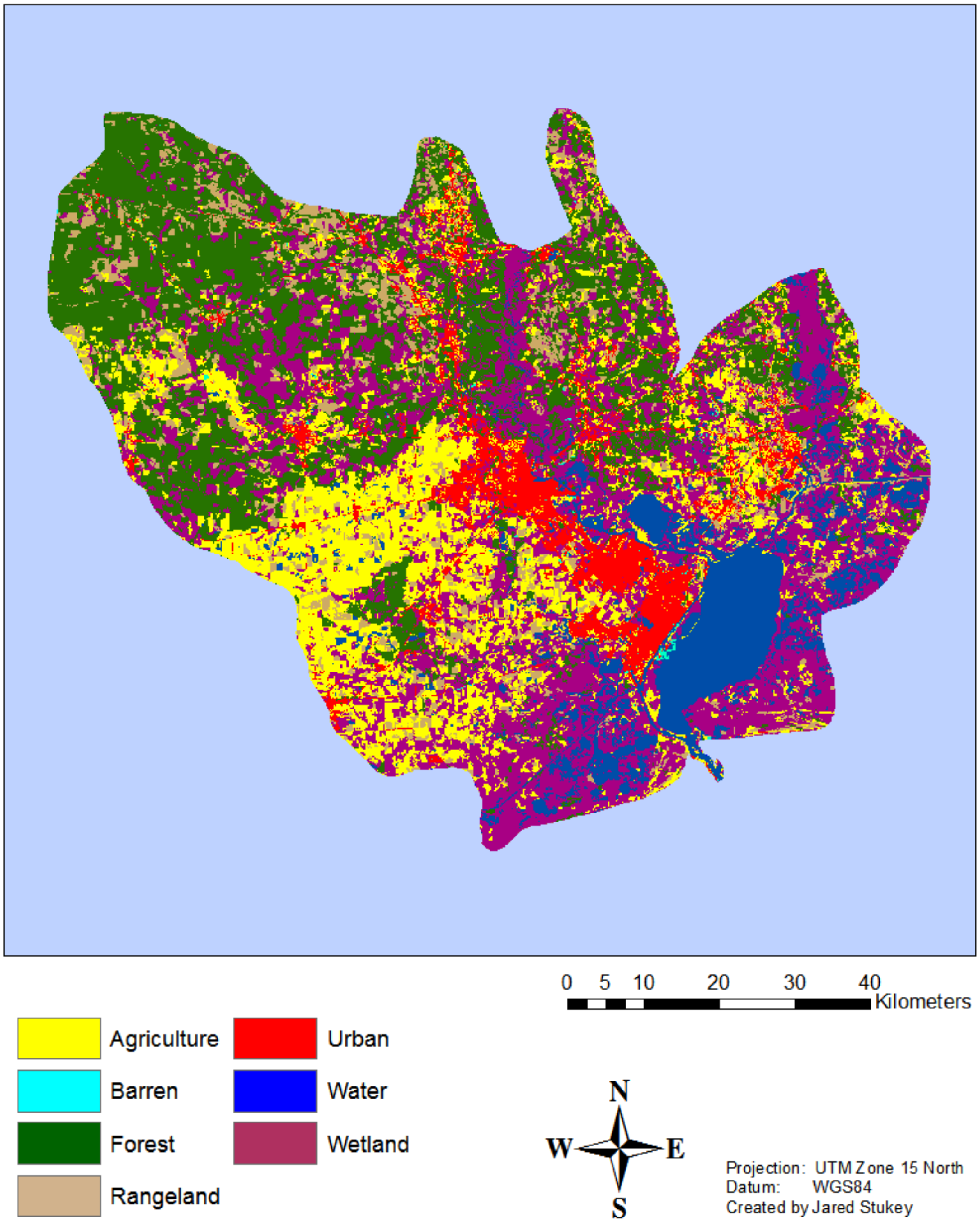

Galveston
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
Percentage of Landcover
1992
1998
2001
2004
Year
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren

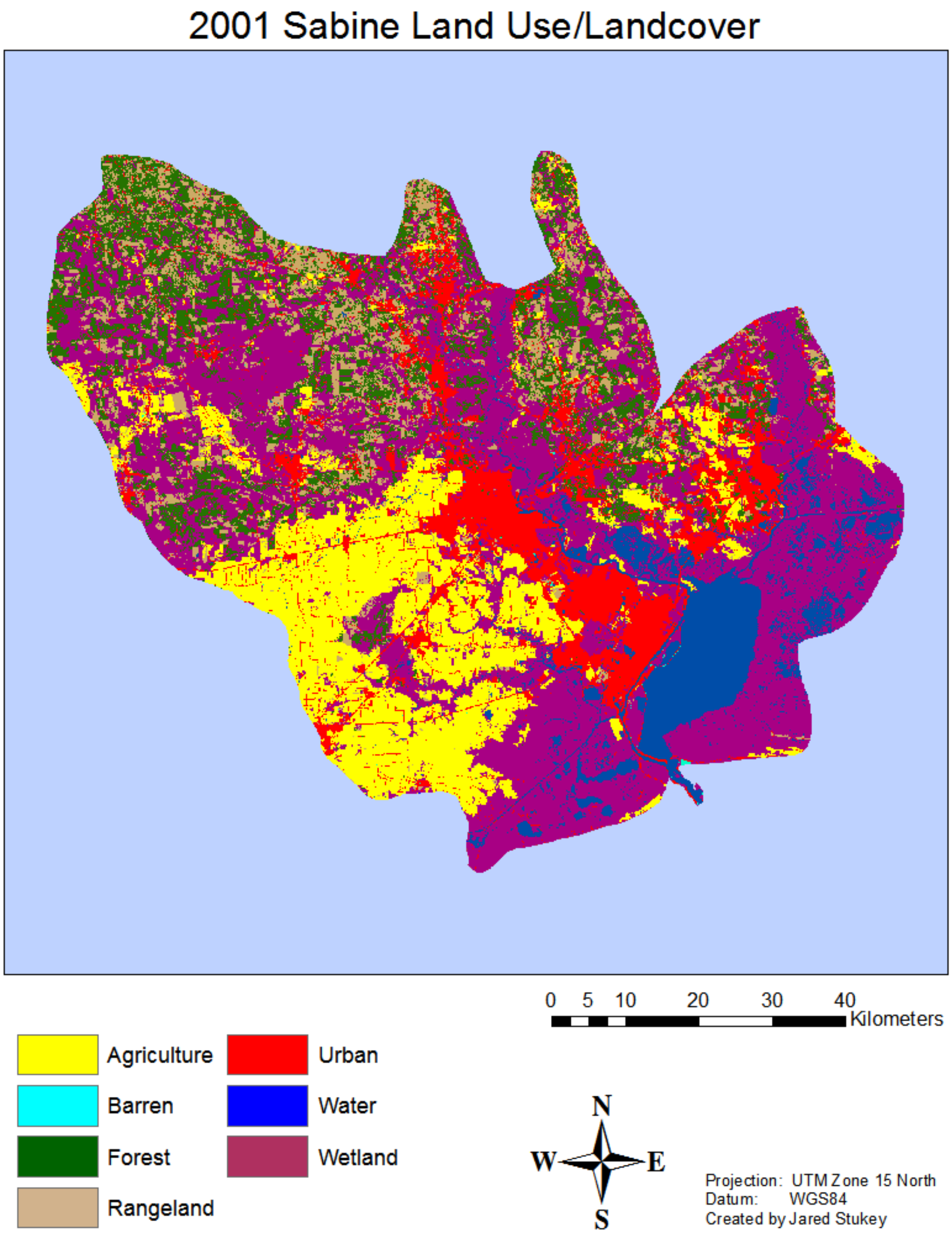
Galveston Classification Statistics

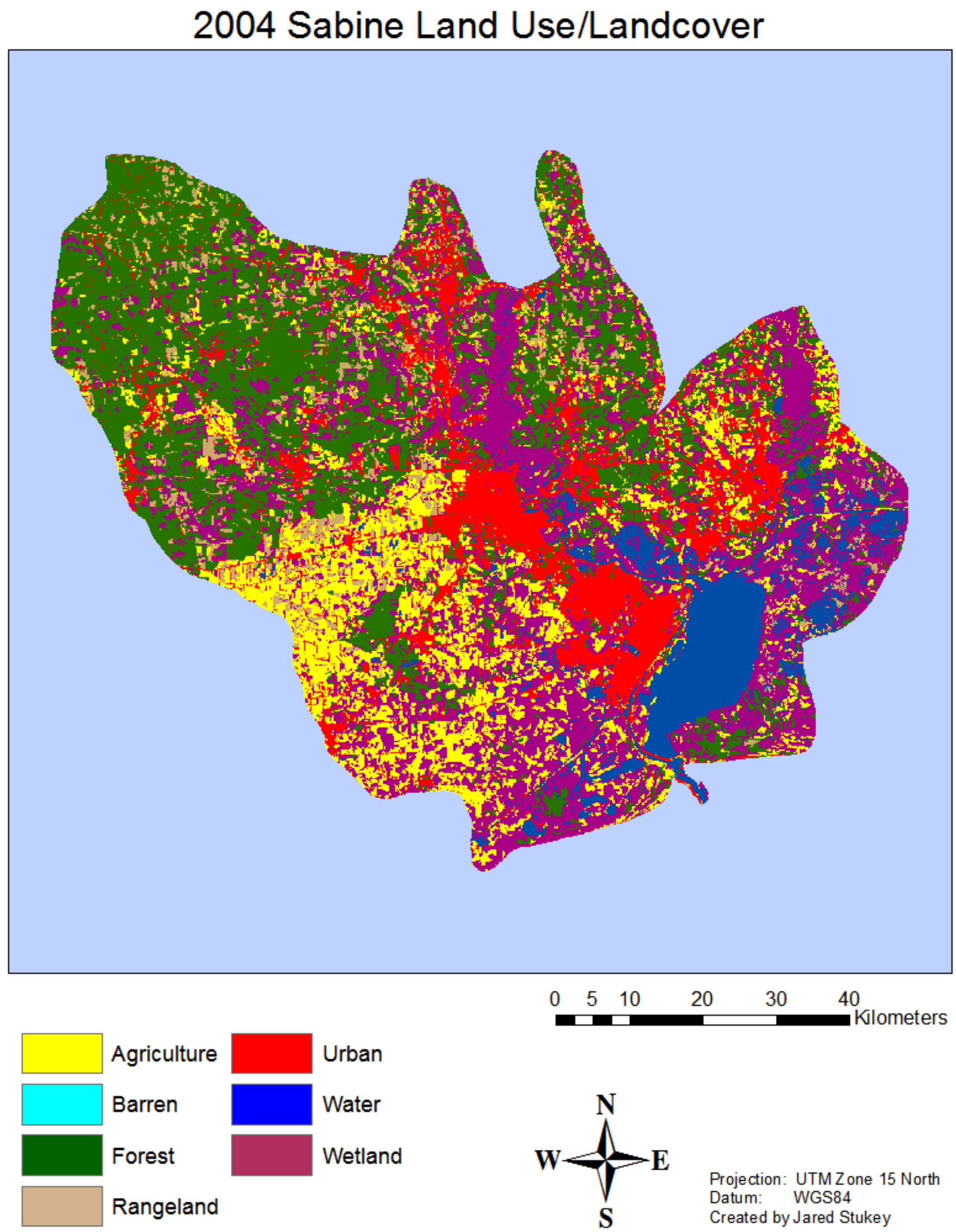
Class	1992	1998	2001	2004
Urban	12.30%	16.69%	24.02%	27.95%
Agriculture	31.88%	24.54%	22.53%	22.36%
Rangeland	2.05%	10.86%	8.32%	7.57%
Forest	34.40%	24.35%	16.03%	20.12%
Water	10.09%	10.75%	9.87%	9.69%
Wetland	8.29%	12.62%	18.69%	12.28%
Barren	0.99%	0.20%	0.53%	0.02%

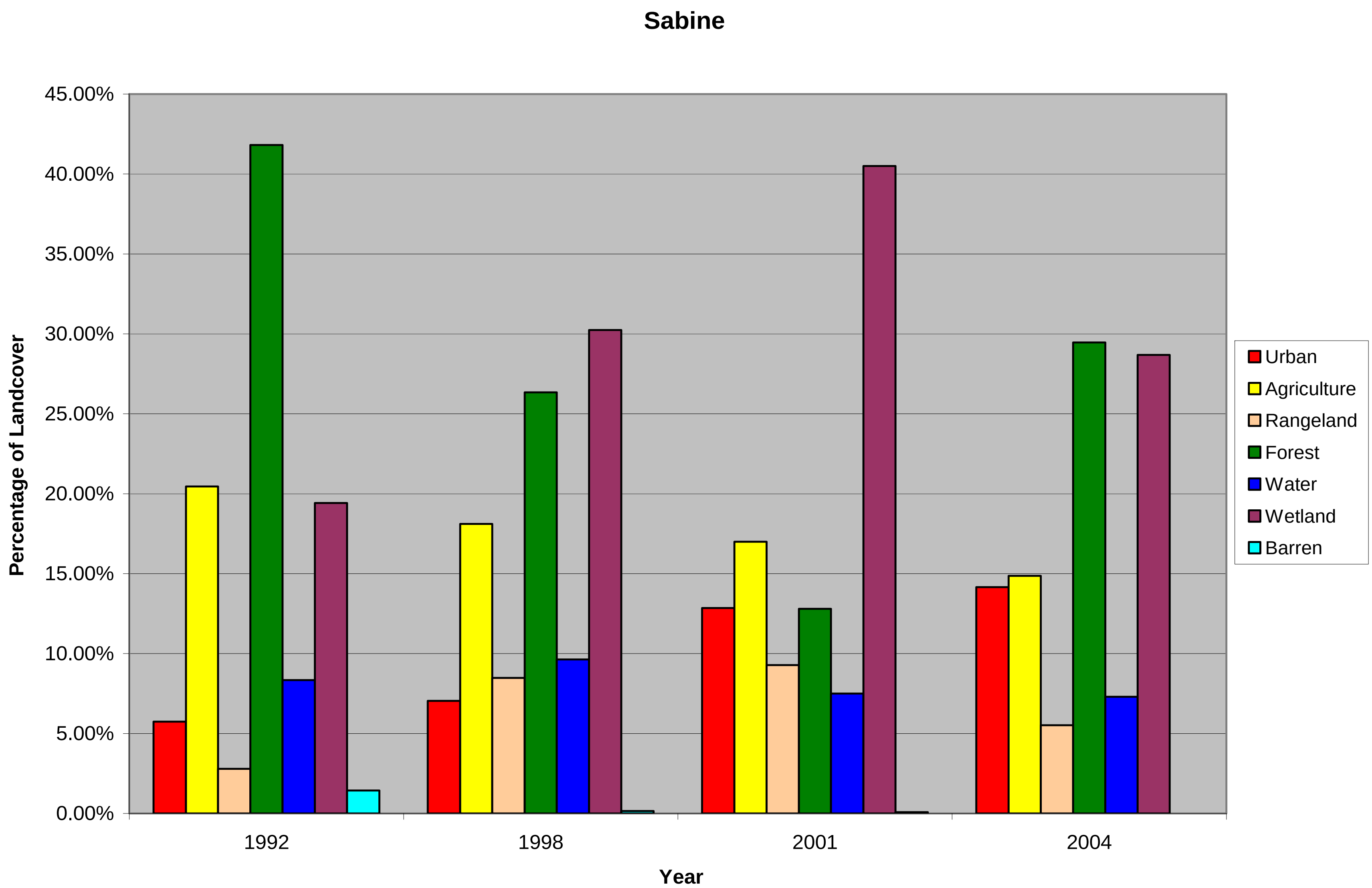

1992 Sabine Land Use/Landcover
0 5 10 20 30 40
Kilometers
Agriculture
Urban
Barren
Water
Forest
Wetland
Rangeland
N
W
E
S
Projection: UTM Zone 15 North
Datum: WGS84
Created by Jared Stukey

1998 Sabine Land Use/Landcover




2001 Sabine Land Use/Landcover
0 5 10 20 30 40
Kilometers
Agriculture
Barren
Forest
Rangeland
Urban
Water
Wetland
N
W
E
S
Projection: UTM Zone 15 North
Datum: WGS84
Created by Jared Stukey


2004 Sabine Land Use/Landcover
0 5 10 20 30 40
Kilometers
Agriculture
Urban
Barren
Water
Forest
Wetland
Rangeland
N
W
E
S
Projection: UTM Zone 15 North
Datum: WGS84
Created by Jared Stukey



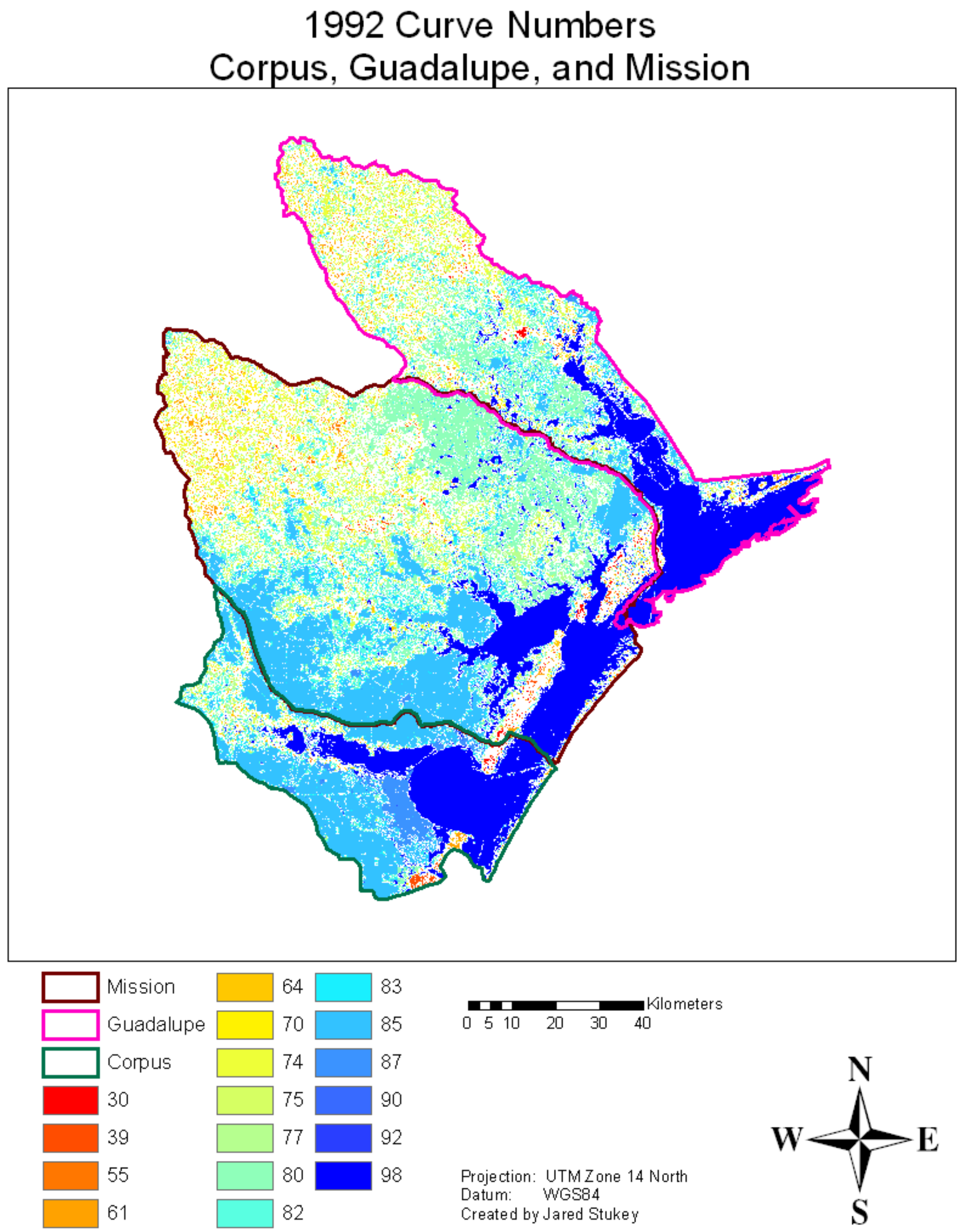
Sabine
45.00%
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
Percentage of Landcover
1992
1998
2001
2004
Year
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren

Sabine Classification Statistics

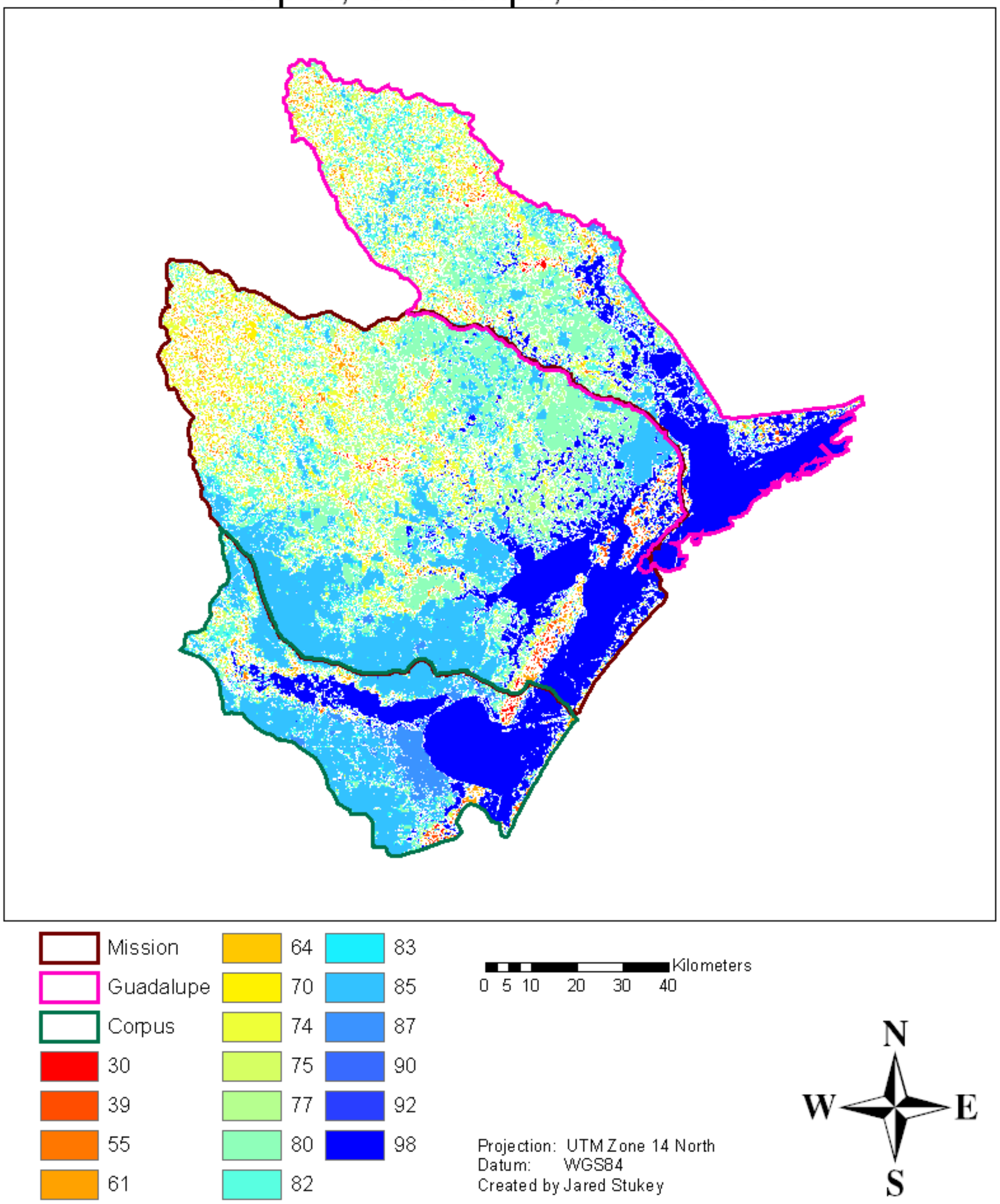
Class	1992	1998	2001	2004
Urban	5.74%	7.05%	12.84%	14.16%
Agriculture	20.46%	18.11%	16.99%	14.86%
Rangeland	2.79%	8.47%	9.29%	5.53%
Forest	41.81%	26.35%	12.80%	29.46%
Water	8.34%	9.64%	7.50%	7.30%
Wetland	19.42%	30.24%	40.50%	28.70%
Barren	1.44%	0.15%	0.07%	0.00%

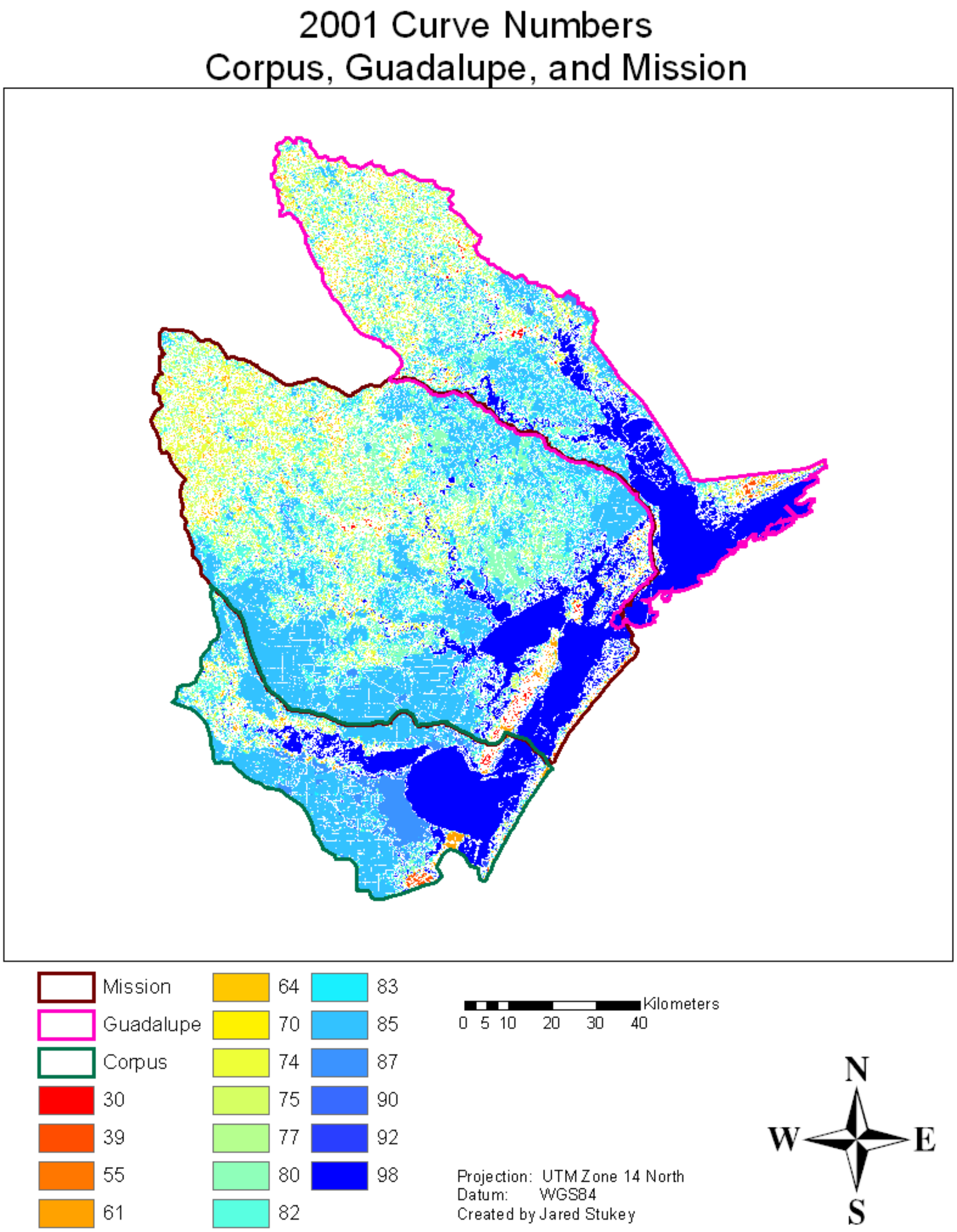
Appendix B

Curve Numbers


1992 Curve Numbers
Corpus, Guadalupe, and Mission
Mission
Guadalupe
Corpus
30
39
55
61
64
70
74
75
77
80
82
83
85
87
90
92
98
Kilometers
0 5 10 20 30 40
Projection: UTM Zone 14 North
Datum: WGS84
Created by Jared Stukey
N
W
E
S

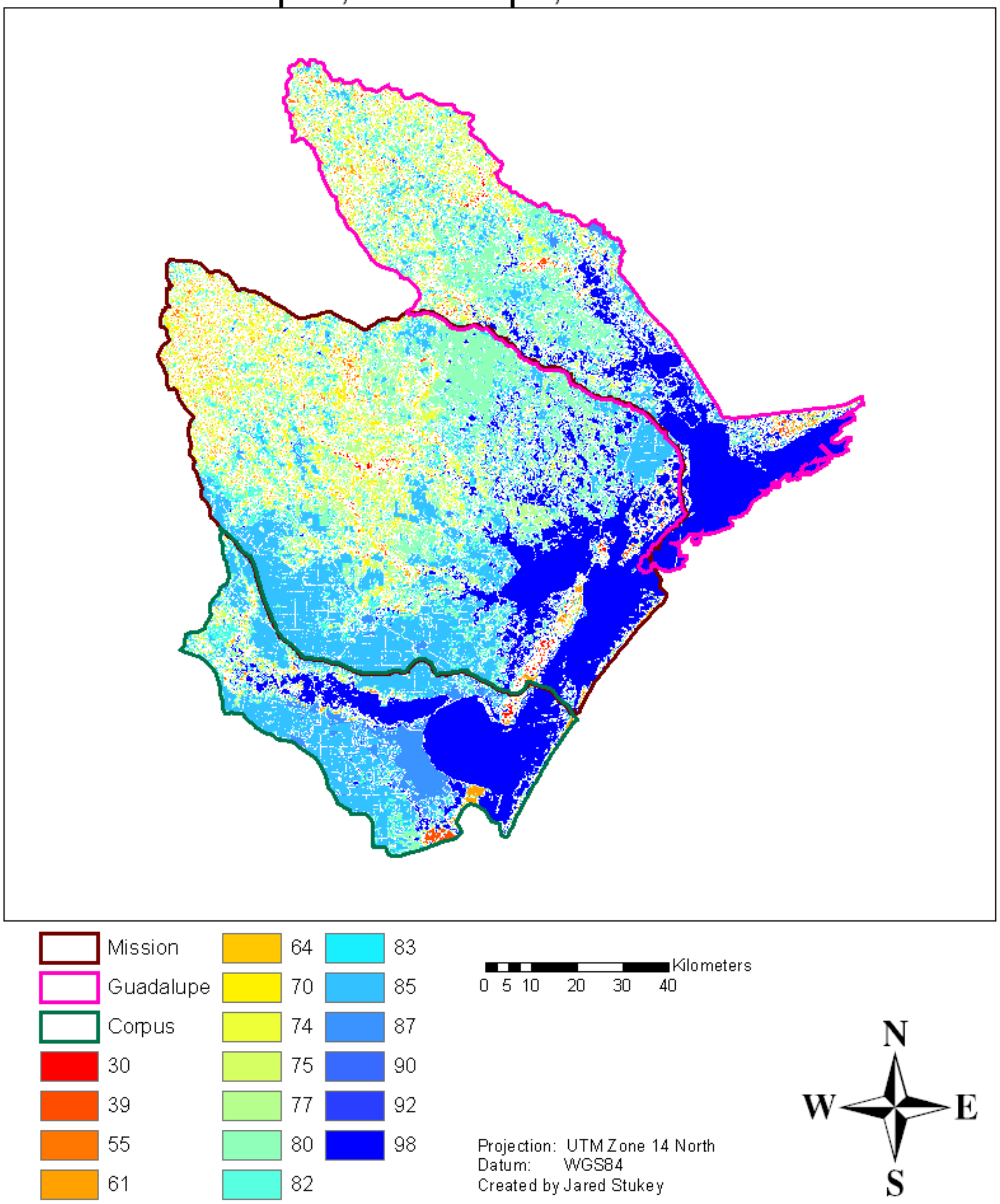
1998 Curve Numbers
Corpus, Guadalupe, and Mission



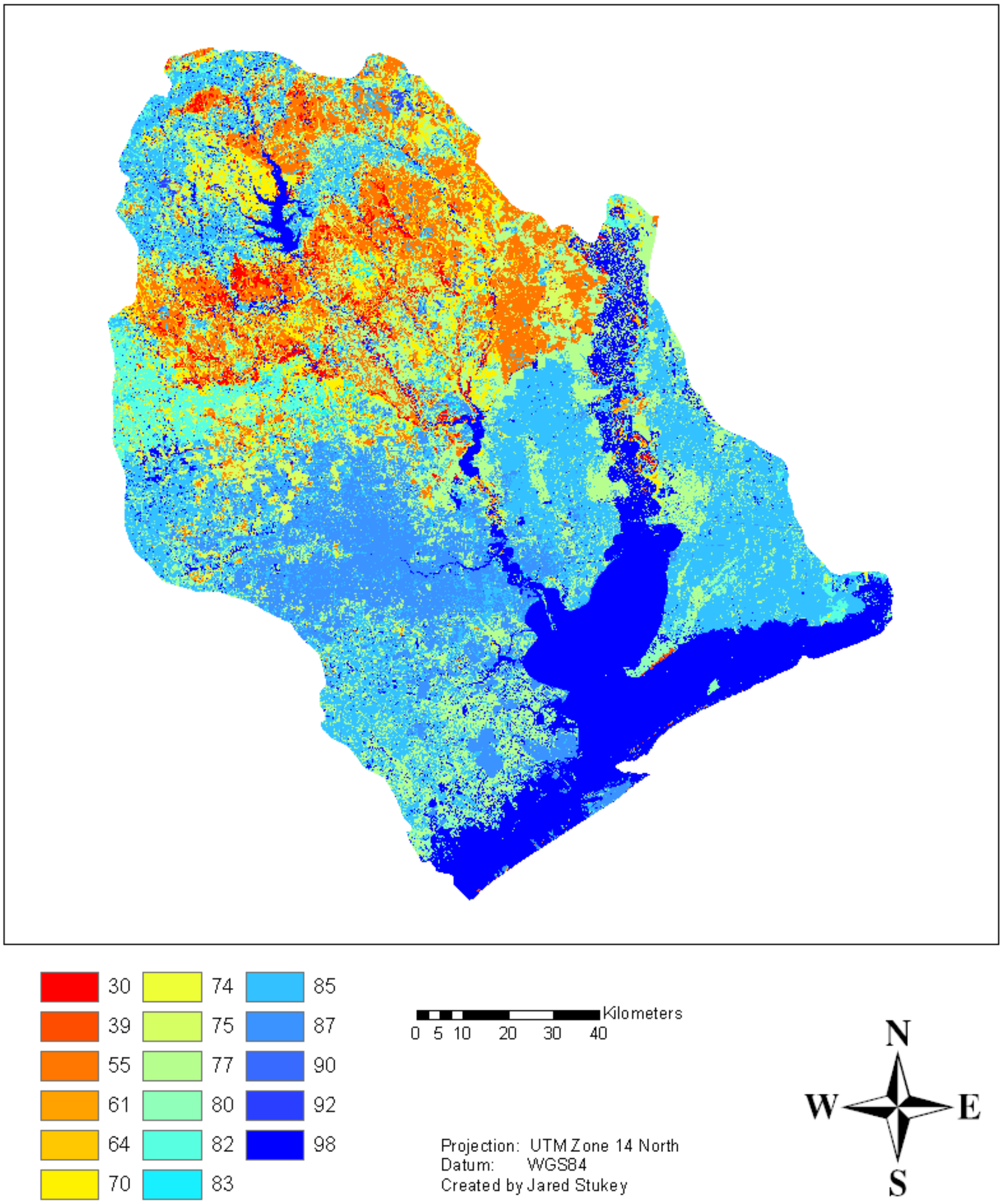


2001 Curve Numbers
Corpus, Guadalupe, and Mission
Mission
Guadalupe
Corpus
30
39
55
61
64
70
74
75
77
80
82
83
85
87
90
92
98
Kilometers
0 5 10 20 30 40
Projection: UTM Zone 14 North
Datum: WGS84
Created by Jared Stukey
N
W
E
S

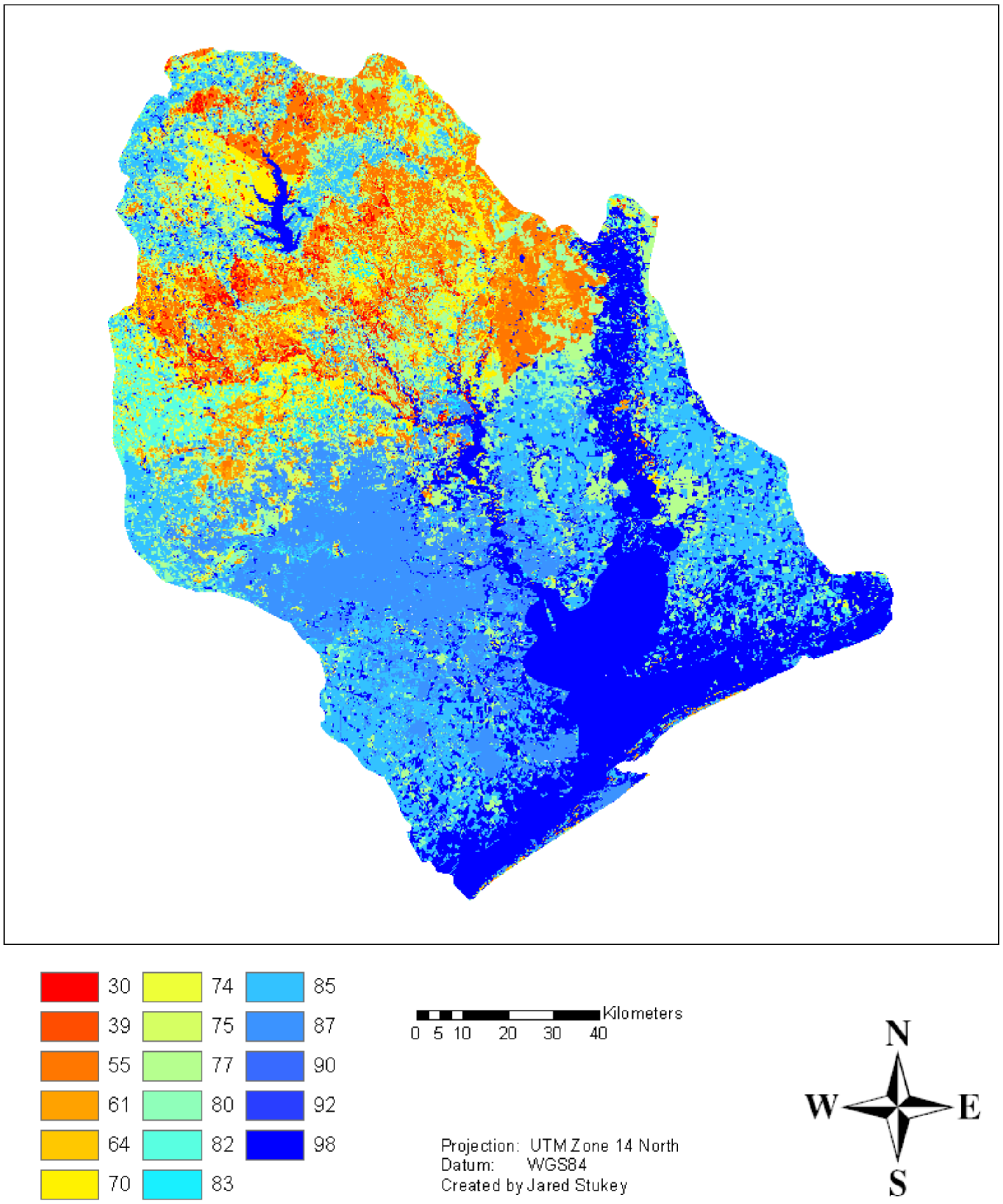
2004 Curve Numbers
Corpus, Guadalupe, and Mission

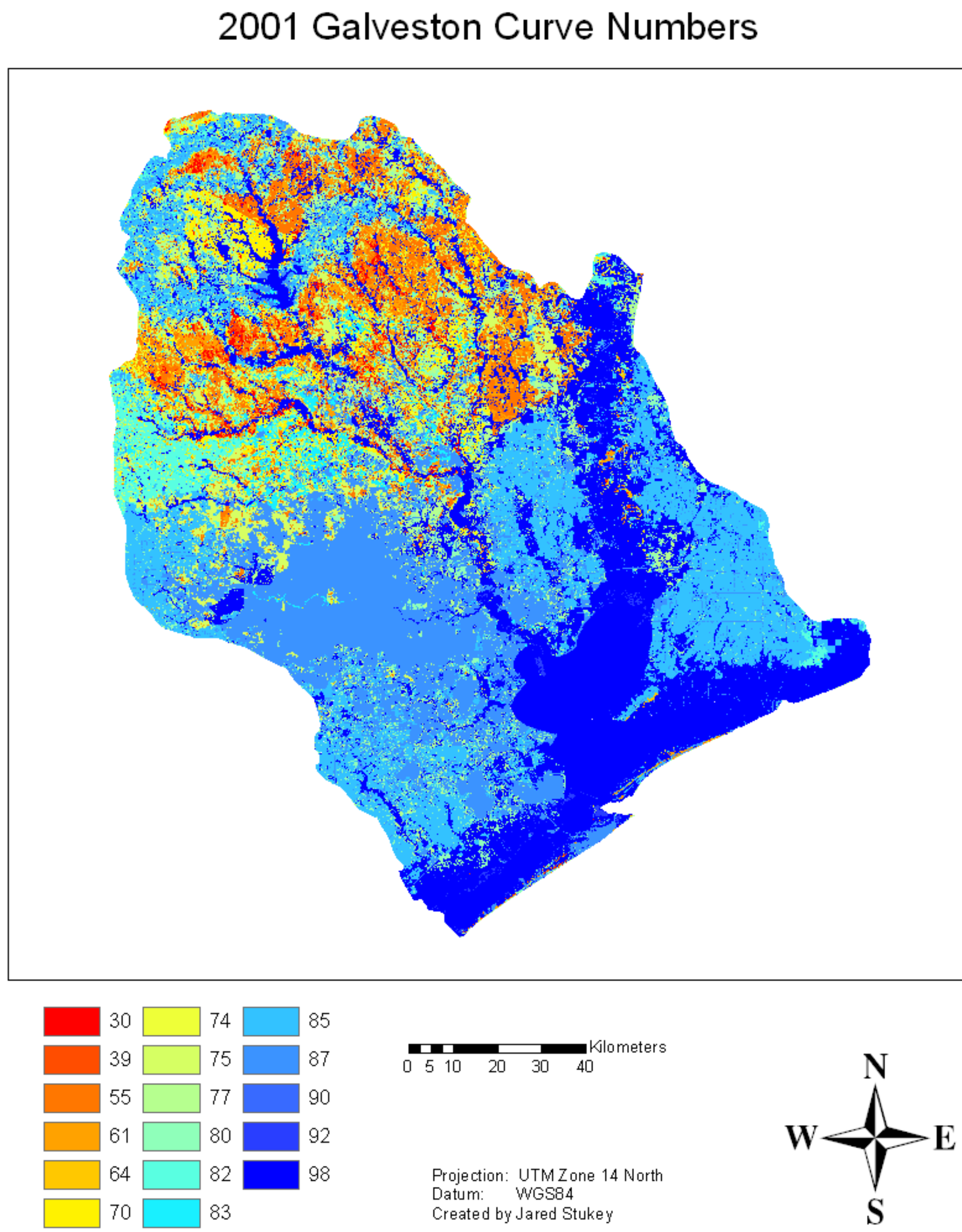


1992 Galveston Curve Numbers

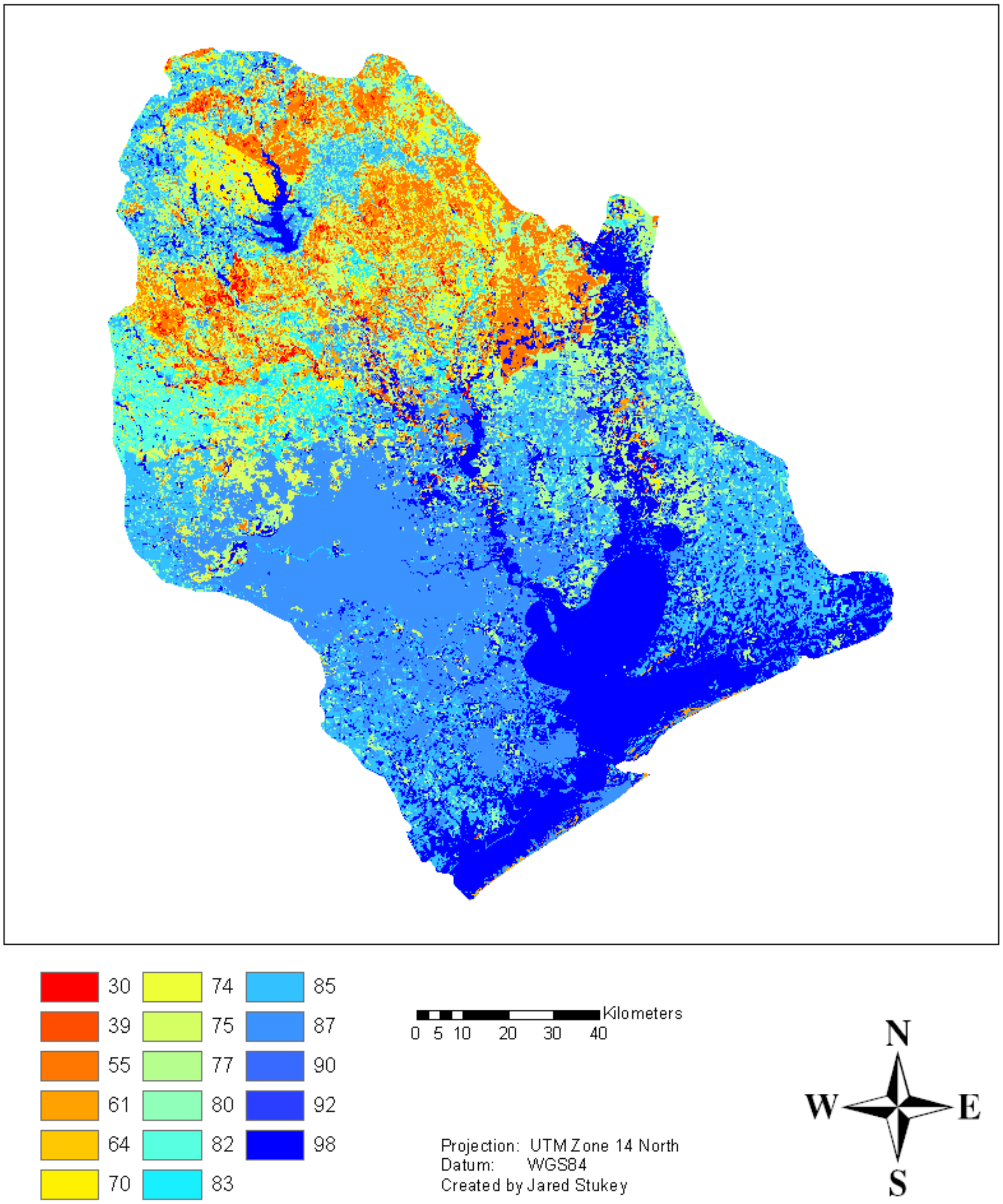


1998 Galveston Curve Numbers

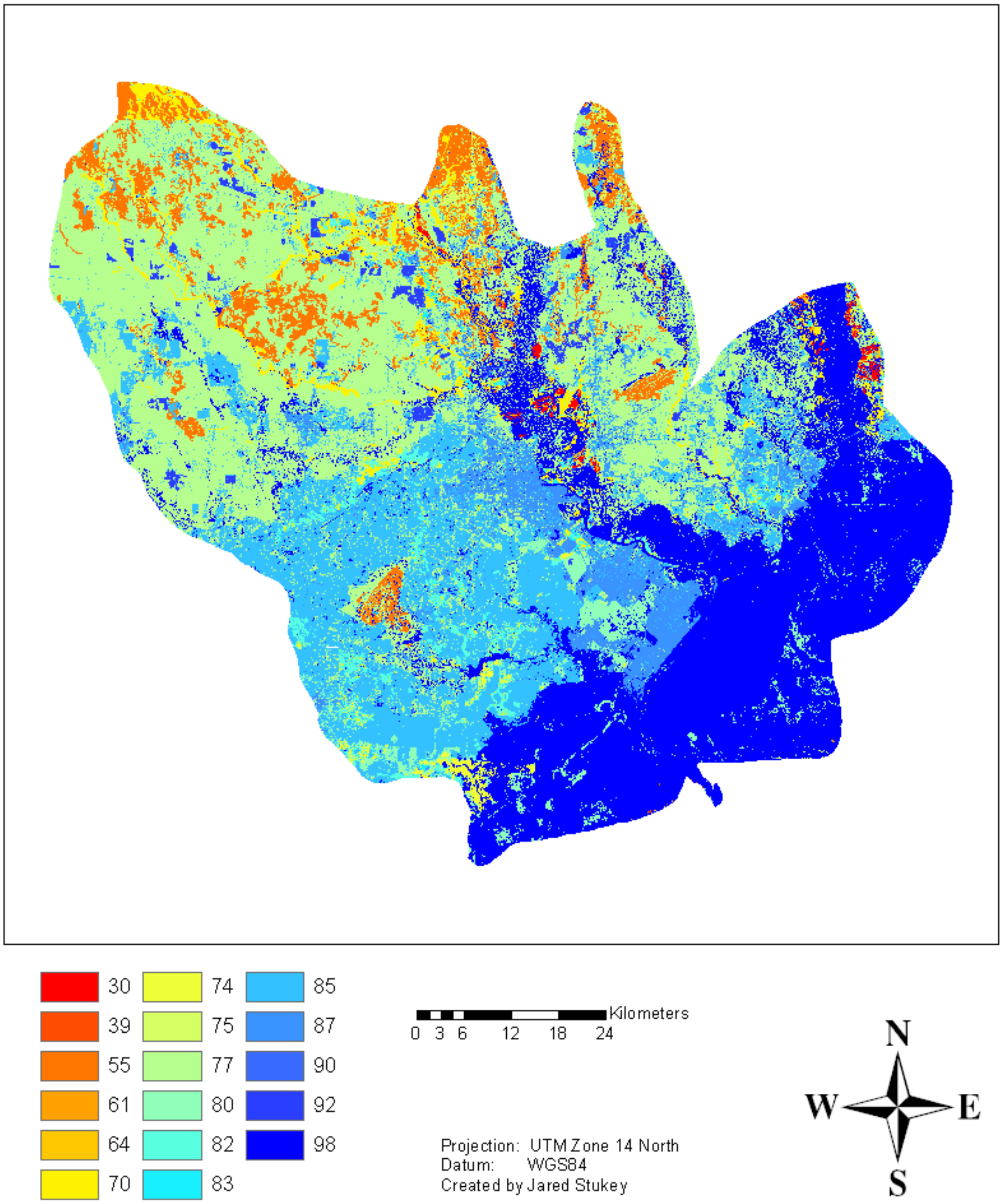



2001 Galveston Curve Numbers
30
39
55
61
64
70
74
75
77
80
82
83
85
87
90
92
98
Kilometers
0 5 10 20 30 40
Projection: UTM Zone 14 North
Datum: WGS84
Created by Jared Stukey
N
W
E
S

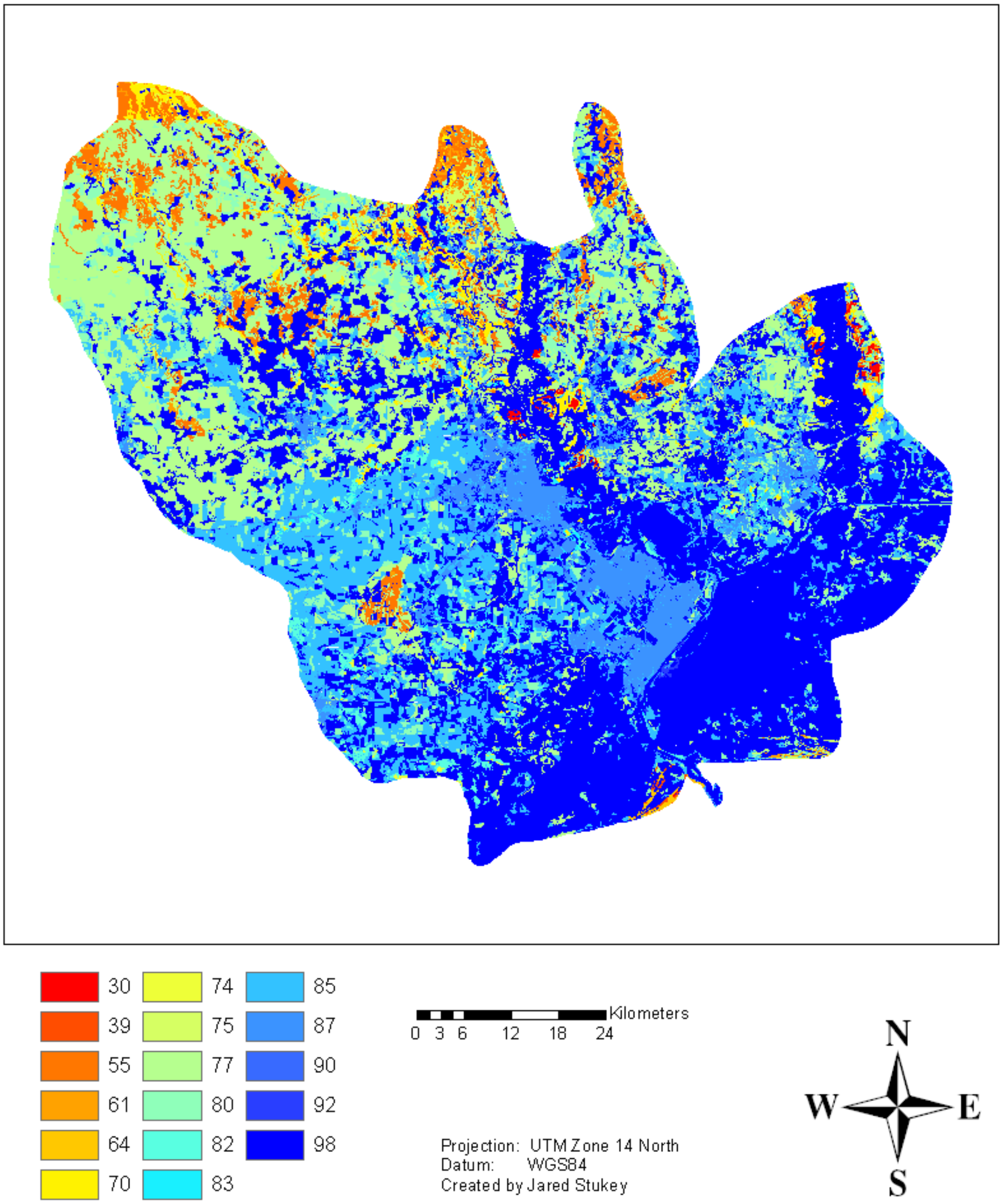
2004 Galveston Curve Numbers



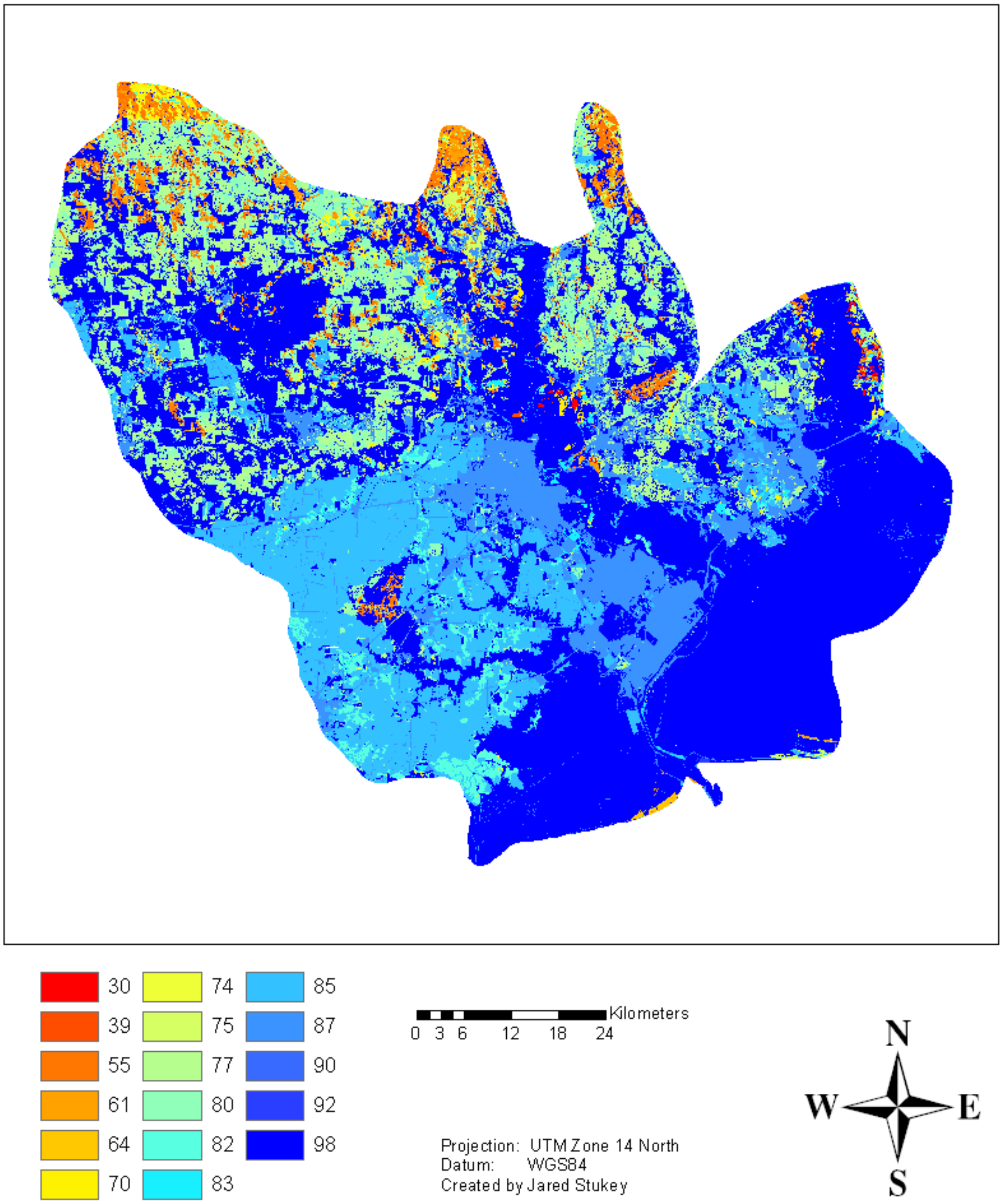
1992 Sabine Curve Numbers



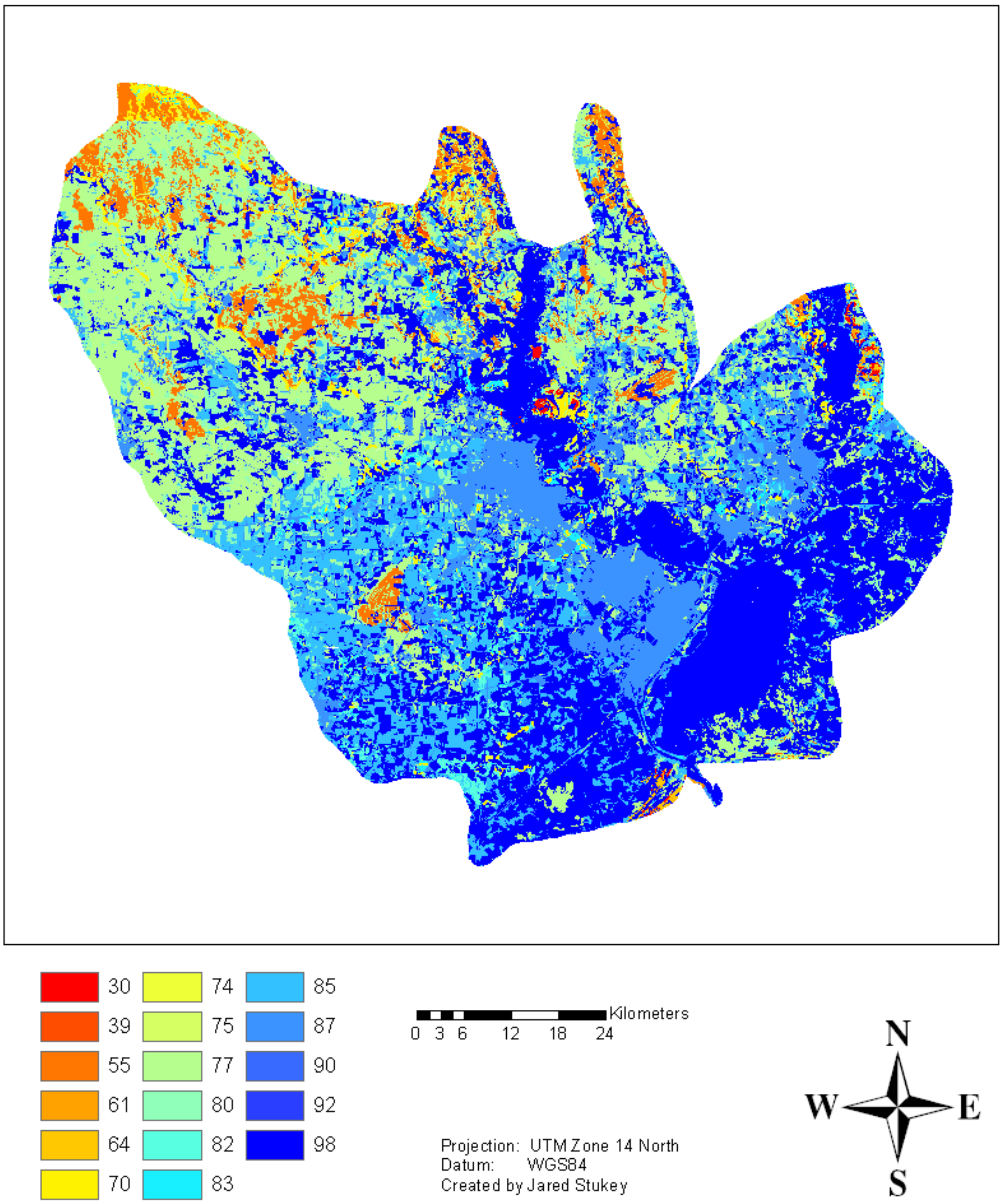
1998 Sabine Curve Numbers



2001 Sabine Curve Numbers



2004 Sabine Curve Numbers



Appendix C

Land Use and Land Cover Change

1992 – 1998 Corpus Land Cover Change Statistics

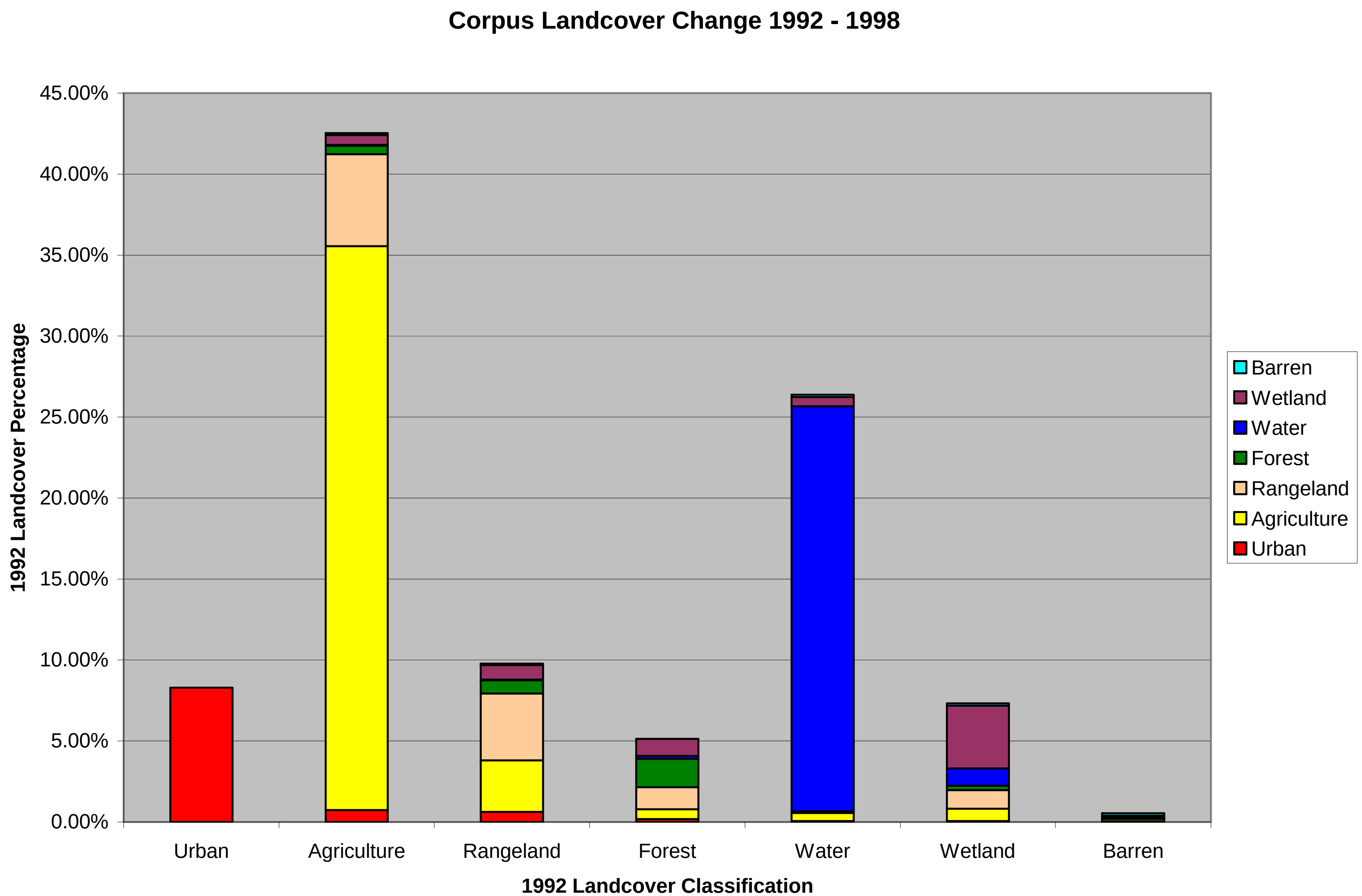
	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Barren	Total After
Urban	8.30%	0.75%	0.62%	0.19%	0.06%	0.07%	0.05%	10.03%
Agriculture	0.00%	34.81%	3.19%	0.60%	0.50%	0.75%	0.13%	39.98%
Rangeland	0.00%	5.66%	4.12%	1.36%	0.09%	1.16%	0.11%	12.50%
Forest	0.00%	0.53%	0.81%	1.75%	0.01%	0.27%	0.00%	3.38%
Water	0.00%	0.05%	0.04%	0.19%	25.01%	1.06%	0.04%	26.39%
Wetland	0.00%	0.61%	0.91%	1.04%	0.57%	3.88%	0.07%	7.08%
Barren	0.00%	0.12%	0.09%	0.02%	0.13%	0.13%	0.14%	0.64%
Total Before	8.30%	42.53%	9.79%	5.15%	26.38%	7.32%	0.54%	100.00%

1998 – 2001 Corpus Land Cover Change Statistics

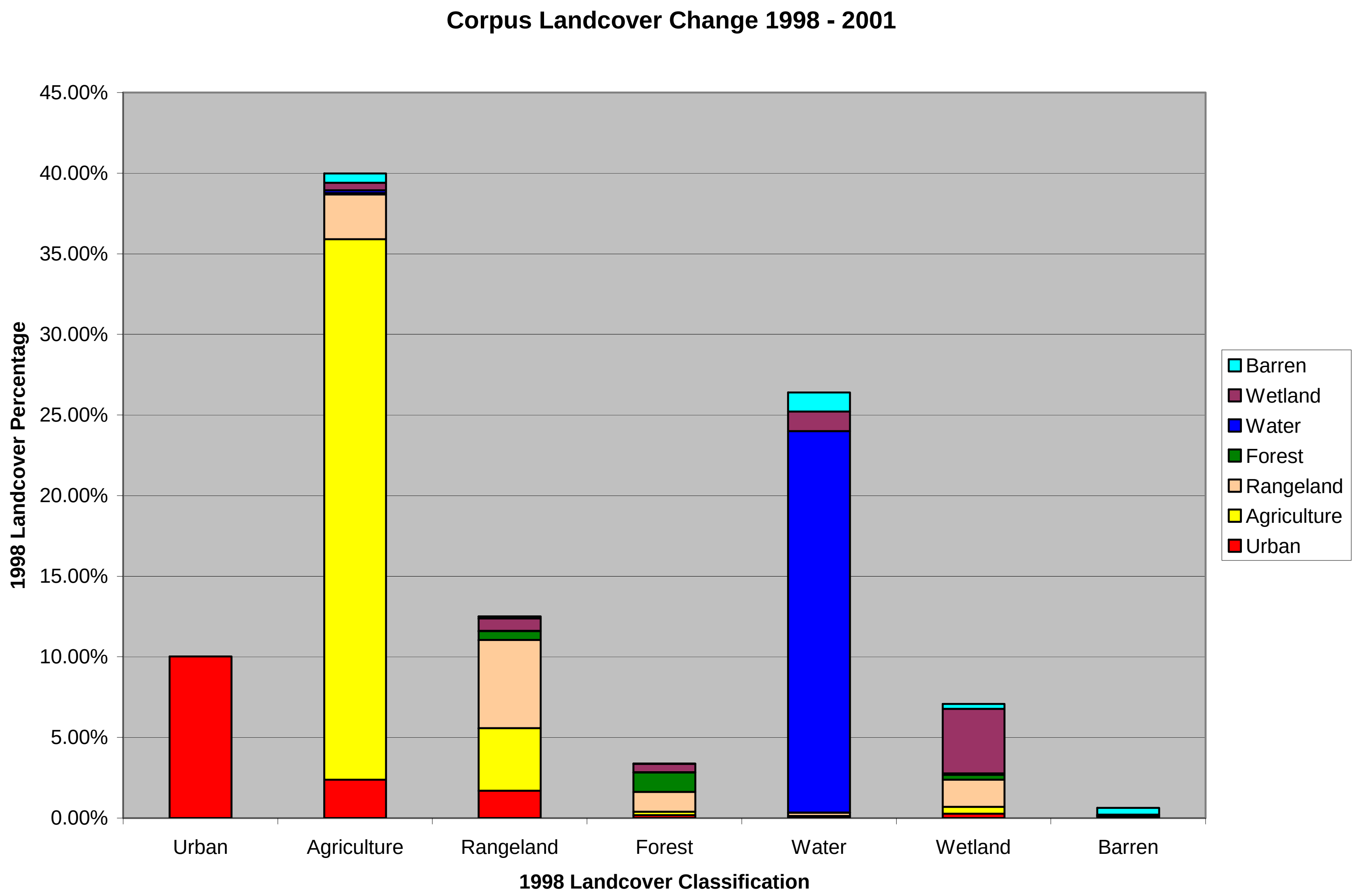
	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Barren	Total After
Urban	10.03%	2.38%	1.70%	0.18%	0.12%	0.28%	0.11%	14.79%
Agriculture	0.00%	33.52%	3.88%	0.21%	0.02%	0.42%	0.04%	38.10%
Rangeland	0.00%	2.77%	5.47%	1.23%	0.19%	1.69%	0.06%	11.40%
Forest	0.00%	0.10%	0.55%	1.22%	0.02%	0.30%	0.00%	2.20%
Water	0.00%	0.16%	0.02%	0.01%	23.66%	0.09%	0.00%	23.93%
Wetland	0.00%	0.47%	0.77%	0.52%	1.20%	4.00%	0.01%	6.98%
Barren	0.00%	0.58%	0.11%	0.02%	1.18%	0.30%	0.42%	2.61%
Total Before	10.03%	39.98%	12.50%	3.38%	26.39%	7.08%	0.64%	100.00%

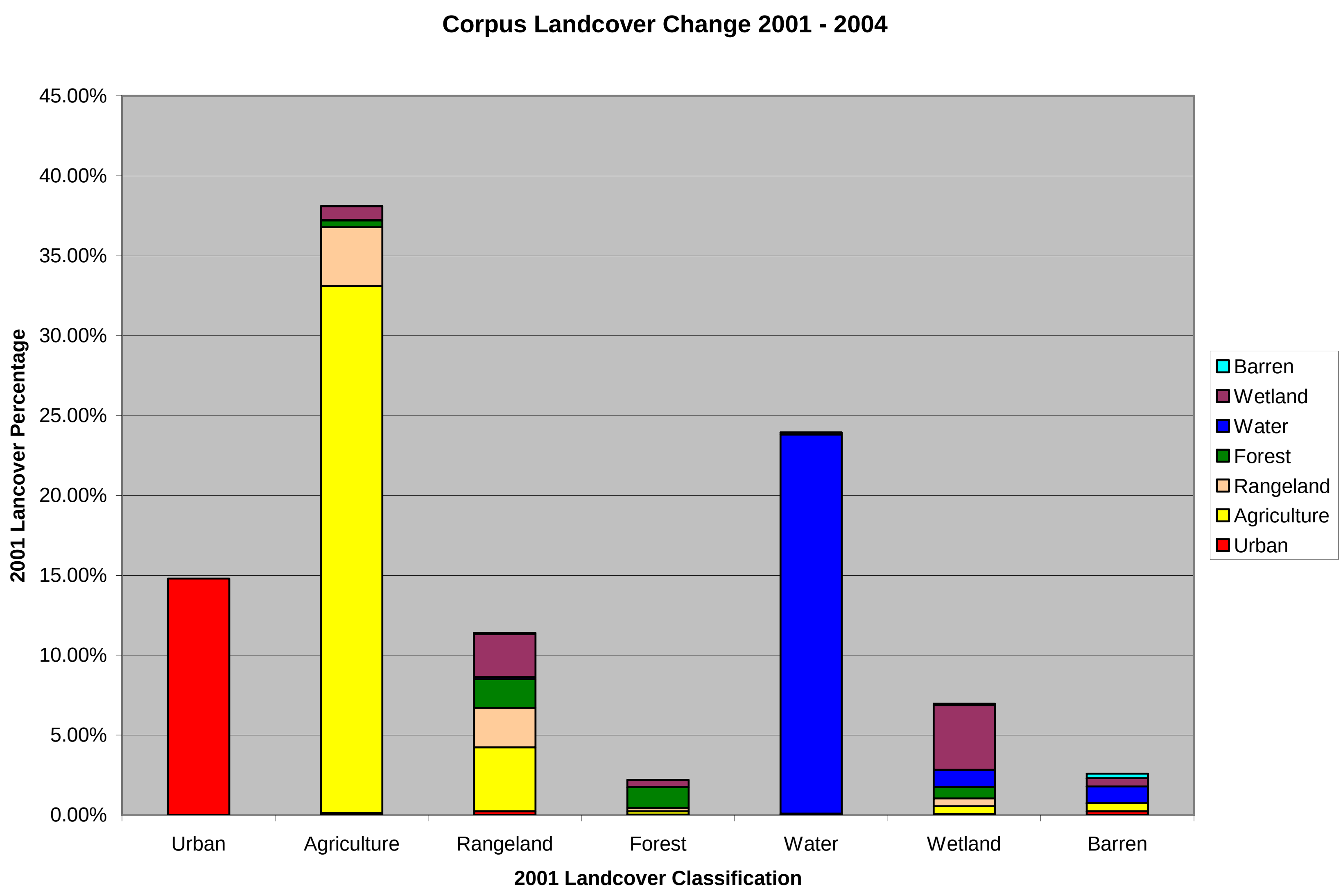
2001 – 2004 Corpus Land Cover Change Statistics

	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Barren	Total After
Urban	14.79%	0.13%	0.24%	0.02%	0.02%	0.07%	0.24%	15.52%
Agriculture	0.00%	32.96%	4.00%	0.21%	0.04%	0.49%	0.51%	38.22%
Rangeland	0.00%	3.70%	2.48%	0.22%	0.01%	0.48%	0.02%	6.90%
Forest	0.00%	0.42%	1.78%	1.30%	0.02%	0.71%	0.01%	4.24%
Water	0.00%	0.04%	0.15%	0.01%	23.70%	1.07%	1.01%	25.97%
Wetland	0.00%	0.84%	2.69%	0.44%	0.13%	4.03%	0.51%	8.65%
Barren	0.00%	0.02%	0.06%	0.00%	0.01%	0.11%	0.30%	0.49%
Total Before	14.79%	38.10%	11.40%	2.20%	23.94%	6.97%	2.60%	100.00%



Corpus Landcover Change 1992 - 1998
45.00%
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
1992 Landcover Percentage
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
1992 Landcover Classification
Barren
Wetland
Water
Forest
Rangeland
Agriculture
Urban


Corpus Landcover Change 1998 - 2001
45.00%
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
1998 Landcover Percentage
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
1998 Landcover Classification
Barren
Wetland
Water
Forest
Rangeland
Agriculture
Urban



Corpus Landcover Change 2001 - 2004
45.00%
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
2001 Lancover Percentage
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
2001 Landcover Classification
Barren
Wetland
Water
Forest
Rangeland
Agriculture
Urban

1992 – 1998 Guadalupe Land Cover Change Statistics

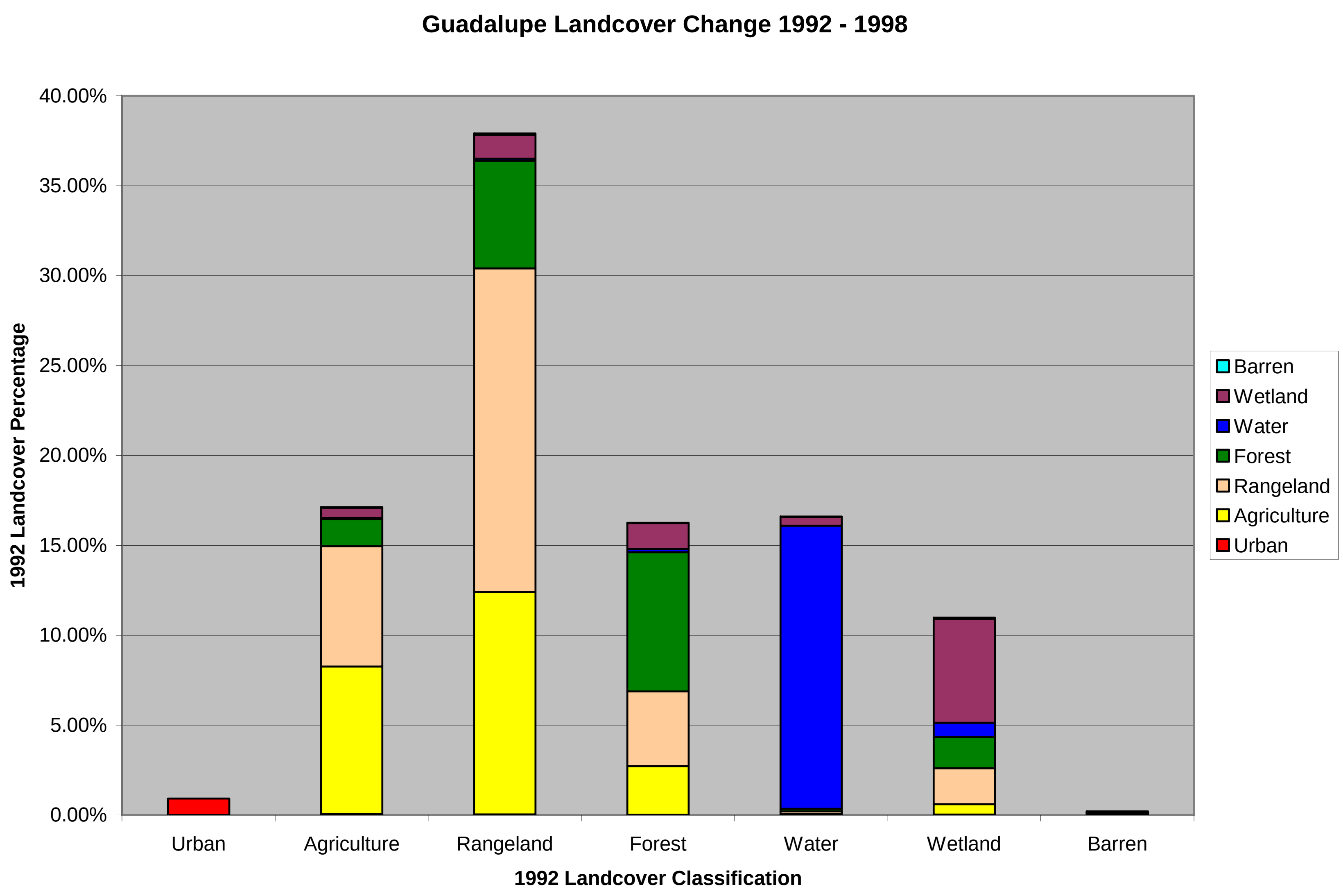
	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Barren	Total After
Urban	0.91%	0.05%	0.04%	0.01%	0.01%	0.02%	0.03%	1.07%
Agriculture	0.00%	8.22%	12.38%	2.71%	0.05%	0.59%	0.05%	23.99%
Rangeland	0.00%	6.69%	18.00%	4.15%	0.14%	1.99%	0.07%	31.03%
Forest	0.00%	1.51%	5.98%	7.76%	0.15%	1.73%	0.01%	17.14%
Water	0.00%	0.06%	0.11%	0.17%	15.75%	0.80%	0.00%	16.89%
Wetland	0.00%	0.57%	1.33%	1.44%	0.49%	5.79%	0.01%	9.62%
Barren	0.00%	0.04%	0.07%	0.02%	0.02%	0.06%	0.04%	0.26%
Total Before	0.91%	17.13%	37.91%	16.26%	16.61%	10.98%	0.21%	100.00%

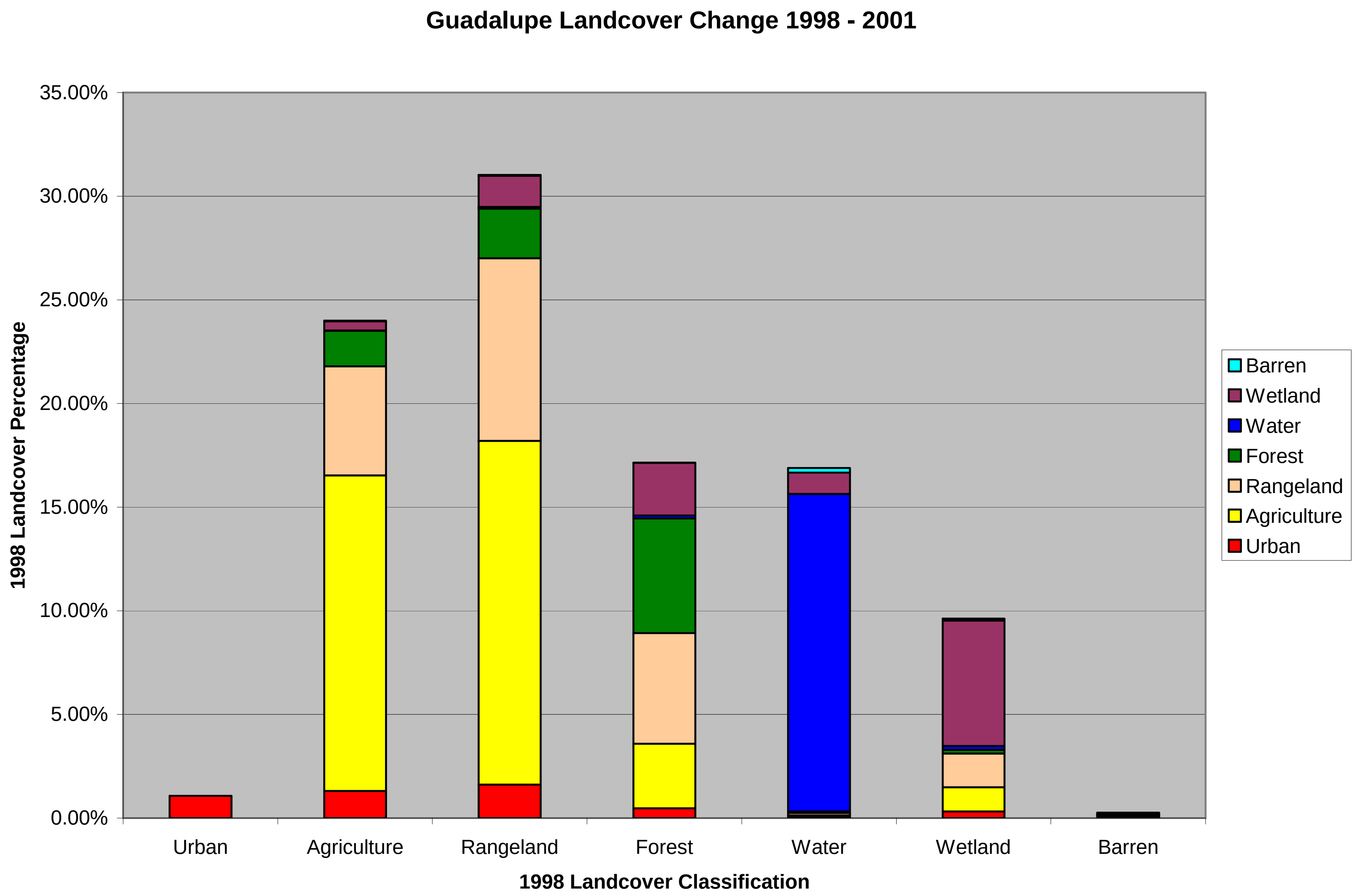
1998 – 2001 Guadalupe Land Cover Change Statistics

	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Barren	Total After
Urban	1.07%	1.31%	1.61%	0.47%	0.04%	0.32%	0.04%	4.86%
Agriculture	0.00%	15.22%	16.59%	3.12%	0.09%	1.18%	0.06%	36.25%
Rangeland	0.00%	5.26%	8.81%	5.33%	0.12%	1.63%	0.05%	21.20%
Forest	0.00%	1.72%	2.39%	5.54%	0.07%	0.17%	0.01%	9.90%
Water	0.00%	0.03%	0.09%	0.14%	15.33%	0.18%	0.01%	15.77%
Wetland	0.00%	0.44%	1.51%	2.53%	1.02%	6.06%	0.01%	11.56%
Barren	0.00%	0.03%	0.03%	0.01%	0.23%	0.09%	0.07%	0.46%
Total Before	1.07%	23.99%	31.03%	17.14%	16.89%	9.62%	0.26%	100.00%

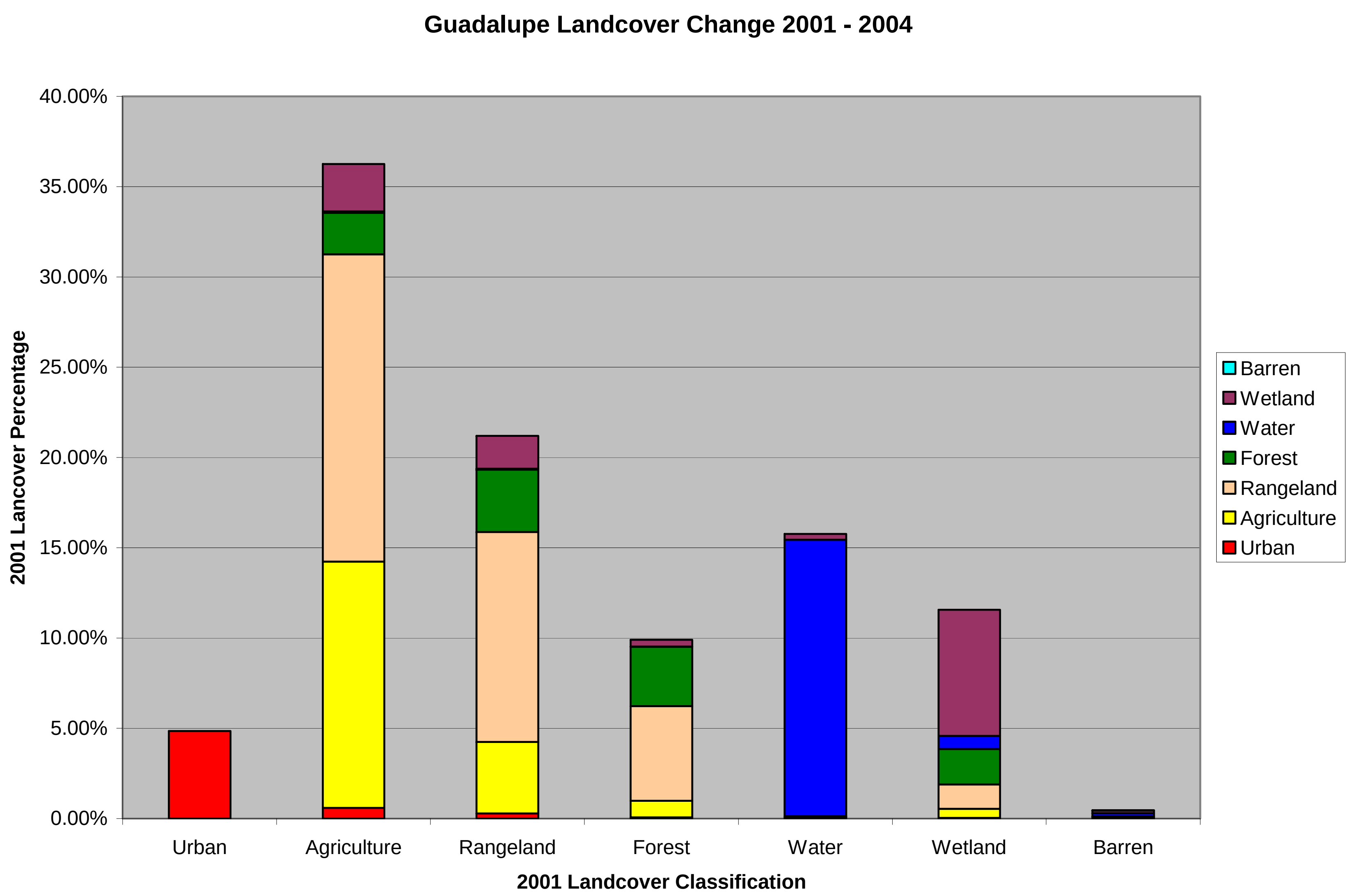
2001 – 2004 Guadalupe Land Cover Change Statistics

	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Barren	Total After
Urban	4.86%	0.59%	0.28%	0.07%	0.02%	0.05%	0.03%	5.89%
Agriculture	0.00%	13.64%	3.97%	0.91%	0.03%	0.49%	0.07%	19.11%
Rangeland	0.00%	17.03%	11.62%	5.24%	0.04%	1.35%	0.02%	35.31%
Forest	0.00%	2.28%	3.45%	3.28%	0.04%	1.97%	0.00%	11.03%
Water	0.00%	0.09%	0.06%	0.01%	15.31%	0.73%	0.18%	16.37%
Wetland	0.00%	2.62%	1.82%	0.38%	0.33%	6.98%	0.15%	12.28%
Barren	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%
Total Before	4.86%	36.25%	21.20%	9.90%	15.77%	11.56%	0.46%	100.00%


Guadalupe Landcover Change 1992 - 1998
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
1992 Landcover Percentage
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
1992 Landcover Classification
Barren
Wetland
Water
Forest
Rangeland
Agriculture
Urban



Guadalupe Landcover Change 1998 - 2001
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
1998 Landcover Percentage
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
1998 Landcover Classification
Barren
Wetland
Water
Forest
Rangeland
Agriculture
Urban


Guadalupe Landcover Change 2001 - 2004
2001 Lancover Percentage
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
2001 Landcover Classification
Barren
Wetland
Water
Forest
Rangeland
Agriculture
Urban

1992 – 1998 Mission Land Cover Change Statistics

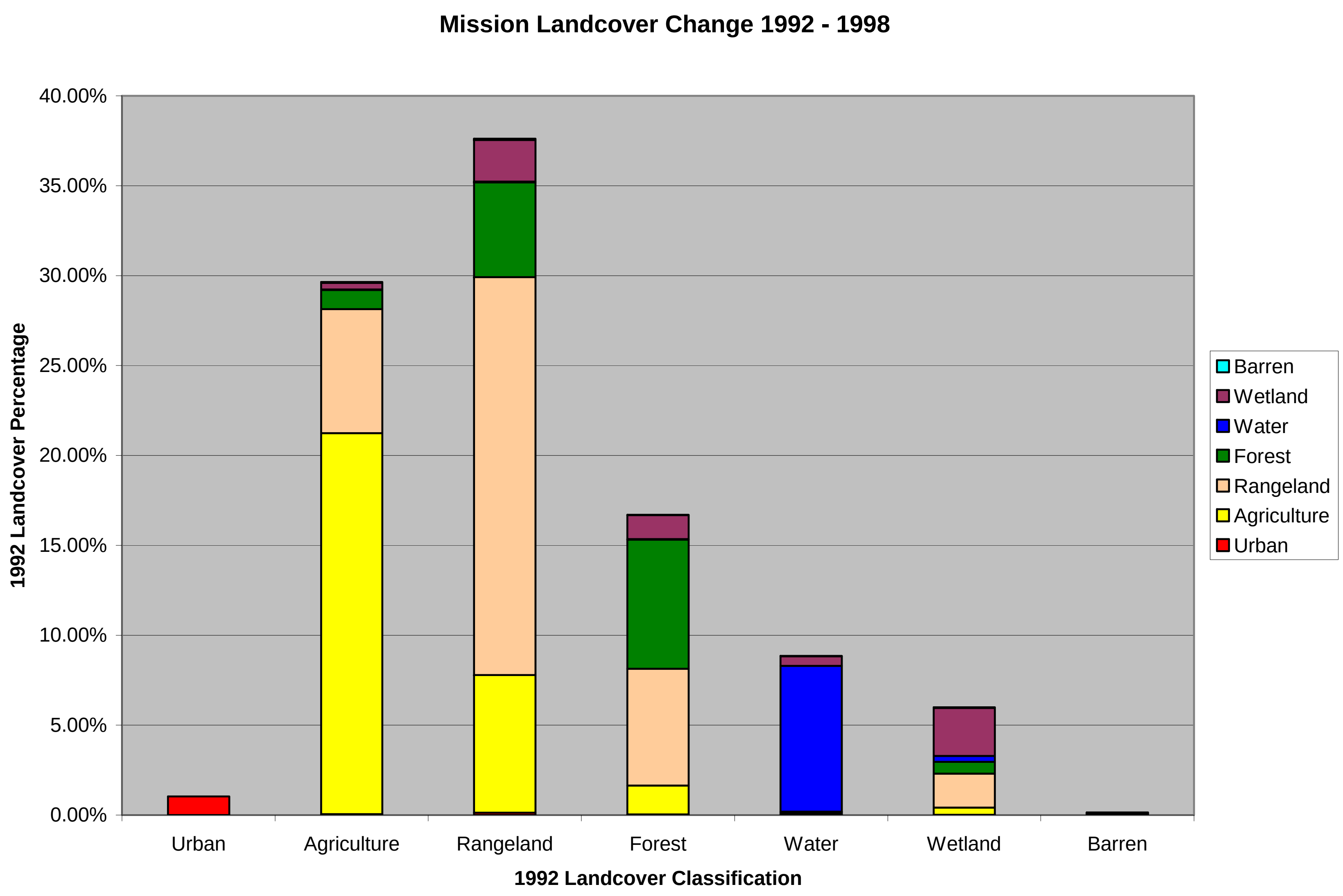
	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Barren	Total After
Urban	1.04%	0.05%	0.14%	0.04%	0.01%	0.01%	0.01%	1.30%
Agriculture	0.00%	21.18%	7.66%	1.60%	0.11%	0.40%	0.04%	31.00%
Rangeland	0.00%	6.91%	22.13%	6.50%	0.06%	1.89%	0.06%	37.55%
Forest	0.00%	1.06%	5.27%	7.18%	0.01%	0.66%	0.01%	14.19%
Water	0.00%	0.02%	0.04%	0.04%	8.11%	0.33%	0.00%	8.54%
Wetland	0.00%	0.37%	2.32%	1.33%	0.54%	2.67%	0.00%	7.22%
Barren	0.00%	0.06%	0.06%	0.01%	0.01%	0.04%	0.02%	0.21%
Total Before	1.04%	29.66%	37.61%	16.70%	8.85%	5.99%	0.15%	100.00%

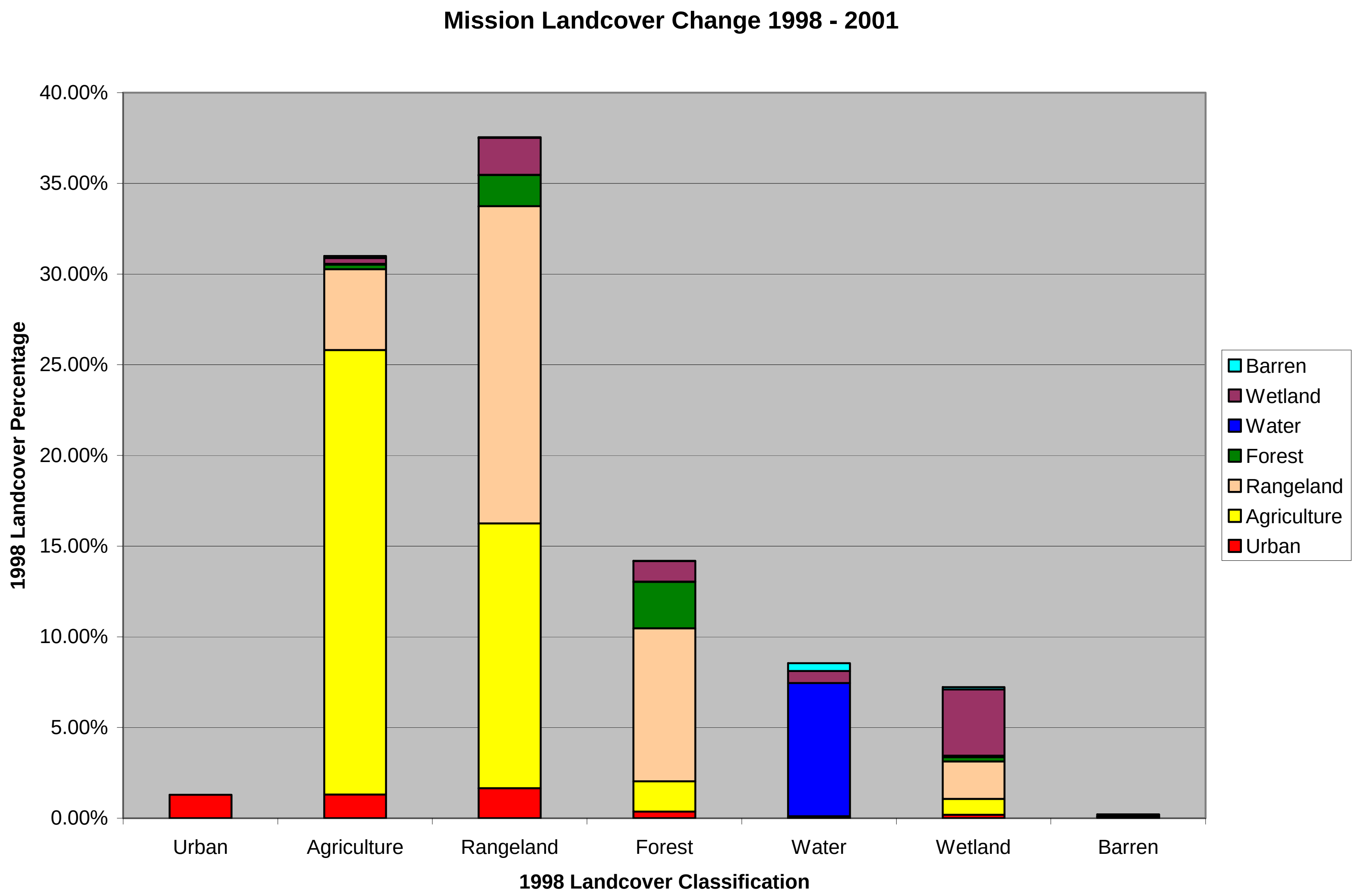
1998 – 2001 Mission Land Cover Change Statistics

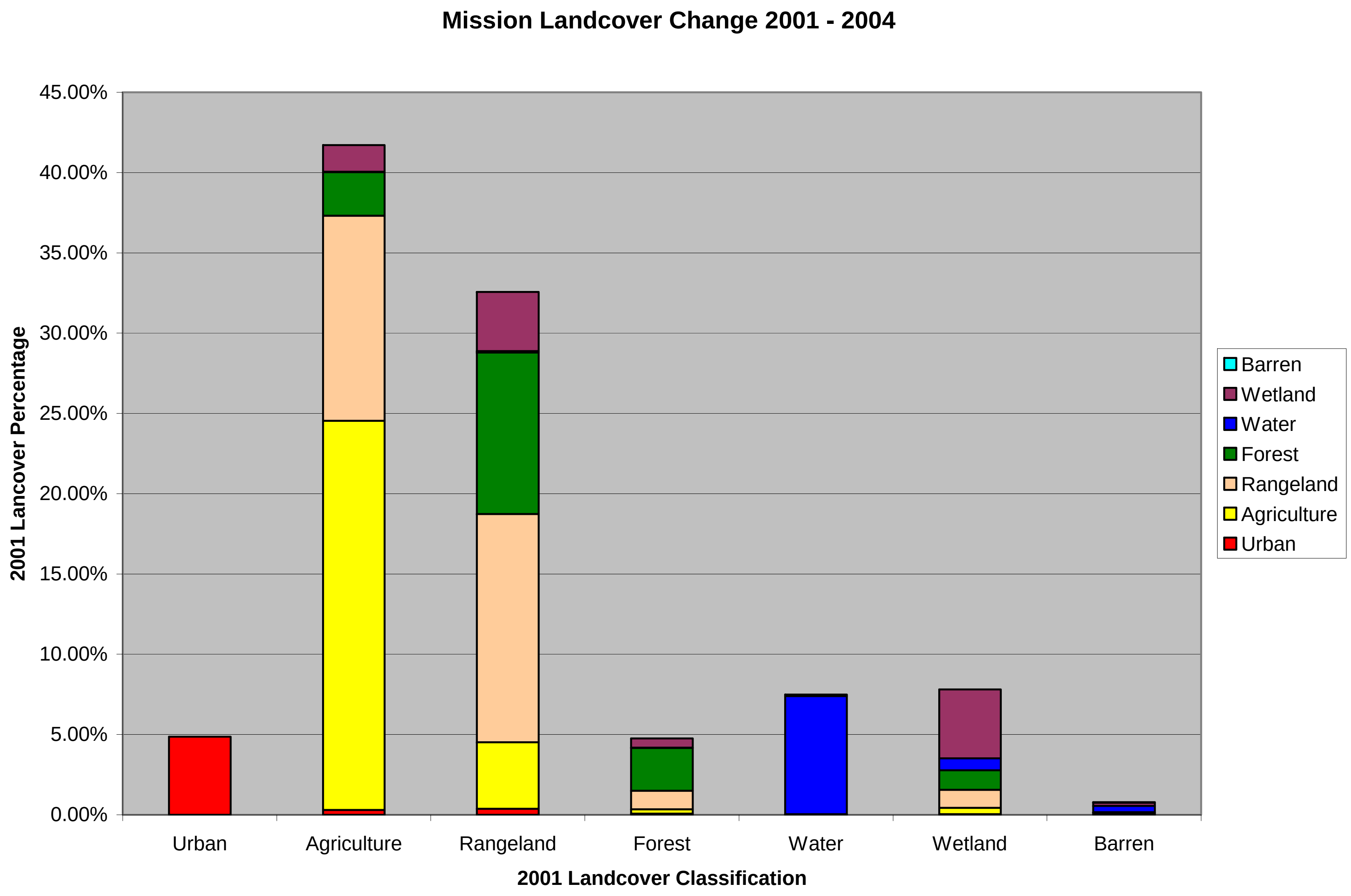
	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Barren	Total After
Urban	1.30%	1.31%	1.65%	0.37%	0.02%	0.19%	0.04%	4.86%
Agriculture	0.00%	24.50%	14.60%	1.66%	0.02%	0.88%	0.04%	41.71%
Rangeland	0.00%	4.47%	17.49%	8.45%	0.06%	2.07%	0.04%	32.57%
Forest	0.00%	0.25%	1.70%	2.56%	0.01%	0.23%	0.00%	4.76%
Water	0.00%	0.03%	0.02%	0.01%	7.34%	0.09%	0.00%	7.49%
Wetland	0.00%	0.33%	2.03%	1.13%	0.66%	3.65%	0.00%	7.81%
Barren	0.00%	0.10%	0.05%	0.01%	0.43%	0.11%	0.09%	0.79%
Total Before	1.30%	31.00%	37.55%	14.19%	8.54%	7.22%	0.21%	100.00%

2001 – 2004 Mission Land Cover Change Statistics

	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Barren	Total After
Urban	4.86%	0.30%	0.38%	0.07%	0.00%	0.04%	0.03%	5.69%
Agriculture	0.00%	24.25%	4.13%	0.28%	0.01%	0.39%	0.09%	29.17%
Rangeland	0.00%	12.76%	14.22%	1.15%	0.01%	1.12%	0.04%	29.31%
Forest	0.00%	2.71%	10.06%	2.67%	0.02%	1.22%	0.01%	16.69%
Water	0.00%	0.02%	0.10%	0.01%	7.35%	0.74%	0.40%	8.62%
Wetland	0.00%	1.66%	3.68%	0.58%	0.09%	4.29%	0.19%	10.49%
Barren	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.03%	0.03%
Total Before	4.86%	41.72%	32.57%	4.76%	7.49%	7.81%	0.78%	100.00%


Mission Landcover Change 1992 - 1998
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
1992 Landcover Percentage
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
1992 Landcover Classification
Barren
Wetland
Water
Forest
Rangeland
Agriculture
Urban


Mission Landcover Change 1998 - 2001
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
1998 Landcover Percentage
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
1998 Landcover Classification
Barren
Wetland
Water
Forest
Rangeland
Agriculture
Urban


Mission Landcover Change 2001 - 2004
45.00%
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
2001 Lancover Percentage
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
2001 Landcover Classification
Barren
Wetland
Water
Forest
Rangeland
Agriculture
Urban

1992 – 1998 Galveston Land Cover Change Statistics

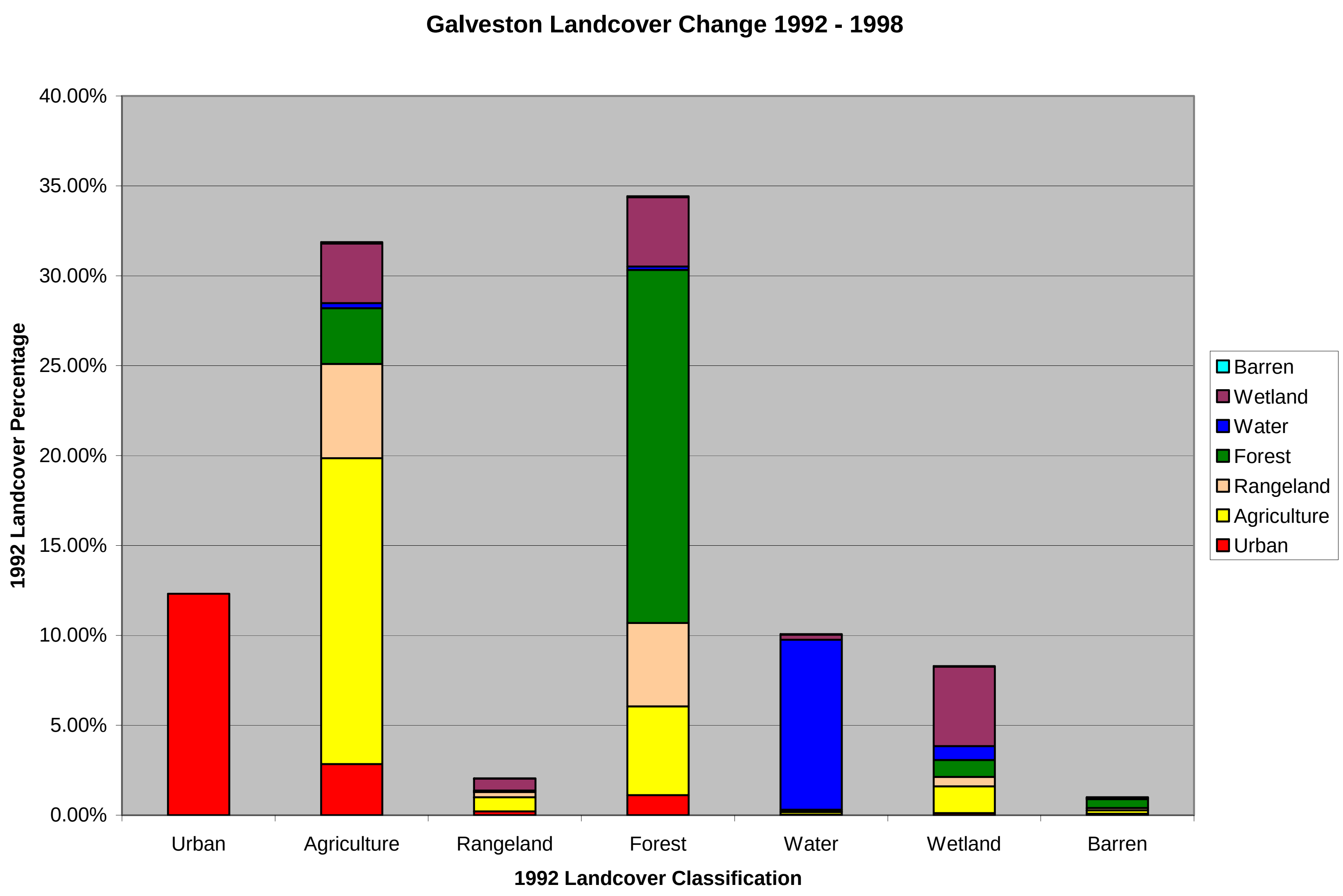
	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Barren	Total After
Urban	12.32%	2.85%	0.21%	1.12%	0.02%	0.13%	0.09%	16.73%
Agriculture	0.00%	17.00%	0.78%	4.93%	0.15%	1.48%	0.18%	24.52%
Rangeland	0.00%	5.25%	0.29%	4.63%	0.03%	0.53%	0.14%	10.86%
Forest	0.00%	3.10%	0.06%	19.64%	0.11%	0.94%	0.49%	24.34%
Water	0.00%	0.29%	0.03%	0.19%	9.44%	0.76%	0.03%	10.74%
Wetland	0.00%	3.32%	0.67%	3.86%	0.29%	4.43%	0.05%	12.60%
Barren	0.00%	0.08%	0.01%	0.05%	0.03%	0.02%	0.02%	0.20%
Total Before	12.32%	31.88%	2.05%	34.42%	10.07%	8.28%	0.99%	100.00%

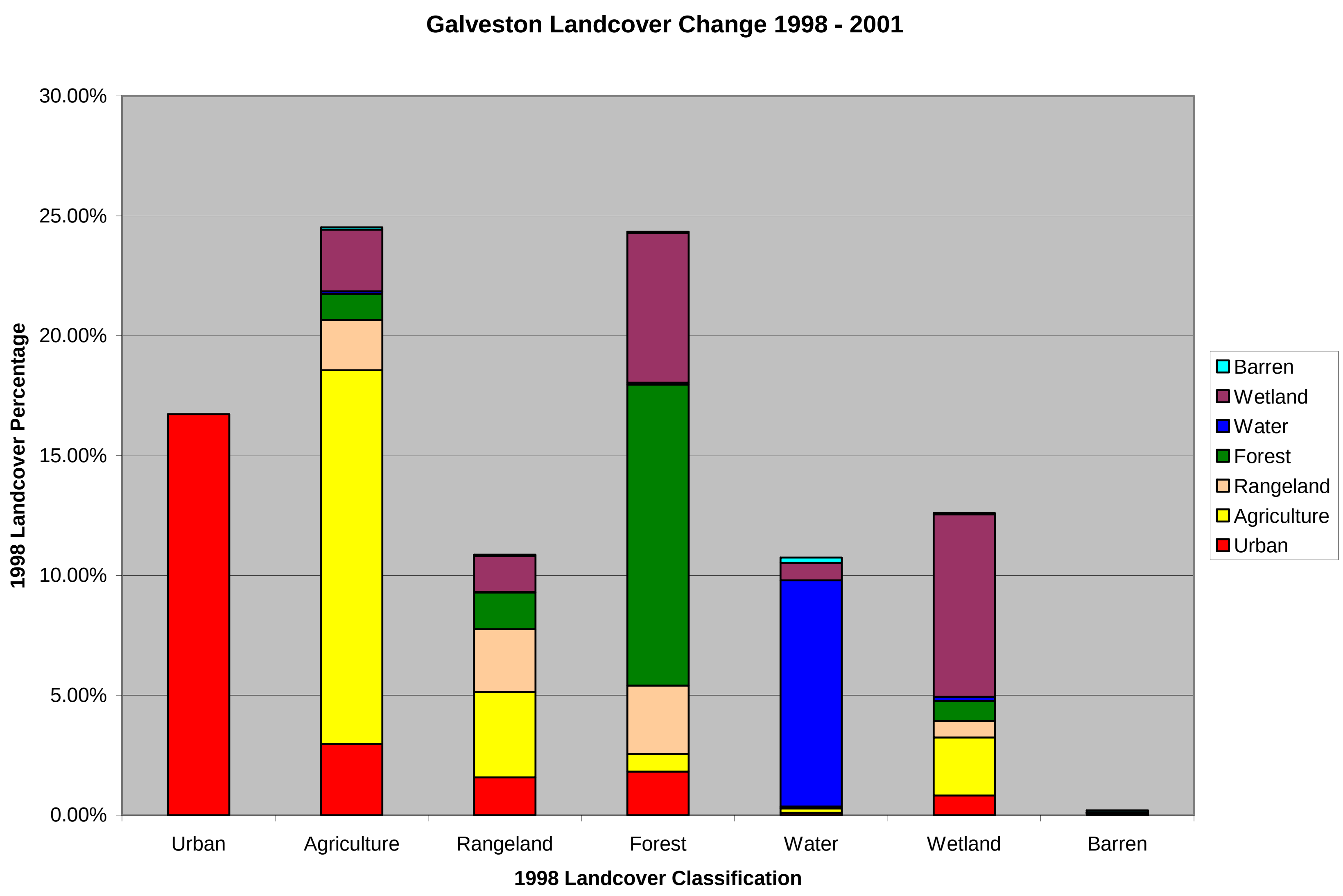
1998 – 2001 Galveston Land Cover Change Statistics

	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Barren	Total After
Urban	16.73%	2.97%	1.57%	1.82%	0.10%	0.81%	0.07%	24.09%
Agriculture	0.00%	15.58%	3.57%	0.73%	0.19%	2.43%	0.03%	22.52%
Rangeland	0.00%	2.11%	2.62%	2.85%	0.05%	0.68%	0.01%	8.31%
Forest	0.00%	1.08%	1.53%	12.55%	0.02%	0.85%	0.00%	16.03%
Water	0.00%	0.11%	0.02%	0.09%	9.44%	0.17%	0.01%	9.84%
Wetland	0.00%	2.58%	1.51%	6.25%	0.73%	7.60%	0.01%	18.68%
Barren	0.00%	0.10%	0.04%	0.05%	0.21%	0.06%	0.07%	0.53%
Total Before	16.73%	24.52%	10.86%	24.34%	10.74%	12.60%	0.20%	100.00%

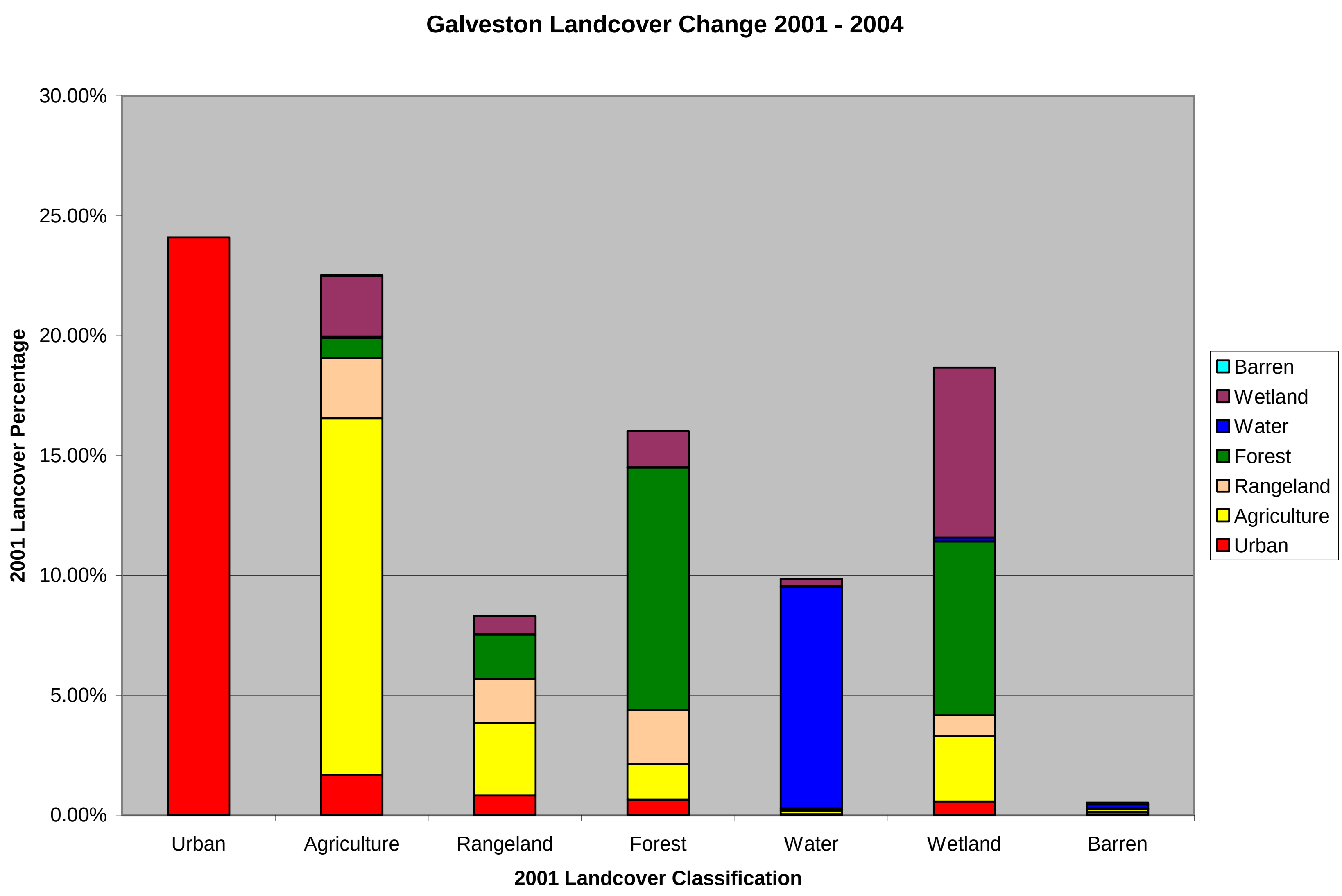
2001 – 2004 Galveston Land Cover Change Statistics

	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Barren	Total After
Urban	24.10%	1.69%	0.82%	0.64%	0.04%	0.58%	0.15%	28.02%
Agriculture	0.00%	14.87%	3.04%	1.49%	0.15%	2.71%	0.09%	22.35%
Rangeland	0.00%	2.51%	1.83%	2.25%	0.03%	0.89%	0.04%	7.56%
Forest	0.00%	0.83%	1.85%	10.12%	0.07%	7.24%	0.01%	20.11%
Water	0.00%	0.07%	0.02%	0.01%	9.25%	0.17%	0.15%	9.68%
Wetland	0.00%	2.53%	0.75%	1.50%	0.31%	7.09%	0.09%	12.27%
Barren	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%
Total Before	24.10%	22.52%	8.31%	16.02%	9.85%	18.67%	0.53%	100.00%


Galveston Landcover Change 1992 - 1998
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
1992 Landcover Percentage
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
1992 Landcover Classification
Barren
Wetland
Water
Forest
Rangeland
Agriculture
Urban



Galveston Landcover Change 1998 - 2001
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
1998 Landcover Percentage
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
1998 Landcover Classification
Barren
Wetland
Water
Forest
Rangeland
Agriculture
Urban


Galveston Landcover Change 2001 - 2004
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
2001 Lancover Percentage
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
2001 Landcover Classification
Barren
Wetland
Water
Forest
Rangeland
Agriculture
Urban

1992 – 1998 Galveston Land Cover Change Statistics

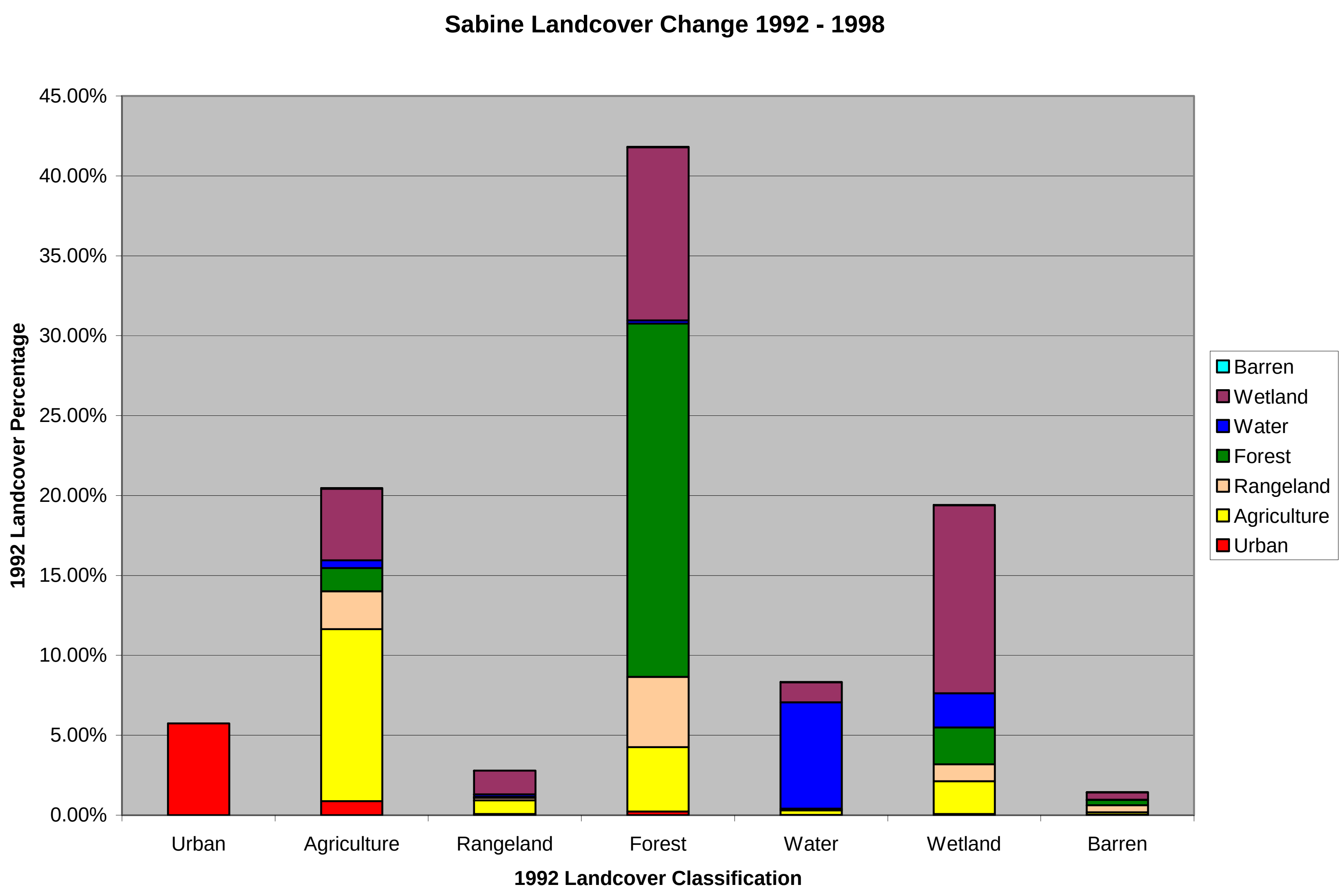
	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Barren	Total After
Urban	5.75%	0.88%	0.08%	0.23%	0.02%	0.08%	0.03%	7.07%
Agriculture	0.00%	10.76%	0.85%	4.03%	0.28%	2.05%	0.15%	18.11%
Rangeland	0.00%	2.37%	0.17%	4.40%	0.05%	1.05%	0.45%	8.47%
Forest	0.00%	1.46%	0.07%	22.11%	0.06%	2.31%	0.34%	26.34%
Water	0.00%	0.49%	0.15%	0.18%	6.66%	2.14%	0.01%	9.63%
Wetland	0.00%	4.48%	1.47%	10.83%	1.24%	11.76%	0.45%	30.23%
Barren	0.00%	0.04%	0.01%	0.03%	0.03%	0.02%	0.02%	0.15%
Total Before	5.75%	20.46%	2.79%	41.82%	8.34%	19.41%	1.44%	100.00%

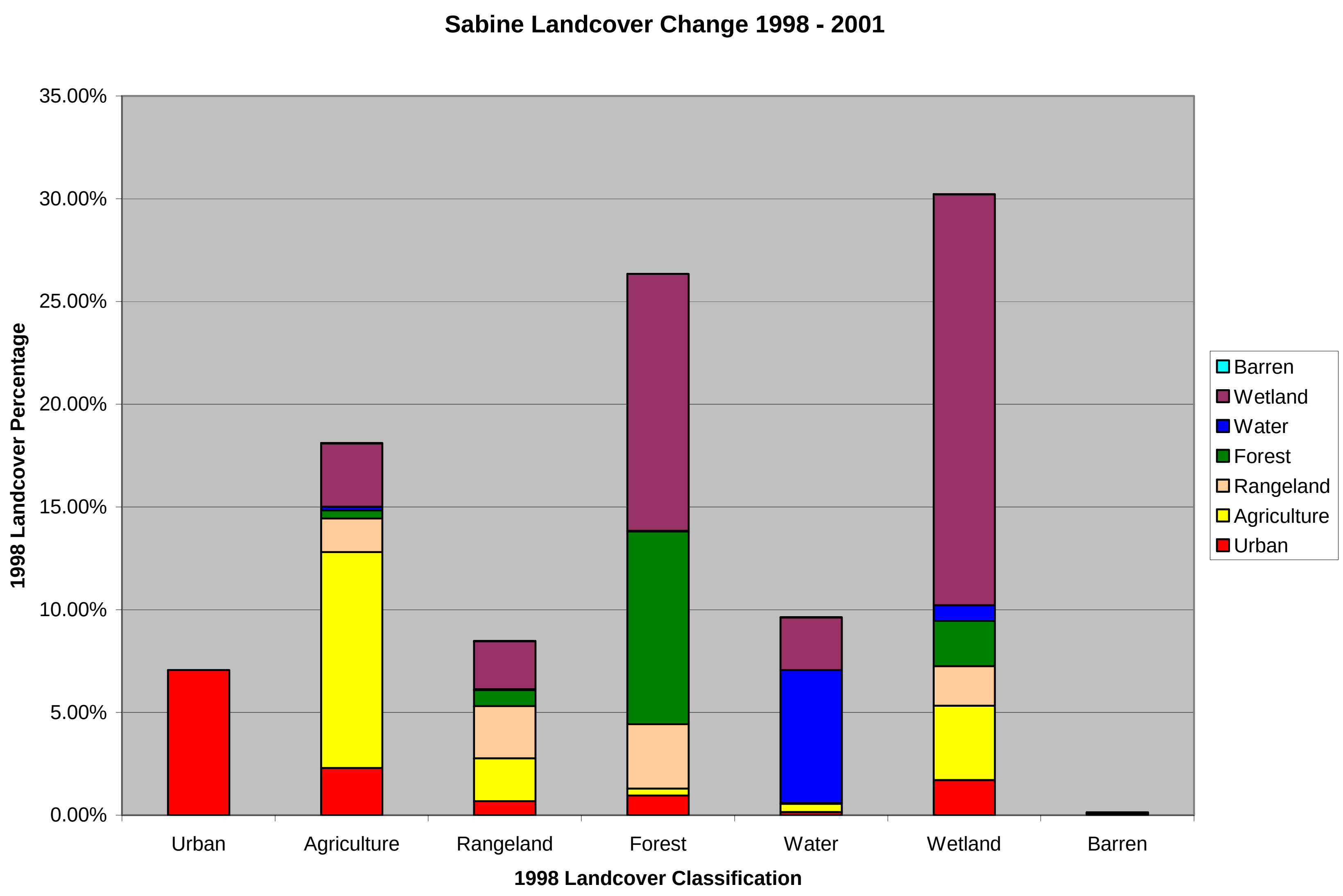
1998 – 2001 Galveston Land Cover Change Statistics

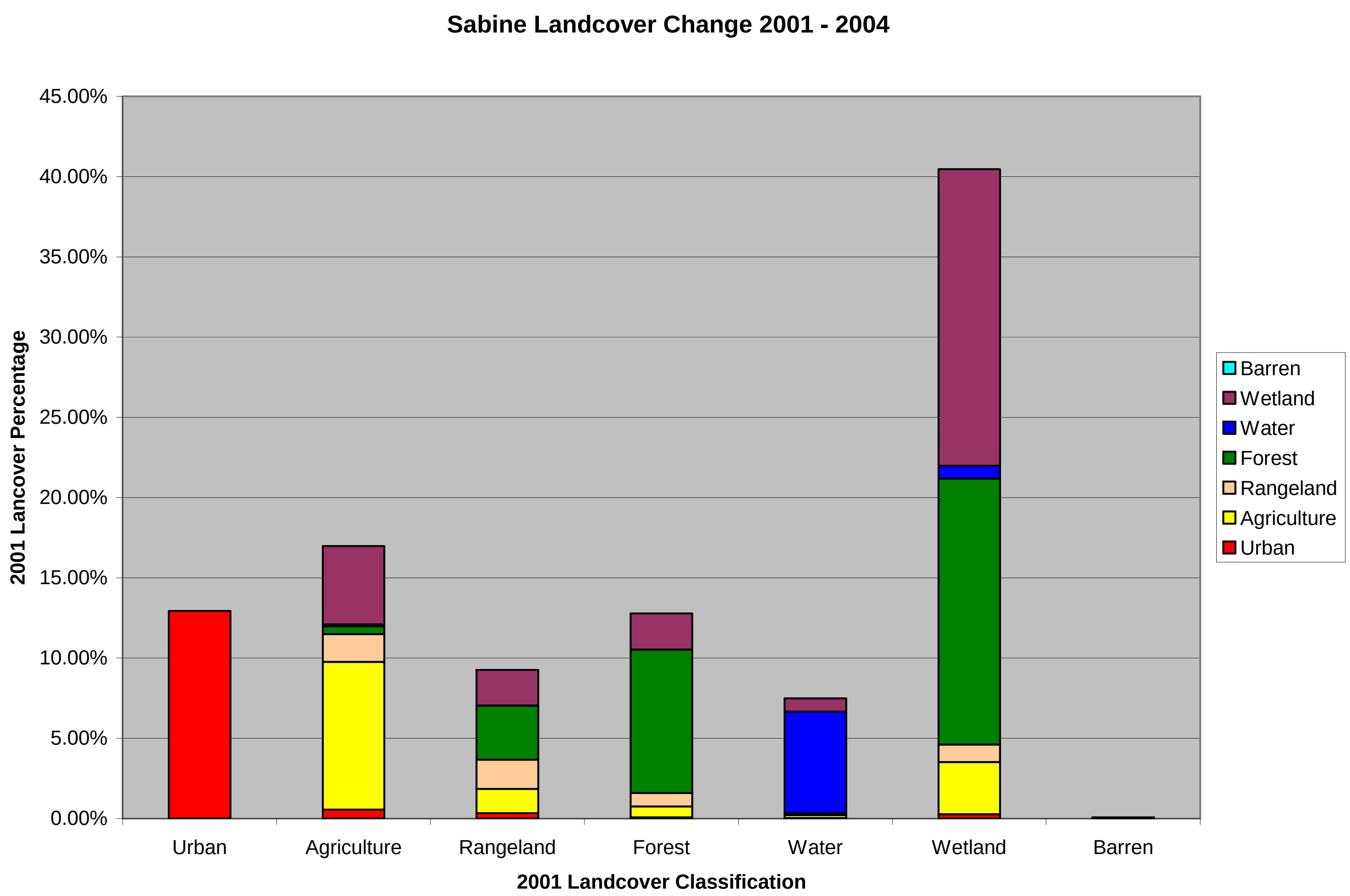
	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Barren	Total After
Urban	7.07%	2.30%	0.68%	0.96%	0.15%	1.71%	0.06%	12.93%
Agriculture	0.00%	10.51%	2.09%	0.34%	0.40%	3.62%	0.02%	16.98%
Rangeland	0.00%	1.63%	2.55%	3.14%	0.02%	1.93%	0.01%	9.27%
Forest	0.00%	0.39%	0.79%	9.38%	0.02%	2.21%	0.00%	12.79%
Water	0.00%	0.17%	0.03%	0.03%	6.47%	0.76%	0.03%	7.49%
Wetland	0.00%	3.08%	2.34%	12.50%	2.55%	20.00%	0.01%	40.47%
Barren	0.00%	0.02%	0.00%	0.00%	0.01%	0.01%	0.02%	0.07%
Total Before	7.07%	18.11%	8.47%	26.34%	9.63%	30.23%	0.15%	100.00%

2001 – 2004 Galveston Land Cover Change Statistics

	Urban	Agriculture	Rangeland	Forest	Water	Wetland	Barren	Total After
Urban	12.93%	0.57%	0.34%	0.08%	0.03%	0.27%	0.01%	14.23%
Agriculture	0.00%	9.19%	1.52%	0.68%	0.18%	3.24%	0.02%	14.84%
Rangeland	0.00%	1.73%	1.82%	0.82%	0.03%	1.10%	0.01%	5.51%
Forest	0.00%	0.48%	3.36%	8.95%	0.09%	16.57%	0.00%	29.47%
Water	0.00%	0.13%	0.01%	0.00%	6.33%	0.80%	0.01%	7.29%
Wetland	0.00%	4.87%	2.22%	2.24%	0.82%	18.48%	0.01%	28.65%
Barren	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total Before	12.93%	16.98%	9.27%	12.79%	7.49%	40.47%	0.07%	100.00%


Sabine Landcover Change 1992 - 1998
45.00%
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
1992 Landcover Percentage
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
1992 Landcover Classification
Barren
Wetland
Water
Forest
Rangeland
Agriculture
Urban


Sabine Landcover Change 1998 - 2001
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
1998 Landcover Percentage
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
1998 Landcover Classification
Barren
Wetland
Water
Forest
Rangeland
Agriculture
Urban


Sabine Landcover Change 2001 - 2004
45.00%
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
2001 Lancover Percentage
Urban
Agriculture
Rangeland
Forest
Water
Wetland
Barren
2001 Landcover Classification
Barren
Wetland
Water
Forest
Rangeland
Agriculture
Urban