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Education Program for Improved Water Quality in Copano Bay

Task Two Report

Prepared for:
Texas State Soil and Water Conservation Board

By:
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Texas Water Resources Institute
and
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Texas Water Resources Institute
make every drop count

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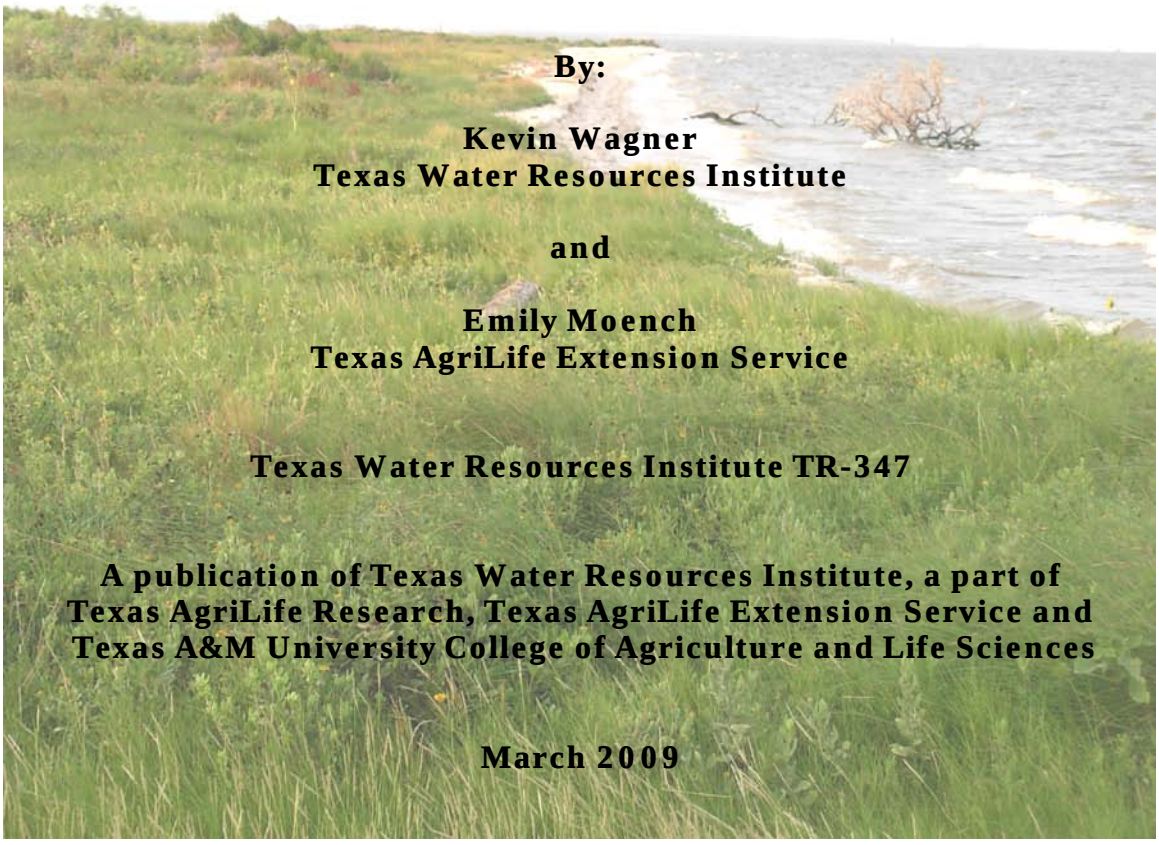

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ac.....acre
AFO.....Animal Feeding Operation
APHIS.....USDA Animal and Plant Health Inspection Service
ASAE.....American Society of Agricultural Engineers
AU.....animal units
BMPs.....best management practices
BST.....bacteria source tracking
CAFO.....Confined Animal Feeding Operation
CBBEP.....Coastal Bend Bays and Estuaries Program
cfu.....colony forming units
Co.....county
EPA.....U.S. Environmental Protection Agency
Extension.....Texas AgriLife Extension Service
GLO.....Texas General Land Office
mi^2.....square miles
mL.....milliliter
NASS.....USDA National Agricultural Statistics Service
NLCD.....National Land Cover Data
NRA.....Nueces River Authority
NRCS.....Natural Resources Conservation Service
RCAP.....Regional Coastal Assessment Program
SWCD.....Soil and Water Conservation Districts
TAMU.....Texas A&M University
TAMU-CC....Texas A&M University-Corpus Christi
TCEQ.....Texas Commission on Environmental Quality
TMDL.....Total Maximum Daily Load
TPWD.....Texas Parks and Wildlife Department
TSSWCB.....Texas State Soil and Water Conservation Board
TWRI.....Texas Water Resources Institute
USDA.....U.S. Department of Agriculture
UT-CRWR....Center for Research in Water Resources at the University of Texas - Austin
WWTF.....wastewater treatment facility

INTRODUCTION

Project Goal

The *Education Program for Improved Water Quality in Copano Bay* is funded through a Clean Water Act §319(h) Nonpoint Source Grant from the Texas State Soil and Water Conservation Board (TSSWCB) and the U.S. Environmental Protection Agency (TSSWCB Project 06-08). The goal of the project is to improve water quality in Copano Bay and its tributaries by increasing awareness of the water quality issues throughout the watershed and providing education and demonstrations for land and livestock owners on methods to decrease or prevent bacteria from entering the waterways.

Project Scope

The project focuses on the entire Copano Bay watershed, which encompasses portions of Aransas, Bee, Goliad, Karnes, Refugio, and San Patricio counties (figure 1). Although the watershed also encompasses a portion of Live Oak County, the county was excluded because it contains less than 1 percent of the watershed (table 1).

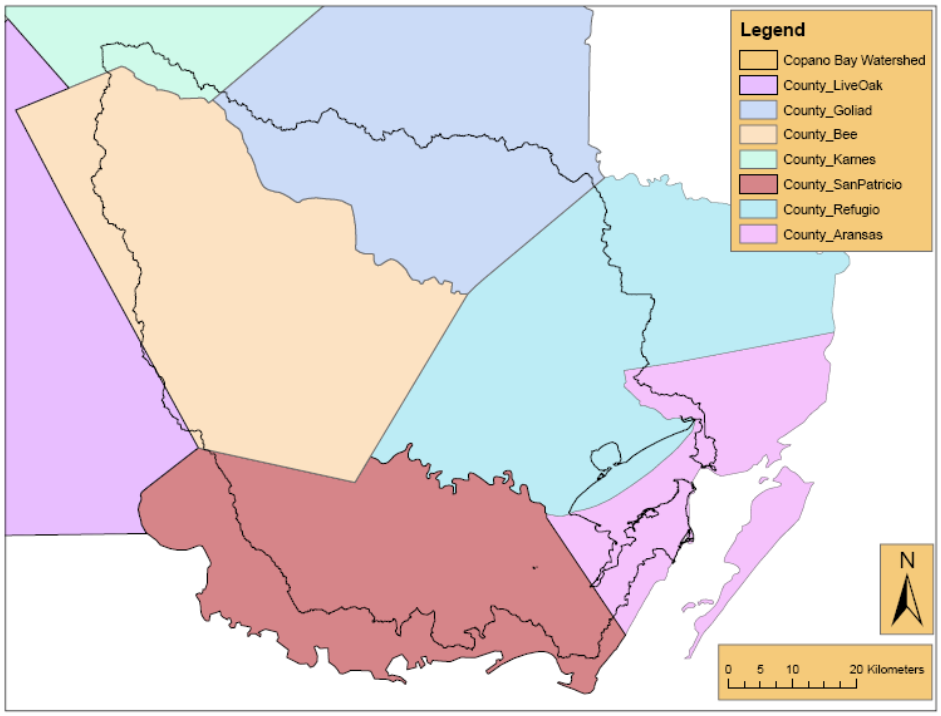

Figure 1. Counties encompassed in the Copano Bay watershed

Table 1. Number of acres and percentage of each county in the Copano Bay watershed

County	Land-Based acres by Co.	Acres of Co. in Watershed (ac)	% of Co. in Watershed	% of Watershed by Co.
Aransas	150,617	52,307	34.7%	3.7%
Bee	564,052	499,755	88.6%	36.0%
Goliad	550,124	208,049	37.8%	15.0%
Karnes	483,079	18,126	3.7%	1.3%
Live Oak	690,618	3,043	0.4%	0.2%
Refugio	504,568	316,345	62.7%	22.8%
San Patricio	452,907	291,106	64.3%	21.0%
Total	3,395,965	1,388,731	-	100.0%

According to the 2001 National Land Cover Data (NLCD) (figure 2), land use is dominated by shrub land, pastureland, and cropland. The watershed is primarily rural with only 5.5 percent of the watershed developed. The northern three-quarters of the Copano Bay watershed are dominated by rangeland, while the southern quarter of the watershed is dominated by cropland (table 2).

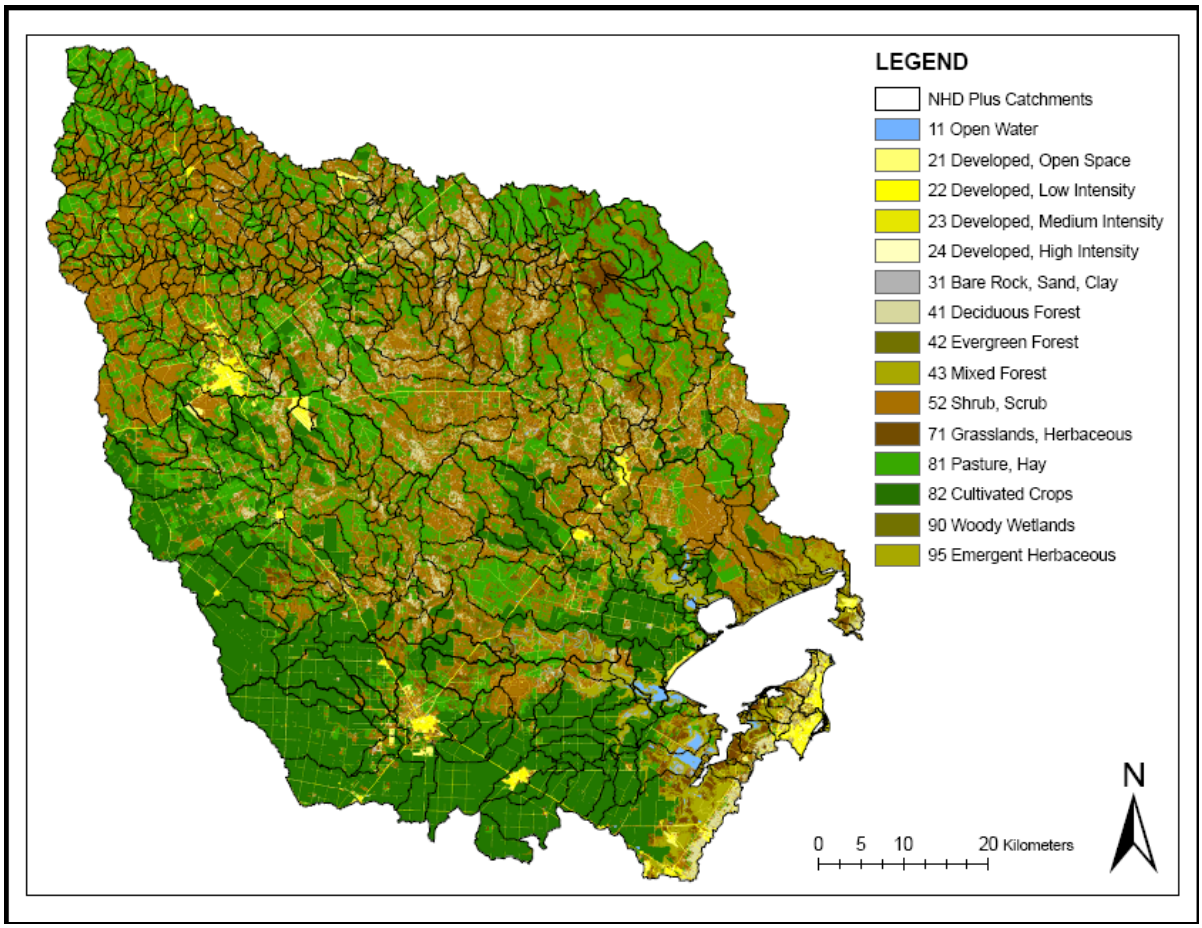

Figure 2. Land use in the Copano Bay watershed (2001 NLCD)

Table 2. Number of acres of each type of land use and corresponding percentages in the Copano Bay watershed according to the 2001 NLCD

Land use Classification	Area (ac)	% Watershed
Open Water	6,794	0.49%
Developed Open Space	53,312	3.84%
Developed Low Intensity	16,473	1.19%
Developed Medium Intensity	4,888	0.35%
Developed High Intensity	1,067	0.08%
Bare Rock/Sand/Clay	4,082	0.29%
Deciduous Forest	67,256	4.84%
Evergreen Forest	4,930	0.35%
Mixed Forest	423	0.03%
Shrub, Scrub	438,417	31.57%
Grasslands/Herbaceous	62,791	4.52%
Pasture/Hay	340,081	24.49%
Cultivated Crops	315,781	22.74%
Woody Wetlands	26,344	1.90%
Emergent Herbaceous	46,092	3.32%
Total	1,388,731	100%

Project Background

Copano Bay and its tributaries, the Mission and Aransas rivers, are identified on the *Texas §303(d) List* as impaired by elevated levels of bacteria. Copano Bay (Segment 2472) was first placed on the *Texas §303(d) List* in 1998 due to the exceedance of water quality standards established to protect oyster waters use. Water quality standards for oyster waters use are as follows:

- The median concentration of fecal coliform bacteria samples should not exceed 14 colony forming units per 100 mL of water (cfu/100 mL).
- No more than 10 percent of fecal coliform samples should exceed 43 cfu/100 mL.

Enterococcus levels in the tidal sections of the Mission and Aransas rivers exceed water quality standards established to protect swimming and other recreational activities. The tidal sections of the Mission (Segment 2001) and Aransas (Segment 2003) rivers were first placed on the *Texas §303(d) List* in 2004. Water quality standards for contact recreation use in tidal waters are as follows:

- The geometric mean of *Enterococci* samples should not exceed 35 cfu/100 mL.
- No more than 25 percent of *Enterococci* samples should exceed 89 cfu/100 mL.

While the upstream, non-tidal portions of both the Mission and Aransas rivers are not impaired, one tributary, Aransas Creek (Segment 2004A), was first placed on the *Texas §303(d) List* in 2006 for not supporting swimming and other recreational activities. Water quality standards for contact recreation in freshwater are as follows:

- The geometric mean of *E. coli* samples should not exceed 126 cfu/100 mL.
- No more than 25 percent of *E. coli* samples should exceed 394 cfu/100 mL.

All four of these water bodies (Segments 2472, 2001, 2003, and 2004A) continue to be identified as impaired for elevated bacteria on the 2008 *Texas §303(d) List*. Many steps have been taken in response to these findings. The Texas Commission on Environmental Quality (TCEQ), initiated development of a Total Maximum Daily Load (TMDL) in September 2003 to determine the sources of the bacteria and the measures needed to lower bacteria levels to those suitable for oyster harvesting/consumption in Copano Bay and contact recreation in the Mission and Aransas rivers. Many agencies, organizations, and landowners have been involved in this TMDL project.

The Center for Research in Water Resources at The University of Texas at Austin (UT-CRWR) conducted a computer modeling study, with funding from TCEQ, to determine bacterial loading in the watershed and reductions needed to attain water quality standards. Preliminary findings suggested that bacteria originating from livestock needed to be reduced by 85 percent in the tidal portion of the Aransas River and 90 percent in the tidal portion of the Mission River to achieve acceptable bacteria levels supporting contact recreation. To meet oyster water standards, the computer modeling study suggested a 15 percent reduction in bacteria originating from livestock was necessary in the Aransas River and a 20 percent reduction was needed in the Mission River. Urban runoff and wastewater treatment facility (WWTF) effluent discharge was also implicated in the computer modeling study (Gibson 2006).

Texas A&M University-Corpus Christi (TAMU-CC) conducted bacterial source tracking (BST) with funding from the Texas General Land Office (GLO) and the Coastal Bend Bays and Estuaries Program (CBBEP) to determine the source of bacteria in Copano Bay. Fourteen monitoring stations in the bay were sampled between October 2003 and May 2004. TAMU-CC found the highest numbers of bacteria were collected from stations surrounding the inflows from Copano Creek, Mission River, and Aransas River, particularly after rainfall. Additional findings indicated that 22 percent of bacteria in Copano Bay originated from human sources, 20 percent from cattle, 35 percent from horses, 21 percent from ducks, and 1 percent from nonavian wildlife and gulls (Mott and Lehman 2005).

Work continues on developing the TMDL. The Nueces River Authority (NRA) is conducting further targeted water quality monitoring with funding from the TSSWCB. UT-CRWR is conducting additional innovative computer modeling with funding from TCEQ. TAMU-CC is conducting additional BST on the tidal portions of the rivers with funding from GLO and CBBEP. The Texas Water Resources Institute (TWRI) and Texas AgriLife Extension Service (Extension) are implementing education programs to increase water quality awareness in the watershed and are also conducting demonstrations on best management practices (BMPs) to decrease or prevent bacteria from livestock from reaching waterways. Local soil and water conservation districts (SWCD) and U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) representatives are involved in all activities in the watershed.

This report summarizes the information compiled to fulfill Task 2 of the *Education Program for Improved Water Quality in Copano Bay* (TSSWCB project 06-08) including:

- existing data on livestock, deer, and feral hog numbers and distribution in the watershed;
- published bacteria loading coefficients from cattle and other livestock;
- comparison of the bacteria levels in Copano Bay to other coastal areas in Texas;
- historical bacteria levels and trends in Copano Bay.

SUBTASK 2.2
LIVESTOCK, DEER, AND FERAL HOG POPULATIONS AND DISTRIBUTION

BST has traced bacteria in Copano Bay to humans, horses, cattle, wildlife, ducks, and gulls. To better assess loading from livestock and wildlife in comparison to these preliminary findings, the number of the major livestock and wildlife categories were estimated.

There are two major sources of agriculture statistics for livestock used to obtain these estimates: the *Texas Agricultural Statistics* (NASS 2004-2008) and the federal *Census of Agriculture* (NASS 2002). Both data sets are compiled and maintained by USDA National Agricultural Statistics Service (NASS). *Texas Agricultural Statistics* are compiled yearly, or monthly, in some cases, by the NASS Texas Field Office in partnership with the Texas Department of Agriculture; the federal *Census of Agriculture* is conducted by NASS every five years. The 2002 *Census of Agriculture* is the most recent, available data; the information from the 2007 *Census of Agriculture* is not expected to be released until February 2009. Texas Parks and Wildlife Department (TPWD) biologists contributed information for deer populations. A study by USDA Animal and Plant Health Inspection Service (APHIS) Wildlife Services and Caesar Kleberg Wildlife Research Institute at Texas A&M University-Kingsville evaluating population estimation techniques for feral hogs was used for extrapolating data to estimate feral hog numbers. All population estimates were converted to animal units (AU) for comparability.

The first step to develop livestock and wildlife population estimates was to determine the number of animals in each county, then multiply that number by the percentage of each county that lies in the watershed. Finally, the estimated numbers were converted to AU to yield the total number of animal units for each livestock and wildlife category assessed. This method was applied to all livestock and deer categories; however, a different method was used to estimate feral hog populations. Additional information on population estimation methods are provided in the following sections.

Cattle

County cattle numbers (tables 3 and 4) in the watershed were estimated using the five-year average number of beef cows as published by the 2004–2008 *Texas Agricultural Statistics*. “Beef cows” are most representative of AU of cattle in watersheds like Copano Bay where cow/calf operations are predominant; thus, an AU conversion of one can be used.

Next, estimated cattle numbers from table 4 (66,348) were distributed throughout the watershed using range site stocking rate estimates from NRCS and land use (table 5).

Table 3. Estimated beef cow numbers by county (*Texas Agricultural Statistics)*

County	2004	2005	2006	2007	2008
Aransas	2,000	1,000	1,000	1,000	1,000
Bee	32,000	29,000	30,000	32,000	45,000
Goliad	39,000	37,000	39,000	45,000	44,000
Karnes	45,000	42,000	41,000	43,000	39,000
Refugio	24,000	23,000	23,000	24,000	23,000
San Patricio	7,000	7,000	7,000	7,000	7,000
Total	149,000	139,000	141,000	152,000	159,000

Table 4. Estimated beef cows in the Copano Bay watershed based on 2004 - 2008 county averages

County	County Average	Percent in Watershed	Beef Cows	AU Conversion	Cattle (AU)
Aransas	1,200	34.7%	417	1	417
Bee	33,600	88.6%	29,766	1	29,766
Goliad	40,800	37.8%	15,418	1	15,418
Karnes	42,000	3.7%	1,571	1	1,571
Refugio	23,400	62.7%	14,674	1	14,674
San Patricio	7,000	64.3%	4,502	1	4,502
Total	148,000	-	66,348	1	66,348

Table 5. Estimated cattle distribution in the Copano Bay watershed

Land Use Classification	Area (ac)	SR (ac/ AU)	Cattle (AU)
Open Water	6794		
Developed Open Space	53312		
Developed Low Intensity	16473		
Developed Medium Intensity	4888		
Developed High Intensity	1067		
Bare Rock/Sand/Clay	4082		
Deciduous Forest	67256	20.0	3,363
Evergreen Forest	4930	20.0	246
Mixed Forest	423	20.0	21
Shrub, Scrub	438417	30.0	14,614
Grasslands/Herbaceous	62791	15.4	4,066
Pasture/Hay	340081	7.7	44,038
Cultivated Crops	315781		
Woody Wetlands	26344		
Emergent Herbaceous	46092		
TOTAL	1,388,731		66,348

Horses

Because data were not available in *Texas Agricultural Statistics* for horses in the counties in the Copano Bay watershed, horse numbers are based on the 2002 USDA Census of Agriculture (table 6).

Table 6. Estimated horse numbers in the Copano Bay watershed (2002 USDA Census of Agriculture)

County	County Total	Percent in Watershed	Horses All	AU Conversion	Horses (AU)
Aransas	46	34.7%	16	1.25	20
Bee	1,391	88.6%	1,232	1.25	1,540
Goliad	887	37.8%	335	1.25	419
Karnes	973	3.7%	36	1.25	45
Refugio	692	62.7%	434	1.25	543
San Patricio	662	64.3%	426	1.25	533
Total	4,651	-	2,479	-	3,100

Goats

The 2005–2008 *Texas Agricultural Statistics* were used for estimating goat numbers. In Bee, Goliad, and Karnes Counties, the *Texas Agricultural Statistics* provided county estimates annually (table 7); however, because goat numbers for Aransas, Refugio, and San Patricio were so low, they were reported by district. District 85, which includes 5 counties, was reported to have an estimated 2,000 goats throughout the district from 2005–2008; thus, it was assumed that there were 400 goats in each county in the district.

Table 7. Estimated goat numbers in Copano Bay watershed (2005 - 2008 *Texas Agricultural Statistics*)

[1] 4 year average goat numbers in county

[2] goat numbers in county estimated from District 85 numbers

County	County Total	Percent in Watershed	Goats All	AU Conversion	Goats (AU)
Aransas[2]	400	34.7%	139	0.17	24
Bee[1]	2,775	88.6%	2,458	0.17	418
Goliad[1]	1,125	37.8%	425	0.17	72
Karnes[1]	2,175	3.7%	81	0.17	14
Refugio[2]	400	62.7%	251	0.17	43
San Patricio[2]	400	64.3%	257	0.17	44
Total	7,275	-	3,611	-	615

Sheep

Because data were not available in *Texas Agricultural Statistics* for sheep in the counties in the Copano Bay watershed, sheep numbers are based on the 2002 USDA Census of Agriculture (table 8).

Table 8. Estimated sheep numbers in the Copano Bay watershed (2002 USDA Census of Agriculture)

County	County Total	Percent in Watershed	Sheep All	AU Conversion	Sheep (AU)
Aransas	0	34.7%	0	0.2	0
Bee	670	88.6%	594	0.2	119
Goliad	162	37.8%	61	0.2	12
Karnes	327	3.7%	12	0.2	2
Refugio	71	62.7%	45	0.2	9
San Patricio	335	64.3%	215	0.2	43
Total	1,565	-	927	-	185

Domestic Hogs

Because data were not available in *Texas Agricultural Statistics* for swine in the counties in the Copano Bay watershed, hog numbers are based on the 2002 USDA Census of Agriculture (table 9).

Table 9. Estimated number of domestic hogs in the Copano Bay watershed (2002 USDA Census of Agriculture)

County	County Total	Percent in Watershed	Hogs All	AU Conversion	Hogs (AU)
Aransas	15	34.7%	5	0.25	1
Bee	113	88.6%	100	0.25	25
Goliad	69	37.8%	26	0.25	7
Karnes	21	3.7%	1	0.25	0
Refugio	22	62.7%	14	0.25	4
San Patricio	741	64.3%	477	0.25	119
Total	981	-	623	-	156

Poultry

There are no poultry CAFOs or AFOs in the watershed. Because data were not available in *Texas Agricultural Statistics* for poultry in the counties in the Copano Bay watershed, poultry numbers are based on the 2002 USDA Census of Agriculture (table 10).

Table 10. Estimated poultry numbers in the Copano Bay watershed (2002 USDA Census of Agriculture)

	Poultry	Aransas	Bee	Goliad	Karnes	Refugio	San Patricio	Total
County Totals	Layers	35	793	859	0	63	464	2214
	Pullets	0	136	75	272	0	595	1078
	Broilers	0	192	252	0	0	634	1078
	Turkeys	13	0	35	111	0	9	168
Percent in Watershed	-	34.7%	88.6 %	37.8%	3.7%	62.7%	64.3%	
Watershed Totals	Layers	12	703	325	0	40	298	1377
	Pullets	0	120	28	10	0	383	542
	Broilers	0	170	95	0	0	408	673
	Turkeys	5	0	13	4	0	6	28
AU Conversion	Layers/ Pullets/ Broilers	0.01	0.01	0.01	0.01	0.01	0.01	-
	Turkeys	0.018	0.018	0.018	0.018	0.018	0.018	-
Watershed AU	Layers	0	7	3	0	0	3	13
	Pullets	0	1	0	0	0	4	5
	Broilers	0	2	1	0	0	4	7
	Turkeys	0	0	0	0	0	0	0

Deer

TPWD county biologists contributed deer population data for each county. Average acres per deer were calculated from TPWD surveys. The deer density provided for each county was multiplied by the acres in each county to determine the total deer per county, which was then multiplied by the percent of the county in the watershed to determine the number of deer in the watershed. That final number was multiplied by 0.112 to determine the number of AUs (table 11). The overall deer density in the watershed is 15.6 ac/deer, which is comparable to the reported deer density in the Texas Hill Country of 15.4 ac/deer.

Table 11. Estimated deer numbers in the Copano Bay watershed based on Texas Parks and Wildlife Department county biologist estimates

County	Density (ac/deer)	Acres of Co. in Watershed (ac)	Total Deer	AU Conversion	Deer (AU)
Aransas	100	52,307	523	0.112	59
Bee	14.11	499,755	35,419	0.112	3,967
Goliad	12.4	208,049	16,778	0.112	1,879
Karnes	20	18,126	906	0.112	101
Refugio	20	316,345	15,817	0.112	1,771
San Patricio	15	291,106	19,407	0.112	2,174
Total			88,850	0.112	9,951

Feral Hogs

A published study (Reidy 2007) completed at the Welder Wildlife Refuge on feral hog population control estimated the density of feral hogs on the Refuge to be 33.3 acres per hog. This density was applied to all agricultural lands in the watershed to determine the total number of feral hogs in the entire watershed (table 12). It is estimated that there are **37,718 feral hogs** in the watershed. To help verify this estimate, another estimate of feral hogs was completed based on a study by the Texas A&M University Department of Veterinary Integrative Biosciences. This study (Rollo et al. 2007) estimated that there were 460,262 hogs in a 33-county area, including most of the counties in the Copano Bay watershed. It was estimated that there were 13,947 hogs per county on average (then applied to percentage of county within watershed) and **40,708 feral hogs** in the watershed. Finally in 1993, the Southeastern Cooperative Wildlife Disease Study (conducted by the College of Veterinary Medicine at the University of Georgia with funding from the USDA Animal and Plant Health Inspection Service) estimated that the feral hog density in the area was at least 10 feral hogs per square mile. Since Taylor (1991) estimated the feral hog population in Texas at approximately 1 million animals, the feral hog numbers in the state have doubled to 2 million hogs in 2004 (Mapston 2004). Based on a doubling of 10 hogs per square mile (i.e. 20 hogs per square mile) applied to 1,388,731 land acres in the watershed, it is estimated that there are **43,398 feral hogs** in the Copano Bay watershed.

Table 12. Estimated Copano Bay watershed feral hog numbers based on TAMU-Kingsville estimates

Land Use Category	Acres	Density (ac/hog)	Feral Hog Pop.	AU Conver-sion	Feral Hogs (AU)
Open Water	6,794				
Developed Open Space	53,312				
Developed Low Intensity	16,473				
Developed Medium Intensity	4,888				
Developed High Intensity	1,067				
Bare Rock/Sand/Clay	4,082				
Deciduous Forest	67,256	33.3	2,020	0.125	252
Evergreen Forest	4,930	33.3	148	0.125	18
Mixed Forest	423	33.3	13	0.125	2
Shrub, Scrub	438,417	33.3	13,166	0.125	1646
Grasslands/Herbaceous	62,791	33.3	1,885	0.125	236
Pasture/Hay	340,081	33.3	10,212	0.125	1277
Cultivated Crops	315,781	33.3	9,483	0.125	1185
Woody Wetlands	26,344	33.3	791	0.125	99
Emergent Herbaceous	46,092				
TOTAL	1,388,731		37,718		4,715

The average of the three methods is 40,608 with a standard deviation of ± 7 percent; thus, all three methods provide fairly consistent population numbers. This provides at least a marginal level of confidence in the estimated numbers of feral hogs in the watershed. For future modeling efforts in the watershed, the method using the in-watershed study results from the Welder Wildlife Refuge as shown in table 12 is recommended. To convert feral hog numbers to AU, the total feral hog population was multiplied by 0.125 AU equivalents. According to most sources, the average size of feral swine is 100-150 pounds. The middle of this range, 125 pounds, was selected as the mean weight and converted to AU by dividing by 1000 pounds.

Animal Population Estimates in the Copano Bay Watershed

Using the method described above, animal population estimates are as follows (table 13).

Table 13. Estimated numbers of livestock and wildlife in the Copano Bay watershed

	Aransas	Bee	Goliad	Karnes	Refugio	San Patricio	Total	AUs
Beef Cattle	417	29,766	15,418	1,571	14,674	4,502	66,348	66,348
Horses	16	1,232	335	36	434	426	2,479	3,100
Goats	139	2,458	425	81	251	257	3,611	615
Sheep	0	594	61	12	45	215	927	185
Hogs	5	100	26	1	14	477	623	156
Layers	12	703	325	0	40	298	1,377	13
Pullets	0	120	28	10	0	383	542	5
Broilers	0	170	95	0	0	408	673	7
Turkey	5	0	13	4	0	6	28	0
Deer	523	35,419	16,778	906	15,817	19,407	88,850	9,951
Feral Hogs	N/A	N/A	N/A	N/A	N/A	N/A	37,718	4,715

SUBTASK 2.3
BACTERIA LOADING COEFFICIENTS FOR LIVESTOCK AND WILDLIFE

Because local data are not available, published fecal coliform production values are used. Initially, Metcalf and Eddy (1991), EPA (2000), and ASAE (2003), some of the primary sources of data for estimating fecal coliform load per animal, (table 14) were evaluated; however, it was quickly observed that the publications were not directly comparable. For example, Metcalf and Eddy (1991) reports fecal coliform contributions on a per capita basis and ASAE (2003) reports on a per 1000 lb live animal mass basis.

Table 14. Daily fecal coliform production - Metcalf and Eddy (1991), EPA (2000), and ASAE (2003)

Animal	**Estimated per capita contribution of fecal coliform (cfu/day)** *Metcalf & Eddy (1991)*	**Fecal coliform (count/animal/ day)** *EPA (2000)*	**Manure characteristics per 1000 lb live animal mass (cfu/day)** *ASAE (2003)*
Beef Cattle	5.4E+09	1.04E+11	1.3E+11
Horses	N/A	4.20E+08	4.2E+08
Goats	N/A	N/A	N/A
Sheep	1.8E+10	1.20E+10	2.0E+11
Hogs	8.9E+09	1.08E+10	8.0E+10
Poultry-chicken & turkey	2.4E+08	1.36E+08 9.30E+07	3.4E+10
Human	2.0E+09	N/A	N/A
Deer	N/A	5.00E+08	N/A
Feral Hogs	N/A	1.08E+10	N/A

To better evaluate loading coefficients for the watershed, the cfu/g of manure (wet weight) was determined from the literature (table 15). Crane et al. performed an extensive review of bacteria levels in feces in 1983. These were updated with more recent publications. Many of the new publications directly report the cfu/g; however, some (i.e. ASAE) were calculated using reported daily fecal coliform and manure production. Published fecal coliform densities varied several orders of magnitude in many cases. The values published by Metcalf and Eddy (1991) were typically the most comparable to other publications and the median value; thus, the fecal coliform densities by Metcalf and Eddy (1991) are recommended for species included in that reference. It is obvious from table 15 that many of the values for Metcalf and Eddy (1991) were obtained from Geldbreich (1962, 1977, and 1978); thus, to maintain consistency, the fecal coliform densities (cfu/g) published by Geldbreich (1977 & 1978) are recommended for horses. For goats, deer, and feral hogs, it is recommended that Cox (2005) be used as this publication provides the only densities for goats and feral hogs and is the median value for deer. Recommended fecal coliform densities for the Copano Bay watershed are outlined in table 17; this data should be used until localized data is available.

Table 15. Fecal coliform densities per gram of feces.

Animal Type	Fecal coliform	Reference
Beef cattle	6.40E+03	*Yagow (2001)*
	1.80E+05	*Cox (2005)*
	2.30E+05	*Geldreich (1977)*
	2.30E+05	*Rosebury (1962)*
	2.30E+05	*Metcalf & Eddy (1991)*
	2.30E+05	*Geldreich et al. (1962)*
	3.20E+05	*Witzel et al. (1966)*
	5.30E+05	*Witzel et al. (1966)*
	6.00E+05	*Maki and Picard (1965)*
	1.36E+06	*Yagow (2001)*
(unconfined)	1.40E+06	*Hrubant et al. (1972)*
	1.87E+06	*Moyer & Hyer (2003)*
(raw waste as collected)	3.30E+06	*Hrubant et al. (1972)*
	4.90E+06	*ASAE (2003)*
Horses	1.26E+04	*Geldreich (1977)*
	1.26E+04	*Rosebury (1962)*
	1.26E+04	*Geldreich (1978)*
	1.80E+04	*ASAE (2003)*
	3.80E+04	*Cox (2005)*
	2.22E+06	*Moyer & Hyer (2003)*
Goats	1.40E+06	*Cox (2005)*
Sheep	6.60E+05	*Cox (2005)*
	1.60E+07	*Rosebury (1962)*
	1.60E+07	*Metcalf & Eddy (1991)*
	1.10E+07	*ASAE (2003)*
	1.60E+07	*Geldreich et al. (1962)*
	1.80E+07	*Moyer & Hyer (2003)*
Hogs	4.05E+05	*Yagow (2001)*
	2.10E+06	*ASAE (2003)*
	3.30E+06	*Geldreich (1977)*
	3.30E+06	*Metcalf & Eddy (1991)*
	3.30E+06	*Geldreich et al. (1962)*
	7.10E+06	*Cox (2005)*
Chicken	1.20E+06	*ASAE (2003)*
	1.30E+06	*Geldreich et al. (1962)*
	1.30E+06	*Metcalf & Eddy (1991)*
	1.30E+07	*Rosebury (1962)*
	1.10E+08	*Cox (2005)*
	1.40E+08	*Crane et al. (1980)*
	1.83E+09	*Moyer & Hyer (2003)*
Turkey	2.90E+05	*Geldreich et al. (1962)*
	2.90E+05	*Metcalf & Eddy (1991)*
	2.90E+05	*ASAE (2003)*
Deer	4.50E+05	*Yagow (2001)*
	2.20E+06	*Cox (2005)*
	4.48E+08	*Moyer & Hyer (2003)*
Feral Hogs	4.10E+04	*Cox (2005)*

Table 16. Daily fecal production (pounds per 1,000 pounds of live weight)

Animal	Fecal production	Reference
Beef Cattle	40	*Yagow (2001)*
	58	*ASAE (2003)*
	60	*PSU (2008)*
	63	*NDSU (2008)*
	66	*Pennsylvania FFA (2002)*
	82	*Mukhtar (2007)*
	104	*NRCS (2008)*
Horses	41	*Yagow (2001)*
	44	*Pennsylvania FFA (2002)*
	45	*PSU (2008)*
	50	*NDSU (2008)*
	51	*NRCS (2008)*
	51	*Mukhtar (2007)*
	51	*ASAE (2003)*
Goats	33	*Pennsylvania FFA (2002)*
	40	*Mukhtar (2007)*
	41	*ASAE (2003)*
Sheep	33	*Pennsylvania FFA (2002)*
	40	*NDSU (2008)*
	40	*NRCS (2008)*
	40	*Mukhtar (2007)*
	40	*ASAE (2003)*
Hogs	45	*Yagow (2001)*
	84	*ASAE (2003)*
	88	*Pennsylvania FFA (2002)*
Gestating sow	25	*NRCS (2008)*
	25	*Mukhtar (2007)*
	27.2	*NDSU (2008)*
Lactating sow	59	*NRCS (2008)*
	59	*Mukhtar (2007)*
	60	*NDSU (2008)*
Boars	19	*NRCS (2008)*
	20.5	*NDSU (2008)*
Nursery swine	87	*Mukhtar (2007)*
	88	*NRCS (2008)*
	106	*NDSU (2008)*
Grow/finish swine	63	*NRCS (2008)*
	63.4	*NDSU (2008)*
	65	*Mukhtar (2007)*
Poultry	25	*Pennsylvania FFA (2002)*
	57	*NRCS (2008)*
Layers	26	*PSU (2008)*
	63	*Mukhtar (2007)*
	64	*ASAE (2003)*
Pullets	48	*PSU (2008)*
Broilers	82	*Mukhtar (2007)*
	85	*ASAE (2003)*
Turkey	47	*Mukhtar (2007)*
	47	*ASAE (2003)*
Deer	15	*Yagow (2001)*

To use the fecal coliform density data, daily fecal production must be known. Although not to the extent of the fecal coliform density data, the published values of daily fecal production per 1,000 pounds of live weight (table 16) were also quite variable. Of the seven publications, Mukhtar (2007) provided the most comprehensive and up-to-date list of fecal production values; generally, his reported values were nearest to the median value of the seven publications. Mukhtar also provided multiple subcategories of domestic hogs and poultry. It was assumed that the fecal production of "grow/finish swine" were most representative of the range of both domestic and feral hogs in the watershed. Additionally, it was assumed that pullets and layers exhibited similar fecal production. Because Mukhtar (2007) did not publish fecal production values for deer, those published by Yagow (2001) were used.

Based on data in tables 15 and 16, daily fecal coliform production per AU was calculated (table 17). Calculated levels are most comparable to ASAE published values (table 14) with the exception of the Beef Cattle category. Calculations are slightly over an order of magnitude lower than ASAE *Beef Cattle* values and are most comparable to Metcalf and Eddy values. This comparability to published values helps further validate the values in table 17; thus, it is recommended that loading coefficients in table 17 be used for the Copano Bay watershed until local data is obtained.

Table 17. Recommended fecal coliform load coefficients for Copano Bay

Animal	Daily fecal production (lbs/day/AU)	Daily fecal production (g/day/AU)	Fecal coliform density (cfu/g)	Fecal coliform (cfu/AU/day)
Beef Cattle	82	37,195	2.30E+05	8.55E+09
Horses	51	23,133	1.26E+04	2.91E+08
Goats	40	18,144	1.40E+06	2.54E+10
Sheep	40	18,144	1.60E+07	2.90E+11
Hogs	65	29,484	3.30E+06	9.73E+10
Layers	63	28,576	1.30E+06	3.71E+10
Pullets	63	28,576	1.30E+06	3.71E+10
Broilers	82	37,195	1.30E+06	4.84E+10
Turkey	47	21,319	2.90E+05	6.18E+09
Deer	15	6,804	2.20E+06	1.50E+10
Feral Hogs	65	29,484	4.10E+04	1.21E+09

Based on the recommended fecal coliform loading coefficients in table 17 and the number of AU in table 13, the total daily and annual fecal coliform production was calculated (table 18). These calculations indicate that cattle and deer account for 88 percent of fecal coliform production from livestock and wildlife in the watershed. It should be stressed that other important wildlife sources such as waterfowl were not assessed by this study and could account for a significant amount of fecal coliform production in the Copano Bay watershed.

Table 18. Estimated fecal coliform production by livestock and wildlife in the Copano Bay watershed

Animal	AU in watershed	Fecal coliform (cfu/AU/day)	Fecal coliform (cfu/day)	Fecal coliform (cfu/year)	Percent of Total
Cattle	66,348	8.55E+09	5.68E+14	2.07E+17	70.2%
Horses	3,100	2.91E+08	9.04E+11	3.30E+14	0.1%
Goats	615	2.54E+10	1.56E+13	5.70E+15	1.9%
Sheep	185	2.90E+11	5.37E+13	1.96E+16	6.6%
Hogs	156	9.73E+10	1.52E+13	5.54E+15	1.9%
Layers	13	3.71E+10	5.12E+11	1.87E+14	0.1%
Pullets	5	3.71E+10	2.01E+11	7.34E+13	0.0%
Broilers	7	4.84E+10	3.25E+11	1.19E+14	0.0%
Turkey	0	6.18E+09	3.08E+09	1.12E+12	0.0%
Deer	9,951	1.50E+10	1.49E+14	5.44E+16	18.4%
Feral Hogs	4,715	1.21E+09	5.70E+12	2.08E+15	0.7%
Total	85,095		8.09E+14	2.95E+17	100%

SUBTASK 2.4
COMPARISON OF COPANO BAY BACTERIA LEVELS TO OTHER TEXAS BAYS

In 2004, the Coastal Bend Bays and Estuary Program conducted a Regional Coastal Assessment Program (RCAP) at sites throughout the Coastal Bend region. The assessment showed that *Enterococci* levels were low (<35 cfu/100 mL) throughout a majority of the Coastal Bend (figure 3), including all sites in Copano Bay.

Enterococcus and fecal coliform levels in bays and estuaries larger than 28 mi^2 from throughout Texas were also compared (table 19). Data for this comparison was derived from the *2006 Texas Water Quality Inventory – Water Body Assessments by Basin* (TCEQ 2008). The average *Enterococcus* and fecal coliform levels were 14 and 8 cfu/100 mL, respectively. In comparison, the *Enterococcus* and fecal coliform levels in Copano Bay were 17 and 4 cfu/100 mL, respectively.

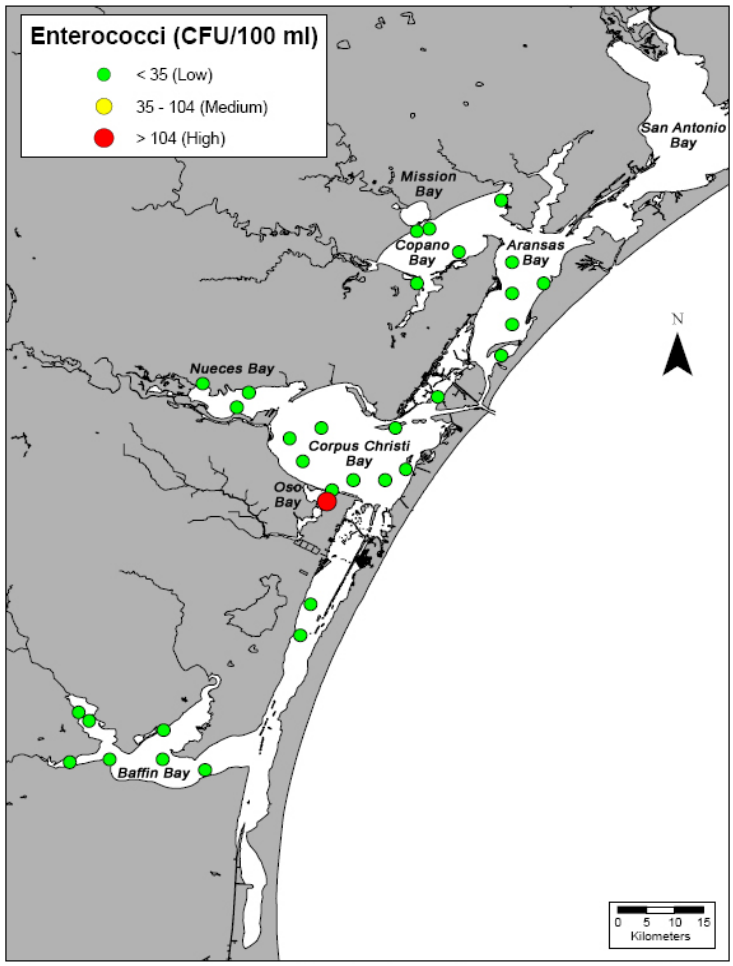

Figure 3. *Enterococci* levels (cfu/100 mL) at Regional Coastal Assessment Program (RCAP) 2004 sampling sites (Nicolau and Nunez 2006)

Thus, *Enterococcus* levels in Copano Bay were 21 percent greater than average levels observed in bays greater than 28 mi^2 in Texas, while the fecal coliform levels were half the average levels observed in bays greater than 28 mi^2 in Texas.

Table 19. Mean *Enterococcus* and fecal coliform concentrations (TCEQ 2008)

WB ID	WB Name	WB Size	*Entero-cocci*	Fecal Coliform
2412	Sabine Lake (entire waterbody)	68.7	12	14
	Upper Galveston Bay	115.7		
2421-01	Redbluff to Five Mile Cut - Houston Pt - Morgan's Pt		21	23
2421-02	West of Bay		15	10
2421-03	East of Bay		15	7
2422-01	Trinity Bay (Upper)	130.1	14	8
2422-02	Trinity Bay (Lower)		18	5
2423-01	East Bay (adjacent to Segment 0702)	52.1	10	9
2423-02	Remainder of Bay		10	4
2424-1	West Bay (main portion of waterbody)	69.3	7	6
2424-02	West Bay (adjacent to lower Galveston Island)		6	9
	Lower Galveston Bay			
2439-01	Adjacent to TX City Ship Channel & Moses Lake	139.6	11	7
2439-02	Main portion of Bay		11	7
2441-02	East Matagorda Bay (remainder of Bay)	59.1	12	4
2451-02	**Matagorda Bay/Powderdown Lake** (remainder)	261.7	12	6
	Tres Palacios/Turtle Bay	31.9		
2452-01	Main portion of Bay		17	8
2452-02	Turtle Bay			7
2452-03	Tres Palacios Creek			16
	Lavaca Bay/Chocolate Bay	59.3		
2453-01	Center portion of Bay		16	7
2453-02	Northeastern portion of Bay near Point Comfort		21	21
2453-03	Chocolate Bay Area			11
2461-01	Espiritu Santo Bay (entire segment)	60.8		2
2462-01	San Antonio Bay/Hynes Bay	119.5	12	5
2463-01	Mesquite Bay/Carlos Bay/Ayres Bay		3	2
2471-01	Aransas Bay (entire segment)	87.8	8	2
2472	**Copano Bay/Port Bay/Mission Bay**	65.2		
2472-01	Mission Bay/Aransas River arm & eastern shoreline		17	4
2472-02	Entire water body		17	4
2481-01	Corpus Christi Bay (entire segment)	123.1	11	5
2482-01	Nueces Bay (entire Bay)	28.9	13	5
2483.01	Redfish Bay (entire segment)	28.8	10	3
2491	**Laguna Madre**	347.4		
2491-01	Upper portion of Bay north of Arroyo confluence		14	24
2491-02	Area adjacent to Arroyo confluence		25	7
2491-03	Lower portion of Bay south of Arroyo Colorado confluence		23	3
2492-01	Baffin Bay/Alazan Bay/Callo de Grullo/Laguna la Salada (entire segment)	101.5	14	1
AVERAGE CONCENTRATION			**14**	**8**

SUBTASK 2.5
HISTORICAL BACTERIAL LEVELS AND TRENDS IN COPANO BAY

Copano Bay is a 65 mi^2 estuary located northeast of Corpus Christi (figure 4). Port Bay, Mission Bay, the Aransas River arm, and the eastern shoreline of Copano Bay (the Copano Creek arm) were first identified in 1998 as impaired for elevated bacteria; they remain on the 2008 *Texas §303(d) List*. To evaluate historical fecal coliform trends in Copano Bay, data were obtained from the TCEQ surface water quality monitoring Web site.

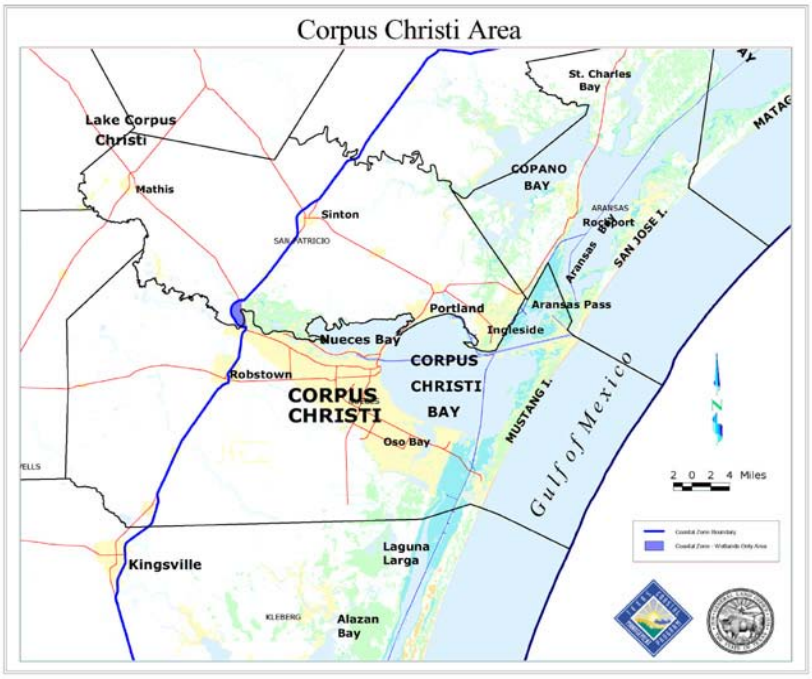

Figure 4. Copano Bay/Coastal Bend region map (GLO 2008)

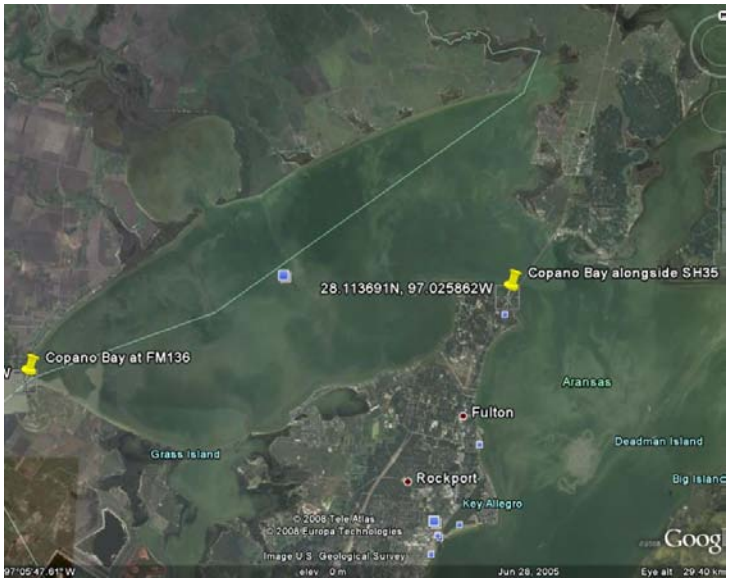

Figure 5. Map of Copano Bay sites evaluated

Two stations in the bay (figure 5) have been tested for fecal coliform since the early 1970's: Copano Bay at FM136 (Station #12945) and Copano Bay alongside SH35 (Station #13404). Fecal coliform data were obtained from Copano Bay at FM136 for the period of 1973 –2003 (appendix A). Fecal coliform data were also obtained from Copano Bay alongside SH35 for the period of 1975–2005 (appendix B). Data obtained from TCEQ were transferred to Microsoft® Excel for analysis and plotted using SPSS®.

No statistically significant trends were observed in the fecal coliform data at either FM136 or SH35 (figure 6). Fecal coliform values were highly variable, ranging from 1 to 6,000 cfu/100 mL at FM136 and from 1 to 360 cfu/100 mL at SH35.

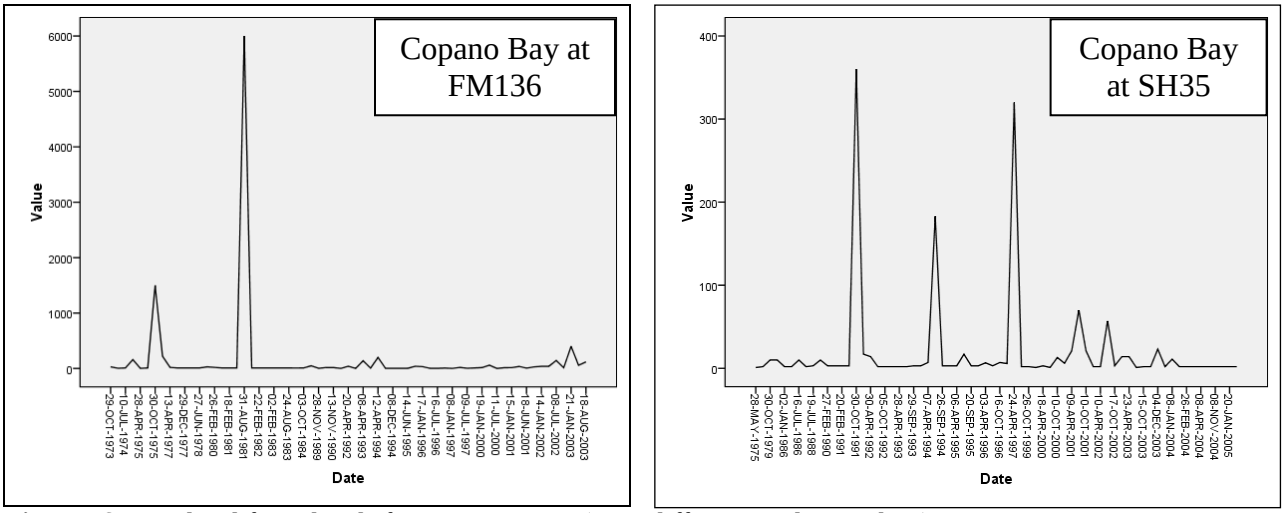

Figure 6. Fecal Coliform levels from 1973-2003 (note differing scales in plots)

To further assess any possible trends or changes in fecal coliform levels, the mean, median, and percent of samples exceeding the water quality standard (43 cfu/100 mL) were determined at five-year intervals for both sites beginning from 1970–2005 (table 20). Copano Bay at SH35 appears to have experienced an increase in fecal coliform levels between 1975 and 1995, but since 1995 the data indicates a possible downward trend. Conversely, fecal coliform levels at FM136 have been highly variable since monitoring was initiated and there is no discernable trend.

Table 20. Median, mean, and percent of fecal coliform values exceeding 43 cfu/100 mL

	Copano at SH35			Copano at FM136		
Date	**Median**	**Average**	**%>43**	**Median**	**Average**	**%>43**
1970-1975				20.0	51.0	25%
1975-1980	2.0	4.3	0%	10.0	182.3	20%
1980-1985				10.0	471.4	8%
1985-1990	3.0	5.6	0%	25.5	25.5	50%
1990-1995	3.0	34.2	11%	11.5	43.0	20%
1995-2000	3.0	31.1	8%	3.8	11.6	0%
2000-2005	2.0	10.2	7%	37.0	66.1	33%

Based on the data in table 20, the only period that Copano at SH35 has been impaired is from 1990–1995 when levels peaked. Copano Bay at FM136, however, has been impaired almost continuously since monitoring began with the exception of 1980–1985 and 1995–2000.

SUMMARY OF FINDINGS

Copano Bay is a 65 mi^2 estuary located northeast of Corpus Christi. Port Bay, Mission Bay, the Aransas River arm, and the eastern shoreline of Copano Bay (the Copano Creek arm) were first identified in 1998 as impaired for elevated bacteria; they remain on the 2008 *Texas §303(d) List*. According to the *2006 Texas Water Quality Inventory – Water Body Assessments by Basin* (TCEQ 2008), the average *Enterococcus* and fecal coliform levels in bays and estuaries larger than 28 mi^2 were 14 and 8 cfu/100 mL, respectively. In comparison, the *Enterococcus* and fecal coliform levels in Copano Bay were 17 and 4 cfu/100 mL, respectively. No statistically significant trends were observed in fecal coliform levels at two long-term monitoring sites in Copano Bay (FM136 and SH35). Based on TCEQ fecal coliform data collected since 1975, the only period that Copano Bay at SH35 has been impaired was from 1990–1995. This is not the case for Copano Bay at FM136, which has been impaired almost continuously since monitoring began in 1973 with the exception of 1980–1985 and 1995–2000.

Livestock and wildlife populations were evaluated to assess potential sources of the fecal coliform. Deer were the most populous category in terms of sheer numbers; however, in terms of AU, cattle were the most populous. An estimated 66,348 cattle (AUs) live within the watershed. As would be expected, application of published loading coefficients to the calculated AU in the watershed indicate that as much as 88 percent of the livestock and wildlife bacteria production may originate from cattle and deer with cattle contributing approximately 70 percent and deer contributing 18 percent. It should be noted that all wildlife categories were not evaluated, which can have a significant impact on the findings of this study. Waterfowl (migratory and non-migratory) and other wildlife species can be the source of a significant amount of loading, especially at localized sites in the bay, and need to be included in future TMDL work.

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APPENDIX A
HISTORICAL FECAL COLIFORM LEVELS (cfu/100 mL) COPANO BAY AT FM136

Date	Value	Date	Value
10/29/1973	30	9/29/1992	2
1/29/1974	4	4/8/1993	140
7/10/1974	10	9/29/1993	7
12/20/1974	160	4/12/1994	200
4/28/1975	3	10/4/1994	3
7/29/1975	10	12/8/1994	3
10/30/1975	1500	4/6/1995	3
1/26/1976	220	6/14/1995	3
4/13/1977	20	9/19/1995	40
9/26/1977	10	1/17/1996	33.33
12/29/1977	10	4/3/1996	3
3/30/1978	10	7/16/1996	3
6/27/1978	10	10/16/1996	7
9/27/1978	30	1/8/1997	1.4
2/26/1980	20	4/30/1997	20
5/30/1980	10	7/9/1997	3.75
2/18/1981	10	10/25/1999	10
5/20/1981	10	1/19/2000	16
8/31/1981	6000	4/17/2000	60
11/24/1981	10	7/11/2000	1
2/22/1982	10	10/9/2000	14
5/12/1982	10	1/15/2001	15
2/2/1983	10	4/10/2001	37
5/25/1983	10	6/18/2001	6
8/24/1983	10	10/8/2001	29
3/22/1984	8	1/14/2002	39
10/3/1984	10	4/9/2002	39
5/7/1986	48	7/8/2002	145
11/28/1989	3	10/15/2002	14
5/15/1990	17	1/21/2003	400
11/13/1990	16	4/22/2003	58
10/7/1991	2	8/18/2003	118
4/20/1992	40		

APPENDIX B
HISTORICAL FECAL COLIFORM LEVELS (cfu/100 mL) COPANO BAY AT SH35

Date	Value	Date	Value
5/28/1975	1	10/16/1996	7
11/3/1976	2	1/8/1997	5.7
10/30/1979	10	4/24/1997	320
3/6/1985	10	7/9/1997	2
1/2/1986	2	10/26/1999	2
4/24/1986	2	1/18/2000	1
7/16/1986	10	4/18/2000	3
10/14/1986	2	7/12/2000	1
7/19/1988	3	10/10/2000	13
4/19/1989	10	1/16/2001	6
2/27/1990	3	4/9/2001	21
8/13/1990	3	6/19/2001	70
2/20/1991	3	10/10/2001	21
8/7/1991	3	1/16/2002	2
10/30/1991	360	4/10/2002	2
1/22/1992	17	7/9/2002	57
4/30/1992	14	10/17/2002	3
8/10/1992	2	1/22/2003	14
10/5/1992	2	4/23/2003	14
12/2/1992	2	8/19/2003	1
4/28/1993	2	10/15/2003	2
7/19/1993	2	11/17/2003	2
9/29/1993	3	12/4/2003	23
2/14/1994	3	12/17/2003	2
4/7/1994	7	1/8/2004	11
6/7/1994	183	2/17/2004	2
9/26/1994	3	2/26/2004	2
12/8/1994	3	3/2/2004	2
4/6/1995	3	4/8/2004	2
6/14/1995	17	10/28/2004	2
9/20/1995	3	11/8/2004	2
1/16/1996	3	12/20/2004	2
4/3/1996	6.67	1/20/2005	2
7/16/1996	3	2/15/2005	2