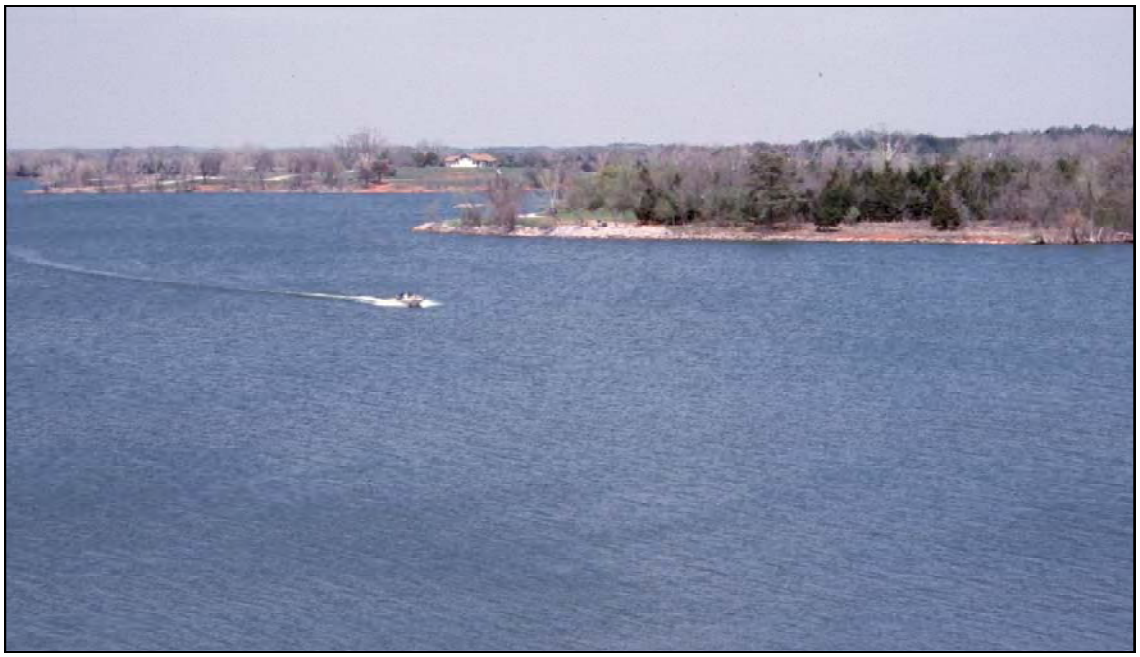
WATERSHED BASED PLAN

FOR THE

FORT COBB WATERSHED



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FORT COBB WATERSHED BASED PLAN

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PREFACE

The Fort Cobb Watershed covers 314 square miles in southwestern Oklahoma in Caddo, Washita, and Custer Counties. Ft. Cobb Reservoir's designated beneficial uses include public and private water supply, warm water aquatic community, agriculture, municipal and industrial uses, primary body contact recreation, and aesthetics. The reservoir is the primary drinking water source for the Cities of Anadarko and Chickasha. The watershed is located in the Central Great Plains Ecoregion in southwestern Oklahoma. Landuse in the watershed includes agricultural fields, cattle operations, rural communities, and one hog operation. Most soils in the watershed are highly erodible, sandy clays and loams. The water quality of the reservoir and its tributaries has been of concern for more than a decade with water quality problems identified beginning in 1981.

Oklahoma Water Quality Standards list Fort Cobb Reservoir as a Nutrient Limited Watershed (due to high primary productivity) and a sensitive public and private water supply. 1998 Oklahoma Water Resources Board (OWRB) data showed the lake was hypereutrophic and in 1999, eutrophic (OWRB 2002). Studies indicated biological, chemical, and habitat degradation within the Ft Cobb Reservoir Watershed. DDT was detected in fish flesh tissue in 1981. Ft. Cobb Reservoir and six waterbody segments in its watershed were listed on the 1998 303(d) list as being impaired by nutrients, pesticides, siltation, suspended solids, and unknown toxicity (Table 1). The Reservoir and three streams, Cobb, Willow, and Fivemile Creek, are currently listed on the 2008 303(d) list as being impaired (see Table 1; ODEQ 2008). In addition, concerns have been expressed by the Master Conservancy District reservoir managers regarding the nutrient and sediment loads.

Table 1. 303(d) Listed Causes of Impairment in Fort Cobb Watershed.

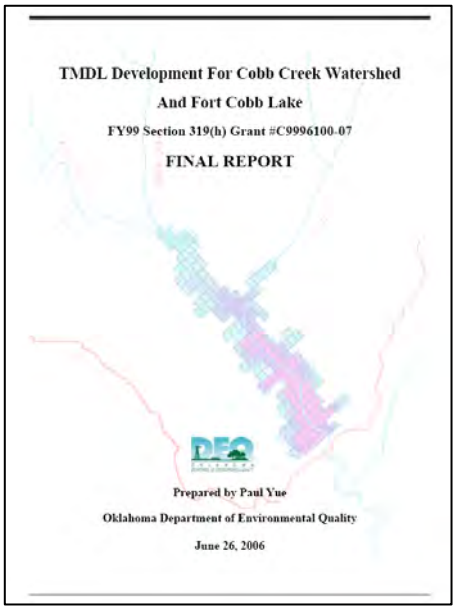
303(d) list year	OK Waterbody ID	Name	Cause of Impairment
1998	OK 310830050020	Fort Cobb Reservoir	pesticides, suspended solids, turbidity
1998	OK 310830060030	Willow Creek	nutrients, siltation, suspended solids
1998	OK 310830060040	Lake Creek	unknown toxicity, pesticides, nutrients, siltation, other habitat alterations, suspended solids
1998	OK 310830060050	Cobb Creek	pesticides, nutrients, siltation, suspended solids
1998	OK 31080060080	Fivemile Creek	nutrients, siltation, suspended solids
1998	OK 31080060130	Crowder Lake	nutrients, organic enrichment/D.O., suspended solids
2002	OK310830050020	Fort Cobb Reservoir	phosphorus
2002	OK 310830060030	Willow Creek	pathogens
2002	OK 310830060040	Lake Creek	low dissolved oxygen[1], turbidity
2004	OK310830050020	Fort Cobb Reservoir	phosphorus
2004	OK 310830060030	Willow Creek	Fecal coliform, Enterococcus, E. coli
2004	OK 310830060040	Lake Creek	selenium
2006	OK310830050020	Fort Cobb Reservoir	phosphorus, turbidity
2006	OK 310830060030	Willow Creek	Fecal coliform, Enterococcus, E. coli
2006	OK 310830060040	Lake Creek	selenium
2006	OK 31080060130	Crowder Lake	turbidity, dissolved oxygen
2008	OK310830050020	Fort Cobb Reservoir	turbidity
2008	OK 310830060030	Willow Creek	Fecal coliform, Enterococcus, E. coli
2008	OK 310830060050	Cobb Creek	ammonia, Enterococcus, E. coli
2008	OK 31080060080	Fivemile Creek	Enterococcus, E. coli
2008	OK 31080060130	Crowder Lake	turbidity, chlorophyll-a, dissolved oxygen

Considerable efforts have been made to identify the causes, sources, and extent of water quality threats and impairments in the basin, and extensive remedial efforts have occurred in the past several years. Previous studies of the reservoir and watershed were conducted by the U.S. Fish and Wildlife Service (USFWS), the Bureau of Reclamation (BOR), and the U.S. Geological Survey (USGS). These studies identified the causes, extent, and some of the sources of water quality impairment in the watershed.

In 2006, the Oklahoma Department of Environmental Quality (ODEQ) released the final draft of a TMDL for phosphorus loading to Fort Cobb Reservoir (Appendix A). This TMDL recommended a 78% phosphorus load reduction to restore beneficial use support to the reservoir. Because there are no point source dischargers in the watershed, this reduction must come entirely from nonpoint sources in the watershed.

1 Listing for D.O. later determined to be in error during TMDL development.

The TMDL was based on watershed data collected between 1990 and 2001; therefore, loading reduction recommendations are based upon loading during that period. Since that period, many changes have taken place in the watershed which suggests that Oklahoma is making significant progress towards the TMDL goal. These efforts include, but are not limited to, a decrease in peanut production in the watershed following the loss of government subsidies of peanut production, a 2001 §319 Project focused on education and demonstration of practices to reduce sediment and nutrient pollution in the watershed, a 2005 §319 Project focused on no-till, and continued effects of previous NPS education programs in the watershed which have resulted in the voluntary implementation of best management practices such as riparian zones, nutrient management, and conservation tillage.


TMDL Development For Cobb Creek Watershed
And Fort Cobb Lake
FY99 Section 319(h) Grant #C9996100-07
FINAL REPORT
Prepared by Paul Yue
Oklahoma Department of Environmental Quality
June 26, 2006

Additional work in the watershed includes education programs developed by the Oklahoma Cooperative Extension Service (OCES), the Deer Creek, West Caddo, North Caddo, and Mountain View Conservation Districts, the Natural Resources Conservation Service (NRCS), and the Oklahoma Conservation Commission (OCC), and various programs to reduce nonpoint source loading in the watershed. As a result of these efforts, Lake Creek was delisted for pesticides and unknown toxicity in 2002.

A Conservation Reserve Enhancement Program (CREP) is planned for the Fort Cobb watershed, which will further address sediment and nutrient loading. This watershed based plan (WBP) discusses the efforts which have already occurred as well as those necessary to expand the programs ongoing in the watershed to reach the load reduction goals established by the TMDL and to restore beneficial use support to Fort Cobb Reservoir and the waterbodies in its watershed.

INTRODUCTION

In 1997, on the 25th anniversary of the 1972 Federal Clean Water Act, Vice President Al Gore initiated development of a nationwide strategy to protect water quality. This initiative resulted in the development of the *Clean Water Action Plan* (CWAP), which established goals and implementation schedules for numerous strategies dealing with point and nonpoint sources. Oklahoma's Office of Secretary of Environment (OSE) was designated as the state lead agency to implement the provisions of the CWAP in Oklahoma.

Under OSE's leadership, Oklahoma has successfully met the CWAP requirement to establish a *Unified Watershed Assessment* (UWA) strategy. Oklahoma's UWA is a written document whose development and implementation relied upon input from the state's UWA Work Group. Through the UWA process, the Work Group identified "Category I" watersheds in Oklahoma that were recognized as significantly impaired and in need of immediate federal and state funding to target restoration activities. Fort Cobb Watershed was one of these high priority watersheds (Figure 1).

EPA's Nonpoint Source Program and Grants Guidelines for States and Territories for FY 2004 and Beyond requires a Watershed-Based Plan (WBP) to be completed prior to implementation using incremental funds. The guidance defines the 9 key components to be addressed in a watershed-based plan, much of which builds from the strategies outlined in a Watershed Restoration Action Strategy (WRAS). These components are: 1) identification of causes and sources that will need to be controlled to achieve load reductions, 2) estimate of load reductions expected from the management measures described, 3) a description of the management measures that will need to be implemented to achieve load reductions, 4) an estimate of the amounts of technical and financial assistance needed, associated costs, and/or the sources or authorities who will bear responsibility, 5) an information/education component that will be used to enhance public understanding of the project and encourage early participation in the overall program, 6) a schedule for implementing the Non-Point Source (NPS) management measures identified in this plan that is reasonably expeditious, 7) a description of interim, measurable milestones for determining whether control actions are being implemented, 8) a set of criteria that can be used to determine whether loading reductions are being achieved over time and substantial progress is being made or whether the Watershed Plan or Total Maximum Daily Load (TMDL) needs to be revised, and 9) a monitoring component to evaluate the effectiveness of the implementation efforts over time.

The WBP for the Fort Cobb Watershed has been developed as a dynamic document that will be revised, when necessary, to incorporate the latest information, address new strategies, and define new partnerships between watershed shareholders following this initial documentation. Also, it is understood that the water quality goals set forth in this WBP, as well as the technical approach to address the goals, may not be comprehensive and it may be necessary to revise or expand them in the future.

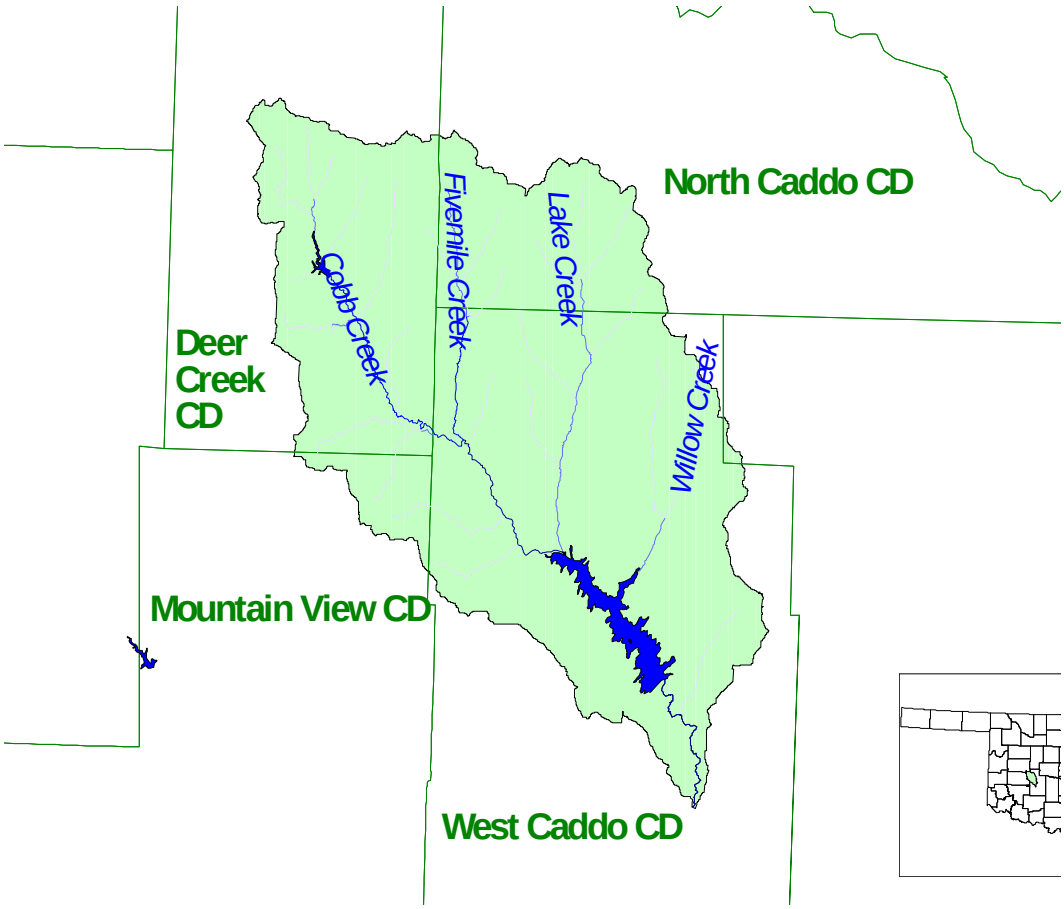


Figure 1. Fort Cobb Watershed.

Federal and state funding allocations for future water quality projects designed to address the Fort Cobb Watershed problems should not be based solely upon their inclusion in this WBP, rather the WBP should be considered a focal point for initial planning and strategy development. In order for this WBP to become an integral part of the entire watershed restoration program, it must be amenable to revision and update. It is anticipated that at least biannual revisions may be necessary, and that the responsibility for such revisions will rest primarily with the OCC with support from the Office of the Secretary of the Environment (OSE) and the NPS Working Group.

CAUSES AND SOURCES

Causes

Currently, Fort Cobb Reservoir, Willow Creek, Cobb Creek, and Fivemile Creek are impaired by turbidity (reservoir), bacteria (all creeks), and ammonia (Cobb Creek) (Table 1). The Fort Cobb TMDL (ODEQ 2006) focuses on phosphorus as the primary cause of impairment in Fort Cobb Reservoir and suggests that the dissolved oxygen listing for Lake Creek was in error. In addition, it confirms that pesticide impairments cited by the 1998 303(d) list are no longer present, as indicated by current water quality and biological data (Appendix A).

Sources

Point Sources

The TMDL verified that there were no permitted point source dischargers in the Fort Cobb Watershed. However, there are two Concentrated Animal Feeding Operation (CAFO) farms in the watershed, both with total retention NPDES permits. Permits on these farms, one a cattle farm with 2700 animal units, and the other a swine farm with 800 animal units allow overflows only under 25 year, 24 hour storm events. According to the TMDL, these provisions are determined sufficient to protect the waters in the Cobb Creek watershed. The TMDL recommends no additional measures for these CAFO farms. In order to rule out effects of these facilities on nearby stream health, the relative load contribution attributable to these facilities should be considered by the State to verify that these facilities are not significant contributors to local or watershed-wide water quality problems. Based on these findings, the TMDL may need to be revised.

Nonpoint Sources

In rural settings, the primary sources of nutrients may include runoff of applied fertilizer and manure to agricultural land, runoff of animal wastes associated with the erosion of sediments in grazing fields, runoff from concentrated animal operations, failing septic tanks, and contributions from wildlife. The TMDL used the Soil and Water Assessment Tool (SWAT) model to estimate NPS loadings from landuse in the watershed (Appendix B). This is the same model and model runs that were used to target NPS implementation with an FY 2001 §319 project in the Fort Cobb Watershed. The model subdivided the basin into 90 subbasins, based on 10-meter USGS Digital Elevation Model data for the basin (Figure 3). Loading estimates for these 90 subbasins as predicted by SWAT are seen in Table 2. Loading estimates from Fort Cobb landuses as predicted by SWAT are seen in Table 3. Figure 4 displays the SWAT predictions related to phosphorus loading from subbasins in the Fort Cobb watershed. The darkest red basins produce the highest phosphorus in runoff. The SWAT model estimated a total sediment load to the lake (excluding roads) of 276,000 metric tons per year and a total phosphorus load of approximately 70,000 kg P/year.

Typical landuse in the Fort Cobb Watershed (photo courtesy of Storm et al. 2003).

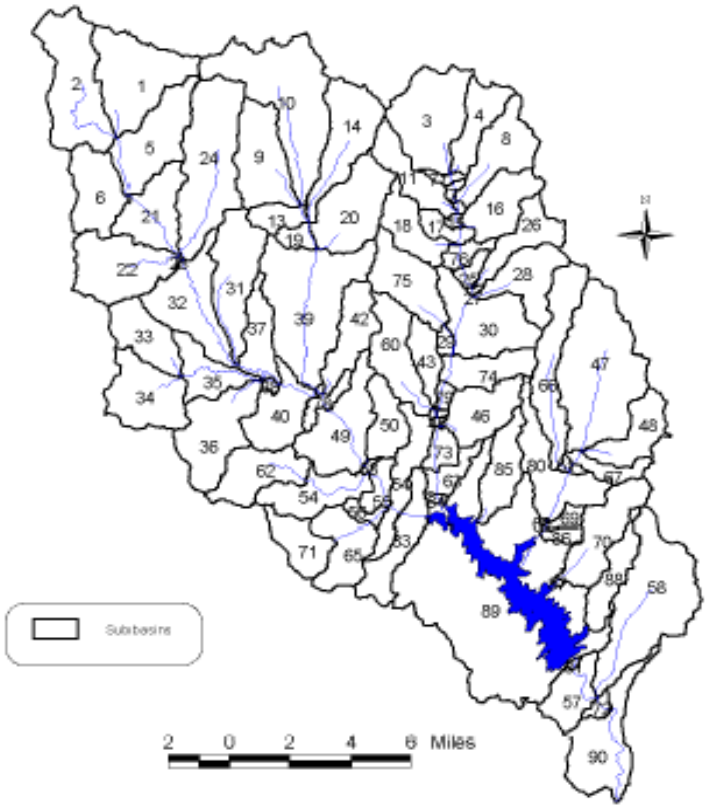


Figure 1. Sub-basin layout used in the Cobb Creek SWAT model (Storm et al. 2003).

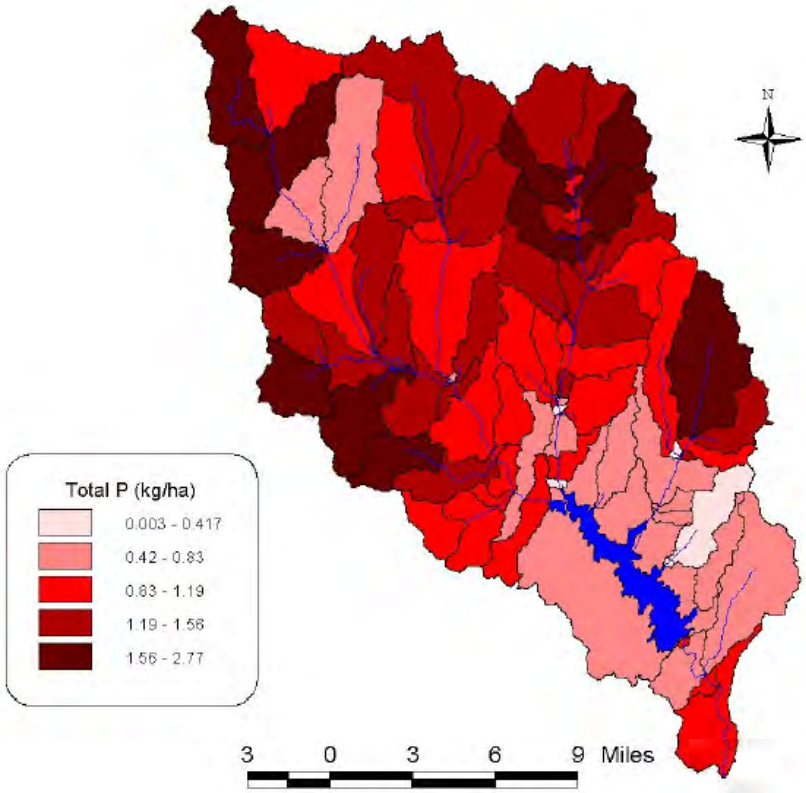


Figure 3. Total phosphorus loading by sub-basin as predicted by SWAT (Storm et al. 2003).

Table 2. SWAT Estimated Sub-basin Loading.

Sub-basin	AREA (km^2)	Surface Runoff (mm)	Baseflow (mm)	Total Water Yield (mm)	Sediment (mg/ha)	Organic Nitrogen (kg/ha)	Organic P (kg/ha)	Nitrate in surface runoff (kg/ha)	Soluble Mineral P (kg/ha)	Sediment bound mineral P (kg/ha)	Total P (kg/ha)
1	1.92E+01	27.198	21.307	51.494	3.02	4.895	0.603	0.106	0.009	0.452	1.064
2	2.12E+01	44.085	35.825	84.136	6.228	6.636	0.803	0.308	0.005	0.828	1.636
3	1.86E+01	45.708	41.17	91.644	4.087	7.324	0.917	0.139	0.015	0.589	1.521
4	8.41E+00	59.531	54.213	121.906	3.919	6.681	0.814	0.173	0.01	0.589	1.413
5	1.51E+01	59.522	35.941	105.415	1.371	9.323	1.123	0.21	0.119	0.951	2.193
6	1.15E+01	54.575	44.673	104.907	1.299	10.146	1.179	0.153	0.092	0.869	2.14
7	7.76E-01	64.588	93.128	175.716	4.213	3.414	0.427	0.221	0.006	0.538	0.971
8	1.18E+01	83.927	68.263	158.491	5.242	7.35	0.92	0.285	0.03	0.837	1.787
9	1.48E+01	50.333	41.2	94.889	2.573	4.644	0.576	0.149	0.012	0.465	1.053
10	2.92E+01	31.725	28.935	64.179	3.398	6.12	0.763	0.081	0.007	0.482	1.252
11	8.49E+00	49.722	43.356	100.008	4.762	7.552	0.933	0.143	0.014	0.688	1.635
12	3.92E-01	81.615	63.218	150.528	4.692	4.613	0.591	0.288	0.008	0.637	1.236
13	4.08E+00	57.373	45.845	109.125	4.154	5.687	0.689	0.172	0.012	0.647	1.348
14	1.49E+01	51.162	45.908	101.745	3.902	6.746	0.844	0.145	0.016	0.619	1.479
15	6.40E-01	67.495	56.309	133.605	4.144	3.42	0.445	0.244	0.006	0.555	1.006
16	1.04E+01	66.203	48.74	118.653	5.349	7.315	0.898	0.219	0.007	0.786	1.691
17	3.25E+00	65.768	53.966	125.363	3.876	5.338	0.673	0.233	0.007	0.628	1.308
18	8.27E+00	61.75	65.052	135.163	4.894	6.626	0.815	0.238	0.009	0.844	1.668
19	2.34E+00	63.825	41.101	109.131	3.083	4.99	0.623	0.227	0.007	0.557	1.187
20	1.56E+01	52.451	43.091	98.176	4.097	6.665	0.816	0.174	0.006	0.643	1.465
21	1.17E+01	62.091	37.157	119.144	2.322	3.437	0.384	0.103	0.026	0.413	0.823
22	1.58E+01	54.363	47.485	112.845	5.096	7.144	0.845	0.14	0.03	0.761	1.636
23	1.54E-01	57.438	54.933	119.686	5.707	6.978	0.85	0.235	0.006	0.7	1.556
24	2.58E+01	63.747	38.638	116.515	1.651	3.385	0.38	0.135	0.035	0.413	0.828
26	8.30E+00	55.895	41.336	102.702	3.631	6.642	0.812	0.148	0.013	0.595	1.42
27	3.16E-01	70.184	82.381	159.887	3.497	3.602	0.441	0.251	0.006	0.47	0.917
28	1.11E+01	58.754	90.282	162.144	3.27	4.629	0.573	0.157	0.01	0.497	1.08
29	1.33E+00	60.497	53.606	127.77	3.833	4.113	0.503	0.207	0.005	0.525	1.033
30	1.63E+01	56.704	79.111	143.377	4.087	5.737	0.709	0.168	0.006	0.602	1.317
31	1.56E+01	59.96	35.11	96.799	3.669	5.706	0.705	0.214	0.008	0.694	1.407
32	1.60E+01	44.063	49.617	102.287	4.17	3.912	0.497	0.155	0.004	0.559	1.06
33	9.64E+00	45.049	45.392	95.578	4.119	5.626	0.685	0.162	0.004	0.61	1.299

Sub-basin	AREA (km^2)	Surface Runoff (mm)	Baseflow (mm)	Total Water Yield (mm)	Sediment (mg/ha)	Organic Nitrogen (kg/ha)	Organic P (kg/ha)	Nitrate in surface runoff (kg/ha)	Soluble Mineral P (kg/ha)	Sediment bound mineral P (kg/ha)	Total P (kg/ha)
34	1.38E+01	42.272	36.619	82.554	4.841	7.858	0.943	0.14	0.018	0.752	1.713
35	8.03E+00	45.779	47.536	103.311	4.865	5.756	0.713	0.147	0.015	0.648	1.376
36	1.63E+01	41.155	36.611	81.13	5.508	8.637	1.034	0.123	0.016	0.808	1.858
37	7.86E+00	71.821	93.901	178.555	3.963	4.737	0.582	0.301	0.009	0.714	1.305
38	6.23E-01	60.379	52.918	117.398	10.491	8.53	1.027	0.221	0.005	1.078	2.11
39	2.97E+01	51.589	100.085	167.169	3.579	4.675	0.575	0.184	0.018	0.599	1.192
40	1.10E+01	32.863	32.221	66.38	3.782	6.5	0.791	0.094	0.003	0.554	1.348
41	2.39E-01	37.573	89.244	141.895	1.859	2.549	0.322	0.117	0.003	0.256	0.581
42	9.76E+00	35.479	57.285	99.696	2.994	5.537	0.682	0.104	0.014	0.562	1.258
43	5.64E+00	50.394	37.238	90.2	2.031	3.753	0.47	0.159	0.007	0.432	0.909
44	2.39E-01	68.272	51.862	126.06	1.636	2.306	0.328	0.197	0.005	0.257	0.59
45	3.41E-01	54.859	69.637	137.479	0.968	1.207	0.175	0.151	0.003	0.149	0.327
46	1.08E+01	44.676	82.178	133.882	2.73	3.618	0.436	0.141	0.005	0.472	0.913
47	3.17E+01	67.633	71.945	148.966	5.84	6.645	0.821	0.233	0.007	0.844	1.672
48	9.09E+00	72.984	51.113	128.756	4.478	6.09	0.747	0.267	0.008	0.694	1.449
49	1.56E+01	48.316	64.608	122.413	2.924	4.499	0.556	0.148	0.018	0.534	1.108
50	7.69E+00	59.272	119.231	185.652	2.76	3.342	0.397	0.198	0.007	0.509	0.913
51	4.69E-01	52.32	99.866	172.358	0.875	0.793	0.11	0.14	0.003	0.14	0.253
52	4.18E-01	72.596	53.314	139.115	4.258	4.933	0.624	0.248	0.006	0.58	1.21
53	4.18E-01	51.149	59.582	117.475	5.527	3.89	0.455	0.164	0.005	0.634	1.094
54	1.02E+01	51.24	42.769	97.537	4.672	5.997	0.734	0.157	0.005	0.678	1.417
55	3.56E+00	55.822	69.517	133.307	3.071	3.307	0.396	0.186	0.006	0.494	0.896
56	1.80E+00	56.706	56.26	120.711	2.619	3.573	0.456	0.177	0.005	0.413	0.874
57	8.04E+00	50.824	75.133	131.671	2.129	3.164	0.4	0.172	0.006	0.418	0.824
58	2.83E+01	37.324	73.863	116.036	1.448	3.002	0.372	0.105	0.01	0.297	0.679
59	2.56E-04	29.149	122.047	151.789	5.553	8.264	0.982	0.258	0.009	0.686	1.677
60	1.20E+01	43.583	55.189	103.275	2.564	4.431	0.551	0.138	0.006	0.494	1.051
61	5.99E-02	92.043	48.162	145.011	1.77	2.39	0.302	0.375	0.009	0.366	0.677
62	1.11E+01	34.114	31.551	67.489	5.613	7.922	0.949	0.099	0.003	0.739	1.691
63	3.92E+00	61.29	95.521	171.36	3.253	3.11	0.386	0.206	0.007	0.551	0.944
64	9.31E+00	45.097	120.841	184.917	3.077	2.532	0.3	0.148	0.005	0.492	0.797
65	1.03E+01	45.126	41.258	88.964	2.588	5.11	0.63	0.123	0.016	0.505	1.151
66	1.57E+01	53.374	106.726	177.098	2.706	3.754	0.457	0.168	0.014	0.48	0.951

Sub-basin	AREA (km^2)	Surface Runoff (mm)	Baseflow (mm)	Total Water Yield (mm)	Sediment (mg/ha)	Organic Nitrogen (kg/ha)	Organic P (kg/ha)	Nitrate in surface runoff (kg/ha)	Soluble Mineral P (kg/ha)	Sediment bound mineral P (kg/ha)	Total P (kg/ha)
67	3.85E+00	59.375	71.051	137.048	2.903	4.243	0.522	0.191	0.005	0.466	0.993
68	8.70E-03	43.584	63.164	112.436	0.007	0.009	0.001	0.094	0.001	0.001	0.003
69	1.80E+00	44.714	46.247	95.734	2.079	3.344	0.417	0.135	0.004	0.344	0.765
70	1.30E+01	26.598	126.714	163.971	1.14	1.639	0.199	0.077	0.003	0.215	0.417
71	7.55E+00	37.126	32.073	71.802	2.793	4.819	0.579	0.094	0.007	0.482	1.068
72	1.40E+00	53.081	82.98	143.678	3.572	5.059	0.614	0.176	0.005	0.548	1.167
73	3.34E+00	45.478	55.954	107.349	1.931	3.024	0.382	0.129	0.004	0.336	0.722
74	8.29E+00	59.304	81.656	151.916	3.641	4.695	0.59	0.187	0.005	0.512	1.107
75	1.24E+01	55.807	87.467	155.92	4.042	5.144	0.618	0.183	0.014	0.651	1.283
76	2.75E+00	96.8	81.318	192.216	12.309	9.954	1.204	0.411	0.012	1.557	2.773
77	1.13E+00	70.043	55.222	132.27	6.565	7.172	0.872	0.246	0.006	0.836	1.714
78	2.70E+00	68.549	64.252	144.007	4.496	5.311	0.699	0.259	0.008	0.717	1.424
79	1.25E+00	68.765	58.196	139.176	4.478	4.673	0.581	0.235	0.006	0.63	1.217
80	1.36E+01	40.901	125.391	186.441	2.599	3.061	0.369	0.132	0.004	0.408	0.781
81	3.33E-01	47.632	90.536	159.356	4.14	4.9	0.674	0.138	0.003	0.388	1.065
82	1.71E-02	35.8	84.674	120.944	1.205	2.99	0.397	0.09	0.004	0.207	0.608
83	9.91E+00	40.605	55.685	99.948	2.405	4.03	0.499	0.123	0.005	0.432	0.936
84	5.80E-01	49.712	86.352	148.054	1.111	1.33	0.175	0.132	0.003	0.17	0.348
85	9.08E+00	53.278	124.399	194.81	2.157	2.228	0.262	0.185	0.021	0.465	0.748
86	1.68E+00	33.15	34.701	69.55	1.149	2.413	0.299	0.092	0.004	0.242	0.545
87	1.96E-01	53.203	84.646	154.727	0.935	1.425	0.2	0.137	0.002	0.121	0.323
88	7.79E+00	39.372	118.206	168.503	1.84	2.465	0.3	0.125	0.005	0.342	0.647
89	8.69E+01	26.772	81.711	113.273	1.679	2.725	0.336	0.076	0.003	0.292	0.631
90	1.62E+01	53.325	61.977	120.823	2.375	4	0.494	0.197	0.006	0.423	0.923

The SWAT model predictions are subject to the following limitations:

- Loads are subject to all the same limitations as those presented in the report: Fort Cobb Basin – Modeling and Land Cover Classification 2003;
- The loads are from upland sources only and do not consider bank or stream bed erosion, instream nutrient processes, or deposition of sediment in reservoirs or flood control structures on main channels;
- These data contain significantly more uncertainty than absolute load predicted to the lake or basin outlet. With limited calibration data, these data would be best utilized to relatively rank subbasins in terms of their nutrient contributions.

Although these predictions are subject to limitations, the estimates provide valuable information about areas contributing most significantly to watershed loading and suggest areas where incentives and other implementation programs should be targeted to have the greatest impact on water resources. These high priority subwatersheds (highest contributing watersheds as depicted in Figure 3) account for approximately 66.17 or 20% of the 329.35 square miles in the watershed and about 30% of the load. Including the next highest contributing set of subwatersheds increases the area to 210.83 square miles or 47% of the watershed and approximately 61% of the load.

The TMDL estimated phosphorus loading from septic tanks to be 3,608 kg/year, assuming all watershed residents used septic systems and using a worst case scenario where:

- All septic tanks were failing,
- Every household was assumed to have one septic tank, equaling 1,124 septic tanks in the watershed,
- Effluent from the tanks (11.6 mg P/L) drained directly to streams and lakes,
- Persons in the watershed produced 75 gallons of wastewater per day.

This loading would be approximately five percent of the total phosphorus loading to the watershed. Given that this is an over estimate of the loading from the current systems, the TMDL determined that loading from septic tanks was insignificant.

The primary crops grown in the watershed are wheat (80% of cropland), peanuts, sorghum, and cotton (Storm et. al 2003). Wheat, peanuts, and sorghum are the landuses that provided the highest nutrient and sediment loading in the watershed (Table 3); croplands, which are about 50.4% of the total land in the watershed, account for 90.4% of total P load. With the loss of peanut subsidies, peanut production has declined in the watershed, and many formerly peanut fields have been converted to cotton fields. The SWAT model estimated that the conversion of peanuts to cotton without BMPs to address cotton could result in increased phosphorus and sediment loading to the lake (Table 4).

Cotton is one of the row crops produced in the Fort Cobb Watershed (photo courtesy of Storm et al. 2003).

Table 3. SWAT simulated loads by land cover for the Fort Cobb Basin for the period 1/1990 - 10/2001 (from Storm et al. 2003).

Land Cover	Fraction of Basin (%)	Surface Runoff (mm)	Total Stream Flow (mm)	Sediment (Mg/ha)	Total N (kg/ha)	Total P (kg/ha)
Forest	6.0%	23.98	178.98	0.01	2.20	0.01
Pasture-Range	41.4%	40.34	105.36	1.61	3.60	0.62
Peanut	7.1%	61.76	147.15	4.06	7.74	1.87
Sorghum	2.8%	96.02	161.33	3.16	6.95	1.20
Urban	0.1%	87.60	100.95	0.05	1.20	0.09
Water	2.1%	0.00	0.00	0.00	0.00	0.00
Wheat for Grain	30.8%	57.58	121.60	5.88	9.90	1.91
Grazeout Wheat	9.7%	56.10	118.77	5.16	8.69	1.81
Basin Average	---	48.47	118.46	3.36	6.26	1.19

Table 4. Load summary for Fort Cobb Basin as predicted by the SWAT model (from Storm et. al 2003).

Crop Scenario	Runoff (CMS)	Total Water Yield (CMS)	Sediment (Mg/yr)	Total P (kg/yr)	Total N (kg/yr)
Current	1.37	3.05	301,277	108,031	543,615
Peanuts converted to cotton	1.28	2.95	307,131	110,103	543,461

Further details about the estimation of causes and sources in the Fort Cobb Watershed can be found in the TMDL (ODEQ 2006) and SWAT model reports (Storm et. al. 2003).

LOAD REDUCTIONS

The draft TMDL estimated that a **78% phosphorus load reduction**[2] would be necessary to restore beneficial use support to Fort Cobb reservoir. This sets a goal of reducing phosphorus loading from 70,000 kg/yr to 15,400 kg/yr. The TMDL addresses both phosphorus and turbidity impairment to the reservoir because most phosphorus is found attached to sediment, one of the primary causes of turbidity. The TMDL reasons that if phosphorus is reduced to meet water quality standards, then turbidity levels in contributing streams will also be reduced to a level that will meet the turbidity standard. Fortunately, BMPs recommended by the TMDL will also work to address the other sources of impairment in watershed streams including pathogens. The TMDL also estimates that every 1.0% reduction in phosphorus will correspond to a 1.33% reduction in total nitrogen and a 1.5% reduction in sediment delivery to the lake. Further explanation of the methodology for arriving at the 78% load reduction can be found in the TMDL and SWAT model reports (ODEQ 2006; Storm et. al 2003).

2 This includes the load reduction to allow for a margin of safety and potential growth in the watershed.

CRITERIA

Fort Cobb Reservoir's designated beneficial uses include public and private water supply, warm water aquatic community, agriculture, municipal and industrial uses, primary body contact recreation, and aesthetics. The reservoir is the primary drinking water source for the Cities of Anadarko and Chickasha.

The goal of the TMDL is to reduce the 1998 – 2001 loading to the lake of approximately 70,000 kg P/year to 15,400 kg P/year. That load reduction is based on the following endpoints, based on Oklahoma's Water Quality Standards (OWRB 2004a, b):

- Trophic State Index (chlorophyll-*a* based) for Fort Cobb Reservoir less than 62
- Dissolved Oxygen (surface water)
    - Summer (June 16 – October 15): 4.0 mg/L
    - Seasonal (October 16 – June 15): 5.0 mg/L
- Anoxic volume in Fort Cobb Reservoir less than 50% of water column.

Additional criteria that apply to causes of impairment in the watershed are (OWRB 2004):

- Turbidity (only applicable during baseflow)
  25 NTU for lakes
  50 NTU for streams
- Coliform bacteria
  Monthly geometric mean <5000 colonies/100 ml at point of intake
- <5% of total samples in any 30 day period will total coliform exceed 20,000 colonies/100 ml
- Enterococci bacteria
  Geometric mean of 33 colonies/100 ml
- *Escherichia coli* (*E. coli*)
  Geometric mean of 126 colonies/100 ml
- Warm Water Aquatic Community
  IBI = 22

These criteria stem from Oklahoma's Water Quality Standards (OWRB 2004a). The procedures by which the data must be collected and analyzed to verify whether or not these criteria have been met are identified in Oklahoma's Use Support Assessment Protocols (OWRB 2004b). Both of these documents fall under the jurisdiction of the Oklahoma Water Resources Board.

NPS MANAGEMENT MEASURES

According to the TMDL, croplands account for about 90% of the phosphorus loading in the watershed; therefore, load reduction efforts should focus on cropland (Table 3). The TMDL SWAT modeling applied various scenarios relative to landuse and BMPs used in the watershed to estimate the possible solutions to achieve the recommended 78% phosphorus load reduction. As shown in Table 5, below, the TMDL evaluated the

effectiveness of various BMPs to achieve a phosphorus load reduction. No single BMP type will fully address the required load reduction; a combination of BMPs will be necessary.

Table 5. Load reductions for different BMPs (from ODEQ 2006).

Practice	% Reduction In Total Basin Load		
	Sediment	Total N	Total P
No-till wheat and row crops	-51.10%	-42.80%	-34.40%
No winter cover on row crops	9.20%	11.10%	6.80%
Worst 1% of cultivated land to pasture	-6.00%	-3.20%	-4.40%
Worst 2.5% of cultivated land to pasture	-11.50%	-8.10%	-8.00%
Worst 5% of cultivated land to pasture	-18.00%	-13.90%	-12.30%
Worst 7.5% of cultivated land to pasture	-23.00%	-18.30%	-15.50%
Worst 10% of cultivated land to pasture	-26.50%	-21.40%	-17.90%
Worst 15% of cultivated land to pasture	-33.00%	-27.10%	-22.10%
Worst 20% of cultivated land to pasture	-37.50%	-31.10%	-25.10%
Worst 25% of cultivated land to pasture	-41.50%	-34.70%	-27.70%
Worst 35% of cultivated land to pasture	-48.00%	-40.40%	-32.00%
Riparian Buffer	-75% to -90%	-35% to -55%	-40% to -60%
Nutrient Management		-15%	-35%

In addition to the BMPs mentioned above, grade stabilization structures are necessary in this watershed due to the highly erodible soils; damage is already evident in the watershed with extensive gullying and rill erosion being relatively common. The SWAT model could not predict areas where grade stabilization structures would be necessary, nor could it predict the loading reduction that would result from installation of these structures. Such a prediction would require extensive reconnaissance in the watershed and ultimately, a conservation plan for every producer. However, an estimate of the need can be roughly extrapolated from the need demonstrated with the FY 2001 §319 project, where approximately 25% of the cooperators required grade stabilization structures to reduce erosion.

The FY 2001 §319 project funded a targeting exercise based on the SWAT model that was later expanded into the TMDL. Results of that exercise were used to focus implementation into areas of origin for the bulk of the sediment and phosphorus loading. Subsequently, the OCC used these results in conjunction with the recommendations of the TMDL as part of a FY 2005 §319 project. Figure 6 displays results of the 2003 targeting effort. Implementation of BMPs in the red areas was expected to reduce nutrient loading to the watershed by approximately 50%. Implementation of BMPs in the yellow areas could reduce nutrient loading by an additional 30%.

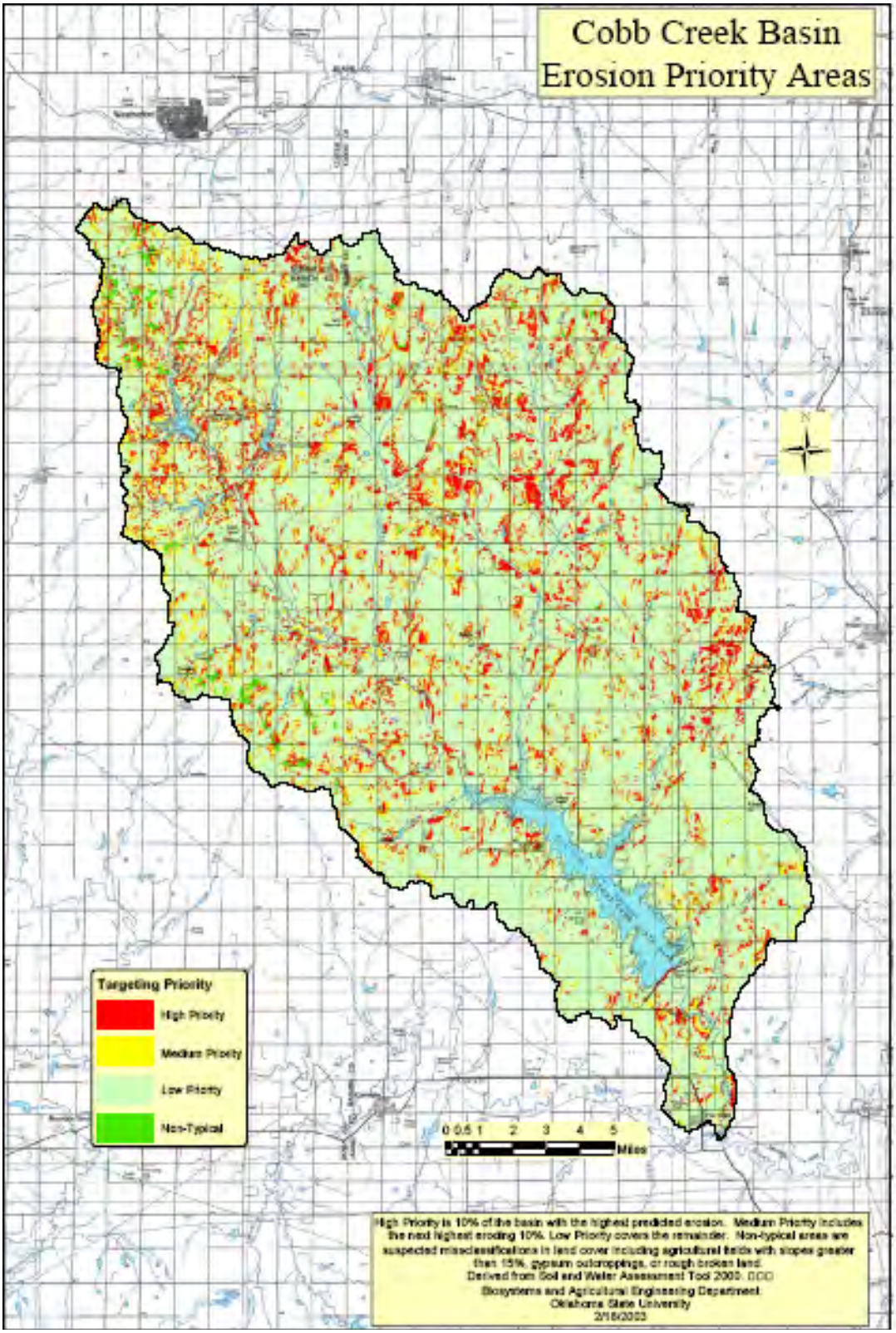


Figure 6. Location of areas in Fort Cobb Watershed most likely contributing the greatest portions of total sediment, and therefore phosphorus loading.

TECHNICAL AND FINANCIAL ASSISTANCE NEEDED

The amounts of technical and financial assistance needed are closely tied to one another. All programs to implement NPS BMPs outlined in the above section require technical assistance in the form of a plan writer, certified by the NRCS. Such a position typically costs a total of $42,000 - $61,000 per year, including benefits. NRCS funds this technical support for their own programs (mainly EQIP in this watershed), but programs like a Conservation Reserve Enhancement Program or §319 must fund technical support through some other means. In addition, part-time help may be required to address the needs of the tri-county area. Any staff that provides technical support would be best served to work through the local conservation district and NRCS offices, as these are the places local landowners are most comfortable in going to for technical support. Therefore, it is beneficial to provide assistance to these districts to help support the program.

Funding necessary to implement the BMPs recommended by the TMDL is estimated using a combination of best professional judgment, based on experience in the watershed, and use of the PRedICT model. These values are seen in Table 6. An initial value of approximately $16 million has been estimated as necessary to implement the TMDL recommended practices. However, this value will likely change as the programs evolve and the Watershed Based Plan is updated. The actual amount of funding for BMP implementation in each of the OCC's projects is given below:

2001 Fort Cobb project (2001-2005):
128 cooperators
$1,386,611 of practices installed, total:
$365,650 from State funds
$498,054 from Federal 319 funds
$522,907 from landowners (38%)

2005 Fort Cobb project (2005-2008):
60 cooperators
$865,403 of practices implemented, total:
$502,556 from State funds
$290,250 from Federal 319 funds
$72,597 from landowners (8%)

Table 7 provides some estimates of funding planned or already implemented for technical support in the watershed. Some of these are multi-year efforts, and some are single-year efforts. At a minimum, around $160,000 is required for technical support each year to provide support to the conservation districts and personnel to meet with landowners and draft conservation plans.

Table 8 estimates funding necessary to support monitoring needs in the watershed. Not all information is available at this time regarding monitoring costs for USGS or Bureau of Reclamation; however, available information suggests that at least $230,000 is needed every five years.

Table 6. Funding Needs for Technical Support for Implementation of BMPs.

Project/Funding Source	Task	Federal	State Cost Share Funds	Total
FY 2001 §319 Fort Cobb Project- five year period	On-Site Coordinator	$225,000		$225,000
	Plan Writer	$80,000		$80,000
	District Support	$75,000		
FY 2005 §319 Fort Cobb TMDL Implementation Project- salaries and support for 2 years beyond 2001 project	On-Site Coordinator	$121,000		$121,000
	District Support	$15,000		$15,000
Conservation Reserve Enhancement Program (CREP)- funding for 2-3 years of technical support	Plan Writer		$94,000 - $312,000	$94,000 - $312,000
NRCS District Conservationists (3)		$52,000 - $85,000[3]		$52,000 - $85,000
	Total	**$609,800 - $642,800**	**$94,000 - $312,000**	**$703,000 - $954,800**

3 Estimated from GS 9/11 salary range + benefits.

Table 7. Funding Necessary to Implement TMDL Recommended Practices to Restore Beneficial Use Support to Fort Cobb Reservoir.

Load Reduction		TMDL Recommended BMP	Project/Funding Source	Federal	State/Local	Total
TMDL target	Anticipated from this project					
17%	7%	No-till in 50% of wheat and other row crop	FY 2005 §319 Fort Cobb TMDL Implementation	$672,380	$586,754	$1,259,134[4]
	10%		CSP, EQIP			$930,000
25%		Convert 20% of worst cultivated land to pasture	FY 2001 §319 Fort Cobb Project			
			EQIP, CSP			$2,050,000[5]
30%	1%	Riparian Areas in 60% of watershed	FY 2001 §319 Fort Cobb Project	$38,802	$25,867	$64,669
	15%		2010 CREP	$4,726,790	$945,358	$5,672,148
	14%		EQIP, CRP, CSP	$4,235,204	$1,058,801	$5,294,005
31.5%	31.5%	Nutrient Management Plans for 90% of producers	FY 2001 and 2005 §319 Programs, EQIP, CRP, CSP			$375,000[6]
???	???	Grade Stabilization Structures	FY 2001 §319 Fort Cobb Project	$92,804	$61,870	$154,674
	???		EQIP,???			
Total						$15,799,630

4 Represents an estimated start-up costs for no-till on 39% of cropland based on purchase of no-till drills for the 4 conservation districts, 30% cost-share on purchase of 10 drills for landowners, and $10/acre incentive payment (rate recommended by Fort Cobb WAG) for a three year period. Does not include technical support costs seen in Table 3.

5 Assumes a cost of $51 per acre (based on pasture costs in 20% of cultivated land (40,192 acres)

6 $5.00/acre/year for 90% of all crop and pastureland in the watershed, based on annual incentives offered through other State 319 programs, plus annual cost of soil testing. Most likely would only need to apply to all cropland, as few producers fertilize pasture, which would reduce costs to $250,000 annually.

Table 8. Monitoring Funding Needs Associated with Fort Cobb Watershed.

Monitoring Program	Parameters assessed	State	Federal	Total
OCC Rotating Basin	Stream water quality, biological community, habitat, hydraulic budget, riparian condition, landuse / landcover,		$10,000 - $30,000 every 5 years	$10,000 - $30,000 every 5 years
OWRB BUMP Program	Lake Water Quality	$10,000 annually		$10,000 annually
Watershed modeling (OSU, ODEQ, ARS)	Landuse / Land Cover, BMP implementation, Load reduction			$150,000 every 5 years
USGS	Groundwater/Surface Water Quality, Load reduction		???	???
Bureau of Reclamation	???		???	???

IMPLEMENTATION SCHEDULE

The TMDL recommends a 78% load reduction from loading seen between 1998 and 2001. Implementation towards this load reduction has progressed with formal programs such as the FY 2001 and 2005 §319 Projects and passive changes resulting from the loss of peanut subsidies. Measures of water quality changes as a result of those efforts are not fully available at this time; however, information is available on the implementation completed through the FY 2001 and 2005 programs such that an estimate of potential load reductions attributed to the project activities thus far has been estimated. These reductions are seen in Table 7 under the “Load Reduction” column under “Anticipated from this project”.

These efforts are initial steps towards full implementation of the TMDL recommendations. Table 9 presents a schedule towards implementation of the remaining TMDL recommendations. Included in table 9 is a column that schedules the evaluation of each program. Failure of the programs to meet planned implementation level or load reduction goals will result in adaptations, as possible during the program period or, as necessary, with follow-up, supplemental programs until the load reduction goals have been met.

The ARS CEAP program provides an excellent opportunity to evaluate the progress of these programs towards the TMDL-established goals. The Watershed Based Plan will be updated following the completion of the ARS effort in 2010 to summarize its findings and to make necessary adaptations to reach the TMDL load reduction goals.

Table 5. Schedule for Implementation of TMDL-Recommended Practices.

TMDL-recommended practice	Program proposed to implement	Begin Date	Completion Date	Date to evaluate	Agency(ies) / Group(s) involved
No-till 50% of row crops and wheat pasture	FY 2005 §319 Project	October 2005	January 2009	Annually during project, and following completion of the CEAP program.	OCC, conservation districts, USDA
	EQIP, CSP, ???	Immediate	Ongoing		
Convert 20% worst cultivated land to pasture	FY 2001 §319 Project[7]	October 2001	September 2006	Annually during the project, and following completion of the CEAP program.	OCC, conservation districts, USDA
	USDA Programs such as EQIP, CRP, etc.	ongoing	ongoing	following completion of the CEAP program	NRCS, FSA, ARS, Conservation Districts
Riparian Buffers in 60% of Watershed	FY 2001 §319 Fort Cobb Project	October 2001	September 2006	Annually during the project, and following completion of the CEAP program.	OCC, conservation districts, USDA
	2010 CREP	2010	2025	Annually during the project period	FSA, NRCS, OCC, Conservation Districts
	EQIP, CRP, CSP, and ???	ongoing	ongoing	following completion of the CEAP program	NRCS, FSA, ARS, Conservation Districts
Nutrient Management Plans for 90% of Producers	FY 2001 and 2005 §319 Programs, EQIP, CRP, CSP, and ???	ongoing	ongoing	Annually during the projects, & following completion of the CEAP program	NRCS, FSA, ARS, Conservation Districts, OCC
Grade Stabilization Structures	FY 2001 §319, EQIP, CSP, and ???	ongoing	ongoing	Annually during the project & following completion of the CEAP program	NRCS, FSA, ARS, Conservation Districts, OCC

7 The project did not implement much of this conversion; however, based on recommendations of the TMDL, the Project Coordinator attempted to contact landowners of the worst-cultivated lands to encourage them towards pasture conversion using either the 319 program or USDA programs.

The following is a summary of the implementation achieved through the OCC's 2001 and 2005 §319 projects (2001-2008):

- 21,086 acres of no-till farming
- 32 grade stabilization structures
- 8 diversions, 7 grassed waterways, and 2 terraces
- 230 acres of riparian area exclusion fencing
- 1 stream crossing
- 10,767 acres of cropland converted to pasture
- 957 acres of grass planting for pasture improvement
- 35,030 linear ft of cross-fencing
- 4 wells
- 4 septic systems

Visible improvements from no-till implemented through the §319 program are obvious throughout the watershed. Often, large piles of sandy soil accumulate along fence lines and in fields when dry and windy conditions occur in this area. No-till helped to hold moisture in the soil and reduce the amount of soil lost by wind and rain erosion, as seen in the photos below (Figure 7). The first two photos are of a no-till field, while the next two photos are of an adjacent, conventional till field. Much of the wheat in the conventional till field has been covered by soil which blew or washed over the plants.

Figure 7. Two adjacent wheat fields, the top in no-till and the bottom in conventional till.

The OCC's no-till program has resulted in implementation of almost 30% of the TMDL goal for no-till. An additional 30% of row crops have been converted to conservation tillage, so at least 60% of the row crop acreage in the watershed is now in some form of conservation tillage (Table 10). In addition, approximately 63% of the TMDL goal for converting row crops to pasture has been achieved through the §319 program. NRCS EQIP has provided funding for both no-till and conservation tillage as well, so additional progress toward the overall TMDL goal has been made.

Table 10. OCC §319 progress toward TMDL goals, 2001-2008.

Total conventional row crop in basin at start of project: 98,289 acres			
BMP	**Total Amount Implemented (acres)**	**Goal for TMDL (acres)**	**% Towards TMDL Goal**
Row Crop Converted to No-Till	16,401	58,973	27.8
Row Crop Converted to Conservation Tillage	17,286	58,973	29.3
Convert Worst Row Crop to Pasture	12,462	19,658	63.4
Establish Riparian Buffers	169	8,547	2.0

A phosphorus load reduction of approximately **20%** has already been accomplished since 2001 due to a dramatic change in crop production in the watershed (ODEQ 2006). Specifically, many acres that were used for peanut production have now been converted to wheat production or pasture. According to the SWAT watershed model (Storm et al. 2006), if there was 100% conversion of row crops and wheat to no-till, total phosphorus loading would be expected to decrease by 34%. Based on the conversion of 16,000 acres to no-till, total phosphorus loading should be reduced by approximately **6%**. The maturation of other BMPs, installed as part of the 2001 and 2005 projects, will further reduce the phosphorus loading in the watershed.

Approximately one-third of the implementation from 2001-2008 occurred in areas that were expected to be contributing high levels of phosphorus, according to the SWAT model:

- Of the 9,188.6 acres that were in the top 10% of phosphorus load supplying areas, 32% now have BMPs on them;
- Of the 10,033.2 acres in the next 10% of high phosphorus areas, 27% have BMP implementation.

Figure 8, below, shows the overlay of implementation and targeting. Further details about the OCC implementation projects can be found in the final reports associated with the 2001 and 2005 projects.

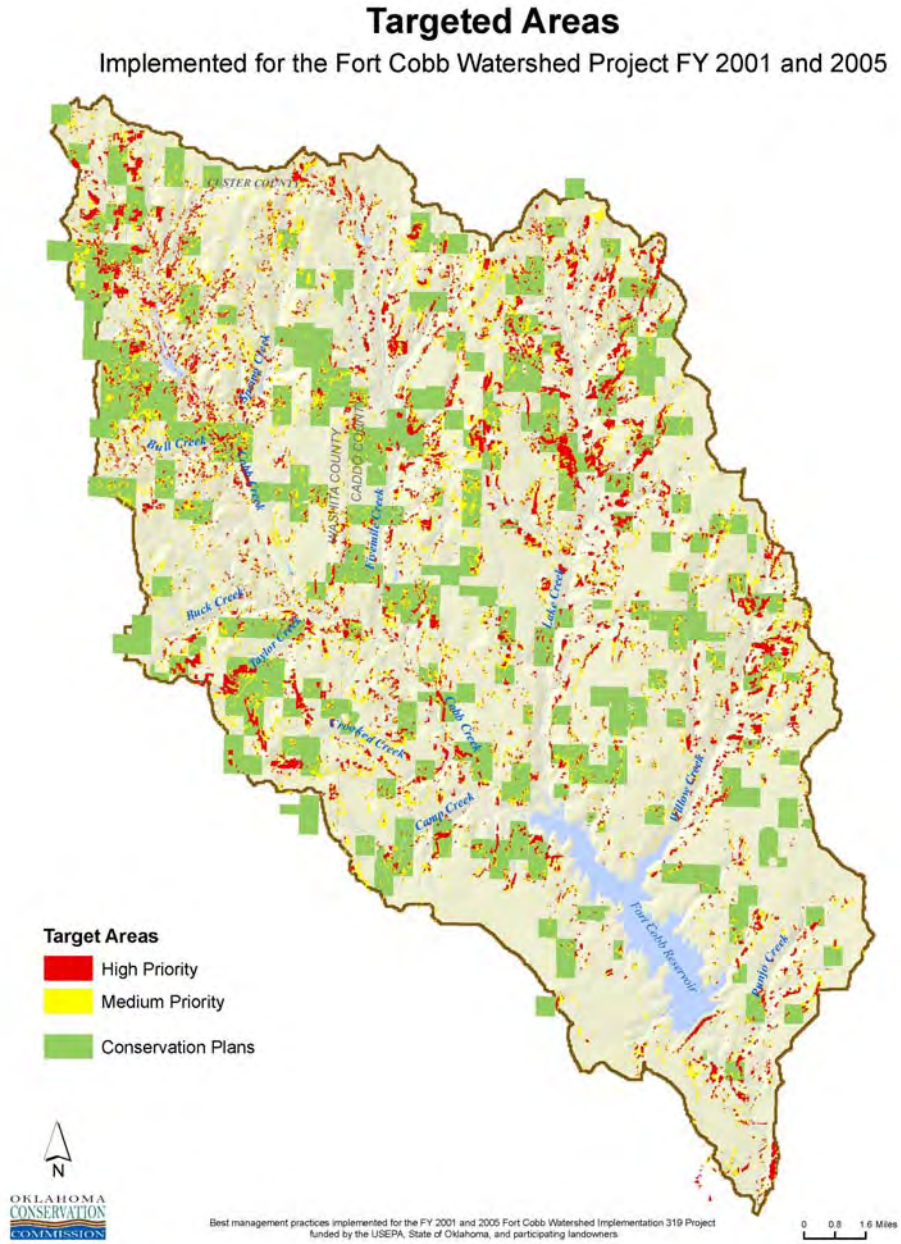


Figure 8. Overlay of regions of high phosphorus loading (targeted regions) onto areas of BMP implementation through the §319 program, 2001-2008.

A Conservation Reserve Enhancement Program (CREP) is planned for the Fort Cobb watershed beginning in 2010. This project aims to restore stable riparian vegetation and riparian buffers and to reduce livestock access to floodplains. This will result in reduced overland flow of pathogens and phosphorus to the streams and will lessen streambank erosion by stabilizing stream banks. Overall, this will lead to better water quality, lower maintenance requirements to the road and highway system, and will help to preserve existing floodplain cropland, pasture, and rangeland. The WBP will be updated at the conclusion of the CREP signup to estimate the load reductions expected from this implementation.

INTERIM MILESTONES

Interim milestones towards addressing the recommendations of the TMDL will continue to be developed as activities are implemented under the Watershed Based Plan. Some of these have already been completed through various project workplans, others are ongoing or planned.

Project	Description	Responsible Party	Target Date	Complete
TMDL	Compile watershed loading model and link to lake model	ODEQ, OSU	2003	**X**
	Calibrate model to water quality monitoring data	ODEQ	2003	**X**
	Develop draft TMDL	ODEQ	2004	**X**
	Solicit public input to draft TMDL	ODEQ	2005	**X**
	Submit to EPA	ODEQ	2005	**X**
2001 §319 Project	Hire Local staff- project and education coordinators and plan writer	OCC, Conservation Districts (CDs)	2002	**X**
	Establish agreements with CDs	OCC, CDs	2001	**X**
	Establish a WAG and EdWAG	CDs	2001	**X**
	Complete GIS-Based Targeting	OCC, WAG	2001	**X**
	WAG selection of BMPs and cost-share rates	WAG, OCC	2001	**X**
	Watershed Implementation Plan	OCC	2002	**X**
	BMP Demonstration	OCC, CDs	2002 – 2006	**X**
	Develop education program to educate producers and other watershed citizens about problems and solutions	EdWAG	2002	**X**
	Identify oil and gas related sources in the watershed	Corp. Comm	2001 - 2002	**X**
	Hire companies to plug abandoned wells	Corp. Comm.	As needed	**Ongoing**
	Educate current operators and when necessary take enforcement actions	Corp. Comm.	As needed	**Ongoing**
	Sample creeks, streams, and agricultural lands in watershed for pesticides and fertilizer-related parameters	ODAFF[8]	2002	**X**
	Conduct pesticide education programs	ODAFF	2001 - 2003	**Ongoing**
	Summary of Project Activities including estimation of load reduction due to practices implemented and comparison of implementation to TMDL recommendations	OCC, ODAFF, Corp. Comm.	2006	**X**

8 Oklahoma Department of Agriculture, Food, and Forestry

Project	Description	Responsible Party	Target Date	Complete
2005 §319 Project	Further delineate targeted areas based on TMDL recommendations	OCC	2006	**X**
	Implement no-till practices	OCC, CDs	2006 - 2008	**X**
	Update WBP	OCC	2008	**X**
	Follow-up GIS evaluation of implementation	OCC	2008 - 2009	**X**
	Instream Habitat Monitoring to Support ARS CEAP Project and evaluate success of BMPs	OCC	2006 - 2008	**X**
CEAP	Water Quality monitoring, watershed modeling, and compilation of BMPs implemented in watershed to evaluate impacts of BMPs	ARS, NRCS, OCC	2005 - 2010	**Ongoing**
CREP	Develop program plan with FSA and NRCS	OCC, FSA, NRCS	2003 – 2005	**X**
	Secure State match and Governor's approval	OCC, OSE	2007	**X**
	Submit plan to USDA	OCC, FSA, NRCS	2009	**Planned**
	Begin implementation	OCC, FSA, NRCS	2010 - 2013	**Planned**
EQIP	Explore possibility of declaring watershed a special emphasis area to secure higher funding level	FSA, NRCS, CDs	Annually	**Ongoing**
	Continue to implement EQIP practices annually in watershed			
CSP	Designate watershed as a CSP priority watershed	FSA, NRCS, CDs	???	**???**
WBP	Update Watershed Based Plan and evaluation of progress towards TMDL goals with watershed modeling at least every five years or more frequently upon completion of major tasks/projects	OCC, WAG	2012	**Ongoing**
Continue water quality monitoring to identify sources, causes, and progress towards TMDL goals		OWRB, Bureau of Recl., USGS, OCC, ARS	Annually	**Ongoing**

PUBLIC OUTREACH

Many local efforts, as well as efforts by state and federal agencies and other organizations, are collectively contributing to the Public Outreach efforts in the Fort Cobb Watershed. Public outreach will need to be continued in order to reach the water quality goals of restoring beneficial use support and attaining water quality standards in the watershed. This section identifies those agencies, organizations, and services that are active in the

watershed (in no particular order). To varying degrees, these groups have been, and will continue to be, active in development and expansion of the Watershed Based Plan and other planning efforts in the watershed. The roles of these groups and programs are summarized below:

1. Deer Creek, West Caddo, North Caddo, and Mountain View Conservation Districts

These agencies are critical to ensuring participation of local landowners in water quality improvement programs. Local Conservation Districts are generally the most effective means to bring a large federal or state program to private citizens because the local agencies know the local people. Local agencies often have the most accurate knowledge concerning current land management practices and local needs. In addition, these agencies have existing programs and mechanisms directed towards the goals of the WBP.

The Conservation Districts, partnered with the OCC, NRCS, and Cooperative Extension, have been among the primary agencies responsible for public outreach in the watershed. The districts and NRCS work one-on-one with citizens of the watershed to reduce pollution and educate about the importance of protecting water resources. These groups also organize or participate in seminars, training sessions, and meetings to interact with local people and provide technical assistance and information. The Deer Creek Conservation District has a very active education program through its outdoor classroom. This program targets mainly elementary school children and teaches them about environmental issues. In addition, Deer Creek has housed the Education Coordinator for the FY 2001 and 2005 §319 Fort Cobb Projects and served as the hub for education activities of that project.

2. Watershed Advisory Group (WAG) and Education Watershed Advisory Group (EdWAG)

The success of water quality protection programs in the Fort Cobb Watershed depends on the approval and cooperation of the local landowners and various government agencies. The WAGs were made up of local shareholders in the watershed (including private citizens, representatives of local industries, and local government) who provided guidance in delivering the §319 programs based on information supplied to them by technical agencies in conjunction with their knowledge of the needs of the watershed residents. The WAGs were developed to help insure that the programs most effectively worked towards reducing water quality impacts, but, at the same time, met the needs of and were acceptable to the local producers and other landowners. The WAG recommended the practices and cost-share rates to reduce the NPS pollution problems in the watershed. The EdWAG considered the issues in the watershed and recommended an education program to help inform watershed citizens about those issues using a “show and tell” approach.

3. The Oklahoma Conservation Commission (OCC)

With the 2001 project, the OCC devoted almost $2.3 million towards a program to educate citizens and implement best management practices to reduce nonpoint source pollution in the watershed. A portion of these funds support the WAG, a portion is devoted to

identifying the major sources in the watershed and monitoring the success of the program, another portion is devoted towards education, but the majority of the funds provides cost-share assistance to farmers to implement WAG-recommended and OCC-approved BMPs to protect the water resources of the watershed. This effort was extended through the FY 2005 program, which focused on recommendations of the TMDL, primarily no-till.

The OCC's main function is to provide oversight for successful completion of the program. To do this, they provide technical guidance and final approval to the WAG and local conservation districts for implementation of the BMPs. The OCC implemented an education program targeted towards citizens of the watershed whose change in behavior could have the most substantial impacts on water quality. The OCC is also responsible for monitoring the success and providing administrative support for the §319 projects, and working with NRCS and FSA to implement a CREP Program in the watershed.

In addition, Blue Thumb, OCC's education program, is active in the Fort Cobb watershed. Streams are monitored by volunteers and school groups are taught about water quality through this program.

4. Oklahoma Cooperative Extension Service (OCES)

The Oklahoma Cooperative Extension Service (OCES) is another leader in promoting water quality education efforts in the State, working closely with the conservation districts and the NRCS to promote water quality awareness. The OCES provides one-on-one meetings and education with landowners along with group presentations and other forms of technical assistance to improve awareness in the watershed. The OCES also develops and utilizes test plots and demonstration sites to educate producers about the effectiveness of certain best management practices. One such set of test plots, developed by the Oklahoma State University Cooperative Extension Service, was utilized to demonstrate methods of integrated pest management and effectiveness of more managed fertilizer application in wheat production. The OCES also holds public meetings and workshops to educate landowners on topics such as pesticide and fertilizer management, animal waste issues, and general BMPs.

5. NRCS Local Offices and FSA (USDA)

The United States Department of Agriculture Natural Resource Conservation Service (USDA/NRCS) and Farm Services Agency (FSA) in Oklahoma have several programs active in or that could be expanded in the Fort Cobb Watershed. These programs include the Environmental Quality Incentives Program (EQIP), Conservation Reserve Program (CRP) and Conservation Reserve Enhancement Program (CREP), Wildlife Habitat Incentives Program (WHIP), and the Wetlands Reserve Program (WRP). These programs are employed by the USDA to help landowners protect natural resources.

6. Oklahoma Corporation Commission (Corp. Comm.)

Corp. Comm., as the state agency with jurisdiction over oil and gas mining activities, has

ongoing efforts in the watershed to identify and reduce impacts from oil and gas activities. These include efforts to identify location and severity of erosion related to well sites and pipelines, followed by cleanup by the operators and pipeline companies. Corp. Comm. will begin additional work in the watershed to further identify problem areas in the watershed and initiate educational and other actions for site operators. These efforts range in extent from informing landowners about who to contact in the case of pollution occurring at well sites or exploration sites to what best management practices can be utilized during exploration and operation of oil and gas sites. Another focus of additional planned Corp. Comm. activities includes efforts to reduce impacts from abandoned oil and gas activities.

7. Oklahoma Department of Agriculture, Food, and Forestry (ODAFF)

The ODAFF has an ongoing project aimed at reducing impacts of fertilizers and pesticides to surface and groundwater in the watershed. The program has attempted to locate sources or likely sources of contamination from these fertilizers or pesticides and conduct educational programs to reduce the impact of those sources.

8. Bureau of Reclamation

Fort Cobb Reservoir is owned by the Bureau of Reclamation, which has played an active role in the watershed with cooperative efforts towards water quality monitoring, land management, and education.

9. Agricultural Research Service (ARS)

The ARS is currently pursuing a project to evaluate the success of BMPs implemented in the watershed through the Conservation Effects Assessment Project (CEAP). This program will involve water quality monitoring, watershed modeling, and cooperation with local conservation districts, NRCS, OCC and similar agencies to obtain current information on management practices in the watershed. Information will be shared regarding the success of programs and can be used to improve efficiency with cost-share and other implementation programs, as well as to evaluate progress towards meeting the goals of the TMDL.

Youth education is a significant effort pursued by OCES, NRCS, and the conservation districts. Most youth education activities focus on general water quality maintenance and improvement and include activities such as 4-H group water quality monitoring and education, “Earth-Day-Every-Day” activities fair where hundreds elementary school children and some of their parents are exposed to environmental education, and various other training sessions.

Newspaper articles and other media are a method that can be used to inform citizens of the watershed about programs focused on water quality. The OCES, Conservation Districts, and NRCS often contribute articles that were released to local papers, covering a wide range of topics related to water quality, and more specifically, advertising education

events and programs. Many articles serve as promotions for various upcoming trainings or other events. Other media related activities such as radio spots and logo contests can be used to further the efforts of the program. However, in using media and advertising in education programs, efforts must focus on measurable results. An information article about water quality is not enough; the article must be associated with some additional effort that is likely to change behaviors. Information alone doesn't often change people's behaviors; people must be persuaded to change their behavior. Persuasion is more likely to occur as part of a program of repeated contact and interaction than as the result of a well-written article in a newspaper.

Current outreach programs in the watershed will need to expand and perhaps partially redirect their public outreach efforts to work towards more measurable results. Although current education efforts are valuable programs, efforts may need to be expanded to insure that the target audience is being reached. The target audience is the people whose change of behaviors could have the most substantial benefits to water quality. In other words, the target audience in the Fort Cobb Watershed should include people such as county commissioners and road maintenance crews, agricultural producers, and people in the oil and gas industry, among others. Existing and planned outreach programs will need to coordinate among themselves and with other ongoing efforts in the watershed in order to educate more watershed citizens and more importantly, change behaviors of land users in the watershed.

Public Outreach to assure support of this and future evolutions the Watershed Based Plan will come from:

- Conservation District Newsletter and/or website
- Continued support the WAG or a similar group
- Public meetings and listening sessions held throughout the local communities (and eventually, throughout the watershed)
- Regular media coverage of activities/issues (both at local and State levels)
- Education programs such as the ones developed in the 2001 and 2005 §319 projects that involve segments of the community ranging from school children to agricultural producers to homeowners and lakeside residents
- Programs that encourage local citizens to experience "ownership and understanding" of environmental issues such as volunteer monitoring, clean-up events, and other educational grassroots efforts to address the problem

MONITORING PLAN

Every Watershed Based Plan requires a monitoring plan to gage overall success of restoration and remediation efforts. The goal of the monitoring plan for this WBP will be to expand current monitoring efforts into a long-range monitoring program with clearly defined milestones that will oversee the progress towards the TMDL recommended load reductions, restoration of the beneficial use support in the watershed, and preservation of natural resources for future generations.

The monitoring plan for this WBP provides for development of individual monitoring plans and associated quality assurance plans and Standard Operating Procedures for each underlying project or effort working toward the ultimate goal of restoration of beneficial use support. These monitoring efforts must be based on Oklahoma's Water Quality Standards and Use Support Assessment Protocols, which define the process by which beneficial use support can be determined. Technical assistance in developing these plans can come from various sources including the Oklahoma State Agency peer review process, and the Oklahoma Water Quality Monitoring Council. In addition, local stakeholders need to be involved in developing these plans to ensure that the plans address monitoring needs identified by stakeholders and that stakeholders remain informed about watershed monitoring activities.

Monitoring methodologies specified in this WBP have been selected to provide: 1) a quantifiable measure of changes in parameters of concern, 2) success measures that can be easily understood by cooperators and stakeholders with a variety of technical backgrounds, and 3) consistent, compatible information throughout the watershed. As the WBP evolves, it is anticipated that this list will expand and contract.

Monitoring will focus on the primary causes of impairment, as listed in the 303(d) list, but will also consider related causes that may exacerbate the impacts of the primary causes or may ultimately reach impairment levels without improved management. The primary types of monitoring to be conducted in the Fort Cobb Watershed include:

- Surface water quality: nutrients, sediments, suspended solids, fecal bacteria, dissolved oxygen, temperature, pH, conductivity, alkalinity, hardness, turbidity, chlorophyll-a, pesticides, BOD
- Hydraulic budget: in-stream flows, infiltration rates, aquifer recovery, groundwater levels
- Groundwater quality: nutrients, metals, pesticides, pH
- Landuse/Land cover: acreage in different landuses, quality and type of land cover, timing and other variables of associated management practices
- Riparian Condition: extent and quality of riparian zones in the watershed, to include quality and type of vegetation, degree of impact or stability, condition of streambanks, and primary source of threat or impact
- Aquatic Biological Communities: assessment of the condition of fish and benthic macroinvertebrate communities related to reference streams and biocriteria
- BMP and other implementation effort coverages: type, extent, and when possible, specific location of practices to include an estimate of the potential load reduction effected by implementation
- Behavioral change: participation in Watershed Based Plan-related activities and behavioral changes of affected communities
- Sediment quality: nutrients, pesticides, other organics of concern

With each WBP-related program, as well as for the WBP as a whole, baseline conditions will be established and monitored prior to implementation. A monitoring schedule and Quality Assurance Project Plan (QAPP) will be developed based on the type of project and

timing of its implementation. Monitoring results will be reported to appropriate local, state, and federal entities as defined in the QAPPs.

Baseline Data

The baseline data to evaluate progress in the Fort Cobb Watershed has been established by the draft TMDL. This includes watershed data from primarily the period between 1998 – 2001. Specifically, this data is listed below:

- 2000 census data to estimate watershed population and septic tank loading in the watershed
- SWAT model used:
    - Land use was determined using data retrieved from June 10, 2001 30 m resolution Landsat TM imagery, a crop type breakdown based on 1999-2001 Oklahoma Agricultural Statistics Service data, and center pivot irrigation locations tagged from aerial photos.
    - 1 meter resolution Digital Orthophoto Quarter Quads (DOQQ) from 1995 for the entire Fort Cobb Basin were used in ground-truthing the Landsat data.
    - Soil test phosphorus for common agricultural land covers was derived from OSU county level averages for the period 1995-1999.
    - The model was calibrated for flow for the period January 1990 through October 2001 and validated for flow in Cobb Creek for the period 1975 – 1989.
    - 10 m USGS DEM
    - 200 m NRCS MIADS Soils Data
    - EPA Reach3 Streams
    - National Inventory of Dams
    - County level National Agricultural Statistics Service (NASS) cattle estimates for the period 1996-2000 were combined with land cover data to estimate the number of cattle within the basin.
    - Approximate CAFO locations and animal numbers were taken from an Oklahoma Department of Agriculture coverage available at the ODEQ website. The metadata are listed at the following address: http://www.deq.state.ok.us/deqmap/help/CAFO.htm.
    - Few stream gage data were available to calibrate the SWAT Model for the period Jan 1990 - Oct 2001. The only suitable gage was Cobb Creek near Eakley (USGS 07325800). The hydrologic calibration was performed almost entirely with data from this gage. Another gage downstream of the Fort Cobb Reservoir was also utilized as a check of the calibration.
- OWRB and USFWS lake data collected in 1998-1999 was used to calibrate the model, and USGS and USFWS data collected in 2000–2001 was used to validate the model.
- Atmospheric deposition of nutrients was based on annual data for Oklahoma downloaded from National Atmospheric Deposition Program's web site. The average of the data from 1998 to 2001 was used in the model.
- Hourly weather data, daily flow data, and daily loadings (from the SWAT model) to the lake were also used in the model. Weather data was obtained from Oklahoma Mesonet for the Fort Cobb station. The data includes hourly atmosphere pressure,

air temperature, wind speed and direction, relative humidity, rainfall, and solar radiation. The hydraulic data was downloaded from Army Corps Of Engineer's web site (http://www.swtwc.usace.army.mil/FCOBcharts.html). The data includes daily inflow, release, pool elevation, and evaporation. Once again, 1998 – 1999 data was used in calibration, and 2000 – 2001 data was used in validation.

Data Collection Responsibilities for Current and Future Monitoring

Responsibility for the collection of additional data of the types described above will reside with project managers of the individual projects as spelled out their individual work plans. These project managers will be responsible for ensuring that the data is submitted to the ODEQ for inclusion in the Oklahoma State Water Quality Database, which will ultimately be uploaded to the National STORET database. Data reporting under individual workplans will also be the responsibility of the project managers. Monitoring results will be made public through the ODEQ's website, at a minimum. In addition, project and monitoring results should be presented locally with a public meeting or to the WAG or similar group.

In addition to those monitors to be identified in the workplans of the individual projects under this WBP, the following groups, at a minimum, will be involved in monitoring activities:

- Oklahoma Water Resources Board: Beneficial Use Monitoring Program and Oklahoma Water Watch Monitoring Program
- Oklahoma Conservation Commission: Rotating Basin Monitoring Program, Priority Watershed Project Monitoring, and Blue Thumb Project Monitoring
- U.S. Geological Survey: Surface and Groundwater quality and quantity monitoring and special studies
- Oklahoma Department of Agriculture, Food, and Forestry: soil sampling associated with CAFO regulations
- ARS: CEAP associated monitoring
- US Bureau of Reclamation

Currently, the OCC has two sites in the Fort Cobb watershed which are part of the Rotating Basin monitoring program. These sites were sampled every five weeks from 2004-2006 and will be sampled again from 2009-2011. The parameters measured include water temperature, dissolved oxygen, pH, specific conductance, alkalinity, turbidity, instantaneous discharge, nitrate, nitrite, orthophosphate, total phosphorous, total Kjeldahl nitrogen (TKN), ammonia, chloride, sulfate, total suspended solids, total dissolved solids, 5-day biochemical oxygen demand (BOD_5), and total hardness, as well as biological (fish and macroinvertebrates) and habitat data.

The OWRB has 6 sites in the reservoir from which physico-chemical data are collected quarterly. The parameters measured include turbidity, true color, dissolved oxygen, metals, chloride, sulfates, total dissolved solids, pH, nutrients, temperature, and chlorophyll-a.

The USGS has 5 "real time" gauging stations in streams in the Fort Cobb watershed, as

well as one reservoir station and a meteorological station from which data may be accessed. The parameters collected include temperature, instantaneous discharge, conductivity, dissolved oxygen, pH, nutrients, suspended sediments, and alkalinity.

The ARS has been monitoring 15 sites in the Fort Cobb watershed since 2004 as part of a national CEAP Watershed Assessment Study. Fortunately, Fort Cobb is included within one of the 12 benchmark watersheds in the US, and as a result, ARS, working collaboratively with the Great Plains RC&D, will complete an extensive bi-weekly water quality monitoring program. This program includes monitoring of the following paramters: pH, dissolved oxygen, conductivity, salinity, total dissolved solids, temperature, turbidity, oxygen reduction potential, nitrate concentration, ammonia concentration, suspended sediment, and phosphorus. The Great Plains RC&D will work collaboratively with ARS to contact farmers to obtain conservation and production management information relevant to the assessments.

Benefits of the Monitoring Plan

Implementation of this monitoring plan will enable Fort Cobb partners to meet the goals of the WBP, which is ultimately to restore beneficial use support to waters of the Fort Cobb Watershed. Implementation of the monitoring plan will help further define areas of the watershed where restoration activities should be focused to realize the optimum benefit for the investment as well as evaluating the impacts (realized and potential) of implementation efforts. Collection of the data described under this monitoring plan will help define the relative contributions from various sources in the watershed and the processes contributing to water quality degradation in the watershed. And finally, continued collection of this data and evolution of the monitoring plan for the watershed will allow the program to adapt to meet the changing needs of watershed protection in the Fort Cobb Watershed.

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APPENDIX A:

TMDL Development For Cobb Creek Watershed And Fort Cobb Lake

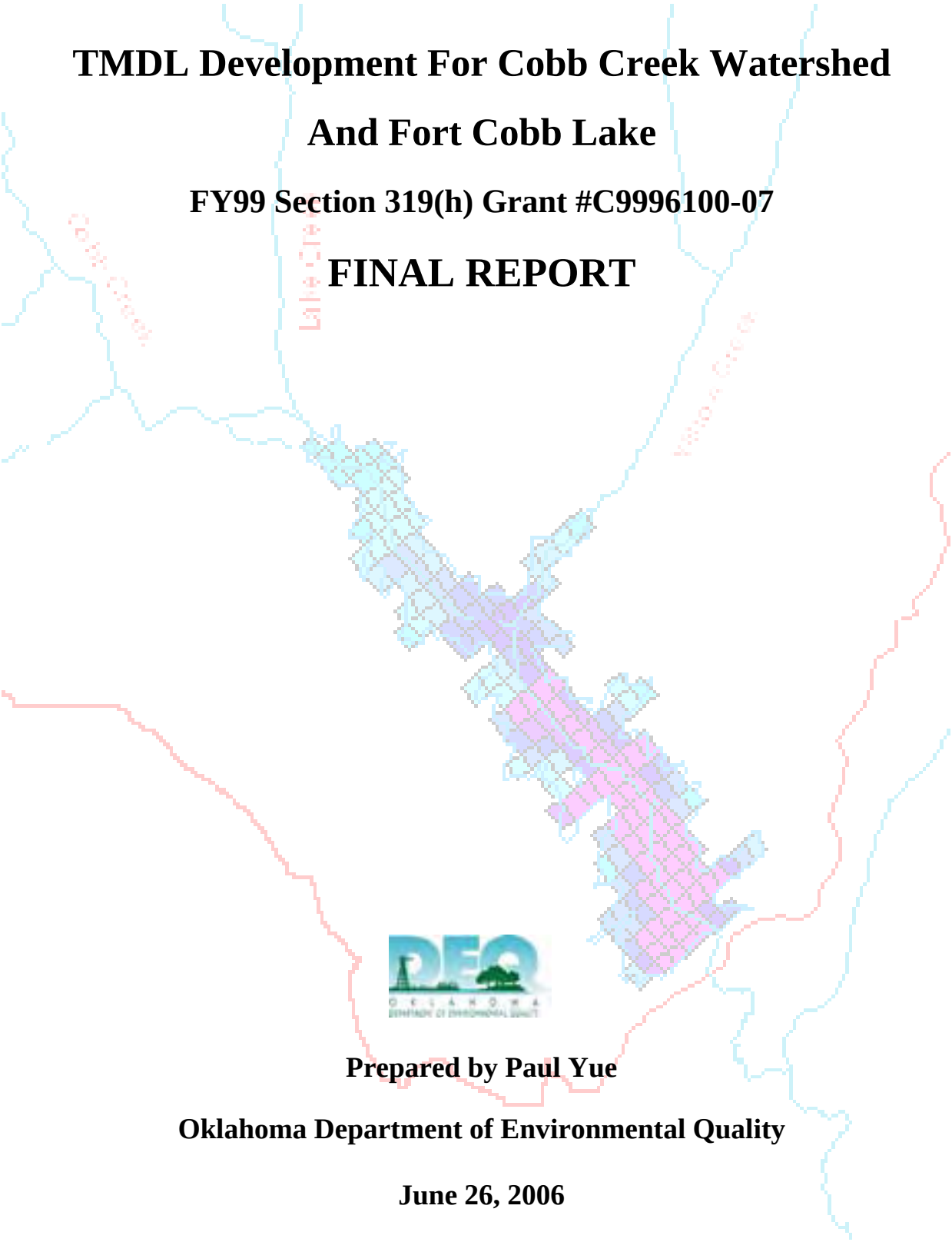
FY99 Section §319(h) Grant #C9996100-07

FINAL REPORT
2006

TMDL Development For Cobb Creek Watershed And Fort Cobb Lake

FY99 Section 319(h) Grant #C9996100-07

FINAL REPORT



Prepared by Paul Yue

Oklahoma Department of Environmental Quality

June 26, 2006

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Executive Summary

Cobb Creek watershed includes two HUC 11 watersheds, 11130302120 & 11130302130 and crosses three counties in west-central of Oklahoma. Fort Cobb is located at the lower end of the watershed and there are four tributaries (Cobb Creek, Lake Creek, Willow Creek, and Fivemile Creek) contributing to the lake. The watershed is primarily rural. There is no point source discharge in the watershed.

Fort Cobb Lake and four tributaries were listed in the Oklahoma 1998 303(d) list for nutrients, suspended solids, siltation, and pesticides. Fort Cobb Lake, Lake Creek and Willow Creek are listed in the 2002 303(d) list. This TMDL report addresses both the 1998 and 2002 303(d) lists.

There are several federal and state agencies collecting water quality data in the watershed. Data used in this project are gathered from U.S. Geological Survey, U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, Oklahoma Water Resources Board and Oklahoma Conservation Commission. The data were first used to check the status of impairments for all tributaries and Fort Cobb Lake. It was concluded that Cobb Creek, Lake Creek, Willow Creek and Fivemile Creek were not impaired with regard to nutrients and pesticides. It was also concluded that the Fort Cobb Lake was not impaired for pesticides.

The Fort Cobb Lake was used as the endpoint in the TMDL project. The TMDL targets were dissolved oxygen, anoxic volume and Trophic State Index (TSI) in the lake. Two water quality models were employed to link pollutant sources to water quality targets. A SWAT (Soil and Water Assessment Tool) model was calibrated to simulate nutrient loads to the lake. A three dimensional EFDC (Environmental Fluid Dynamic Code) model was calibrated and verified to model water quality in Fort Cobb Lake. The calibrated EFDC model was then used to predict how much reduction would be needed to restore the Fort Cobb Lake to meet all Oklahoma water quality standards. As a result, the model called for 78% reduction in nutrient load from the watershed. Due to the BMPs implemented in the recent years, it was estimated by the SWAT model that about 20% nutrient reduction had been achieved as of 2005. In order to achieve the recommended nutrient reduction, sediment load to streams and the lake will also be reduced. Therefore, the suspended solids and siltation impairments in Cobb Creek, Lake Creek, Willow Creek and Fivemile Creek are also addressed by this TMDL.

1. Introduction

1.1 Latest Revision

This TMDL report for Cobb Creek Watershed and Fort Cobb Lake was first drafted in 2004 and went through peer reviews among state agencies. Then, the report was sent to the EPA for technical review. After receiving the EPA's technical approval, the report was open for public review on November 24, 2004. A public meeting was held in the Town of Fort Cobb on January 13, 2005. The public review period ended on February 25, 2005. Five written comments were received during the public review period. Not all comments are addressed through the response to the comments process because the SWAT model for the watershed was recalibrated which leads to recalibration of the EFDC model for the lake. As a result, the following significant changes have been made to the TMDL reduction goal and this TMDL report:

1). Update on the SWAT Model

Since there were many questions on land use, tillage, fertilizer application rate, hydraulic calibration and so on, Oklahoma State University conducted a new survey in the Cobb Creek watershed to collect additional data. A detailed survey was given in 2005 to Oklahoma State University (OSU) Cooperative Extension Service Agents and Specialists to gain an understanding of agricultural practices and land cover that occurred from 1996 to 2001. This survey went into great detail about the different types of crops in the basin along with different tillage practices, common double crops, fertilization rates, cattle stocking rates, and harvest dates. With the newly collected data, OSU recalibrated the SWAT model. A pond option was also added to the SWAT model during the recalibration process. As a result, the SWAT model calibration was greatly improved. The newly calibrated model was used to generate nutrient inputs to the Fort Cobb Lake.

It should be emphasized that the SWAT model was calibrated to the conditions when water quality data were collected. Since then, the land cover in the watershed has been changed and certain BMPs have been implemented. In order to evaluate the improvement in nutrient

reduction that has occurred in the past few years, OSU also updated the SWAT model with 2005 land cover. The updated SWAT model predicted that on average 20% phosphorus reduction has been achieved since 2001.

2). Update on the EFDC Model

Although there is little difference in the average annual total phosphorus loadings (1995-2000) between the current and previous SWAT model, the difference in loadings from year to year ranges from -37% to 43%, especially for the calibration and verification periods of the EFDC model (as shown in red in the following table). The difference is significant enough to require a new calibration of the EFDC model for the Fort Cobb Lake.

Year	Total P (kg/yr)		Difference
	Previous Model	Current Model	
1995	257794	197000	30.9%
1996	34543	50000	-30.9%
1997	93353	104000	-10.2%
1998	**75933**	**53000**	**43.3%**
1999	47922	76000	-36.9%
2000	**53741**	**81000**	**-33.7%**
Average	**93881**	**93500**	**0.4%**

Trophic State Index (TSI) is the only TMDL target which is not met currently in the Fort Cobb Lake. Thus, TSI is the control factor in determining the reduction goal for this TMDL. A point-to-point comparison between predicted and observed TSI data and R^2 which measures the goodness-of-fit were added to the TMDL report in the model calibration. In addition, the same comparison was made for lake elevation and temperature calibration. Vertical temperature profiles were also added to the report to enhance the hydrodynamic calibration.

The recalibrated EFDC model was then used to predict the nutrient reduction rate needed to meet all TMDL targets. Due to the significant change in nutrient inputs to the lake, the TMDL reduction goal increased from 65% to 78%.

3). Nutrient Input from Migratory Birds

One comment suggested that direct defecation by migratory birds or waterfowl might be an important nutrient source. One section was added to this report to address the potential nutrient additions from waterfowl to Fort Cobb Lake.

Annual mid-winter waterfowl surveys were obtained from U.S. Fish and Wildlife Service for this assessment. Waterfowl in the lake are primarily ducks and small Canadian geese. The waterfowl phosphorus addition to the lake is estimated less than 2% of non-point source loading and primarily occurs in the winter. Therefore, we believe that waterfowl will have little impact on algae growth in the summer.

4). Other Revisions

In addition to the above major updates, many other changes were also made to this report. These changes include annual precipitation plot and EFDC control files etc. The annual rainfall data from 1975 to 2001 were plotted so that one would be able to see the representativeness and appropriateness of the calibration and verification period. The EFDC's master control files were attached at the end of this report so that those interested in the model parameters could check the final parameters used in the EFDC model.

1.2 Introduction

Under Section 303(d) of the Clean Water Act (CWA) as amended by the Water Quality Act of 1987 and the United States Environmental Protection Agency's (EPA) Water Quality Planning and Management Regulations [Title 40 of the Code of Federal Regulation (40 CFR), Part 130], states, territories, and authorized tribes are required to develop lists for those waters within their boundaries not meeting water quality standards applicable to their designated uses. States are also required to establish priority rankings for waters on the list and develop Total Maximum Daily Loads (TMDLs) for all pollutants violating or causing violation of applicable water quality standards for each identified waterbody in the list.

A TMDL specifies the maximum amount of a pollutant that a waterbody can receive while still meeting water quality standards, and allocates pollutant load among all point and nonpoint pollution sources. Such loads are established at levels necessary to meet the applicable water quality standards with consideration given to seasonal variations and margins of safety. The TMDL process establishes the allowable loadings of pollutants or other quantifiable parameters for a waterbody based on the relationship between pollution sources and in-stream water quality conditions. States then establish water quality-based controls and programs to reduce pollution from both point and nonpoint sources and restore and maintain the quality of their water resources [2].

Oklahoma's 1998 303(d) list identified all major streams (Cobb Creek, Lake Creek, Willow Creek, Fivemile Creek) and Fort Cobb Lake in the Cobb Creek watershed as not supporting their designated beneficial uses due to nutrients, suspended solids, siltation, pesticides, exotic species, unknown toxicity, and/or other habitat alterations. By definition, TMDLs can only be developed for specific pollutants. Exotic species, unknown toxicity and other habitat alterations are not pollutants that cause impairments of water being studied and are not within the scope of this report. This report addresses the remaining pollutants in the Cobb Creek watershed.

Cobb Creek watershed includes two HUC 11 watersheds, 11130302120 & 11130302130, which include portions of Caddo, Washita, and Custer counties in Oklahoma (Figure 1-1). At the lower end of the Cobb Creek watershed is Fort Cobb Lake.

Land use in the Cobb Creek watershed consists of forest (6%), pasture (41.4%), agricultural land (50.4%), water (2.1%) and urban area (0.1) [17]. The watershed is in one of the most intensive agricultural farming areas of the state. Over half of the state's peanuts are grown in or near the watershed, along with wheat, alfalfa and many other row crops [6]. The soils are very coarse and fragile, allowing for high infiltration rates and excessive erosion.

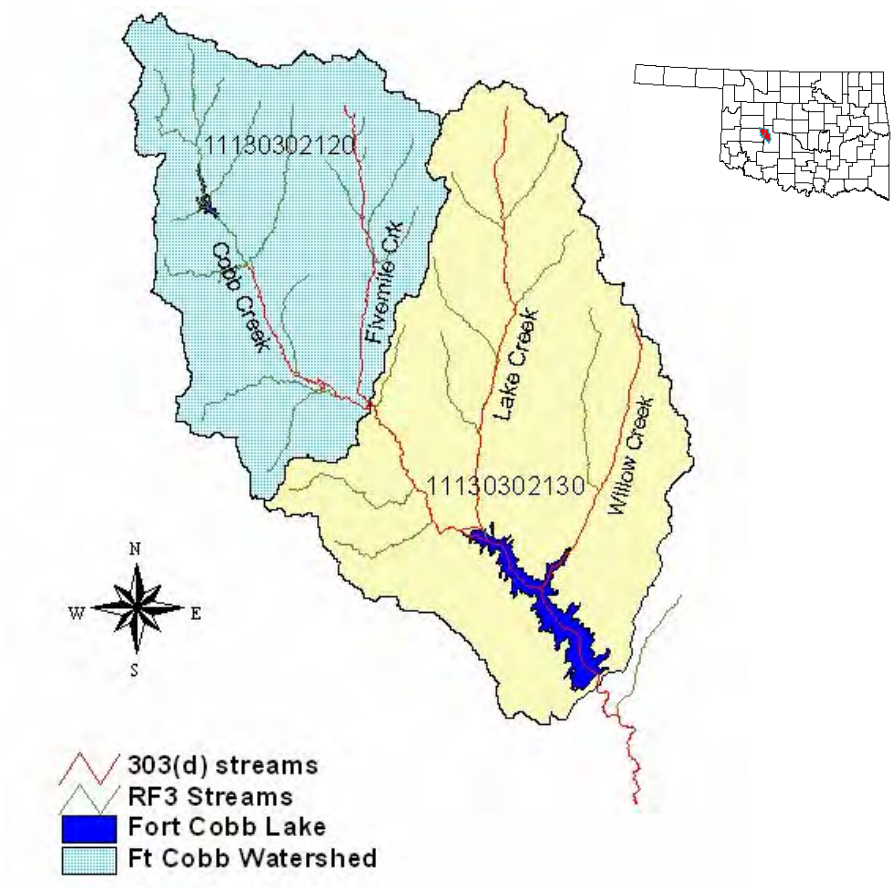


FIGURE 1-1. COBB CREEK WATERSHED STUDY AREA

This study consists of two modeling efforts: a watershed model to estimate non-point source loadings to the Fort Cobb Lake and a lake model to simulate hydrodynamics and water quality conditions in the lake and make comparisons to the applicable water quality criteria.

2. Problem Definition

Fort Cobb Lake and four streams were included in the Oklahoma 1998 303(d) list due to nutrients, suspended solids, siltation, pesticides, exotic species, unknown toxicity, and/or other habitat alternations. Since exotic species, unknown toxicity and other habitat alterations are not pollutants, they will not be included in this TMDL study and are not included in the following table.

TABLE 2-1: 1998 303(d) LIST FOR THE COBB CREEK WATERSHED

Waterbody ID	Name	Area (acres)/ Length (miles)	Nutrients	Siltation	Suspended Solids	Pesticide
OK310830060020	Fort Cobb Lake	3806			X	X
OK310830060010	Cobb Creek	17.3	X	X	X	X
OK310830060080	Fivemile Creek	12.2	X	X	X	
OK310830060040	Lake Creek	16.3	X	X	X	X
OK310830060030	Willow Creek	11.0	X	X	X	

All stream segments in Table 2-1 were assigned priority 3 in the 1998 Oklahoma 303(d) list. Since there are no permitted point source discharges in the entire watershed, the potential impairments are caused by the non-point sources in the watershed such as agricultural activities, cattle and limited small concentrated animal feeding operations (CAFO) in the watershed. There are two CAFOs in the watershed that are considered to be insignificant in the Soil and Water Assessment Tool (SWAT) model conducted by Oklahoma State University.

Because of the way the 303 (d) list was compiled and new information obtained through continuing data collection efforts, the 1998 303(d) list was revisited and reevaluated to determine whether the beneficial uses of waterbodies were still impaired by the listed pollutants. The Oklahoma 2002 Water Quality Assessment Integrated Report indicated that siltation impairments for Cobb Creek, Lake Creek, Willow Creek and Fivemile Creek and suspended solids impairments for Fort Cobb Lake, Cobb Creek, Lake Creek Willow Creek and Fivemile Creek were listed in error based on samples collected under high flow conditions. The siltation and

suspended solids impairments for Lake Creek were corrected to turbidity impairment in the Oklahoma's 2002 303(d) list.

The Oklahoma 2002 303(d) list (Table 2-2) shows the latest status of impairments and impairment source codes for streams and lakes in the watershed. The source code of 9000 in Table 2-2 stands for unknown source. The impairments for Cause Unknown and Pathogens are beyond the scope of this study and therefore will not be addressed in this report. The remaining pollutants, together with those in Table 2-1, are re-evaluated in this TMDL report.

TABLE 2-2. 2002 303(D) LIST FOR COBB CREEK WATERSHED

Waterbody ID	Name	Cause Unknown	Turbidity	Phosphorus	Low DO	Pathogens
OK310830060020_00	Fort Cobb Lake			9000		
OK310830060040_00	Lake Creek	9000	9000		9000	
OK310830060030_00	Willow Creek					9000

Fort Cobb Lake and all the streams in the watershed are designated in Oklahoma Water Quality Standards for the following beneficial uses:

- Public and Private Water Supply
- Warm Water Aquatic Community
- Agriculture
- Industrial & Municipal Process and Cooling Water
- Primary Body Contact Recreation
- Aesthetics
- Sensitive Public and Private Water Supply

In addition, the Fort Cobb watershed is also classified as a Nutrient Limited Watershed (NLW).

3. Applicable Water Quality Standards

3.1 Standards for Streams

3.1.a. Standards for nutrients

The Oklahoma Water Quality Standards (OWQS) do not have numerical criteria for nutrients that apply to the streams in the Cobb Creek Watershed. However, they contain the following narrative standard that applies to all streams and lakes in the state:

> "**785:45-5-19 (c) (2) Nutrients**. Nutrients from point source discharges or other sources shall not cause excessive growth of periphyton, phytoplankton, or aquatic macrophyte communities which impairs any existing or designated beneficial use".

The rules for implementation of Oklahoma's Water Quality Standards (OAC 785-46-15) [4] provide a framework that is used in assessing threats to waterbodies or impairments to beneficial uses by nutrients. The implementation rules describe a dichotomous process to be used in determining whether or not a stream is nutrient-threatened. If the dichotomous process indicates a stream is not threatened by nutrients, the stream will be considered not impaired by nutrients.

The dichotomous process uses the follow factors to determine if a stream is threatened by nutrients:

- Stream order
- Stream slope
- Total-Phosphorus (P) concentration
- Nitrate plus nitrite concentration
- Canopy shading
- Turbidity

The application of this dichotomous process to streams in Cobb Creek watershed was utilized to derive the threshold concentrations for Total-P and nitrate plus nitrite. If the mean value of Total-P and nitrate plus nitrite samples in a stream is below their corresponding threshold value,

the stream is considered not threatened by nutrients. Table 3-1 shows stream order, slope and the threshold values for Total-P and nitrate plus nitrite for streams in the Cobb Creek watershed.

As shown in Figure 3-1, the stream order is determined using the BASINS rf3 reach file [9]. The stream orders given in Table 3-1 are for those segments where samples were taken.

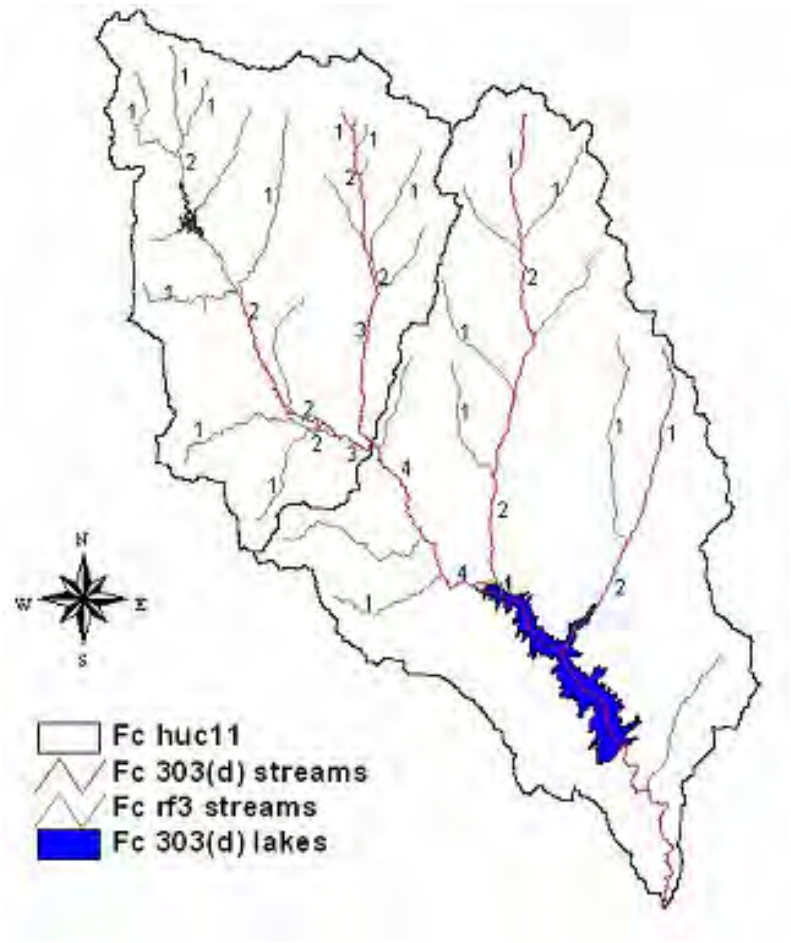


FIGURE 3-1. STREAM ORDER (COBB CREEK WATERSHED)

TABLE 3-1: THRESHOLD VALUES FOR STREAM TOTAL-P AND NO_2+NO_3

Stream	Stream Order	Slope (ft/mile)	Total-P (mg/L)	NO_2 + NO_3 (mg/L)
Willow Creek	2	<17	0.15	2.40
Lake Creek	2	<17	0.15	2.40
Trib to Lake Creek	1	≥ 17	0.24	4.95
Cobb Creek	4	<17	0.36	5.00

3.1.b. Standards for Dissolved Oxygen

The Oklahoma Water Quality Standards (OWQS) has the following criteria for dissolved oxygen:

Summer (Jun 16 – Oct 15): 4 mg/L

Seasonal (Oct 16 – Jun 15): 5 mg/L

The dissolved oxygen criteria must be maintained at all time.

3.2 Standards for Fort Cobb Lake

The Oklahoma Water Quality Standards do not contain numerical standards for nutrients and suspended solids; only narrative standards for nutrients and suspended solids can be found in the OWQS. However, it is very difficult to use narrative standards as the targets of this TMDL. The targets of a TMDL need to be numerical or quantified in some way.

Fort Cobb Lake and its watershed are classified in the OWQS as Nutrient-Limited Watershed (NLW). Nutrient-Limited Watershed, by definition, means a watershed of a waterbody with a designated beneficial use that is adversely affected by excess nutrients as determined by Carlson's Trophic State Index (using chlorophyll-a) of 62 or greater. According to the Implementation of Oklahoma's Water Quality Standards [4], the beneficial uses designated for Fort Cobb Lake are presumed to be fully supported but threatened. Since the lake is considered threatened when Carlson's Trophic State Index (TSI) is 62 or greater, a TSI value less than 62 was chosen as one endpoint of this TMDL.

In addition to TSI, dissolved oxygen criteria in the Oklahoma Water Quality Standards and the Implementation of Oklahoma's Water Quality Standards also apply to Fort Cobb Lake. The following endpoints are identified for this TMDL:

- Dissolved Oxygen (DO) for the surface water must meet the following requirements:
  - Summer (Jun 16 – Oct 15): 4.0 mg/L
  - Seasonal (Oct 16 – Jun 15): 5.0 mg/L
- Anoxic volume of water column in the lake must be less than 50%. The anoxic volume is defined as the vertical water column where the dissolved oxygen concentration is less than 2 mg/L.
- Carlson's Trophic State Index (TSI) must be less than 62. TSI can be calculated as follows:

$$TSI = 9.81 \times \text{Ln (chlorophyll-}a\text{)} + 30.6$$

  The unit of chlorophyll-*a* is μg/L.

Dissolved oxygen criteria must be maintained at all times. Anoxic volume and TSI criteria could not be exceeded more than 10% of the time in order to achieve compliance.

3.3 Pesticide Standards

Because Alachlor and Aldicarb were detected in both surface water and streamside seepage samples, pesticides were identified in the1998 303(d) list as a cause of impairment.

To determine whether the surface water is actually impaired, water quality criteria for the surface water need to be checked. Review of the pesticide monitoring data for Lake Creek indicates that none of the pesticides tested exceeds any water quality standards. .

Oklahoma Water Quality Standards do not have any numerical criteria specifically for Alachlor or Aldicarb. The following requirements for toxic substances in general apply:

> "For toxicants not specified in Table 2 of Appendix G of this Chapter, concentrations of toxic substances with bio-concentration factors of 5 or less shall not exceed 0.1 of

published LC_{50} value(s) for sensitive representative species using standard testing methods …".

"For toxicants not specified in Table 2 of Appendix G of this Chapter, concentrations of toxic substances with bio-concentration factors greater than 5 shall not exceed 0.01 of published LC_{50} value(s) for sensitive representative species using standard testing methods …".

Both Alachlor and Aldicarb are not specified in Table 2 of Appendix G of the OWQS.

The technical fact sheets of EPA's National Primary Drinking Water Regulations [12][13] indicate that the bio-concentration factors (BCF) for Alachlor and Aldicarb are 6 and 42, respectively. Since both BCF values are greater than 5, the target values for Alachlor and Aldicarb will be 0.01 of their published LC_{50} values.

Published LC_{50} values for Alachlor and Aldicarb were found from the following public resources:

- EXTOXNET, Extension Toxicology Network[15], which is a pesticide information project of Cooperative Extension Offices of Cornell University, Oregon State University, the University of Idaho, and the University of California at Davis and the Institute for Environmental Toxicology, Michigan State University. The USDA/Extension Service/National Agricultural Pesticide Impact Assessment Program provided major support and funding.
- Virginia Corporative Extension [14], Virginia Tech and Virginia State University.
- PAN Pesticides Database [8], derived from the U.S. EPA AQUIRE (AQUatic toxicity Information REtrieval) Database.

TABLE 3-2. PUBLISHED LC_{50} VALUES FROM DIFFERENT SOURCES

Reference	Chemical Name	LC_{50} (µg/L)		
		Fathead Minnow	Catfish	Common, mirror, colored, carp
EXTOXNET Extension Toxicology Network	Alachlor	-	6500	-
	Aldicarb	-	-	-
Virginia corporative Extension	Alachlor	-	-	-
	Aldicarb	-	-	-
U.S. EPA AQUIRE Database	Alachlor	5700	15700	5600
	Aldicarb	2700	23300	1000

Using the general methodology in the Oklahoma Water Quality Standards and the most stringent LC_{50} values in Table 3.2 for sensitive representative species, the target values for Alachlor and Aldicarb are calculated as 56.0 µg/L and 10.0µg/L, respectively.

3.4 Antidegradation Policy

Oklahoma antidegradation policy (OAC 785:45-3) requires protecting all waters of the state from degradation of water quality. The targets of this TMDL, resulting load reduction, and load allocations in this report were set with regard for all elements of the Oklahoma Water Quality Standards which includes the antidegradation policy. With the implementation of this TMDL, the water quality in Fort Cobb Lake and the streams in the watershed will be improving rather than degrading.

4. Impairment Assessment & TMDL Targets

Oklahoma's 2002 Water Quality Assessment Integrated Report has concluded that siltation and suspended solids impairments were listed in error for Cobb Creek, Lake Creek, Willow Creek and Fivemile Creek in the Oklahoma's 1998 303(d) list based on high flow high flow suspended solids and turbidity sampling. The siltation and suspended solids impairments for Lake Creek were corrected to turbidity impairment in the Oklahoma's 2002 303(d) list. Therefore, siltation and suspended solids will not be addressed in this report.

4.1. Status of Nutrient Impairment in Streams

Lake Creek, Willow Creek, Cobb Creek and Fivemile Creek are listed for nutrient impairment in the 1998 303(d) list. The Oklahoma Conservation Commission (OCC) conducted quarterly sampling on Lake Creek and its tributary during 1998 and 1999. The U.S. Geological Survey (USGS) sampled Fort Cobb Lake and its contributing streams during 2000 and 2001. These data are used to determine the status of nutrient impairment for Lake Creek, Willow Creek, and Cobb Creek

4.1.a. Data from OCC

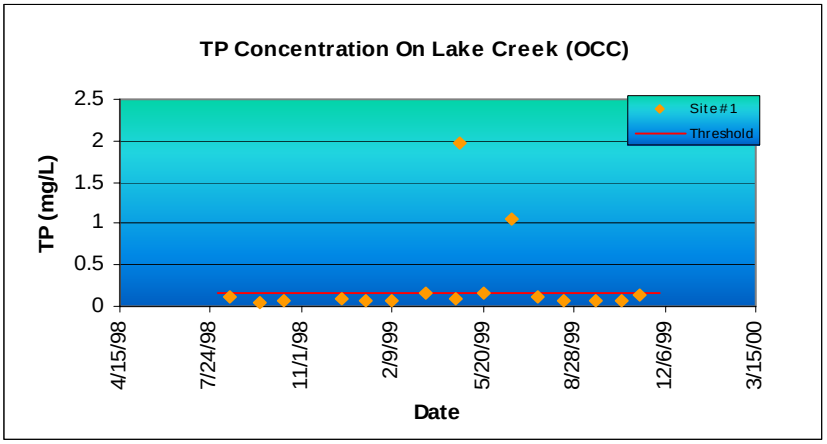
The Oklahoma Conservation Commission sampled five (5) sites in Lake Creek from August 1998 to October 1999. Table 2 shows the legal descriptions of the five monitoring sites.

Samples were collected monthly at Sites 1 & 4 for nutrients and salt analysis which included nitrate/nitrite, total Kjeldahl nitrogen, total P, sulfate, total suspended solids, chloride, and hardness. Monthly field data were collected concurrently at all five sites. Field monitoring included flow rate, dissolved oxygen, temperature, pH, specific conductivity, turbidity, and alkalinity. In addition to regular monthly monitoring, two high flow events were sampled for water quality and field data at Site 1 on April 25, 1999 and June 21, 1999.

TABLE 4-1. OCC WATER QUALITY MONITORING STATIONS

Monitoring Sites	Latitude	Longitude	Legal	County
Lake Creek #1	35° 15' 30.4" N	98° 31' 54" W	S12, T9N, R13W	Caddo
Lake Creek #2	35° 18' 16.6" N	98° 31' 36.2" W	S36, T10N, R13W	Caddo
Lake Creek #3	35° 20' 01.2" N	98° 31' 36.2" W	S24, T10N, R13W	Caddo
Lake Creek #4	35° 21' 45.7" N	98° 30' 56.8" W	S7, T10N, R12W	Caddo
Lake Creek #5	35° 24' 21.9" N	98° 31' 14.5" W	S 25, T11N, R13W	Caddo

Sampling Site #1 was located on Lake Creek and Site #4 on a tributary to Lake Creek. Figures 4-1 and 4-2 show the total phosphorus (TP) and nitrogen (NO2 + NO3) data and the corresponding threshold values for Lake Creek and its tributary.



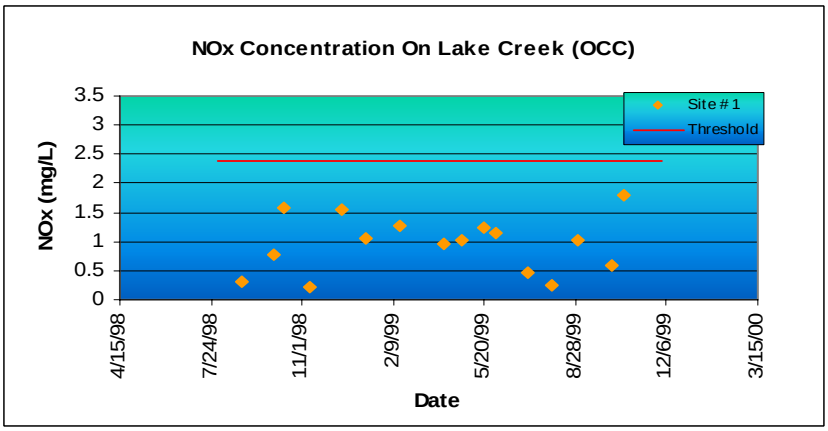
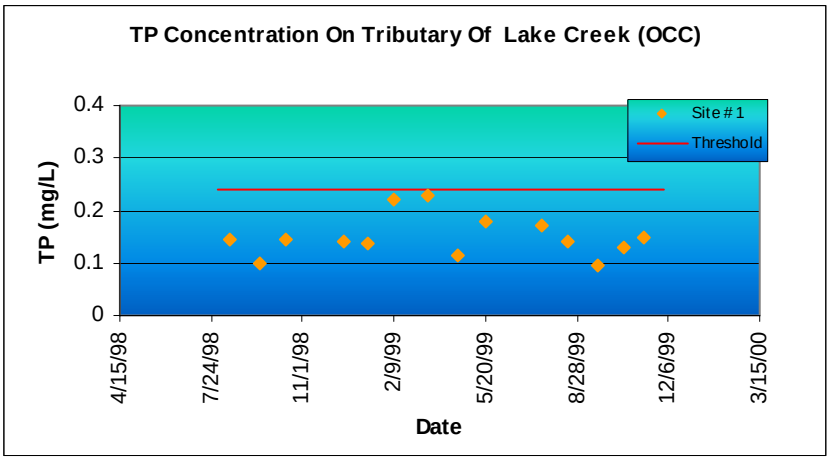


FIGURE 4-1. TOTAL-P, NO_3/NO_2 CONCENTRATION IN LAKE CREEK



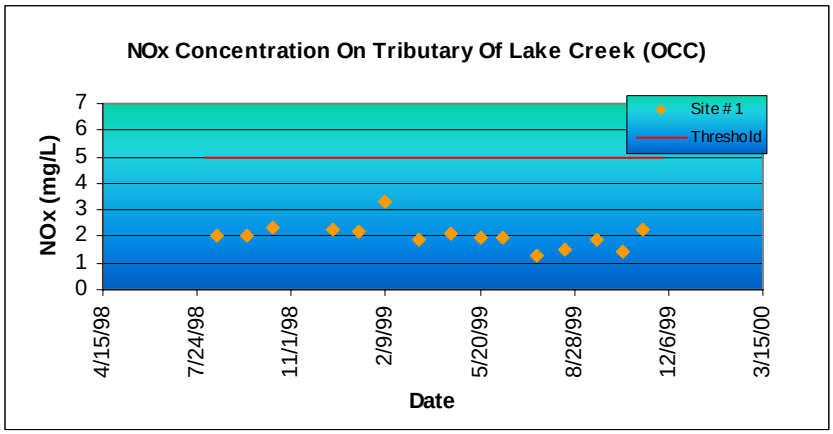


FIGURE 4-2. TOTAL-P, NO_3/NO_2 CONCENTRATION IN TRIBUTARY OF LAKE CREEK

If the mean of the samples does not exceed the threshold, according to the dichotomous process, the stream is not threatened by nutrients.

As shown in Figure 4-1 & 4-2, the mean values of TP or NO_2 + NO_3 of all samples are well below their corresponding threshold values. Both Lake Creek and its tributary are not nutrient-threatened so they are not nutrient-impaired.

4.1.b. Data from USGS

Bi-monthly monitoring was conducted from June 2000 to June 2002 at 26 sites (Figure 4-3). Sixteen sites are located in Fort Cobb Lake and ten sites in three major tributaries, namely Lake

Creek, Cobb Creek and Willow Creek. The sites in the lake were designed to characterize the spatial trend of the lake water quality. The sites in the tributaries were intended to determine the source and load of nutrients to the lake.

Parameters monitored included temperature, pH, DO, specific conductivity and Oxidation Reduction Potential (ORP), hardness, nitrate/nitrite, ammonia, total nitrogen, total phosphorus, Soluble reactive phosphorus (SRP), particulate organic carbon.

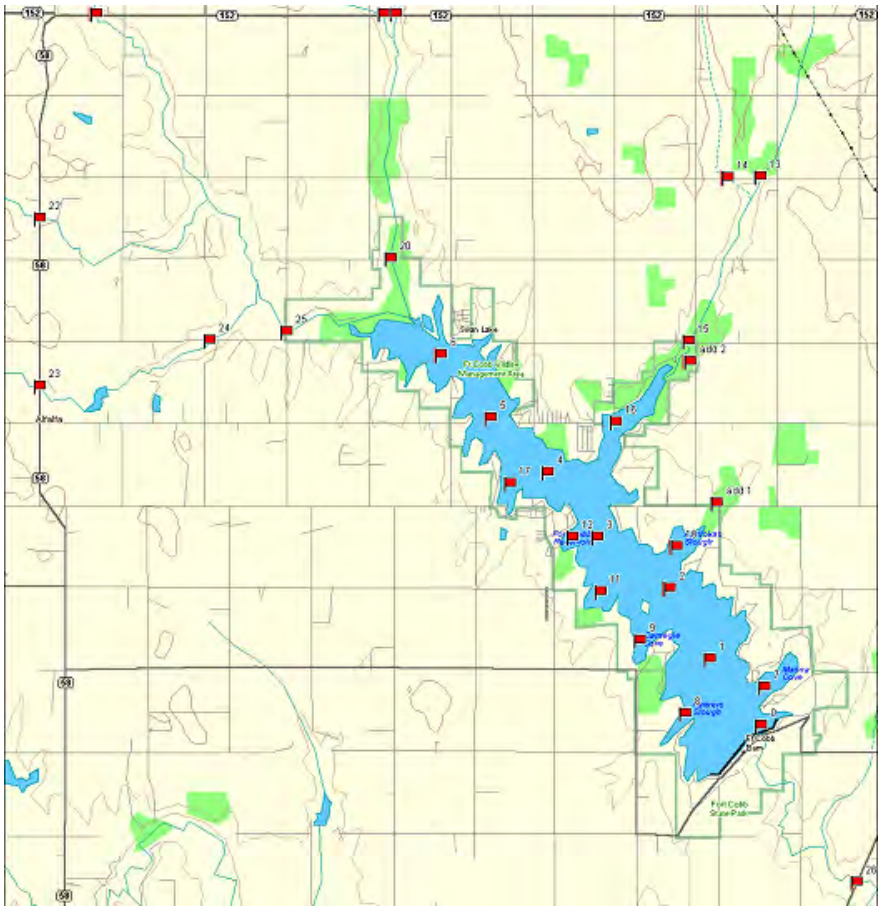
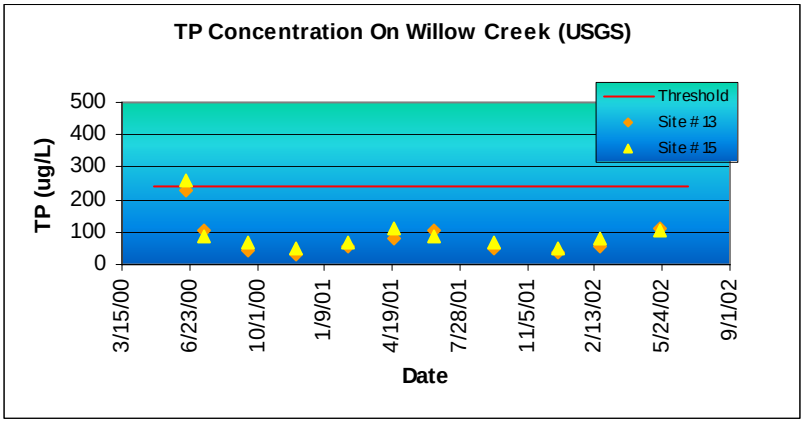


FIGURE 4-3. USGS MONITORING STATIONS (PROVIDED BY USGS)



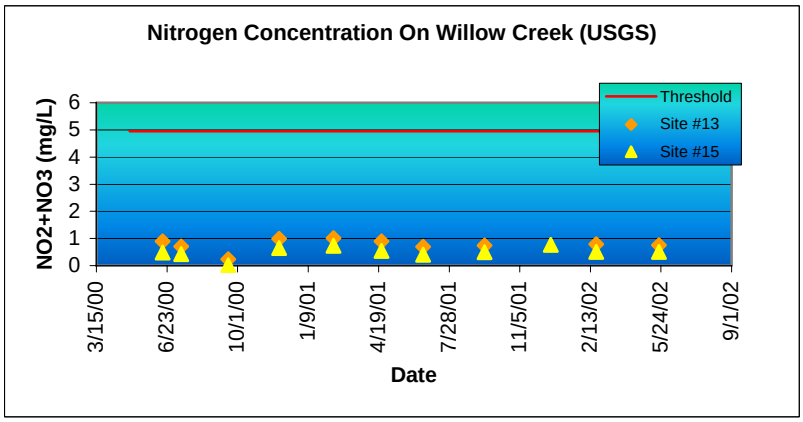
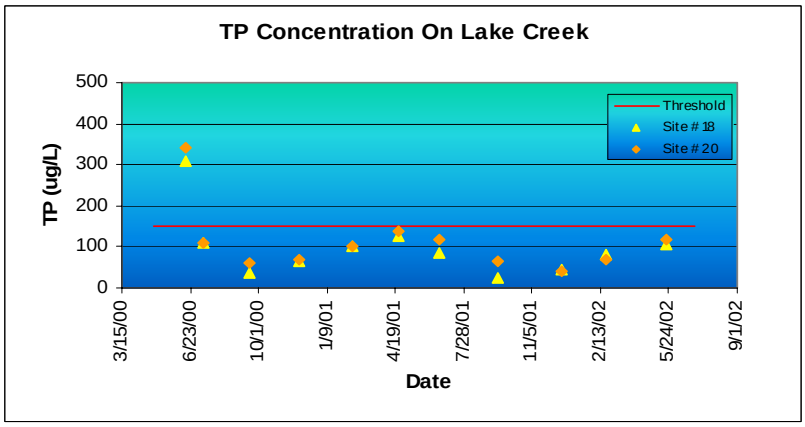


FIGURE 4-4. TOTAL-P, NO_3/NO_2 CONCENTRATION IN WILLOW CREEK



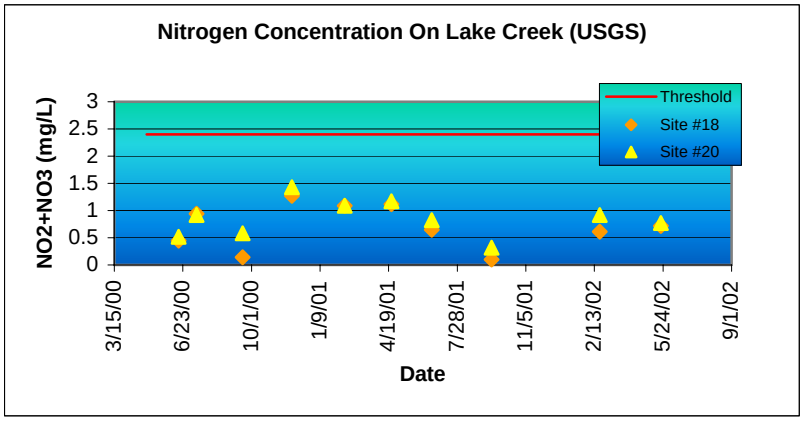
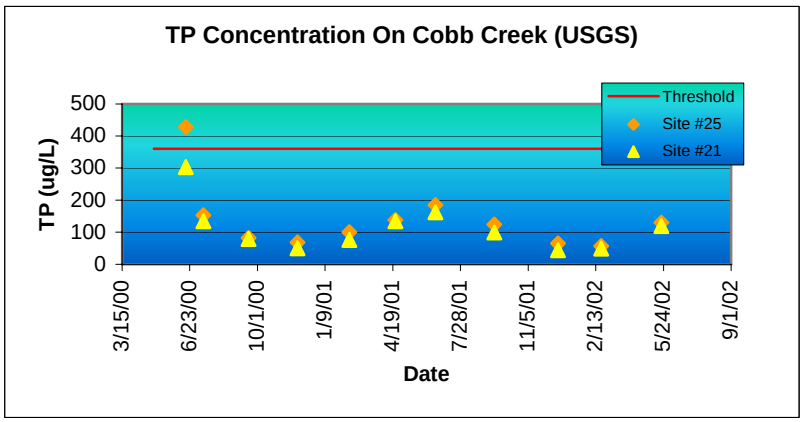


FIGURE 4-5. TOTAL-P, NO_3/NO_2 CONCENTRATION IN LAKE CREEK



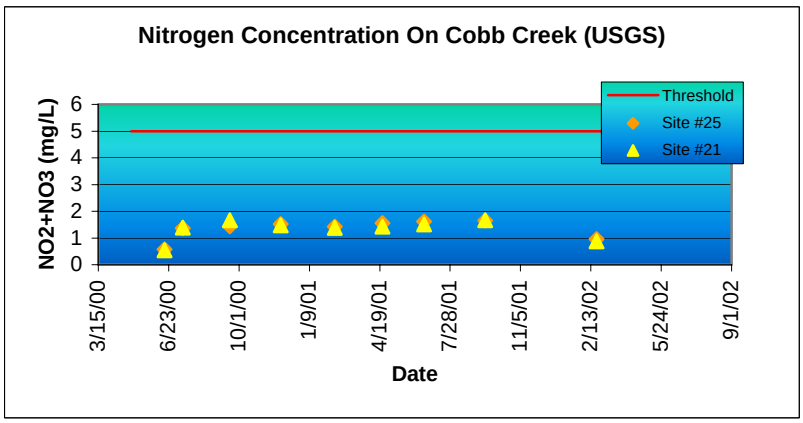


FIGURE 4-6. TOTAL-P, NO_3/NO_2 CONCENTRATION IN COBB CREEK

As shown in Figure 4-4, 4-5 & 4-6, the mean values of TP or NO_2 + NO_3 are well below their corresponding threshold values (Table 3-1). Cobb Creek, Lake Creek and Willow Creek are not nutrient-threatened and therefore are not nutrient-impaired.

There is not enough data on Fivemile Creek to assess the status of nutrient impairment. USGS collected only three samples on site 29 & 30. No samples exceeded TP or TN threshold values. In addition, the 2002 Water Quality Assessment Integrated Report [16] indicated that the nutrient impairment for Fivemile Creek was listed in error in the 1998 303(d) list.

4.2. Status of Nutrient Impairment in Fort Cobb Lake

In addition to the data collected by USGS in Fort Cobb Lake, Oklahoma Water Resources Board (OWRB) and U.S. Fish & Wildlife Service (USFWS) also conducted quarterly sampling in the lake. These data are used to determine the status of nutrient impairment for Fort Cobb Lake.

Fort Cobb Lake was not listed in the 1998 303(d) list for nutrient impairment but was included on the 2002 list. The available data support the listing.

Oklahoma Water Resources Board has conducted quarterly water quality monitoring at six sites in Fort Cobb Lake from July 1998 to July 1999. Figure 4-7 shows the six sampling sites. The monitored water quality parameters include NH_3, NO_2, NO_3, Total N, Organic N, TKN, Ortho-P, Total P, Settleable and Suspended Solids, Chloride, Chlorophyll-*a* and Turbidity. Field data include temperature, dissolved oxygen, pH, Conductivity, Total Dissolved Solid (TDS) and other parameters at different depths in the water column. USGS conducted bi-monthly water quality sampling on sixteen sites in Fort Cobb Lake, (Figure 4-3). The sampling started in June of 2000 and ended in June of 2002. Depth profiles of temperature, pH, DO, specific conductivity and Oxidation Reduction Potential (ORP) were conducted for sites in the lake. Water samples for laboratory analysis were collected as a surface composite and analyzed for nutrients (TN, TP, NO_2/NO_3, NH_3, SRP), Chlorophyll-*a*, particulate organic carbon (POC) and physical chemistry (pH, alkalinity, hardness, turbidity, conductivity, and total dissolved solids). In addition, samples were collected for algae taxonomy.

U.S. Fish & Wildlife Service, sponsored by U.S. Bureau of Reclamation, conducted quarterly water quality sampling on sixteen sites on Fort Cobb Lake, its tributaries and outflows (Figure 4-8). The sampling started in November of 1997 and ended in June of 2000 [11].

FIGURE 4-7. OWRB MONITORING STATIONS IN FORT COBB LAKE

The constituents analyzed include conductivity, turbidity, chlorophyll-*a*, COD, total phosphorus, soluble reactive phosphorus, total alkalinity, chloride, sulfate, total nitrogen, nitrate, nitrite and ammonia. In addition, other constituents such as metals etc. were also analyzed in water samples. However, these parameters are not in the scope of this TMDL. A review of the data for these parameters does not show any violations of water quality standards.

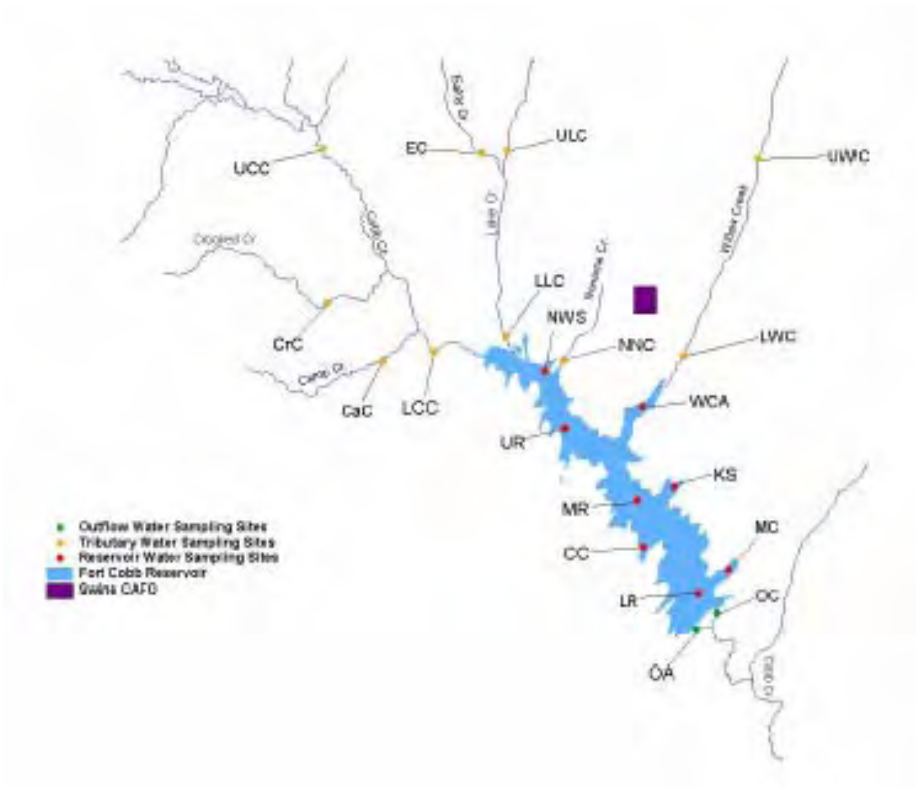


FIGURE 4-8. USFWS MONITORING STATIONS

The TSI data from USGS, OWRB and USFWS is summarized in Table 4-2. The aesthetics beneficial use for Fort Cobb Lake is considered not threatened with respect to nutrients if planktonic chlorophyll-*a* samples in the water column indicate a Carlson's Trophic State Index of less than 62.

TABLE 4-2. SUMMARY OF TSI DATA

Agencies	Median TSI	Min TSI	Max TSI	# Of TSI >= 62	Total # Of TSI	% Of TSI >= 62
OWRB	63.7	34.0	77.6	21	34	62%
USGS	61.2	38.8	85.2	67	158	42%
USFWS	61.8	41.7	78.8	34	72	47%

Data in Table 4-2 support the 303(d) status that Fort Cobb Lake does not support the Aesthetics beneficial use with respect to nutrients.

4.3. Status of Pesticide Impairment

Samples for organics and herbicides were taken by the OCC from August 1998 to June 1999. Immunoassays for pesticides (2,4-D, Alachlor, Aldicarb, Atrazine, Captan, Carbofuran, Chlorothalonil, Chlorpyrifos, Cyanazine, Metolachlor, Metribuzin, Paraquat, Picloram, and Triclopyr) were performed twice monthly during the spring & summer (March – October) and once monthly during fall and winter (November – February).

TABLE 4-3. LC-50 VALUES AND TARGET CRITERIA FOR PESTICIDES

Pesticides	LC-50 (µg/L)			Target Criteria (µg/L)
	Fathead Minnow	Channel Catfish	Common, mirror, colored, carp	
2,4-D	191500	7000	58271	70.0
Alachlor	5700	15700	5600	56.0
Aldicarb	2700	23300	1000	10.0
Atrzine	15000	4982	28467	49.8
Captan	155	78.3	250	0.78
Carbofuran	1264	629	1405	6.29
Chlorothalonil	-	81.5	110	0.82
Chlorpyrifos	178.5	457	76.9	0.77
Cyanazine	18630	12862	-	128.6
Metolachlor	8200	4900	-	490.0
Metribuzin	-	32540	-	325.4
Paraquat	-	100000	78500	785.0
Picloram	64033	13571		135.7
Triclopyr	NA for above species, but >1000 for all other tested species			10.0

Table 4-3 shows the target criteria for each pesticide. The target criteria are determined by multiplying the minimum LC_{50} by 0.01 for each pesticide. The LC_{50} values are derived from the U.S. EPA AQUIRE database.

The pesticide data collected by the OCC were compared with the criteria in Table 4-3 for each pesticide to determine the status of pesticide impairment for Lake Creek. Since no pesticide data exists for Cobb Creek and Fort Cobb Lake, the evaluation of the status of pesticide impairment relies on the comparison of the data for Lake Creek and the prediction of the Soil and Water Assessment Tool (SWAT) model performed by Oklahoma State University.

4.3.a. Lake Creek

OCC collected pesticide data on different sites of Lake Creek from August 1998 through October 1999. Alachlor and Aldicarb are the only two pesticides that were detected in both surface water and streamside seepage samples. We believe this is the reason that Alachlor and Aldicarb were listed in the 1998 303(d) list. Alachlor was detected in 13 of the 76 total samples and Aldicarb was detected in 19 of the 62 total samples. The highest concentration measured was 0.26 µg/L for Alachlor and 1.58 µg/L for Aldicarb. Both values are well below the corresponding target values.

Other pesticides were screened against the target criteria (Table 4-3). None of the measured data exceeds the corresponding target criteria. Therefore, it can be concluded that pesticides do not impair Lake Creek.

4.3.b. Cobb Creek

In addition to Lake Creek, Cobb Creek and Fort Cobb Lake are listed in the 1998 303(d) list for pesticide impairment. No monitoring data are available for either of the water bodies.

Oklahoma State University has performed a SWAT model to simulate nutrient and pesticide loadings from the Fort Cobb Watershed [17]. The model is calibrated for flow and nutrients, but it is not calibrated for pesticides because of limited pesticide data. The model is not suitable for predicting the actual pesticide mass loadings from the watershed but is adequate for comparison of the relative pesticide loadings from different sub-watersheds.

A comparison of land uses in Lake Creek sub-basin and Cobb Creek sub-basin are made in Table 4-4. Both sub-basins have a majority of land used for agricultural practices where pesticides are normally applied. The percentage of agricultural land in the Lake Creek sub-basin is slightly

higher than that in the Cobb Creek sub-basin. The SWAT model was calibrated for pesticides based on data collected in Lake Creek. When the same calibrated parameters are applied to the Cobb Creek sub-basin, the model should give a conservative prediction of pesticides on a relative basis.

TABLE 4-4. LAND USE COMPARISON FOR COBB CREEK AND LAKE CREEK SUB-BASINS

Land Use Name	Land Use (%)	
	Cobb Creek Sub-basin	Lake Creek Sub-basin
Urban or Built-up Land	0.3%	0.5%
Agricultural Land	85.7%	92.2%
Forest Land	0.1%	1.8%
Range Land	13.6%	5.5%
Barren Land	0.0%	0.0%
Water	0.3%	0.0%

Pesticide loadings and concentrations from the Cobb Creek sub-basin and the Lake Creek sub-basin as predicted by the SWAT model are shown in Table 4-5.

TABLE 4-5. PESTICIDE LOADINGS (APRIL 1999 – AUGUST 1999)

	Pesticide Loading (kg)	Total Accumulative Flow (m^3)	Average Pesticide Concentration (µg/L)
Cobb Creek	394.9	1.42E+07	0.28
Lake Creek	300.4	9.78E+06	0.31

The pesticide loading in Table 4-5 is the loading from April 1999 to August 1999. The loading for other months of the year is negligible because little or no pesticides are applied in these months.

As shown in Table 4-5, the predicted pesticide concentration in Cobb Creek is even lower than that in Lake Creek. Because the observed pesticide concentrations in Lake Creek are well below the standards and the pesticide concentrations in Cobb Creek are relatively lower than those in

Lake Creek, we can conclude that the pesticide concentration in Cobb Creek is well below the standards. In other words, pesticides do not impair Cobb Creek.

4.3.c. Fort Cobb Lake

It is safe to assume that the only source of pesticides to Fort Cobb Lake is pesticides in stream flows of the tributaries to Fort Cobb Lake. Since none of Fort Cobb Lake's tributaries are impaired by pesticides, a simple mixing model can show that Fort Cobb Lake is not impaired by pesticides.

Assume :

V_i = volume from stream i, (i = 1,2,…n)

V = volume after mixing, $V = V_1 + V_2 + \ldots + V_n$

C_i = concentration in stream i, (i = 1,2,…n)

C_0 = critical concentration, $C_0 > C_i$ for i = 1,2,…n

C = concentration after mixing

Based on mass balance, we get:

$$V \cdot C = V_1 \cdot C_1 + V_2 \cdot C_2 + \ldots + V_n \cdot C_n$$

Substitute C_i with C_0:

$$V \cdot C < C_0 \cdot (V_1 + V_2 + \ldots + V_n)$$

Cancel volume on both sides:

$$C < C_0$$

Therefore, we can conclude that the water after mixing is not impaired if none of the tributaries is impaired.

4.4. Status of Dissolved Oxygen Impairment for Lake Creek

Dissolved oxygen for Lake Creek is not listed in 1998 303(d) list. However, it is listed in 2002 303(d) list (Table 4-5). Further inquiry showed that low DO for Lake Creek was added on the 2002 list based on data from Oklahoma Conservation Commission (OCC).

Oklahoma Conservation Commission measured dissolved oxygen on five sites in Lake Creek from May 1998 to October 1999. A total of 119 dissolved oxygen samples were taken. All measurements are above dissolved oxygen standards for streams. Therefore, Lake Creek is not impaired by low dissolved oxygen. We believe the low DO listing was listed in error in 2002 303(d) list.

4.5. Endpoint and Targets for Fort Cobb TMDL

This TMDL addresses turbidity impairment for Lake Creek and phosphorus impairment for Fort Cobb Reservoir. Since phosphorus is mostly found attached to sediment or TSS (which is closely related to turbidity), if phosphorus loading is reduced to meet water quality standards in Fort Cobb Lake, turbidity levels in the contributing streams, including Lake Creek, will also be reduced, thus meeting the turbidity standard.

This TMDL study consists of two modeling efforts: a watershed model to estimate non-point source loadings to Fort Cobb Lake and a lake model to simulate hydrodynamics and water quality conditions in the lake. Following are the selected endpoint targets of the TMDL:

- Trophic State Index (chlorophyll-*a* based) less than 62
- Dissolved Oxygen (surface water)
  - Summer (Jun 16 – Oct 15): 4.0 mg/L
  - Seasonal (Oct 16 – Jun 15): 5.0 mg/L
- Anoxic volume less than 50% of water column

5. Source Assessment

This TMDL report examined the major potential sources of nutrients in the Fort Cobb watershed. The source assessment was used as the basis for developing the modeling strategy and ultimate analysis of the TMDL allocation options. To evaluate sources, loads are characterized by the best available information, monitoring data, literature values, and local management activities. This section documents all the available information and interprets it for modeling analysis.

5.1. Assessment of Point Sources

There is currently no permitted wastewater discharge in Fort Cobb watershed. Regulated storm water discharges are also considered as point source pollution and must be addressed by the wasteload allocation component of a TMDL. In Oklahoma, storm water discharge permits are divided into two categories: industrial and construction. The database for storm water discharges (updated as of May of 2004) shows no permitted storm water discharge in the Fort Cobb watershed (Figure 5-1) and no regulated municipal separate storm sewer system discharge. This does not necessarily mean there will be no storm water permits in the watershed in the future. The conditions in storm water permits will be sufficient to protect waters in the watershed.

There are four Concentrated Animal Feeding Operation (CAFO) farms in the Fort Cobb watershed (Table 5-0). All four CAFOs are located in Caddo County.

TABLE 5-0. CAFO FACILITIES IN COBB CREEK WATERSHED

Name	Location	Farm Type	Total units
Harvey Farms	NE of S33, T11N, R13W	Cattle	2700
Terry Lierle	SE of S30, T11N, R13W	Swine	800
Maschhoff West Randolph sow & nursery	NW/SW/SW of S09, T11N, R13W	Swine	3096
Farmers F & F Farms Inc	SE/NE of S20, T08N, R12W	Cattle	750

A CAFO is an animal feeding operation that confines and feeds 1,000 animal units or more for 45 days or more in a 12 month period. An animal unit is a measure that is used to compare different animal species. According to the EPA, 1000 animal units is equivalent to 1000 cattle

excluding mature dairy and veal cattle, 10,000 swine weighed 55 pounds or less, or 100,000 chickens.

The NPDES permit for CAFOs with less than 1000 animal units is encouraged but not required. Both Harvey Farms and Terry Leirle have a total retention permit. Overflows are allowed for these farms only under 25-year 24-hour storm events. The provisions in these NPDES permit are sufficient to protect the waters in the Cobb Creek watershed. No additional measures will be required for these CAFO farms. The animal waste produced by CAFOs is considered non-point pollution that is addressed in the following section.

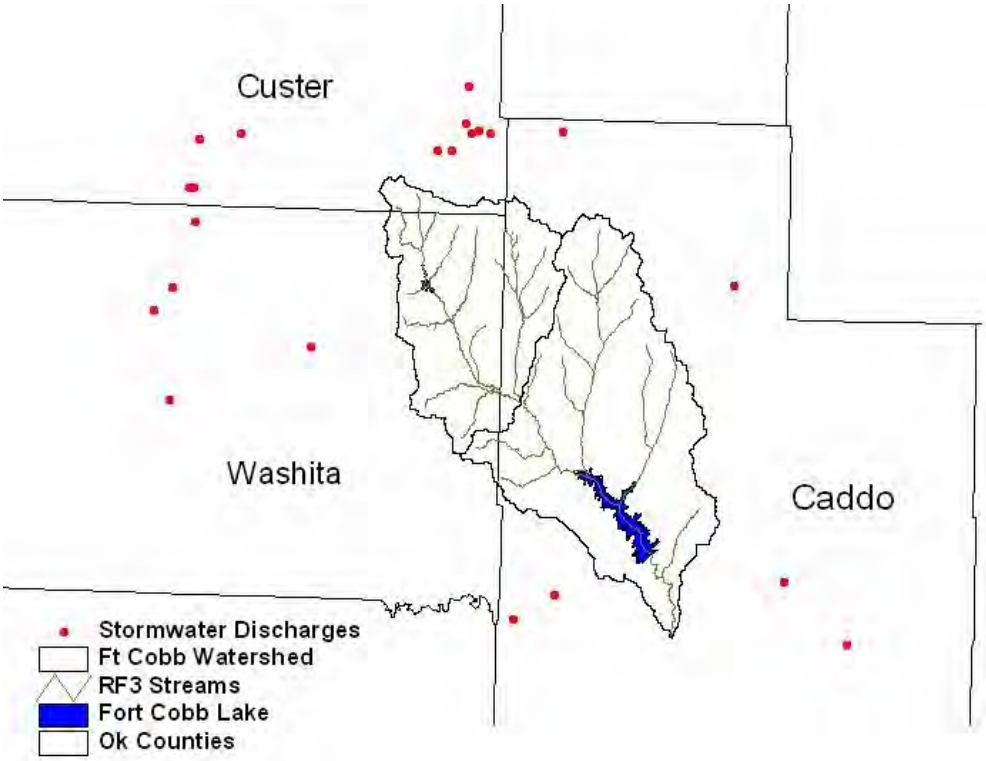


FIGURE 5-1 STORM WATER DISCHARGES

5.2. Assessment of Nonpoint Sources

Nonpoint sources of pollutants are typically separated into urban and rural categories. Surface storm runoff is an important source of loading in urban or residential settings with high amounts of paved, impervious areas. In rural settings, the amount of impervious area is usually much lower; but the sources of nutrients may include runoff of applied fertilizer and manure to agricultural land, runoff of animal wastes associated with the erosion of sediments in grazing fields, runoff from concentrated animal operations, failing septic tanks and contributions from wildlife.

5.2.a. Septic Systems

Septic systems are the most commonly used on-site treatment system in the United States. The system consists of the septic tank and soil absorption area (drainfield). In optimal operating conditions, septic systems treat domestic wastewater as well as, or even better than, mechanical treatment systems. In contrast to the highly mobile nitrate nitrogen, most phosphate reacts vigorously with soils. Phosphate ions are removed from the soil solution by several mechanisms, including adsorption, precipitation, plant uptake, and biological immobilization [22]. Effluent from septic tanks is not likely to reach surface water unless the systems are close to drainage ditches, streams, or lakes. A query of the complaint database at the Oklahoma Department of Environmental Quality shows a total of two incidences of surfacing sewage in the Cobb Creek watershed since 1994. In order to evaluate Total P loading from septic tanks, we need to estimate the number of septic tanks in the watershed.

Since there is no point source discharge in the watershed, we assume that all households in the watershed use a septic tank system for wastewater treatment. 2000 U.S Census data were used to estimate the number of people living in the Cobb Creek watershed. Table 5-1 shows population and number of persons per household for each census block and estimated population in the watershed. The estimated population is for the watershed area above the Fort Cobb dam. Figure 5-2 shows the census blocks in the watershed area.

TABLE 5-1. ESTIMATED POPULATION IN COBB CREEK WATERSHED

State ID	County ID	Tract	Blkgroup	Population	Persons Per Household	% Basin in Blkgroup	Estimated Population
40	15	9616	4	891	2.68	37.5%	334
40	15	9616	5	909	2.54	11.0%	100
40	15	9617	2	331	2.67	30.4%	101
40	15	9617	3	701	2.54	100.0%	701
40	15	9618	1	801	2.36	100.0%	801
40	15	9618	2	491	2.67	23.9%	117
40	15	9619	1	553	2.46	34.6%	191
40	39	9606	5	1354	2.54	15.2%	206
40	39	9607	1	1632	2.79	7.0%	114
40	149	9654	1	936	2.56	6.3%	59
40	149	9654	2	833	2.43	33.2%	277
				Average	**2.57**	**Total**	**3001**

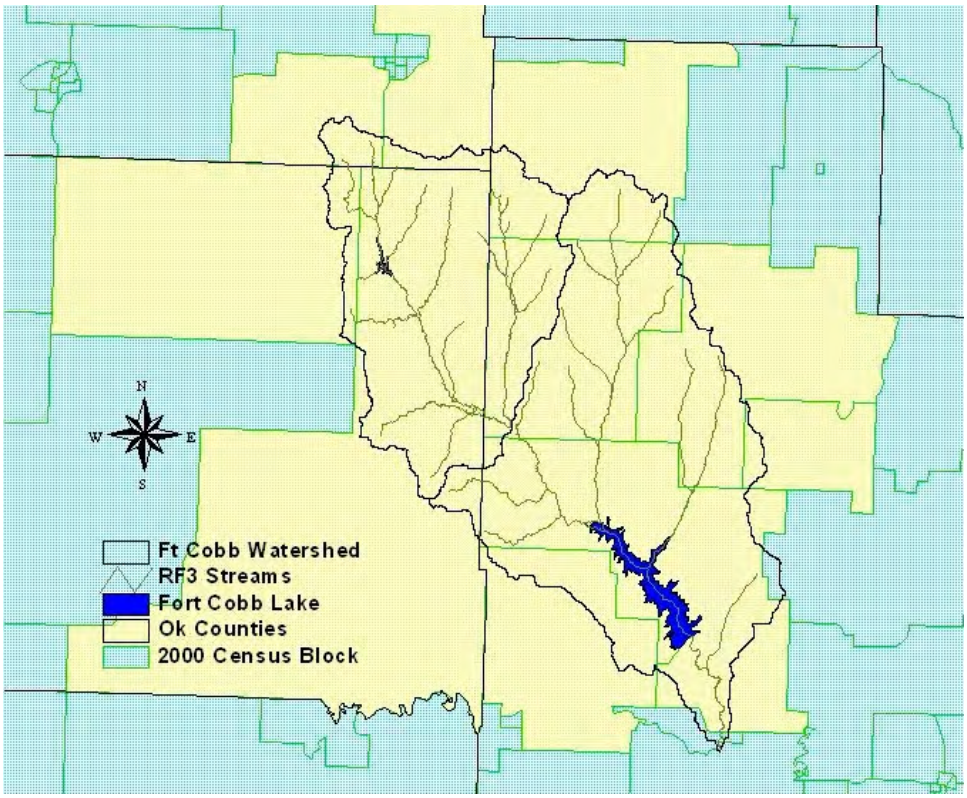


FIGURE 5-2. 2000 U.S. CENSUS BLOCKS IN COBB CREEK WATERSHED

First, phosphorus loading from septic tanks was estimated under the worst case scenario:

- All septic tanks failing
- Every household is assumed to have one septic tank system
- The total number of septic systems is estimated to be 1124
- Effluent from septic tanks drained directly to streams/lakes (drainfield not considered)
- Wastewater produced per person per day: 75 gallons
- Phosphorus concentration in septic tank effluent: 11.6 mg/L

Based on these assumptions, total P produced per person per year can be calculated as follows:

$$(75/1{,}000{,}000) \times 8.34 \times 11.6 \times 365 = 2.65 \text{ lbs/person/year}$$

Total P loading from septic tanks under the worst case scenario would be 3608 kg/year which is about 5% of the current average total P loading from all non-point sources as predicted by the SWAT model. In reality, this worst case scenario does not exist. The effluent from septic tanks is distributed into a drainfield. The effluent may reach groundwater and resurface in the stream banks or lakesides. Total P in the effluent may be adsorbed, precipitated, or removed by plant uptake. The direct contribution of total P to surface water from septic tanks in this watershed is much less than 5%, which is not significant. Any total P from septic tanks would contribute primarily to background loadings.

5.2.b. Migratory Birds

There are a large number of migratory birds (ducks & Canadian geese) staying in the Fort Cobb Lake in the winter. The concerns are that that direct defecation by waterfowl might be a significant nutrient input to the lake. An Integrated Assessment of the Trophic Status of Fort Cobb Reservoir by U.S. Bureau of Reclamation and USGS [23] also suggested that waterfowl might be a significant source of bacteria and ammonia.

To evaluate nutrient addition to Fort Cobb Lake by waterfowl, annual mid-winter waterfowl surveys were obtained from the U.S. Fish and Wildlife Service. Waterfowl in the lake are

primarily ducks and small Canadian geese. According to the survey data, the average waterfowl population from 1998 to 2001 is 124,321.

The phosphorus loading to the lake was estimated in two ways: 1.) Average annual loading per waterfowl in other lake studies; 2.) P content in duck manure.

Method #1

The following table summarizes annual phosphorus loading to lakes from three studies. As shown in the table, when the size of the lake and the number of waterfowl increase, phosphorus addition to lakes per waterfowl decreases dramatically. For the same lake, when bird population increases, birds will need to go farther away from the lake to feed because the amount of food available in the lake does not increase with the number of birds.

TABLE 5-2. PHOSPHORUS LOADING TO LAKES FROM WATERFOWLS

References	Lake Size (ha)	# of waterfowl	Annual P (kg)	P (g/bird/year)
Manny et al (1975)[24]*	15	2,100	59	28.10
Manny et al (1994)[25]*	15	10,700	88	8.22
Marion et al (1994)[26]**	6300	1,021,600	2,000	1.96
Marion et al (1994)[26]**	6300	2,435,000	2,530	1.04
			Average	9.83

* Both studies were conducted on the same lake
** Study was conducted in two years.

We can see from Table 5-2 that the average phosphorus contribution to the lakes by each bird decrease as the bird population increases. This may be because the birds have to go farther away from lakes to feed so that they spend less time in the lakes.

Fort Cobb Lake is about 3806 acres or 1540 hectares. The average waterfowl population is 124,321. Average phosphorus loading to the lake can be estimated as follows:

TP loading = 9.83/1000*124,321 = 1,222 (kg/year)

The average total phosphorus loading to the lake from nonpoint sources is 70,000 kg/yr. The contribution from waterfowls is about 1.75% of total phosphorus loading.

Method #2

Manure characteristic tables from North Carolina State University Cooperative Extension and Michigan State University Extension show that the phosphorus content in fresh duck manure is 0.0038 lbs/day/bird in form of P_2O_5 [28]. For comparison purpose, the unit needs to be converted to lbs/day/bird as of P. The conversion factor is 0.4365.

The following assumptions were made in calculation of phosphorus loading to the lake:

- Waterfowls leave the lake to feed during the day and return to lake at night
- Waterfowls stay in the lake for three months a year

Defecation rate for Canadian geese and ducks varies significantly during the day and night. Manny et al. [25] made conservative estimates of Canadian geese defecation rate during the day and night equal to 1.96 and 0.37 droppings per goose per hour. This means that less than 16% of daily manure was directly added to the lake.

Based on the above assumptions and information, the phosphorus loading was calculated as follows:

P loading = 0.0038*0.4365*124,321*90*0.16*0.454 = 1378 (kg/year)

This estimated loading is only 1.97% of total phosphorus loading from nonpoint sources.

It is also worth noting that the surveys were conducted in the middle of the winter when waterfowl population is at its highest. In addition, the nutrient content for domestic ducks is believed to be higher than that for wild waterfowl. As a result, the above estimates are considered to be conservative.

The waterfowl phosphorus addition to the lake is relatively small (less than 2% of NPS loading) and occurs in the winter. Therefore, we believe that waterfowl will have little impact on algae growth in the summer.

5.2.c. SWAT model for Nonpoint Source Loadings

The Biosystems and Agricultural Engineering Department at Oklahoma State University (OSU) produced the nonpoint source loading analysis and estimates used to develop this TMDL. The Soil and Water Assessment Tool (SWAT) model was utilized in the assessment. The analysis and results are detailed in the report "Fort Cobb Basin – Modeling and Land Cover Classification [17]".

To spatially analyze nutrient loading, the Fort Cobb Lake watershed was divided into 90 sub-basins (Figure 5-3). The delineation of the 90 sub-basins was based on the 10-meter United States Geological Survey Digital Elevation Model (USGS DEM) data for the basin. The 30-meter land use data layer was created by Applied Analysis Inc. based on Landsat 7 ETM+ imagery collected on June 10, 2001. The follow seven land cover were defined with the imagery.

- Barren (Bare Soil)
- Forest
- Pasture
- Planted/Cultivated 1
- Planted/Cultivated 2
- Urban
- Water

Planted/Cultivated categories 1 & 2 differ by the amount of vegetation present. Figure 5-4 shows land use coverage throughout the Fort Cobb watershed. To adequately model the basin, a detailed survey was given in 2005 to Oklahoma State University (OSU) Cooperative Extension Service Agents and Specialists to gain an understanding of agricultural practices and land covers that occurred from 1996 to 2001. This survey went into great detail about the different types of crops in the basin along with different tillage practices, common double crops, fertilization rates,

cattle stocking rates, and harvest dates. Based on the survey results, the planted/cultivated land cover was further divided into twelve separated agriculture land covers (Table 5-3).

Soil test phosphorus for common agricultural land covers was derived from OSU county level averages for the period 1995-1999. The number of cattle in the watershed was based on county level National Agricultural Statistics Service cattle estimates for the period 1996 – 2001 and the land cover data. Cattle were assumed to be evenly distributed across all agricultural land in each county.

TABLE 5-3. LAND USE COVERAGE IN THE FORT COBB LAKE WATERSHED

Land Use	Percentage of Basin (%)
Alfalfa	1.1
Bare Soil	0.2
Forest	6.2
Pasture	41
Peanut with Double Crop Winter Wheat (Conventional Tillage)	2.9
Peanut with Double Crop Winter Wheat (Conservation Tillage)	1
Peanut Winter Fallow	3.8
Rye (Conventional Tillage)	7.6
Rye (Conservation Tillage)	3.2
Grain Sorghum w/ Double Crop Winter Wheat	4.8
Grain Sorghum Winter Fallow	5.2
Urban	0.1
Water	2.4
Corn With Double Crop Winter Wheat	1.2
Winter Wheat for Grain (Conservation Tillage)	4.4
Winter Wheat for Grain (Conventional Tillage)	9.2
Winter Wheat for Pasture	5.6
Total	100.0%

The SWAT model was calibrated for flow for the period January 1995 through October 2001 and validated for flow in Cobb Creek for the period 1970 – 1989. Watershed loadings were calibrated for a longer period to cover a wider range of climatic and hydrologic conditions within the drainage area, allowing for a more representative analysis of source loading and in-stream conditions. The SWAT model was then calibrated for total phosphorus. The model was calibrated reasonably well for total phosphorus and but poorly for nitrogen. This is not

considered to be a significant limitation for the current study because phosphorus is the limiting nutrient. The normal N:P ratio for algae is 7:1 which means that it takes about 7 nitrogen and 1 phosphorus to form algae cells. N:P ratio calculated from 1998-1999 OWRB data has an average of 30, maximum of 73. None of the calculated N:P ratio is less than 7. N:P ratio calculated from 2000-2001 USGS data shows an average of 17.5, and maximum of 43. Only four of 154 samples (2.6%) has N:P ratio less than 7 and all four samples are collected from sites near shoreline. No samples in main water body of the lake have the ratio less than 7. All data show that phosphorus is the limiting nutrient. In addition, blue-green is the dominant algae group in the lake. Blue-green algae can fix nitrogen through the air that supplies an unlimited source of nitrogen. Therefore, total phosphorus is much more important than total nitrogen in determining the trophic state of Fort Cobb Lake.

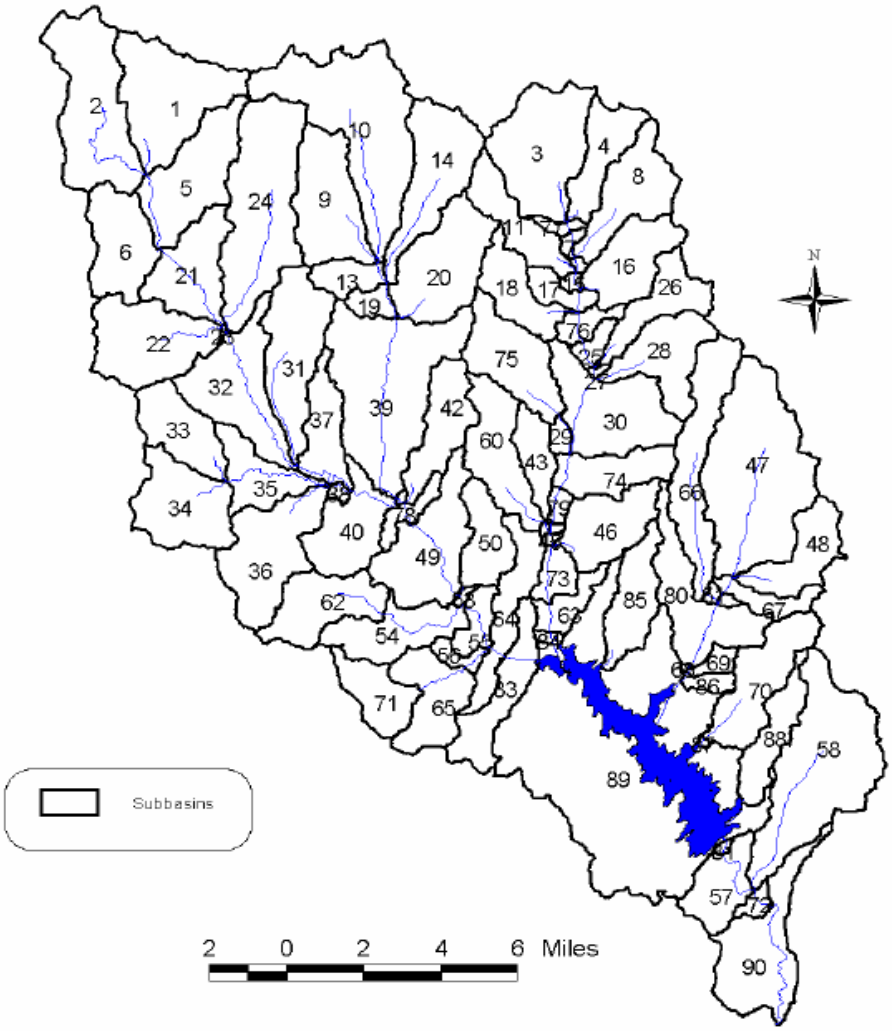


FIGURE 5-3. SUBBASIN LAYOUT USED IN THE COBB CREEK SWAT MODEL

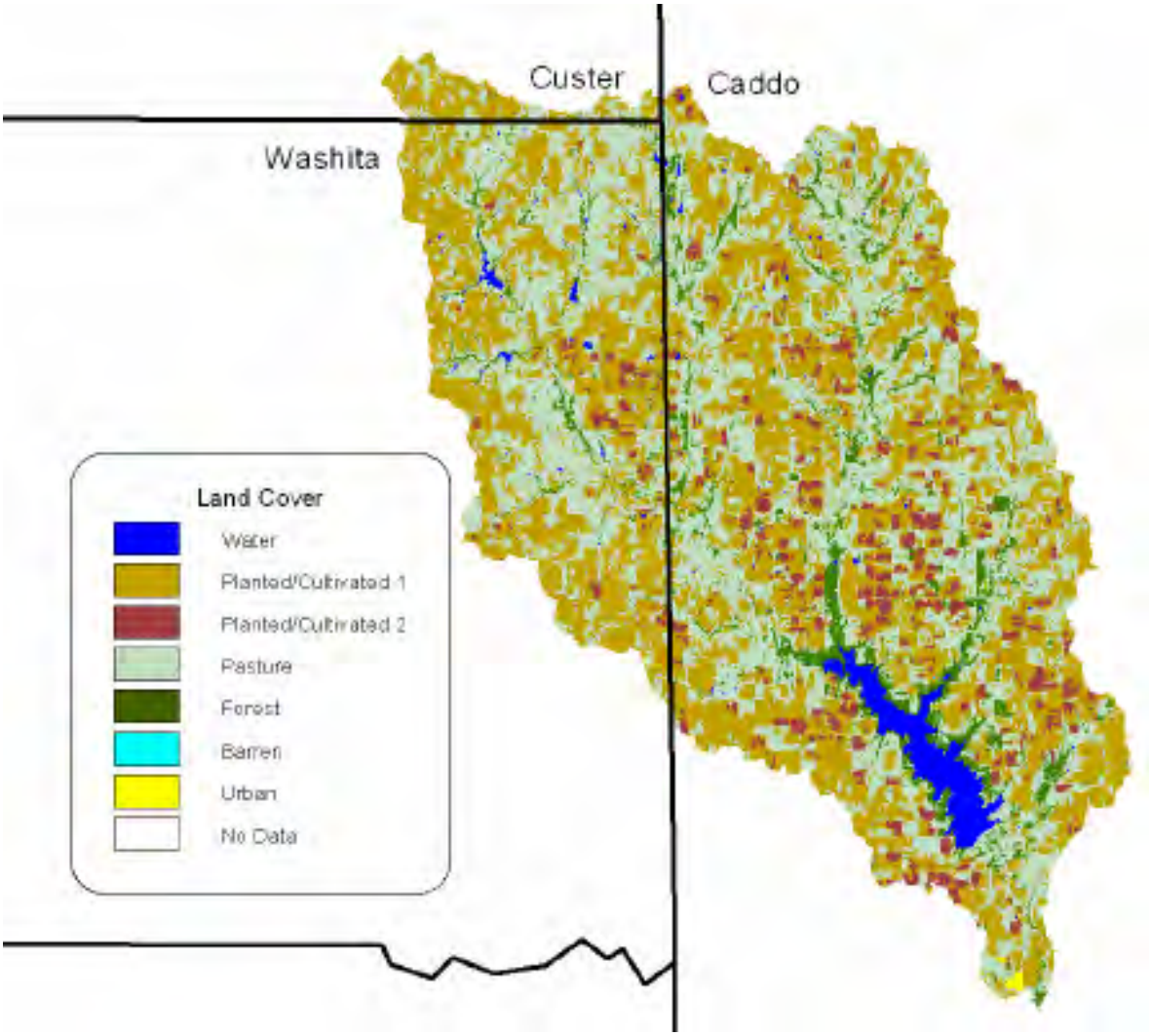


FIGURE 5-4. LAND USE COVERAGE BASED ON 2001 ETM IMAGERY

6. Model Development

The link between the Fort Cobb Lake water quality targets and identified source loads was established through sophisticated modeling techniques. This section discusses the model selection, setup, calibration and validation.

6.1. Model Selection

Lakes are usually stratified in the summer and mixed in the winter. Normally, the deeper a lake is, the more vertically stratified it gets. Fort Cobb Lake is well mixed for most of the year but is still stratified in the summer. Due to the lake's three-dimensional variability and seasonality, a three dimensional, time-dependent water quality model will best describe the system. The widely used models, which are also supported by the EPA, include the Environmental Fluid Dynamics Code (EFDC) and Water Quality Analysis Simulation Program (WASP). The EFDC model is a DOS-based program. All input files need to be compiled with a text editor. The WASP model is a windows-based program. It is more user-friendly than the EFDC model. However, the EFDC model was chosen for the study due to the following considerations:

- The WASP model is for modeling water quality only and the hydrodynamic inputs to WASP need to be generated by EFDC.
- WASP uses a one-dimensional array to represent computational cells, which makes it difficult to find the physical location of a cell in the lake. EFDC uses a three-dimensional array (i – row, j – column, k – layer) to reference grid and layers and users can easily pinpoint the location of a cell.
- EFDC has a much shorter running time. Each EFDC model run took approximately 16 to 18 hours. If the WASP model were used, the running time would be much longer. As a result, the time needed to calibrate the model would be increased dramatically.

The EFDC model was used to simulate water quality processes in Fort Cobb Reservoir. EFDC is a state-of-the-art hydrodynamic water quality model that has evolved over the past two decades to become one of the most widely used and technically defensible hydrodynamic models in the

world [18]. EFDC has also been used in other TMDL projects in Oklahoma, such as Lake Tenkiller and Lake Eucha.

6.2. Model Setup

6.2.a. Watershed Representation

The watershed representation is both a conceptual and a mathematic definition of the drainage area contributing to the waterbody. The SWAT model developed by Oklahoma State University was used to calculate nonpoint source pollutant loadings based on meteorological data, land cover and land use distribution, soil characteristics, and pollutant dynamics in the watershed.

6.2.b. Lake Representation

The setup of the EFDC model required evaluation of the lake's physical and chemical characteristics, including bathymetry, outflow, temperature, and water quality. The EFDC model configuration involved the construction of a horizontal grid for Fort Cobb Lake, the development of EFDC input files, and compilation of the FORTRAN source code with appropriate parameter specification of array dimensions. EFDC was set up for dynamic scenario modeling of hydraulics and water quality constituents. The hydrodynamic variables of the EFDC model included velocity, water surface elevation, temperature and mixing. The following were considerations for setting up the EFDC model:

- Linkage to the watershed model: Pollutant loads entering the lake were represented by the watershed model. Watershed loadings were carried into the lake model in the form of daily average flows and daily total loading from four inflow cells representing Cobb Creek, Lake Creek, Willow Creek, and two tributaries, respectively. The watershed model generated output values for Chlorophyll-*a*, CBOD, Nitrate, Organic N, Mineral P and Organic P. These quantities were further subdivided into carbon, nitrogen species, and phosphorus species and then directly streamed into the lake model. Twenty-one water quality state variables were simulated in the lake model, including DO, algae, carbon, nitrogen, and phosphorus. The EFDC hydrodynamic variables included velocity, water surface elevation, and temperature.

- Computational grid: As part of the model development, the lake area was divided into a grid of discrete cells. To ensure that the grid conformed closely to the actual lake geometry, an orthogonal mapping procedure was used to represent the horizontal surface of the lake as a two-dimensional grid domain. The bathymetric data for Fort Cobb Lake were interpolated to further define the lake in three dimensions. The bathymetric data were obtained from the U.S. Bureau of Reclamation (USBR). The numerical grid consisted of 179 total cells. Since Fort Cobb Lake is only stratified shortly in the summer and stays well mixed most of the year, five vertical layers were chosen to represent the vertical structure of temperature and DO profiles in the lake. As a visual check, the EFDC model grid was overlaid on an aerial photo of Fort Cobb Lake and surrounding area (Figure 6-1). The surface area and lake volume of the model were also calculated and compared with the actual surface area and volume of the lake. Table 6-1 shows the comparison results.

TABLE 6-1. SURFACE AREA AND VOLUME OF FORT COBB LAKE

	Model	Actual	Difference (%)
Surface Area (Acres)	3747	3806	1.56%
Volume (Acre-ft)	73752	73833	0.11%

6.2.c. Selection of Model Simulation Period

The time period used for calibration and verification of the EFDC model for Fort Cobb Lake was determined according to available data. The OWRB collected water quality data in Fort Cobb Lake in 1998 and 1999. The USGS collected data in 2000 and 2001. The USFWS also collected some data from 1998 to 2000. Data collected in 1998-1999 was used to calibrate the model and data collected in 2000–2001 was used to validate the model.

Annual precipitation for the watershed was plotted in Figure 6-0. The average annual precipitation from 1975 to 2001 was 31.8 inches. The annual rainfall for 1998 was 24.2 inches and the annually rainfall for 2000 was 33.1 inches.

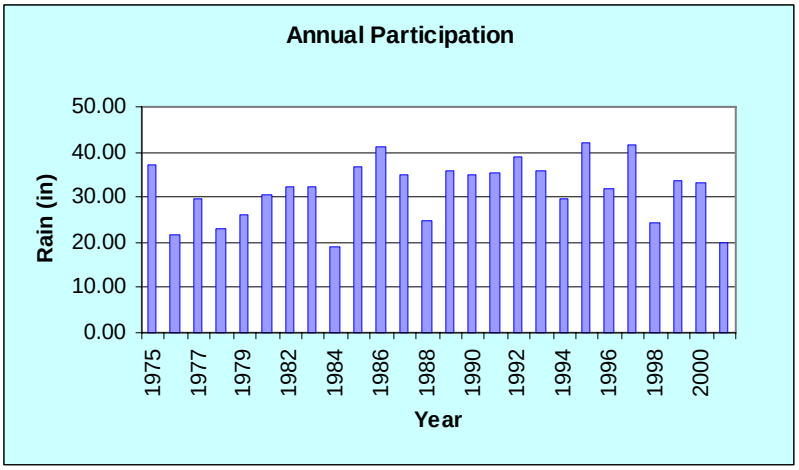


FIGURE 6-0. ANNUAL PRECIPITATION FOR FORT COBB WATERSHED

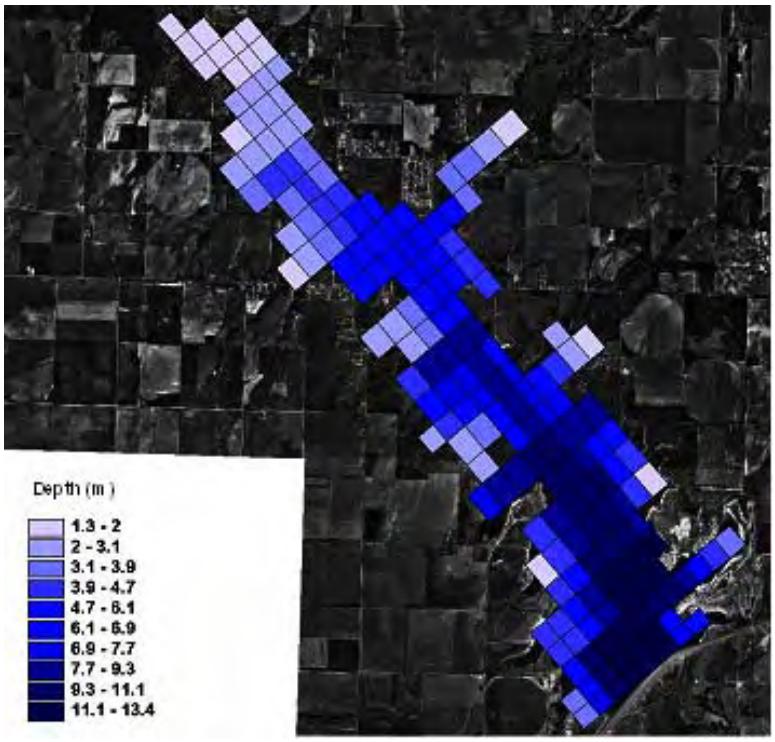


FIGURE 6-1. BATHYMETRIC AND COMPUTATIONAL GRID OVERLAY - FORT COBB LAKE

6.2.d. Model Inputs

The inputs of the EFDC model for Fort Cobb Lake include hourly weather data, daily flow data, and daily loadings to the lake.

The weather data for the model was obtained from Oklahoma Mesonet for the Fort Cobb station. The data includes hourly atmosphere pressure, air temperature, wind speed and direction, relative humidity, rainfall and, solar radiation. Since the weather station is close to the lake, the data provides a good representation of the weather conditions being modeled.

The hydraulic data was downloaded from Army Corps of Engineer's web site (http://www.swt-wc.usace.army.mil/FCOBcharts.html). The data include daily inflow, release, pool elevation, and evaporation.

Flows to the lake were input in four cells:

(12, 37) ----- Cobb Creek and Lake Creek
(15, 33) ----- unnamed tributary to the lake
(21, 26) ----- Willow Creek
(18, 18) ----- unnamed tributary to the lake

Flows were evenly distributed in all five layers because the average water temperature in streams is very close to the water temperature in the lake. Using USGS's temperature data, we calculated average water temperature on all tributaries and compared that to site #6 (upper lake). The average water temperature in streams is only 0.4 degrees lower than that in the lake.

The loadings to Fort Cobb Lake were simulated with the SWAT watershed model developed by OSU. The output parameters of the SWAT model include flow, CBOD, Nitrate and Nitrite, Organic N, Mineral P, Organic P, and sediment. These quantities were further subdivided into carbon, nitrogen species, and phosphorus species based on literature values or regression relationships from the data. Portions of nitrogen and phosphorus species were treated as calibration parameters and were further adjusted in the calibration process.

In addition to loadings predicted by the SWAT model, the atmospheric deposition of nutrients was considered in the EFDC model for Fort Cobb Lake. The annual data for Oklahoma was downloaded from National Atmospheric Deposition Program's web site. The data from 1998 to 2001 was downloaded and the average of the downloaded data was input in the EFDC model.

Sediment input to the lake was assumed because reliable sediment loading was not available. Sediment was introduced to the lake primarily during high flow events which normally occur in the spring. Most sediment (in the form of TSS) has been settled out of water column by the summer. Fort Cobb Lake does not have any turbidity problems according to monitoring data, which indicates a low TSS concentration in the water column.

To obtain the sediment chemical concentrations, the EFDC model was run repeatedly for the calibration period. Approximately 10 years worth run was performed. Then the resulting sediment chemical concentrations were used in the model calibration.

6.3. Model Calibration

The EFDC model was calibrated for hydrodynamics and water quality to simulate actual conditions in the lake. Calibration is the process of modifying the input parameters in the EFDC model until the output from the model matches an observed set of data.

6.3.a. Hydrodynamics

Hydrodynamic calibration is needed to properly characterize the nature, behavior, and patterns of water flow within the modeled geometry of the lake. Modeled versus observed water surface elevations near the dam were compared to verify the lake's hydrodynamic behavior. As shown in Figure 6-2, modeled surface elevation is very close to that observed except for the period from the middle of October to December 15, 1998. The observed lake elevation had a sudden change on December 15, 1998. The rainfall data was checked to see if there was a rainfall event to cause the sudden elevation change. No rainfall event was found on or a week before December 15, 1998. This effort proves to some extent that the predicted lake elevation is likely to be correct. Then, the lake elevation data was carefully reviewed for its accuracy and possible errors. It was found that an adjustment to the stage gauge accounts for the apparent elevation

change. The magnitude of the adjustment was approximately the same as the difference between the modeled and observed surface elevation. After the gauge adjustment, the modeled elevation matches the observed very well. Therefore, we have enough reason to believe that the elevation data from the middle of October to December 15, 1998 were not accurate. A simple regression was performed between the modeled and observed elevations (Figure 6-2). The slope of 1.00 and R^2 of 0.96 indicate an excellent match. The R^2 value could have been even higher if the stage gauge did not drift prior to December 15, 1998.

Temperature is a good indicator of hydrodynamic behavior. A temperature profile will show if the lake is mixed or vertically stratified. Because temperature influences algal growth and dissolved oxygen, an accurate temperate calibration is also very important to the success of water quality modeling. The results of temperature calibration are shown in Figure 6-3.

In Figure 6-3, the red and orange points are observed data by OWRB and USFWS and the lines are modeled temperature at different depths. The modeled temperature fits the observed data very well. Observed temperatures were also plotted against predicted temperatures at the depth where temperatures were observed. A regression line with slope of 1.0 and R^2 of 1.0 indicates a perfect match between the modeled and observed. For the temperature prediction in Fort Cobb Lake, the slope is 1.04 and R^2 is 1.00, which shows the EFDC model predicts water temperatures extremely well.

6.3.b. Water Quality

Water quality conditions in the lake vary at different locations. Measured data show that the upper part of the lake has a higher chlorophyll-*a* concentration than the lower part of the lake. To better reproduce the water quality conditions for Fort Cobb Lake the model predictions were compared with the measured data at three locations upper, middle, and lower parts of the lake.

Since the targets of this TMDL are TSI or chlorophyll-*a*, DO, and anoxic volume, the calibration is focused on these parameters. Figures 4 through 15 show the comparison of the prediction to the available data. The observed data is plotted in points and the model prediction is plotted in lines.

Overall, the calibrated model makes good predictions on Chlorophyll-*a*, dissolved oxygen and anoxic volume. The observed data indicates dissolved oxygen and anoxic volume criteria were not violated in the lake. However, most measured TSI values were higher then the target value of 62. As a result, the TSI target becomes the controlling factor for TMDL development. The model predictions also show that dissolved oxygen and anoxic volume meet water quality standards all the time. The model predicts chlorophyll-*a* or TSI very well.

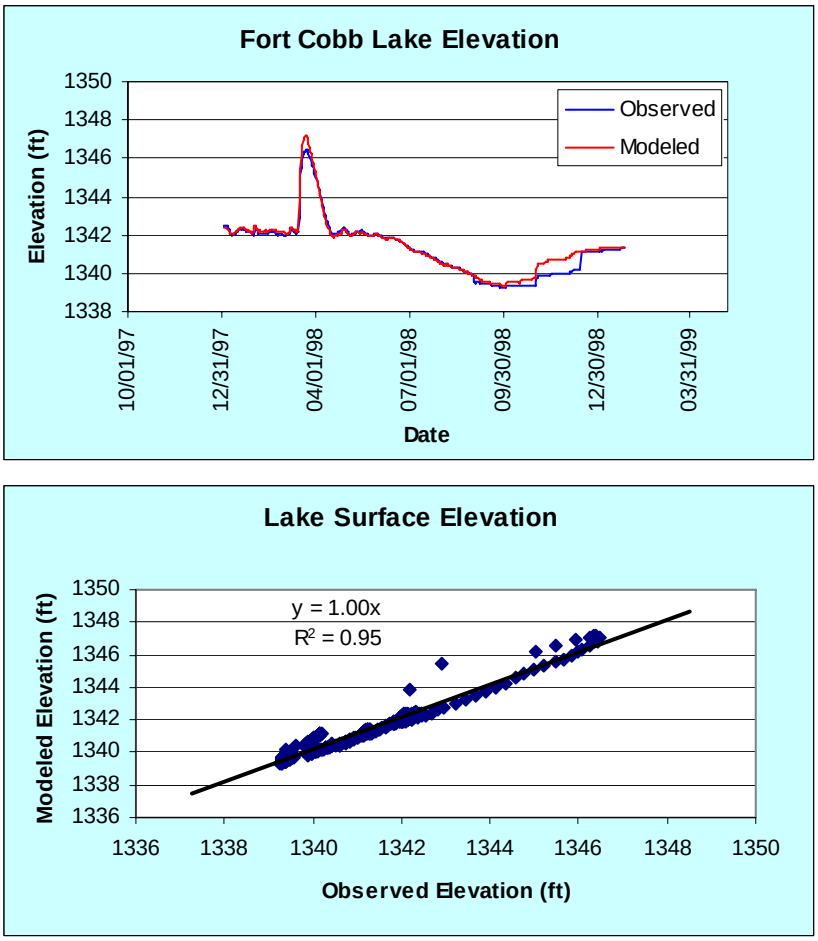
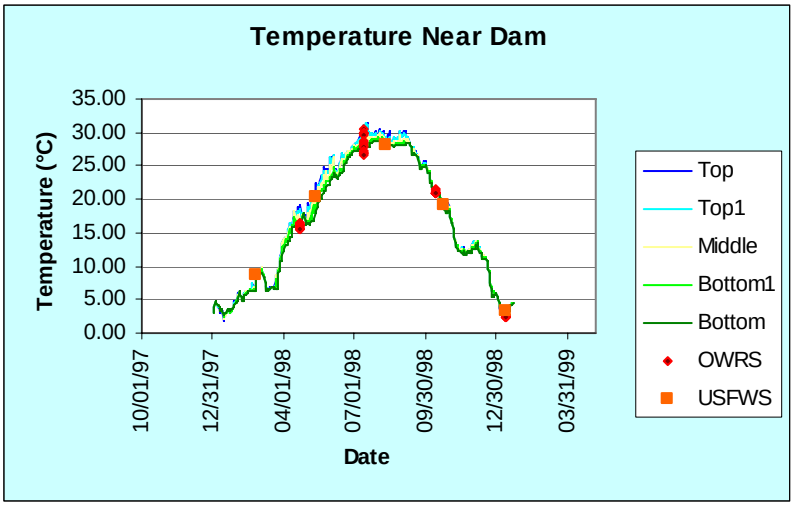


FIGURE 6-2. COMPARISON OF MODELED AND OBSERVED LAKE ELEVATION



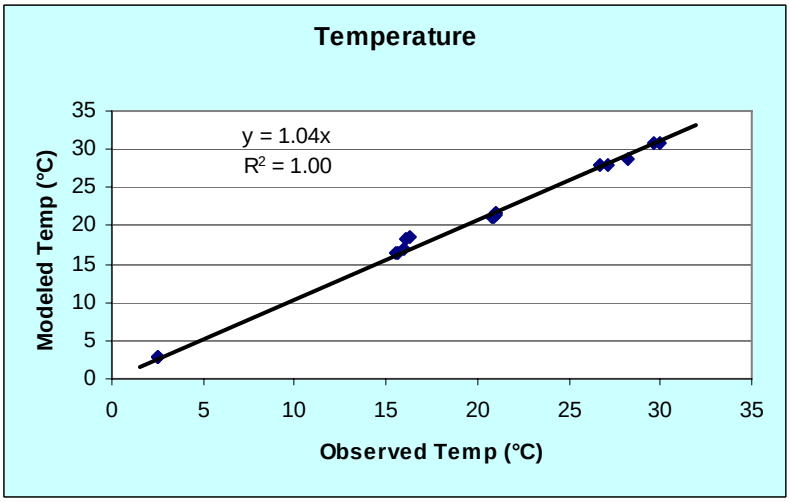


FIGURE 6-3. TEMPERATURE PROFILE NEAR THE DAM

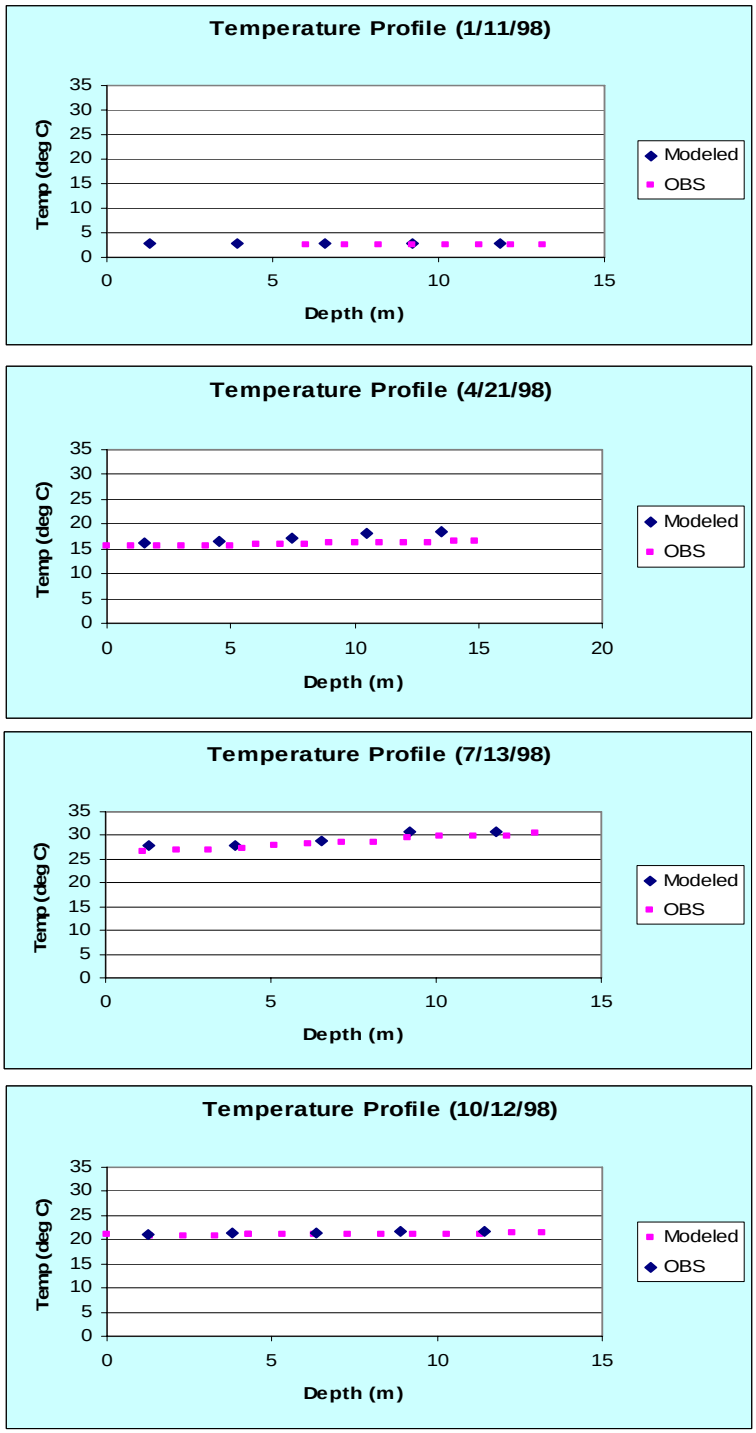


FIGURE 6-3A. TEMPERATURE PROFILE NEAR THE DAM

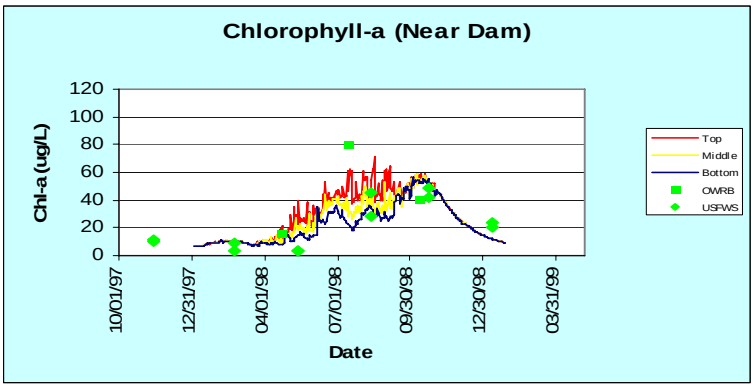


FIGURE 6-4. CHLOROPHYLL-A CONCENTRATION NEAR THE DAM

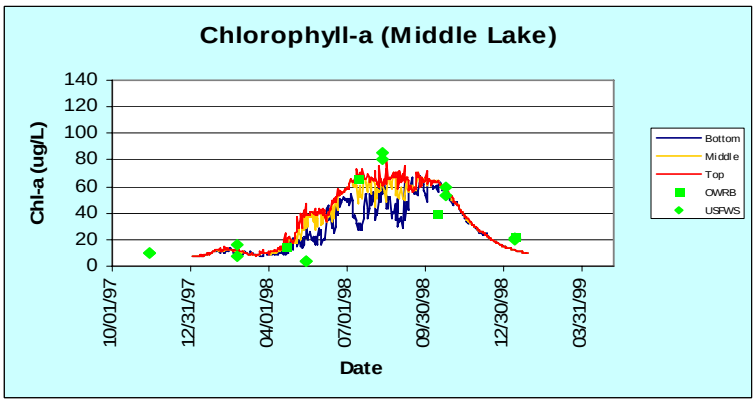


FIGURE 6-5. CHLOROPHYLL-A IN THE MIDDLE PART OF THE LAKE

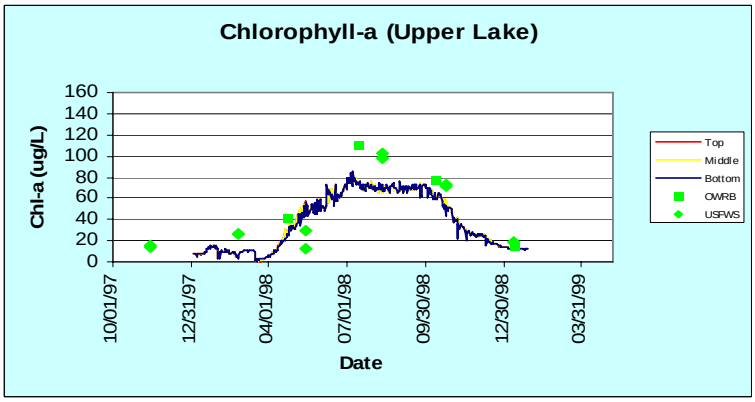


FIGURE 6-6. CHLOROPHYLL-A IN THE UPPER PART OF THE LAKE

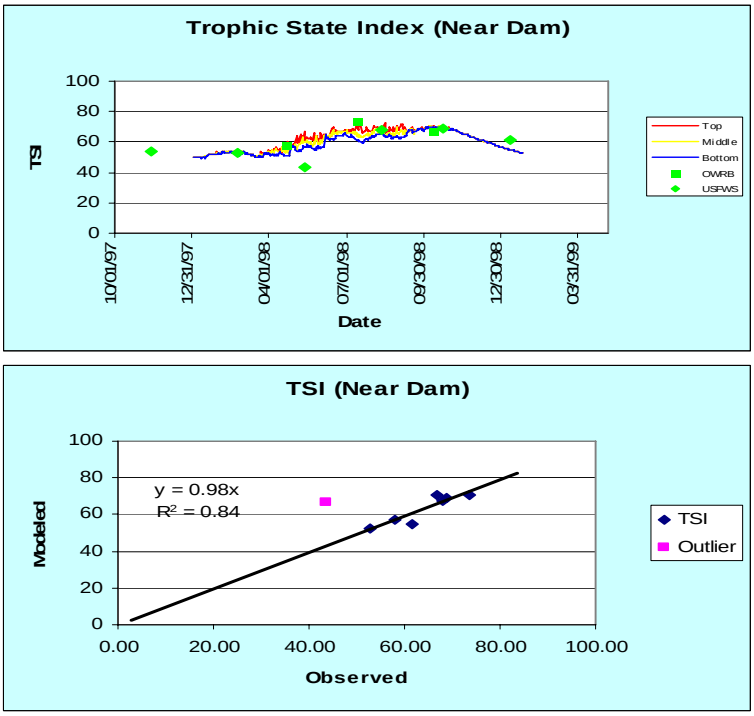


FIGURE 6-7. TROPHIC STATE INDEX NEAR THE DAM

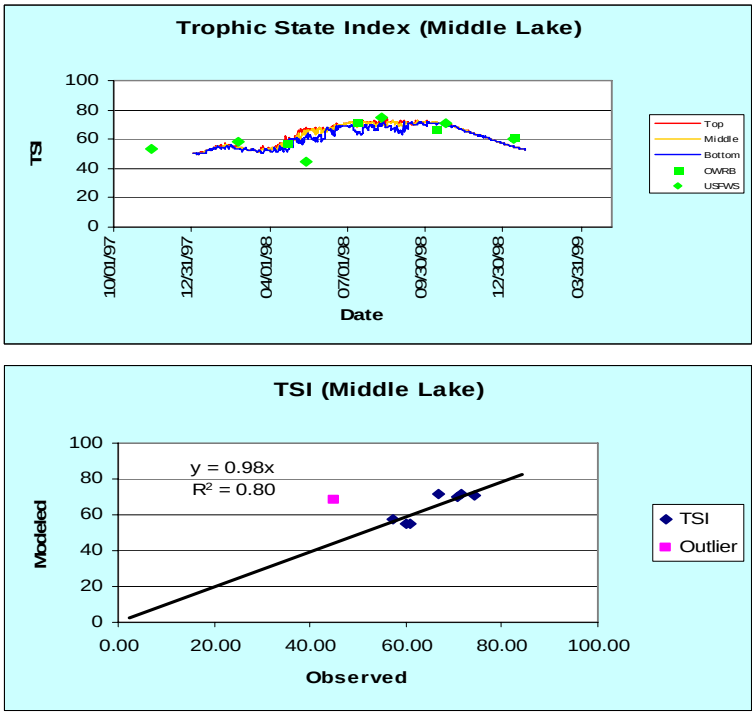


FIGURE 6-8. TROPHIC STATE INDEX IN THE MIDDLE PART OF THE LAKE

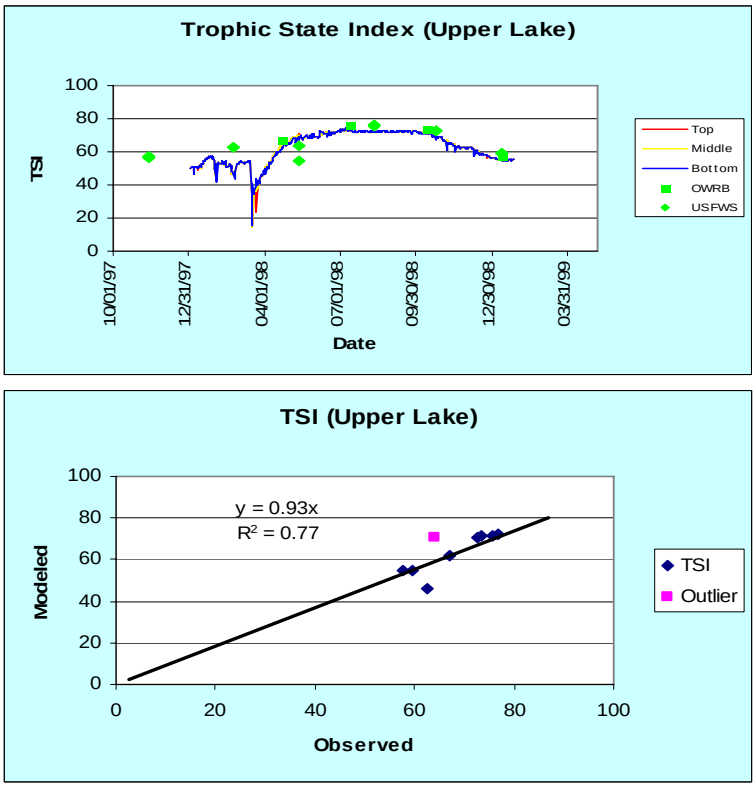


FIGURE 6-9. TROPHIC STATE INDEX NEAR IN THE UPPER PART OF THE LAKE

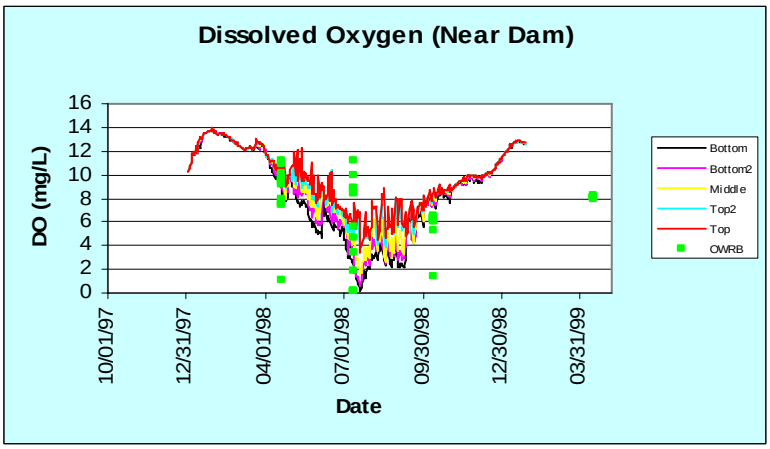


FIGURE 6-10. DISSOLVED OXYGEN NEAR THE DAM

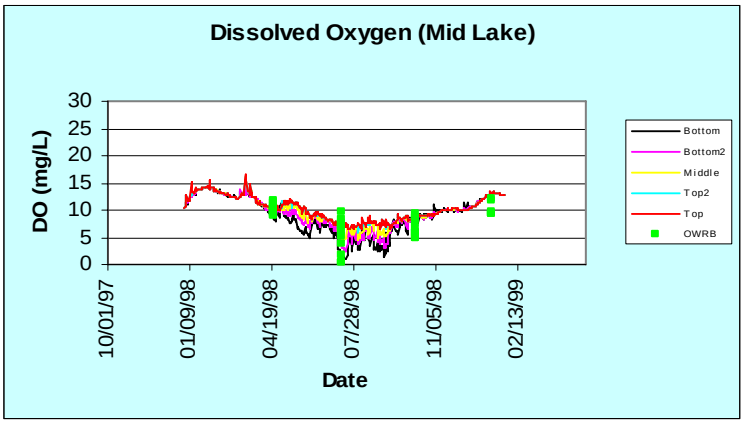


FIGURE 6-11. DISSOLVED OXYGEN IN THE MIDDLE PART OF THE LAKE

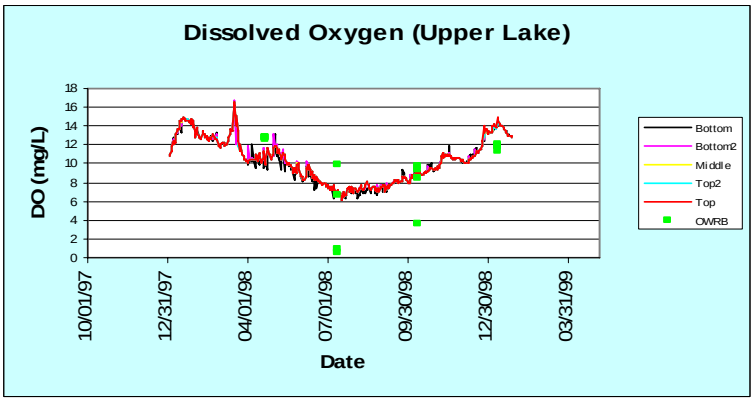


FIGURE 6-12. DISSOLVED OXYGEN IN THE UPPER PART OF THE LAKE

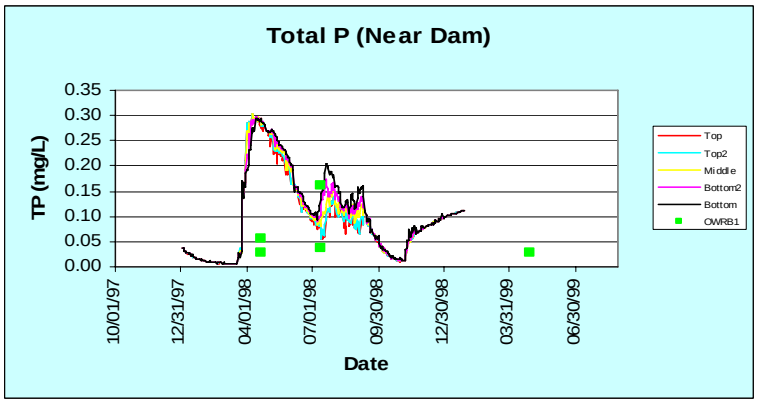


FIGURE 6-13. TOTAL-P NEAR THE DAM

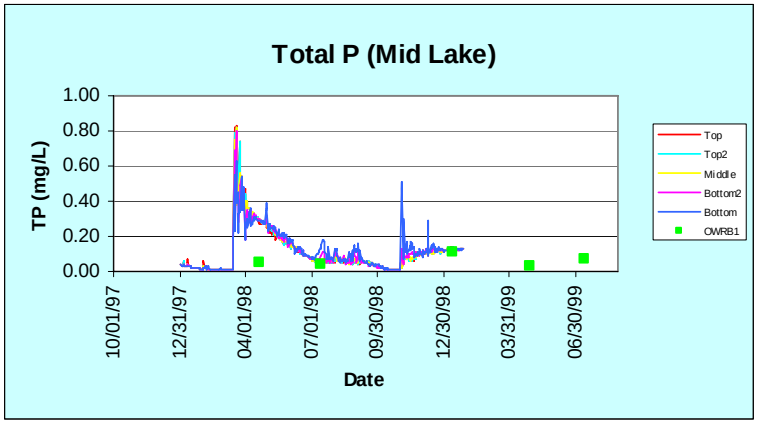


FIGURE 6-14. TOTAL-P IN THE MIDDLE PART OF THE LAKE

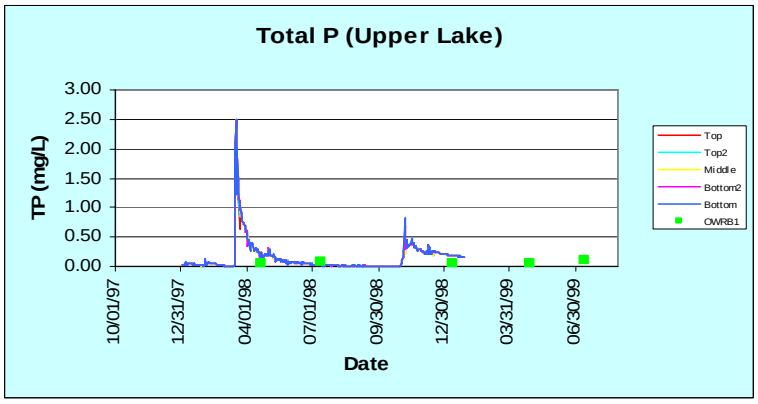


FIGURE 6-15. TOTAL-P IN THE UPPER PART OF THE LAKE

Data from both the OWRB and USFWS were used in the Chlorophyll-*a* (Figures 6-4 through 6-6) and TSI calibration (Figures 6-7 through 6-9). The chlorophyll-*a* concentration is significantly higher in the upper part of the lake than the lower part of the lake. The chlorophyll-*a* concentration predicted by the model matches the data well at the upper, middle and lower parts of the lake. The predicted TSIs were plotted against the data at the upper, middle and lower parts of the lake. The R^2 ranges from 0.77 to 0.84 and the slope ranges from 0.93 to 0.98 which indicates a very good fit for a natural system. Both the model and data show that the TSI target

was exceeded in May through October. The TSI target of 62 was met in Fort Cobb Lake during the winter months.

Figures 6-10 through 6-12 show the comparison of dissolved oxygen in the upper, middle and lower part of the lake. There are three measured dissolved oxygen profiles at each monitoring site in 1998. The predicted DO matches the data well in overall trend and vertical profile. The observed surface DO is generally higher because the predicted DO is a daily average while samples are taken during the day. Both data and the model show that the lake is stratified near the dam and the anoxic volume is about 40%.

The model predicted an unusual DO spike in the upper and middle part of the lake in March of 1998. The DO load to the lake and other input files were reexamined for accuracy. No errors were found. The DO spike is coincident with the only high-flow event. After consulting with experts in the EFDC model, we believe that the DO spike occurs because the model is not stable during the high-flow event. We tried to increase the number of time steps to the maximum allowed by our version of EFDC. No noticeable changes were observed. The model recovered in about a week and was stable in the rest of simulation period. The DO spike which occurred months before the critical period will not have much impact on the results of the TMDL. Therefore, it is not a significant concern for the model predictions.

Total phosphorus (TP) concentration in the lake is important for algae growth. When TP concentration is lower than a threshold number, it limits algae growth in the lake. On the other hand when algae have enough phosphorus for growth, additional phosphorus will not necessarily promote more algae growth. Comparisons of the predicted and observed TP are shown in Figures 6-13 through 6-15. The observed data for TP on July 13, 1998 is not available and the ortho-P data was used in plots for this date. The predicted TP concentrations match observed data reasonably well in the middle and upper part of the lake but miss the observed data collected on April 21, 1998 near the dam. Since TP data are only available on three dates, it is really not sufficient to judge the quality of TP calibration. In the model verification section, more data will be used to justify the TP calibration.

Comparing the peaks of lake elevation and TP plots, it is clear that a significant amount of TP is delivered to the lake during storm events.

After the EFDC model was calibrated, the data collected in 2000 and 2001 were used to verify the model calibration. The calibrated model input files (WINEFDC.inp & WQWIN.inp) were attached in Appendix A of this report.

6.4. Model Verification

Model verification is a process in which the calibrated model is applied to the same system for a different period of time to see if it still can reproduce observed conditions. Model verification is also a confidence building process. Once the model is verified, it can be used to predict load reduction with more certainty.

6.4.a. Hydrodynamics

The modeled water surface elevation and temperature profiles were compared with the measured data near the dam (Figures 6-16 & 17). Both lake surface elevation and water temperature matched the observed data well.

6.4.b. Water Quality

As in the calibration phase, Trophic State Index (TSI), chlorophyll-*a*, dissolved oxygen, and TP are plotted against the observed data. During the verification process, parameters in the calibrated model stayed the same.

The comparison of model output and observed data are shown in Figure 6-18 through Figure 6-29. Overall, the calibrated model for Fort Cobb Lake reproduces the observed water quality conditions reasonably well at different parts of the lake and for all of the calibrated parameters.

As in the model calibration, several dissolved oxygen spikes in the upper and middle part of the lake were predicted by the model. Some of the DO spikes occurred at the bottom layer of the model. Model instability during high-flow events was believed to the cause of those DO spikes. We tried to increase the number of time steps to the maximum allowed by our version of EFDC. No noticeable changes were observed. Fortunately, all the DO spikes occurred only in the spring

which is not the critical period of time of the model and the EFDC model recovered quickly after high-flow events. Therefore, these DO spikes will not have much impact on the results of this TMDL. We believe that the DO spikes, although unreal, are not a significant concern for the model.

From the lake elevation and TP plots, it can clearly be seen that the phosphorus loadings to the lake are directly related to the storm events. Most sediments and nutrients are washed off to the lake during storm events. Because of the close tie between sediment and nutrients, if the sediments to the lake are effectively reduced, the nutrients to the lake will also be reduced.

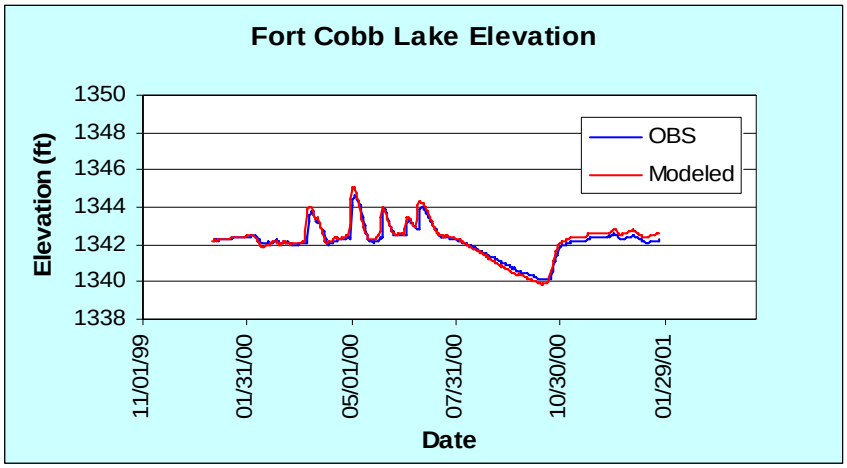


FIGURE 6-16. LAKE ELEVATION (2000)

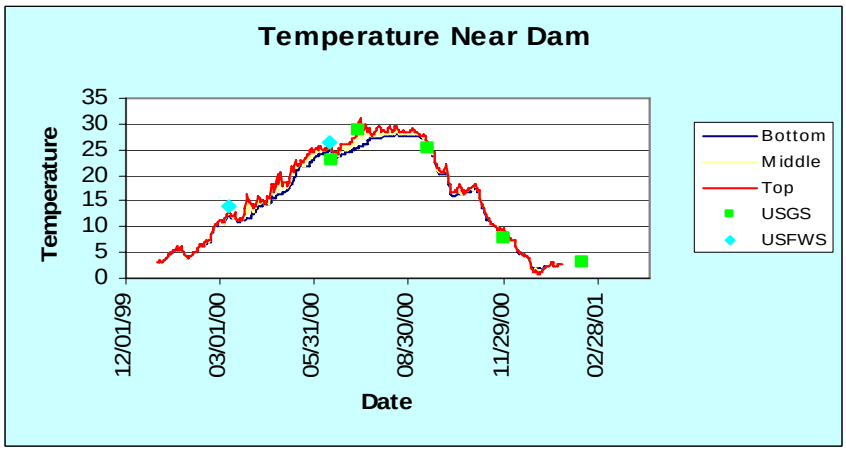


FIGURE 6-17. WATER TEMPERATURE NEAR THE DAM (2000)

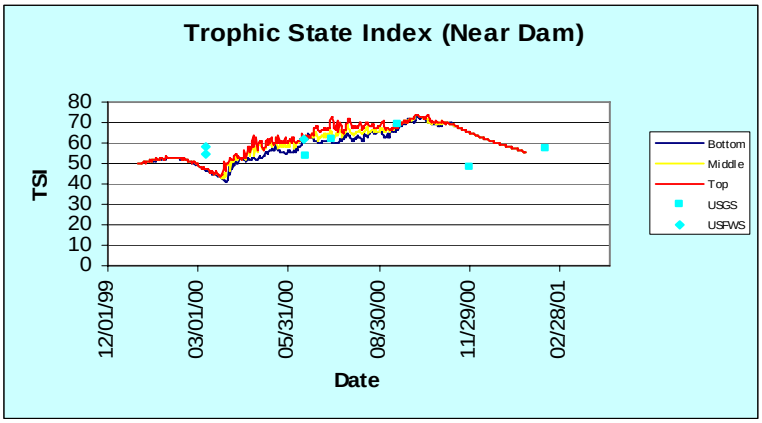


FIGURE 6-18. TROPHIC STATE INDEX NEAR THE DAM (2000)

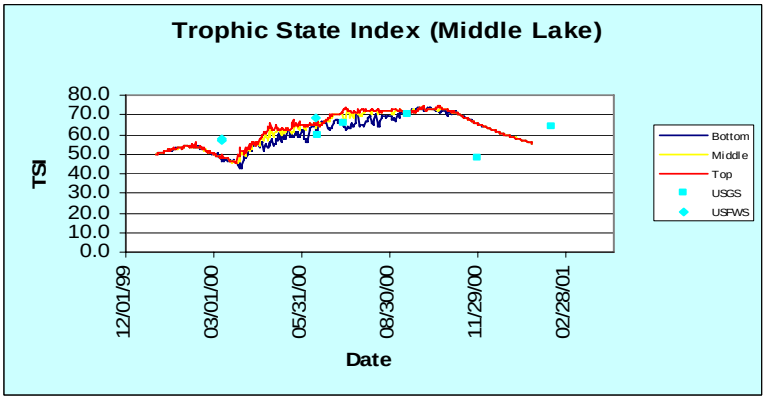


FIGURE 6-19. TROPHIC STATE INDEX IN THE MIDDLE PART OF THE LAKE (2000)

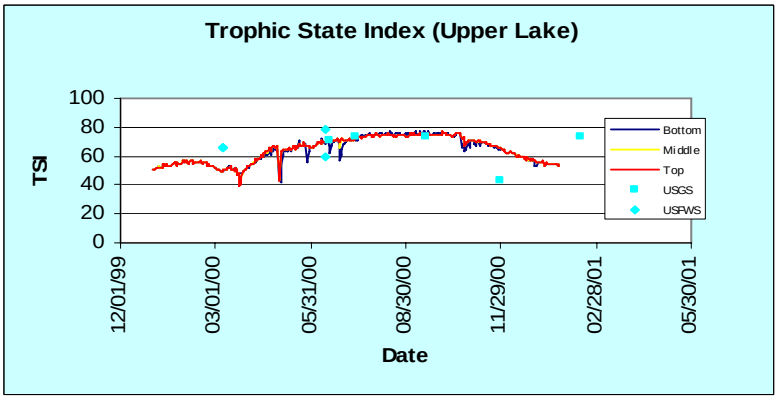


FIGURE 6-20. TROPHIC STATE INDEX IN THE UPPER PART OF THE LAKE (2000)

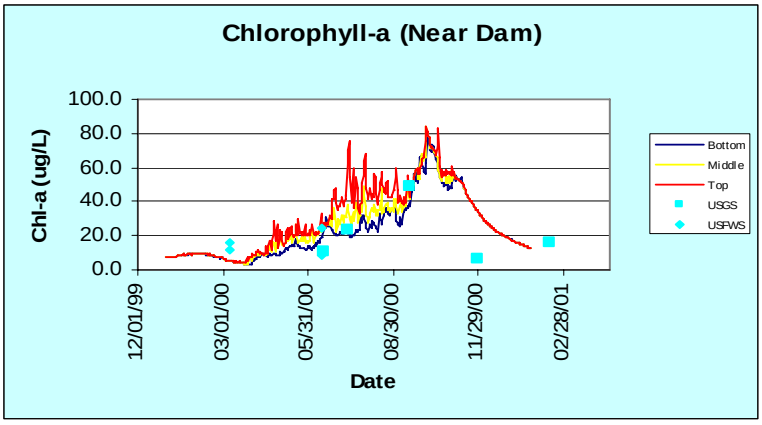


FIGURE 6-21. CHLOROPHYLL-*a* NEAR THE DAM (2000)

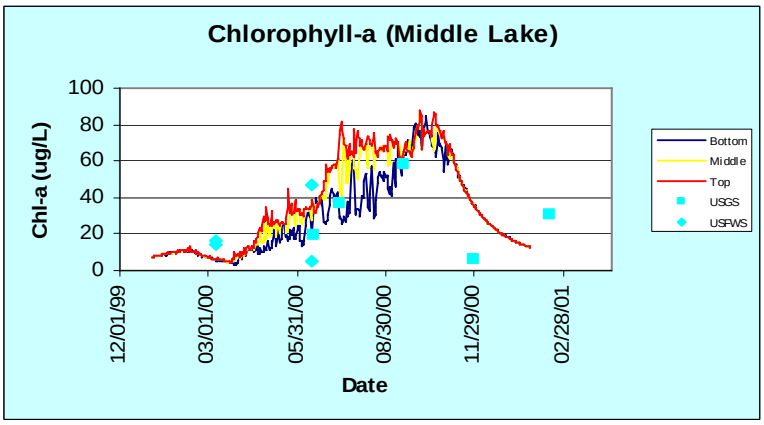


FIGURE 6-22. CHLOROPHYLL-*a* IN THE MIDDLE PART OF THE LAKE (2000)

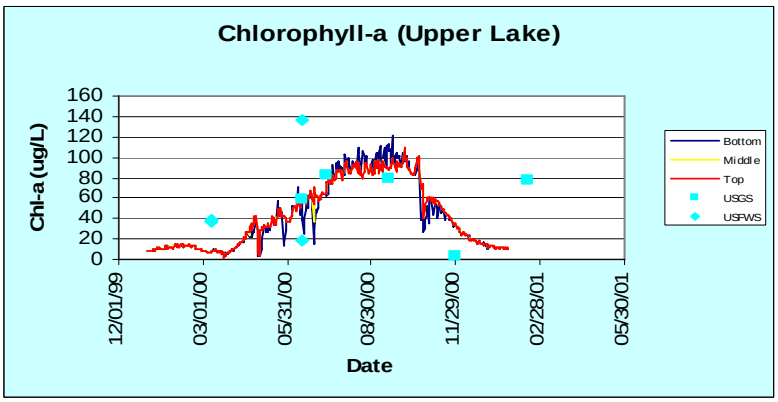


FIGURE 6-23. CHLOROPHYLL-*a* IN THE UPPER PART OF THE LAKE (2000)

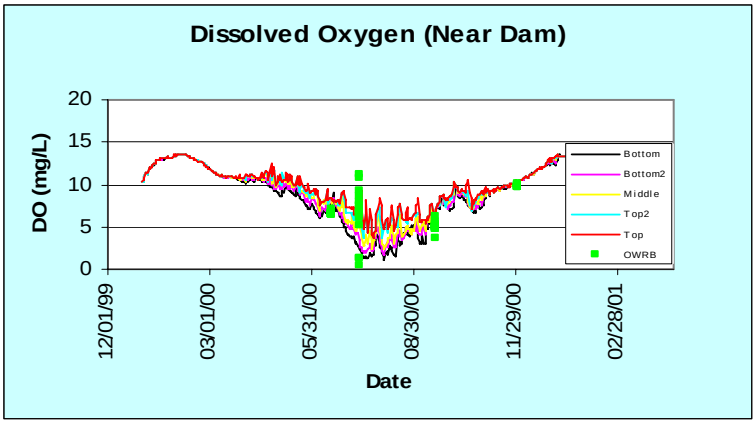


FIGURE 6-24. DISSOLVED OXYGEN NEAR THE DAM (2000)

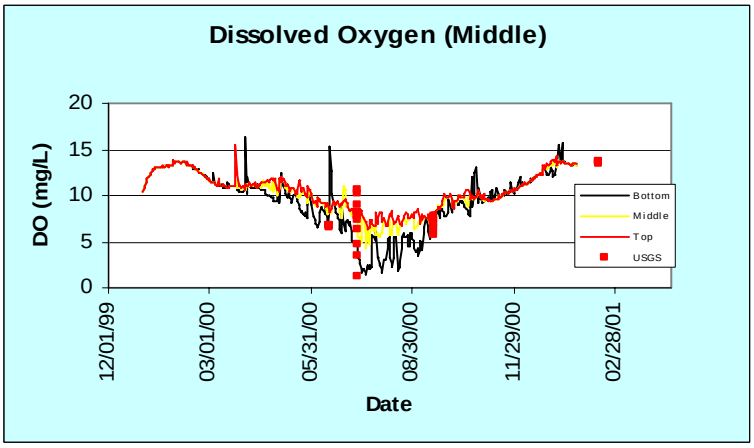


FIGURE 6-25. DISSOLVED OXYGEN IN THE MIDDLE PART OF THE LAKE (2000)

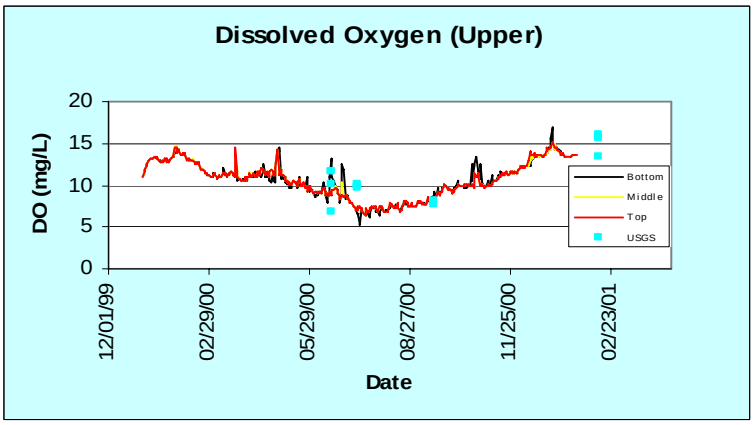


FIGURE 6-26. DISSOLVED OXYGEN IN THE UPPER PART OF THE LAKE (2000)

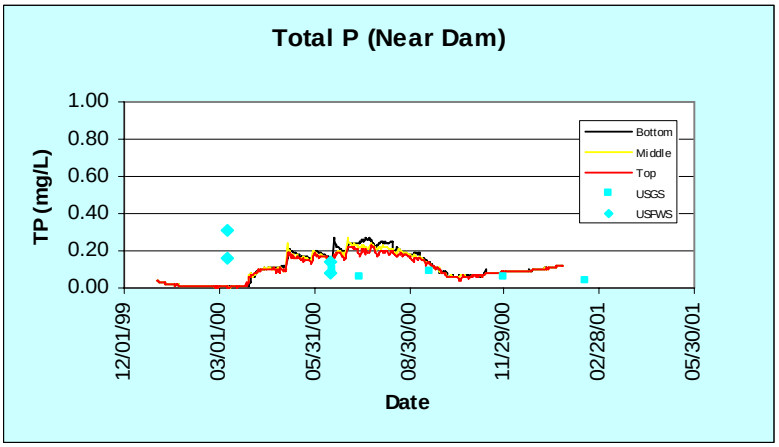


FIGURE 6-27. TOTAL-P NEAR THE DAM (2000)

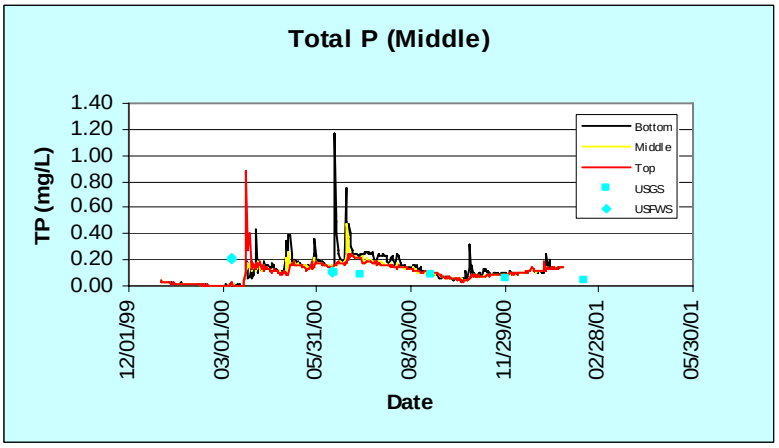


FIGURE 6-28. TOTAL-P IN THE MIDDLE PART OF THE LAKE (2000)

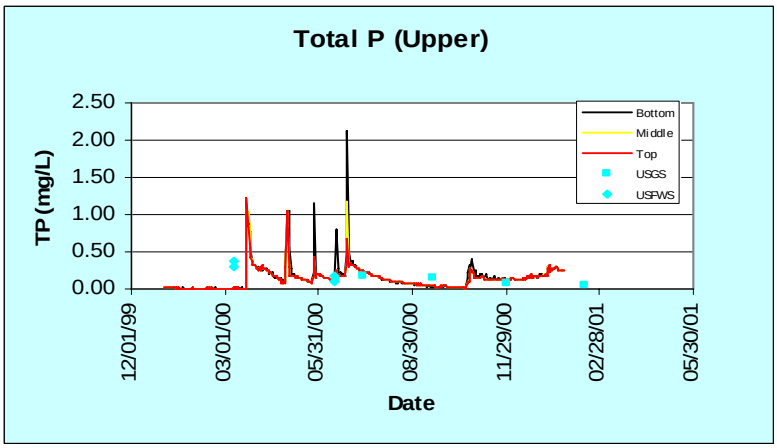


FIGURE 6-29. TOTAL-P IN THE MIDDLE PART OF THE LAKE (2000)

7. Nutrient Reduction

7.1. Load Reduction

Using the calibrated and verified model, reduction scenarios were evaluated to determine the nutrient load reductions required to reach the selected target endpoints. It is important to understand the impact of nutrients on the water quality conditions in the lake. In this study, the influence of nitrogen and phosphorus loadings were studied numerically using the calibrated and verified model for the Cobb Creek watershed. Though Fort Cobb Lake is phosphorus limited and eutrophication in the lake is more sensitive to changes in phosphorus loadings, both nitrogen and phosphorus loadings were reduced at the same percentage in the load reduction simulations. The nutrient reduction would come from various Best Management Practices (BMPs). Some BMPs remove more phosphorus and some BMPs remove more nitrogen. For example, converting some of the worst cultivated land to pasture would remove more nitrogen [17] and nutrient management plan would remove more phosphorus [21]. Without any knowledge what BMPs will be implemented in the watershed and the degree of implementation, we believe that the most reasonable assumption would be for phosphorus and nitrogen to have the same reduction rate.

Iterative model runs with progressively larger reductions were used to determine the reduction in lake loading required to meet the water quality standards. Since the dissolved oxygen and anoxic volume criteria are met currently without any load reduction, the reductions calculated are required to meet the target for Carlson's TSI of 62. The TSI target is considered to be met if the average number of days at three sites (near dam, mid-lake and upper-lake) with TSI greater than 62 is less than 36 days in a year. This assessment method is consistent with that used by Oklahoma Water Resources Board in the BUMP report in the sense that all data from the lake were put together to make an overall assessment.

For the calibration period, the TSI target was not met at 65% nutrient reduction but was met at 70% reduction. Therefore, the required reduction rate should be between 65% and 70% for the calibration period. However, this is not the final reduction goal because we still need to check if the TSI target is met at this reduction rate for the verification period. Iterative model runs with

progressive load reductions showed that a 78% load reduction was required to meet the TSI target for the verification period. This reduction rate was chosen as the reduction rate for this TMDL study. Since the verification period is the critical condition, modeling results were shown for this period only. Figures 7-1 through 7-12 show the model predictions on TSI, chlorophyll-a, DO and TP after 78% load reduction. Table 7-1 shows TSI information at three locations of the lake resulting from different reduction rates.

Fort Cobb Lake is rarely stratified. The lake was stratified for only about two weeks in the calibration period and was not stratified at all in the verification period. Because the lake is well mixed and aerated, nutrient flux from the sediment is at minimum and is not likely to have a significant impact on the reduction rate. Ignoring the impact of internal nutrient loads would add implicitly to the margin of safety of the TMDL.

TABLE 7-1. NUTRIENT REDUCTION RATE

Reduction Rate	Location	TSI		Days (TSI ≥ 62)	Average Days (TSI ≥ 62)
		Max	Median		
0%	Near Dam	74.1	61.5	187	216
	Mid Lake	74.5	64.1	225	
	Upper Lake	76.6	66.0	235	
70%	Near Dam	69.7	51.0	48	76
	Mid Lake	71.1	53.5	83	
	Upper Lake	72.1	55.6	97	
75%	Near Dam	68.3	50.2	23	62
	Mid Lake	69.8	51.8	74	
	Upper Lake	70.9	54.6	89	
78%	Near Dam	65.9	48.9	2	32
	Mid Lake	67.4	49.8	29	
	Upper Lake	69.2	52.2	64	

It is worth noting that the reduction goal of 78% was determined based on the land use information in 1998 through 2000 when the data were collected. The land uses in the model do

not reflect the current condition. Oklahoma State University updated the SWAT model with 2005 land use coverage. The model with the most recent land covers indicates that 20% total phosphorus reduction has been achieved since 2001. One dominant factor for the reduction could be the dramatic change in land use. Many farmers are shifting from row crops to wheat and pasture in the basin. After 2001, peanut acreage dropped by 61%, a 9500 acre reduction [29].

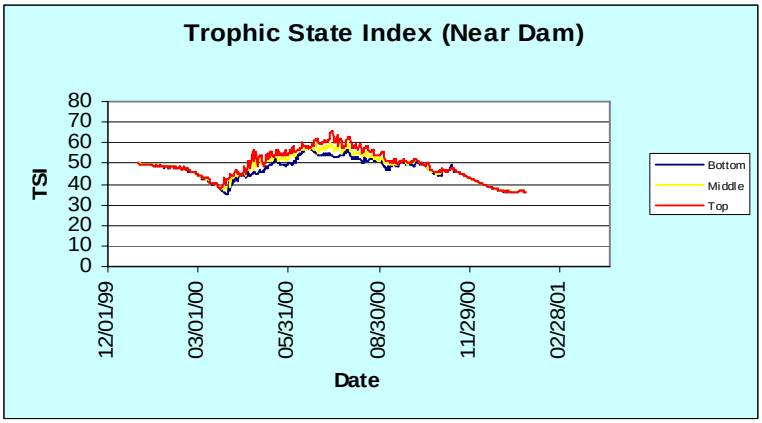


FIGURE 7-1. CARLSON'S TSI NEAR THE DAM (REDUCTION)

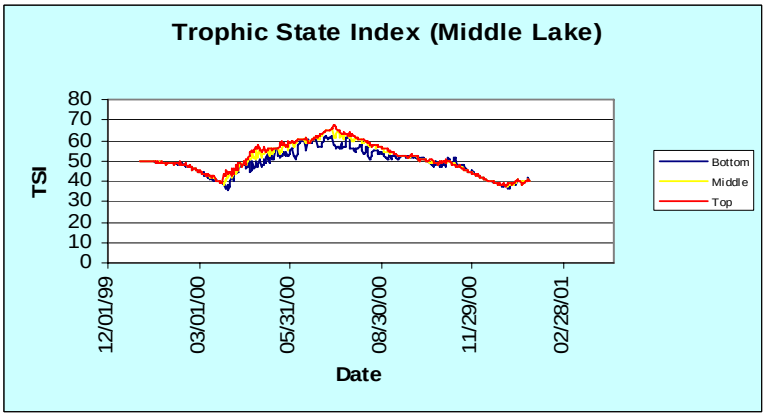


FIGURE 7-2. CARLSON'S TSI IN THE MIDDLE PART OF THE LAKE (REDUCTION)

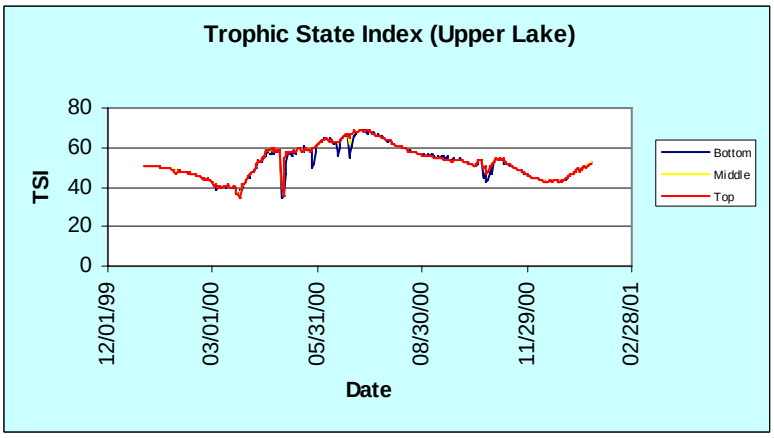


FIGURE 7-3. CARLSON'S TSI IN THE UPPER PART OF THE LAKE (REDUCTION)

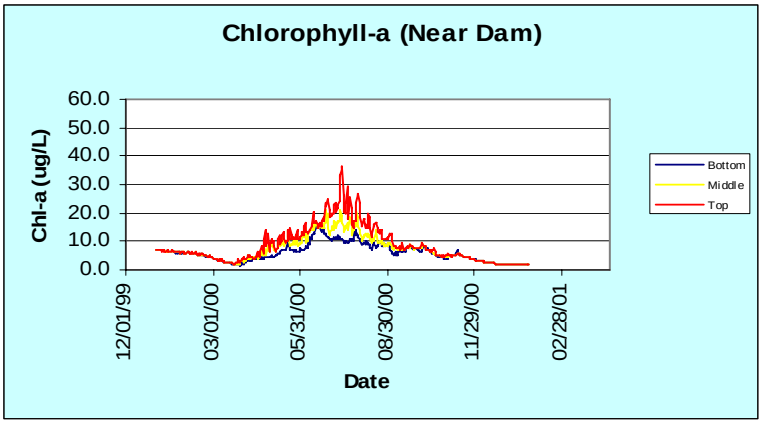


FIGURE 7-4. CHLOROPHYLL-A NEAR THE DAM (REDUCTION)

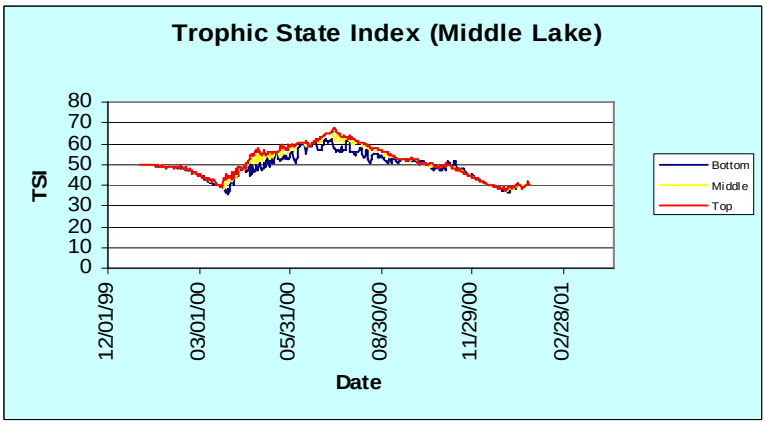


FIGURE 7-5. CHLOROPHYLL-A IN THE MIDDLE PART OF THE LAKE (REDUCTION)

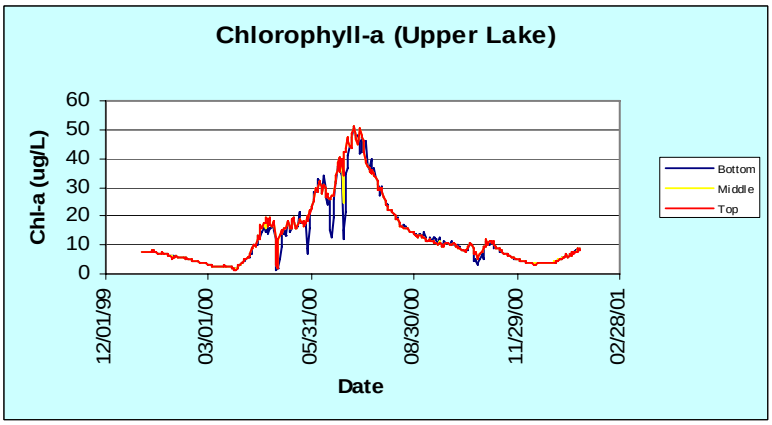


FIGURE 7-6. CHLOROPHYLL-A IN THE UPPER PART OF THE LAKE (REDUCTION)

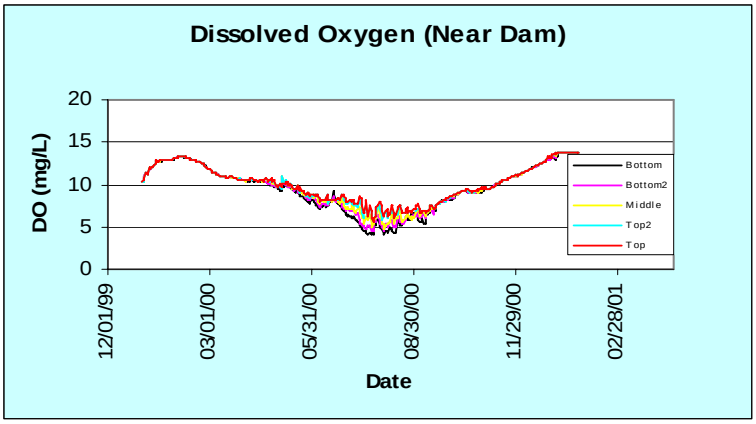


FIGURE 7-7. DISSOLVED OXYGEN NEAR THE DAM (REDUCTION)

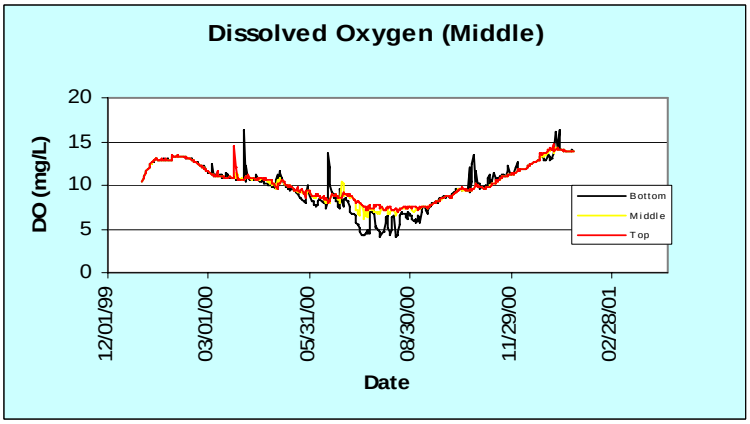


FIGURE 7-8. DISSOLVED OXYGEN IN THE MIDDLE PART OF THE LAKE (REDUCTION)

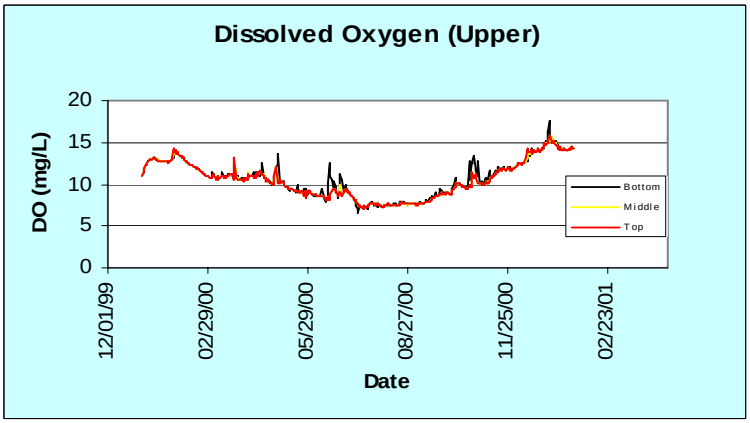


FIGURE 7-9. DISSOLVED OXYGEN IN THE UPPER PART OF THE LAKE (REDUCTION)

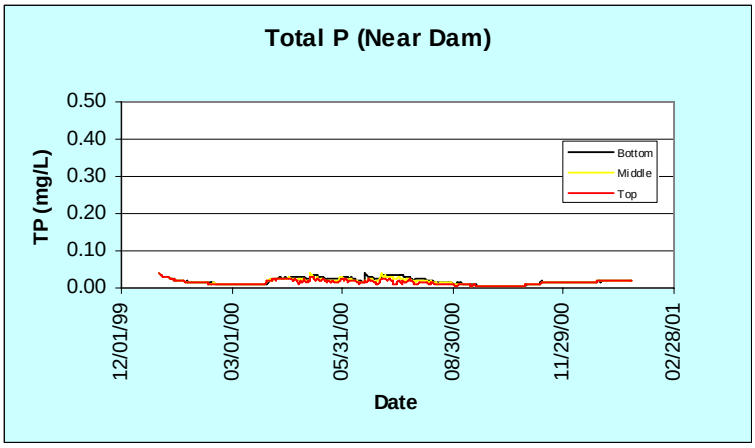


FIGURE 7-10. TOTAL-P NEAR THE DAM (REDUCTION)

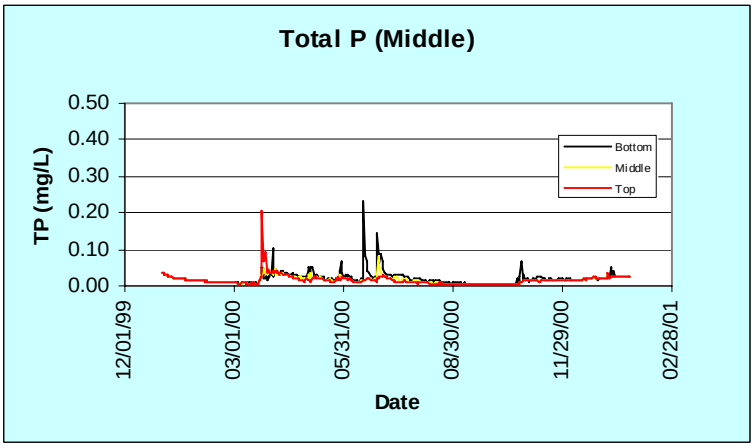


FIGURE 7-11. TOTAL-P IN THE MIDDLE PART OF THE LAKE (REDUCTION)

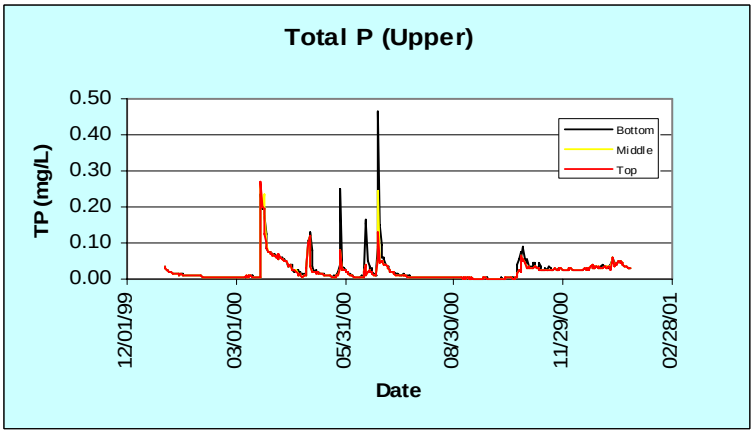


FIGURE 7-12. TOTAL-P IN THE UPPER PART OF THE LAKE (REDUCTION)

7.2. Margin of Safety and Load Allocation

Since the model is calibrated and verified, a 5% margin of safety (MOS) is recommended to satisfy the TMDL requirements. The model predicted a reduction in nutrients of 78% is necessary. In other words, 22% of the current nutrient load is allowed in order to achieve the targets of this TMDL. After applying the 5% margin of safety, only 17% of current load will be allocated as background load, wasteload, reserved load and non-point source load.

The Total Maximum Daily Load can be described as follows:

TMDL = BA + WLA + LA + MOS

Where

BA = Background Allocation

WLA = Wasteload Allocation (point source discharges)

LA = Load Allocation (non-point sources)

MOS = Margin of Safety

There is no wastewater discharge in the Cobb Creek watershed. There are two CAFO farms in the watershed. The NPDES permits for the CAFOs are total retention. The provisions in these permits are sufficient to protect waters in the Cobb Creek watershed. No wasteload allocation is assigned to the CAFOs.

There is currently no stormwater permit in the watershed. Therefore, no wasteload allocation is assigned for stormwater permits either. This does not mean that stormwater permits in the watershed cannot be issued in the future. A reserved load is allocated to accommodate any future stormwater discharges. The provisions in the stormwater permits are stringent enough to protect waters in the watershed.

The background allocation is established based on data collected under low flow conditions. Daily stream flows are sorted from low to high and three flow regimes are defined as follows:

Let Q_i represent daily stream flow

High Flow: if $Q_i \geq 75$ percentile

Normal Flow: if 25 percentile $\leq Q_i < 75$ percentile

Low Flow: if $Q_i < 25$ percentile

Monitoring data for total phosphorus under low flow conditions were separated and used to calculate the mean concentration for TP. This concentration was selected as the background concentration. The background concentration was calculated to be 0.069 mg/L. Average low flow was also calculated to be 0.38 cfs using flow data from 1998 through 2000. Then, the multiplication of background TP concentration and average low flow produced the background load to the lake.

BA = 23.5 kg/year.

The load allocation accounts for non-point source contributions. Since most of the total P load comes from non-point sources, it depends largely on rainfall and runoff events. The EFDC model predicts that a 78% reduction rate would bring Fort Cobb Lake into compliance for both calibration and verification periods. The average annual total P load from 1998 to 2000 predicted by the SWAT model is about 70,000 kg/year. Applying the 78% load reduction, the maximum allowable load is 15,400 kg/year. The load assigned for margin of safety (5%) is 3500 kg/year.

TABLE 7-2. LOAD ALLOCATIONS

Maximum Annual Load (kg/year)	Background Load (kg/year)	Wasteload Allocation (kg/year)	Load Allocation (kg/year)	Reserved Load (kg/year)	Margin of Safety (kg/year)
15400	24	0.0	11856	20	3500

Since there is no point discharge in the watershed, nothing is assigned to the wasteload allocation. To accommodate potential growth in the watershed, an annual load of 20 kg/year is reserved for storm water permits.

7.3. Best Management Practices

The Best Management Practices discussed in this section are intended to show with a reasonable assurance how nutrient reduction may be achieved in Fort Cobb watershed. The implementation of Best Management Practices is not a requirement of this TMDL report. Reduction of nonpoint source pollutant loadings relies on voluntary programs.

7.3.a. Effectiveness of Best Management Practices

The calibrated SWAT model was used to predict sediment and nutrient load from different land uses. Table 7-3 shows the simulated average annual sediment and nutrient loads for various land uses in the basin.

Forest (6% of the entire watershed) accounts for only 0.1% of total P load. Pasture or range (41.4%) accounts for 8.3% of total P load. Croplands (peanuts, sorghum, wheat for grains and grazeout wheat), which are about 50.4% of the total land in the watershed, account for 90.4% of total P load. Among the croplands, peanuts, sorghum and grazeout wheat fields (19.6%) are the major sources of total P contributing 65% of total P load. Therefore, load reduction efforts should focus on reducing nutrient load from cropland. Establishing riparian buffers, no-till cultivation, winter cover for row crops, conversion of cultivated land to pasture, grade stabilization structures, diversions, and terraces are examples of effective Best Management Practices (BMP) to reduce sediment and nutrient load to Fort Cobb Lake.

TABLE 7-3. SIMULATED ANNUAL LOADS BY LAND USE FOR THE FORT COBB BASIN FOR THE PERIOD 1990-2000

Land Use	Fraction of Basin (%)	Sediment (Mg/ha)	Total N (Kg/ha)	Total P (Kg/ha)
Forest	6.0%	0.01	2.20	0.01
Pasture-Range	41.4%	1.61	3.60	0.62
Peanut	7.1%	4.06	7.74	1.87
Sorghum	2.8%	3.16	6.95	1.20
Urban	0.1%	0.05	1.20	0.09
Water	2.1%	0.00	0.00	0.00
Wheat for Grain	30.8%	5.88	9.90	1.91
Grazeout Wheat	9.7%	5.16	8.69	1.81

Using the calibrated SWAT model for the Cobb Creek watershed, Oklahoma State University evaluated several Best Management Practices (BMPs) [17]. The scenarios evaluated are as follows:

- Winter cover crops on row crops
- No-till wheat and row crops
- Conversion of selected highly erodible crop to permanent pasture.

The impacts of each practice on sediment and nutrient reduction are summarized in Table 7-4.

It is estimated that approximately one third of wheat fields are currently moldboard plowed. The reduction in sediment load we would expect if everyone quit moldboard plowing would be 28.6% * 0.33 = 9.5%. Certain farmers were considering changing their peanut production to cotton production. This change as predicted by the SWAT model would increase sediment and nutrient load and therefore should be discouraged.

TABLE 7-4. LOAD REDUCTIONS FOR DIFFERENT BMPS

Practice	% Reduction In Total Basin Load		
	Sediment	Total N	Total P
Calibrated Model*	0.00%	0.00%	0.00%
Notill wheat and row crops	-51.10%	-42.80%	-34.40%
No winter cover on row crops	9.20%	11.10%	6.80%
Worst 1% of cultivated land to pasture	-6.00%	-3.20%	-4.40%
Worst 2.5% of cultivated land to pasture	-11.50%	-8.10%	-8.00%
Worst 5% of cultivated land to pasture	-18.00%	-13.90%	-12.30%
Worst 7.5% of cultivated land to pasture	-23.00%	-18.30%	-15.50%
Worst 10% of cultivated land to pasture	-26.50%	-21.40%	-17.90%
Worst 15% of cultivated land to pasture	-33.00%	-27.10%	-22.10%
Worst 20% of cultivated land to pasture	-37.50%	-31.10%	-25.10%
Worst 25% of cultivated land to pasture	-41.50%	-34.70%	-27.70%
Worst 35% of cultivated land to pasture	-48.00%	-40.40%	-32.00%

* Calibrated model assumes conventional tillage without moldboard plow and small grains winter cover on all row crop

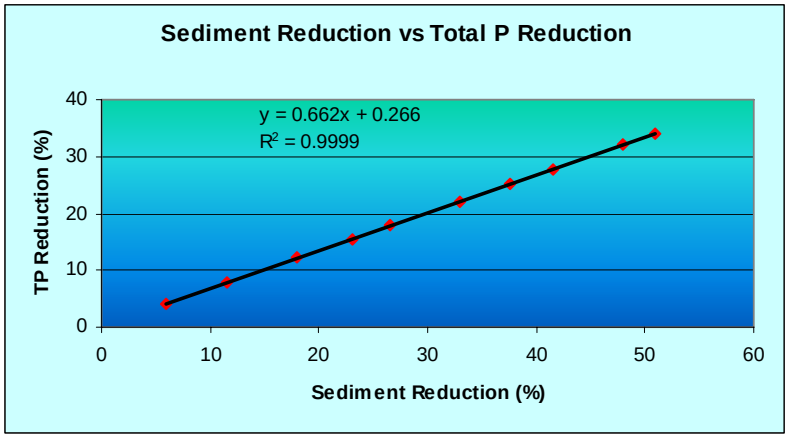


FIGURE 7-13. SEDIMENT REDUCTION VS. TOTAL-P REDUCTION

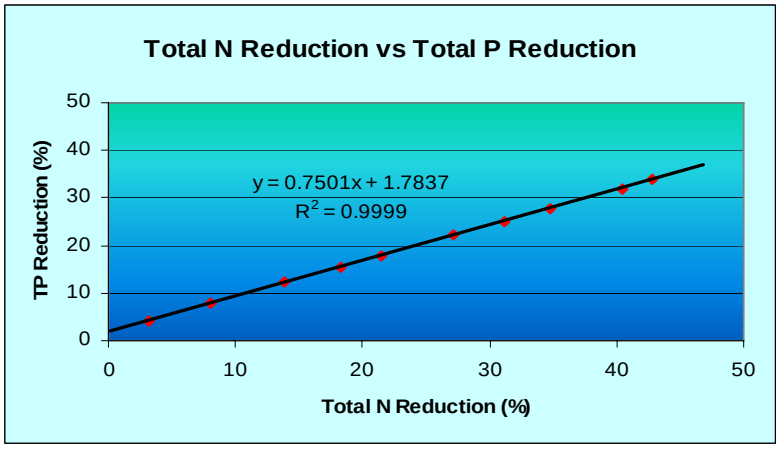


FIGURE 7-14. TOTAL N REDUCTION VS. TOTAL-P REDUCTION

Reduction rates for sediment, total P and total N have a linear relationship between each other as shown in Figure 7-13 and 7-14. For every percent (1.0%) reduction in total P, 1.33% reduction in total N and 1.5% reduction in sediment would be achieved. These reduction rates and relationships were predicted by the calibrated SWAT model for converting some of the worst cultivated land to pasture and no-till wheat and row crops. The reduction rates for other types of management practices will be different. Figure 7-15 shows the relationship between sediment load reduction and conversion of cultivated land to pasture [17].

More details on the impacts of the listed scenarios can be found in the OSU's "Fort Cobb Basin - Modeling and Land Cover Classification" report [17].

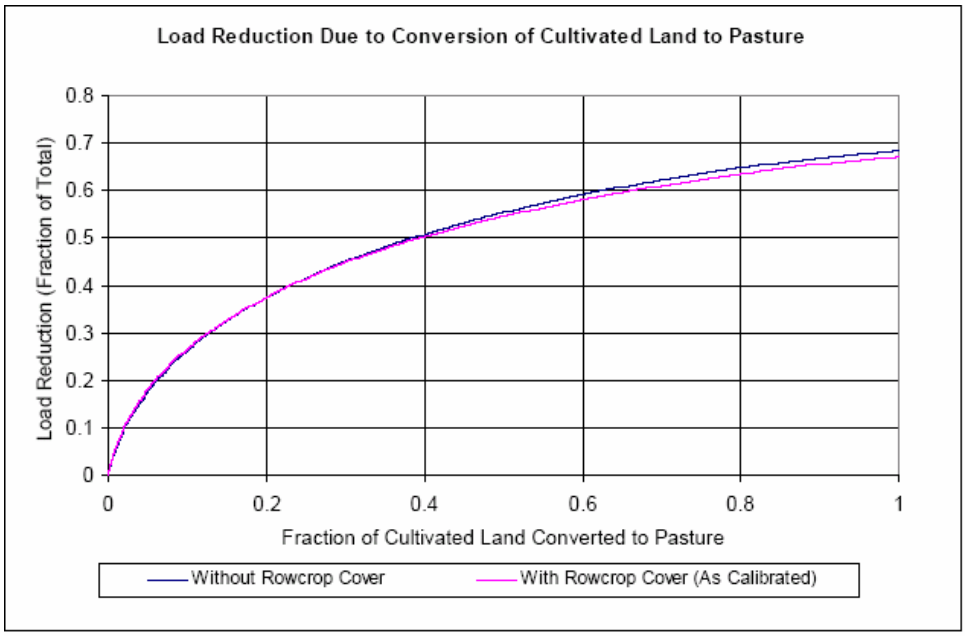


FIGURE 7-15. SEDIMENT LOAD REDUCTION DUE TO CONVERSION OF CULTIVATED LAND TO PASTURE

The highest sediment reduction rate through the BMPs evaluated by OSU is 65.8%, which is equivalent to 44.0% reduction in TP. To achieve this reduction rate, 100% no-till on all crops is required and 100% cover-crops need to be used on all row crops. These practices are almost impossible to implement in reality. This tells us that 65% reduction in total P cannot be achieved through no-till and row crop and the conversion of worst cultivated land to pasture alone. Other practices will be needed to help reduce sediment and nutrient load to Fort Cobb Lake. These practices include riparian buffer restoration, limiting access to creeks for cattle, nutrient management plans, grade stabilization structures, and education on fertilizer application.

Riparian buffers are an effective way to reduce sediment and nutrient load from agricultural fields. Riparian buffers slow and disperse flow of surface runoff, and promote settling of sediment. Riparian buffers are especially good for filtering larger-sized sediment such as sand, soil aggregates, and crop residue, but are generally less effective for clay sediments. Riparian

buffers are good for removal of sediment-attached nutrients but are less effective on dissolved nutrients. Riparian buffers along agricultural lands benefit the farmer and the stream in many ways. However, due to the limitation of the SWAT model, OSU did not simulate the impact of riparian buffers.

A buffer can hold 50 to 80% of nutrients in the soil, keeping them out of the stream where they can cause algal blooms and degrade water quality. A sufficient buffer can also help trap 75-90% of sediment before it leaves the farm [19]. Charles J. Barden and Kyle R Mankin et al [20] studied the effectiveness of three types of riparian buffer vegetation for filtering agricultural field runoff, namely fallow, plum & native grass, and plum & fallow. Total P reduction is above 40% for all vegetation and ranges from 40% to 60%. Reduction in TSS concentration is over 90% for all vegetation types.

The goal of nutrient management is to minimize edge of field delivery of nutrients and minimize leaching of nutrients from the root zone. Pollution prevention through nutrient management is achieved by developing a nutrient budget for the crop, applying nutrients at the proper time, and applying only the types and amounts of nutrients necessary to produce a crop. A summary of the literature findings regarding the effectiveness of nutrient management in controlling nitrogen and phosphorus is given in the following table [21].

TABLE 7-5. RELATIVE EFFECTIVENESS OF NUTRIENT MANAGEMENT

Practice [a]	Percent Change in Total Phosphorus Loads	Percent Change in Total Nitrogen Loads
Nutrient Management [b]	-35	-15

[a] Most observations from reported computer modeling studies

[b] An agronomic practice related to source management; actual change in contaminant load to surface and ground water is highly variable.

According to the Oklahoma Conservation Commission, gully erosion is common and significant in the Cobb Creek watershed. The implementation of structural BMPs, such as grade stabilization structures and diversions could be critical in some areas. Grade stabilization structures will prevent formation or advance of gullies and trap sediment, nutrients and other chemicals, thus improving downstream water quality. Without the structural BMPs, other

management practice such as riparian buffer, grasses or tillage practices may not be as effective due to erosion already ongoing. Though the structural BMPs are vital to the success of non-point source project in the watershed, it is very difficult to estimate the effectiveness of such structures in reduction of sediments and nutrients.

With the combination of riparian buffer, no-till and row crop, conversion of worst cultivated land to pasture, nutrient management plan, bank stabilization, grade stabilization structures and other BMPs, it is likely the required reduction in sediment and nutrients can be achieved. Due to the complexity of the water quality system and the inherit uncertainties in the watershed and lake models, it is difficult to quantify the actual reduction in sediment and nutrient. More monitoring and study will be needed to evaluate the actual effectiveness of the proposed BMPs.

Table 7-6 summarizes the estimated reduction rates for sediment and nutrients for various Best Management Practices.

TABLE 7-6. REDUCTION RATE FOR SEDIMENT AND NUTRIENTS FOR VARIOUS BMPS

Best Management Practices	Sediment (%)	Total nitrogen (%)	Total P (%)
Notill wheat & row crops [17]	-51	-43	-34
Convert up to 20% worst cultivated land to pasture [17]	~ -38	~ -31	~ -25
Riparian Buffer [19][20]	75 ~ 90	35-55	40 ~ 60
Nutrients management plan [21]	NA	-15	- 35
Grade stabilization structures	Unknown	Unknown	Unknown

When several BMPs are implemented at the same time, we assume that the reduction on sediment and nutrients will be additive. Following example is used to show how the overall reduction of several BMPs is calculated:

- Assume no-till wheat and row crop and riparian buffer is implemented in the watershed. The reduction rate on total P for no-till wheat and row crop and riparian buffer is 34% and 50%, respectively.
- After no-till wheat and row crop is implemented, 34% of total P is removed from current loading. In other word, the percentage of total P remaining is (1–0.34) = 66%.
- When riparian buffer is implemented, there is another 50% reduction in total P which leaves 0.66 × (1-0.5) = 33% total P remaining.
- The overall reduction will be (1 – 0.33) = 67%.

This procedure can keep going when more BMPs are implemented. In reality, different BMPs may interact with each other and the actual reduction rate may not be additive. However, this procedure provides the best estimate on overall reduction we can possibly have without any monitoring.

7.3.b. Options for Implementing BMPs

There are many combinations of different BMPs. The most feasible combination will depend on a number of factors such as the degree of implementation for each BMP, number of land owners who will participate the proposed BMPs, costs and incentives for each BMP, public education, etc. In this section, we are trying to give a few examples on options to achieve reduction rate of 78% in total P through a combination of BMPs.

Option #1:

- No-till wheat and row crop: 34%
- Convert 20% worst cultivated land to pasture: 25%
- Riparian buffer: 50%
- Nutrient Management Plan: 35%
- Grade stabilization structures: unknown

The overall reduction rate in total P is calculated to be 84%. This is the potential reduction rate that may be achieved in the watershed through the proposed BMPs. However, this reduction rate may be unrealistic because it assumes that the above BMPs are fully implemented.

Option #2:

- 60% No-till wheat and row crop: (0.34 * 0.65) = 22.1%
- Convert 20% worst cultivated land to pasture: 25%
- 90% Riparian buffer: (0.5 * 0.9) = 45%
- 90% Nutrient Management Plan: (0.35 * 0.9) = 31.5%
- Grade stabilization structures: unknown

The overall reduction in total P would be 78% for this option.

These BMP options only serve as examples of what might be done to achieve the TMDL reduction goal. We recognize this TMDL reduction goal may be difficult to achieve because the extent of reduction required and the implementation of nutrient reduction BMPs are voluntary. The BMPs may not be unrealistic related to the required extent to achieve the goal of the TMDL, but are not necessarily readily agreeable to farmers given current programs in the watershed. Additional support to help implement these practices will likely be necessary.

As noted in Section 7.1, the TMDL reduction goal was determined using the land cover when the data was collected. Since then, approximately 20% reduction has been achieved according to OSU's SWAT model with 2005 land cover information. Although this reduction is still far short from reaching the TMDL reduction goal, it is a big step forward. For those who are interested in BMPs recently implemented in the watershed, please refer to the Watershed Based Plan for the Fort Cobb Watershed report by Oklahoma Conservation Commission [30].

8. Public Participation

This report has been submitted to EPA for technical review and technical approval was received in November 2004. The TMDL report was open for public review on November 24, 2004 and the public review period ended on February 25, 2005. A public meeting was held in the Town of Fort Cobb on January 13, 2005. It was estimated that more than 60 persons attended the public meeting and 45 attendants registered. The attendants include farmers and stakeholders living in or near the Fort Cobb watershed, representatives from West Caddo Conservation District, Farm Bureau and their consultants, USGS, USDA, OCC, and Oklahoma Department of Agriculture etc. A brief presentation about the TMDL was given in the public meeting followed by questions and answers. All questions except specific technical questions from Farm Bureau's Consultants were answered. OCC and USGS also helped to clarify some of the questions. We stayed until all questions were answered and all meeting attendants left.

To address the unanswered technical questions, we committed an additional meeting with Farm Bureau and their consultants. That meeting was held on February 8, 2005 in the DEQ office. Farm Bureau and their consultants, DEQ and OSU attended the meeting.

At the end of public review period, five comments were received. All comments were considered, formally responded and included as an appendix of this report. As a result of public comments, Oklahoma State University refined or recalibrated the SWAT model. Since the TP load to the Fort Cobb Lake predicted by the SWAT model changed significantly from year to year although the overall annual average loading stayed almost the same, we recalibrated the EFDC model based on the new TP load to the lake. Due to a significant increase in TP load in 2000, the required reduction rate went up from 65% to 78%. The TMDL allocation was changed accordingly. The TMDL report was also revised to reflect all changes resulting from public comments.

The second public comment period was open on May 24, 2006 for the revised TMDL report and the public comment period ended on June 23, 2006. No comments were received during this public comment period.

9. References

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APPENDIX B:

Fort Cobb Basin –

Modeling and Land Cover Classification

FINAL REPORT

Submitted under FY 01 319h C9-996100-09 Project 4 Output 2.2
Approved by EPA October 2003

Fort Cobb Basin -
Modeling and Land Cover Classification

FINAL REPORT

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Acknowledgment

We would like to thank Oklahoma Conservation Commission personnel, specifically Monty Ramming, for providing the ground truth data and crop management information which are critical to developing a good model.

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Introduction

Background and Purpose

The Oklahoma Conservation Commission (OCC) is concerned about water quality issues in the Fort Cobb Reservoir/Cobb Creek Basin. The Fort Cobb Basin is located in Southwestern Oklahoma in Caddo, Washita, and Custer Counties. The basin area is 314 square miles and the surface area of the Fort Cobb reservoir is 4,100 acres. Fort Cobb Reservoir and six stream segments in its basin are listed on the 1998 303(d) list as being impaired by nutrients, pesticides, siltation, suspended solids, and unknown toxicity. In order to mitigate the effects of nonpoint source pollution in the basin, OCC has crafted a large-scale implementation program to address the sources of pollution.

The purpose of the project is to demonstrate the benefits of nonpoint source (NPS) implementation on the water resources of the Fort Cobb Reservoir Basin. The objectives of the project are to promote protection and re-establishment of buffer zones and riparian areas; demonstrate practices necessary to achieve the sediment, nutrient, and pesticide control needed to protect the Cobb Creek and Fort Cobb Reservoir; and implement practices identified by the Watershed Restoration Action Strategy and a TMDL to improve water quality.

The project was separated into two components. Applied Analysis Incorporated was subcontracted by Oklahoma State University to develop a current land cover theme for the basin. The report submitted by Applied Analysis Incorporated to Oklahoma State University is listed in Appendix A. Oklahoma State University performed the modeling portion of the study which is detailed in the bulk of this report.

Modeling Sediment and Nutrient Loading for the Fort Cobb Basin

Two separate modeling components were performed by Oklahoma State University. The first task was estimating erosion from county roads using the Water Erosion Prediction Project (WEPP) Model. The second task was modeling nutrient and sediment loads from upland areas using the Soil and Water Assessment Tool (SWAT) Model.

Erosion Estimates From County Roads

The density of unpaved county roads was estimated using available Geographic Information Systems (GIS) data and ground truth data. The accuracy of these GIS data were greatly improved using detailed ground truth by Oklahoma Conservation Commission personnel. A USGS Digital Elevation Model (DEM) was used to estimate slope and slope length along these roads. The WEPP Roads Model (WEPP: Road, Elliot, William et al., USDA, Forest Service Rocky Mountain Research Station,1999) was applied to estimate average annual erosion.

Nutrient and Sediment Loading Using SWAT

Loading to the reservoir was estimated as well as loading from different portions of the basin using SWAT 2000 (Arnold, Jeff. et al., USDA, Agricultural Research Service. Grassland, Soil, and Water Research Laboratory, 2002). Land cover specific loading was simulated to show the fraction of the total load to the reservoir originating from each land cover type. Areas that contribute a disproportionate amount of sediment were identified to target OCC water quality programs.

County Roads Erosion Estimates

County roads in the Fort Cobb Basin were considered a potentially significant contributor of sediment to the reservoir by the OCC. The Water Erosion Prediction Project (WEPP) for roads model was used to estimate road and bar ditch erosion.

Input Data

The WEPP: Road interface is accessible via the internet at http://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/wr/wepproad.pl. The interface requires:

- Climate Station
- Soil Texture
- Road Design
- Road Surface
- Road Gradient
- Flow Length
- Road Width

Climate Data

Climate data collected at a station in Weatherford, Oklahoma were utilized in the analysis. Thirty years of data were simulated for use in WEPP based on statistics collected at the Weatherford station. This process was performed by the online interface.

Soil Texture, Road Surface, and Design

Oklahoma Conservation Commission personnel performed extensive ground truthing of the roads in the basin. Data on road surfaces, soil textures, and bar ditch conditions were collected for each 1/4 mile and attributed onto US Census Bureau Topologically Integrated Geographic Encoding and Referencing System (TIGER) road location data (Table 1). The result is shown in Figure 1. Roads were assumed to be 10 meters wide including both bar ditches.

Road Gradient and Flow Length

Slope was derived from USGS 10 meter DEMs. Individual quads were stitched together to cover the entire basin. These data were integer grids with elevation in meters. Slopes derived from an integer grid in low relief areas are inaccurate. Therefore, these data were converted to a floating point grid by converting the original grid to contour lines, then to a Triangulated Irregular Network (TIN), and finally back to a grid (Figure 1). Converting the grid to contour lines extracts data at locations where integer data were most likely to be accurate. The conversion to a TIN extrapolates the elevations for the areas between the contour lines. The resulting grid was suitable for slope derivations the WEPP Roads model.

Road length was derived from a simplified TIN (using a Z tolerance of 3 meters) and the TIGER road theme attributed with ground truth data. This resulted in a vastly simplified TIN which ignores small undulations in topography. This TIN was used to break the road theme into sections with similar aspects. The road network for the basin was separated into approximately 11,000 segments with each having different properties.

Methods

The only WEPP roads interface available is web based and does not allow batch processing. With 11,000 road segment it is not feasible to run each manually. Therefore, a set of 432 computer simulations covering a variety of conditions were run manually via the web interface. These data were used in conjunction with software written specifically for this task to interpolate sediment yield for each of the 11,000 road segments.

Results

Assuming a 10 m road width, roads cover 1.07% (916 ha) of the basin and contribute 6029 Mg (6,029,000 kg) of sediment annually as predicted by the WEPP Roads model. The sediment contribution of the different road surfaces and bar ditch conditions are shown in Table 1. The fraction of roads in each category and their average length are shown in Tables 3 and 4. At first glance sediment rates for paved roads appear disproportionally high as compared to dirt roads, but the paved roads have longer segment lengths on average for some bar ditch conditions. Paved roads also have virtually no infiltration, thus producing more surface runoff. Bar ditch erosion is very sensitive to segment length and runoff volume.

Table 1 Road ground truth categories reported by Oklahoma Conservation Commission personnel.

Bar Ditch Conditions	Road Surface	Soil Types*
Stable and Vegetated	Paved	Sand
Stable and Rocky	Gravel	deep sand
Starting to Erode	Gravel and Dirt mix	Clay
Actively Eroding	Dirt	Bedrock
Deep Erosion and Cutting		
Flume		

* Soil types reported for dirt roads only.

Table 2 Road and bar ditch erosion by road surface type and bar ditch condition as predicted by the Water Erosion Prediction Project (WEPP) Model.

Average Sediment Yield (Mg/km/yr)				
	Stable	**Eroding**	**Flume**	**All Ditch Types**
Paved	2.1	10.2	0.0	**3.2**
Gravel	7.7	14.9	13.1	**10.0**
Gravel and Paved	6.5	18.0	24.2	**13.8**
Dirt	4.9	9.0	11.5	**7.9**
All Surfaces	**3.6**	**12.8**	**6.2**	**6.6**

Total Annual Sediment Yield (Mg/yr)				
	Stable	**Eroding**	**Flume**	**All Ditch Types**
Paved	898	689	0	1587
Gravel	763	657	11	1430
Gravel and Paved	340	1539	39	1917
Dirt	180	910	4	1095
All Surfaces	**2180**	**3795**	**54**	**6029**

Table 3 Total length of roads in the Fort Cobb Basin by surface type and bar ditch condition.

Total Road Length (km)				
	Stable	**Eroding**	**Flume**	**All Ditch Types**
Paved	423	67	6	496
Gravel	99	44	1	143
Gravel and Paved	52	85	2	139
Dirt	37	101	0	138
All Surfaces	**611**	**297**	**9**	**917**

Table 4 Average length of road segments in the Fort Cobb Basin by surface type and bar ditch condition.

Average Road Segment Length (m)			
	Stable	**Eroding**	**Flume**
Paved	84.3	76.8	93.7
Gravel	85.3	75.7	80.3
Gravel and Paved	80.8	83.9	51.5
Dirt	73.8	77.9	64.6

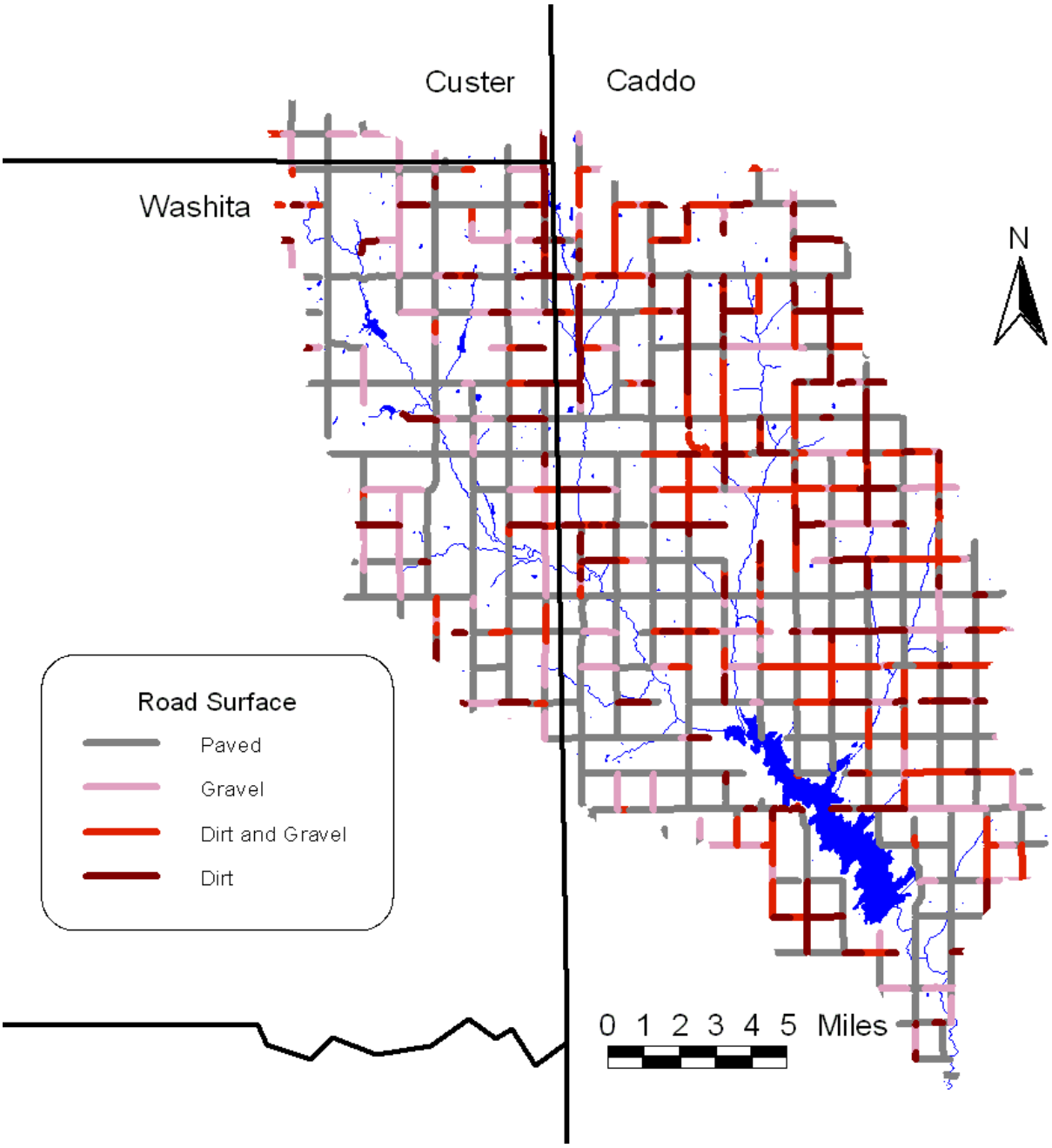

Figure 1 Road surface conditions in the Fort Cobb Basin derived from US Census Bureau Topologically Integrated Geographic Encoding and Referencing system TIGER data and ground truth collected by Oklahoma Conservation Commission personnel.

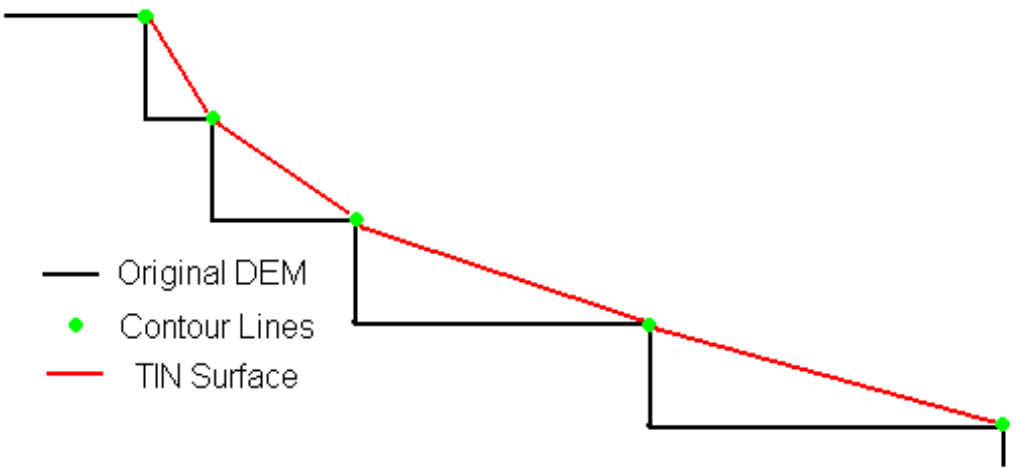

Figure 2 Illustration of how the TIN, the original USGS DEMs, and the contour lines compare.

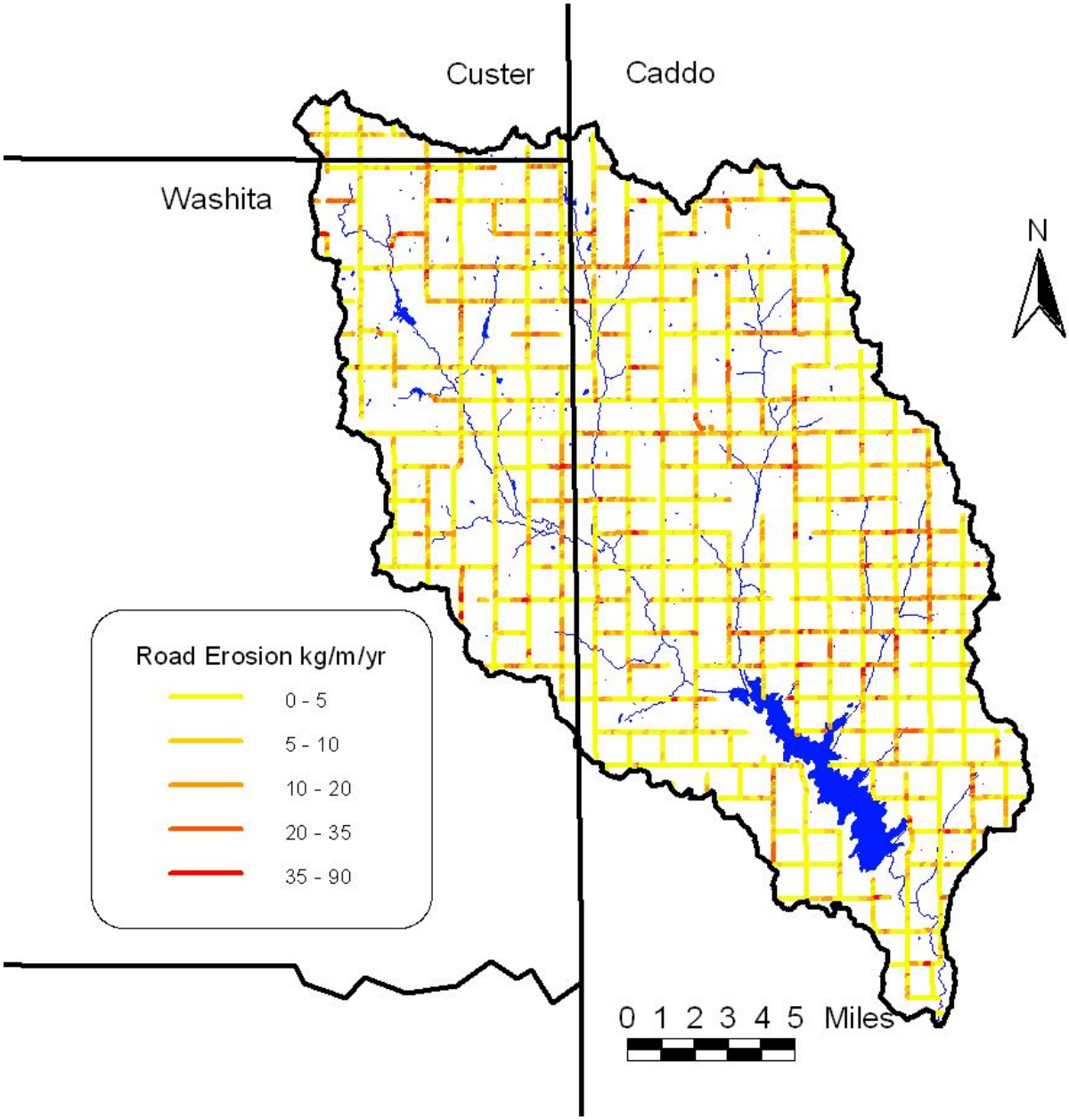

Figure 3 Water Erosion Prediction Project (WEPP) predicted road erosion in the Fort Cobb Basin.

Nutrient and Sediment Loading Using SWAT

The SWAT 2000 model was used to estimate erosion and nutrient loading from the upland areas of the basin. SWAT is a distributed parameter basin scale model developed by the USDA Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas. SWAT is included in the Environmental Protection Agency's (EPA) latest release of Better Assessment Science Integrating Point and Nonpoint Sources (BASINS).

Input Data

Because SWAT is a distributed model, data requirements are vast and data manipulation is difficult. These requirements are met using a ArcView GIS interface, which generate model inputs from commonly available GIS data. These GIS data are summarized by the interface and converted to a form usable by the model. Below is a list of GIS data that were utilized:

- 10 m USGS DEM (Figure 4)
- 200 m NRCS MIADS Soils Data
- 30 m AAI Land Use Data Layer (Figure 5)
- EPA Reach3 Streams

In addition, tabular weather data from the NOAA Cooperative Observation Network (Surface Data, Daily, NOAA National Climatic Data Center, 2003) were used in all modeling. The hydrologic portion the model was calibrated using USGS stream gage data and the observed weather data.

Land cover data from AAI were combined with a crop type breakdown based on 1999-2001 Oklahoma Agricultural Statistics Service data (Table 5) (http://www.nass.usda.gov/ok/, USDA, 2002) and center pivot irrigation locations tagged from aerial photography (Figure 6) (ftp://okmaps.onenet.net, Digital Orthographic Photography, dates vary). These data allowed us to separate the Agricultural category from AAI into four separate crops categories (Figure 7).

Land cover specific data, such as soil test phosphorus and current fertilization practices, are not widely available. Soil test P for common agricultural land covers were derived from OSU county level averages for the period 1995 -1999. Current fertilization and management practices are based on OSU recommendations and knowledge of local OSU Extension and Conservation District personnel (primarily Monty Ramming) (Table 6). Table 6 includes SWAT predicted sediment yields based on model runs of each management scenario on a single HRU, with a Woodward soil and a slope of 3.6%. Single cropped peanuts and sorghum are included in Table 6 but were not used in the model.

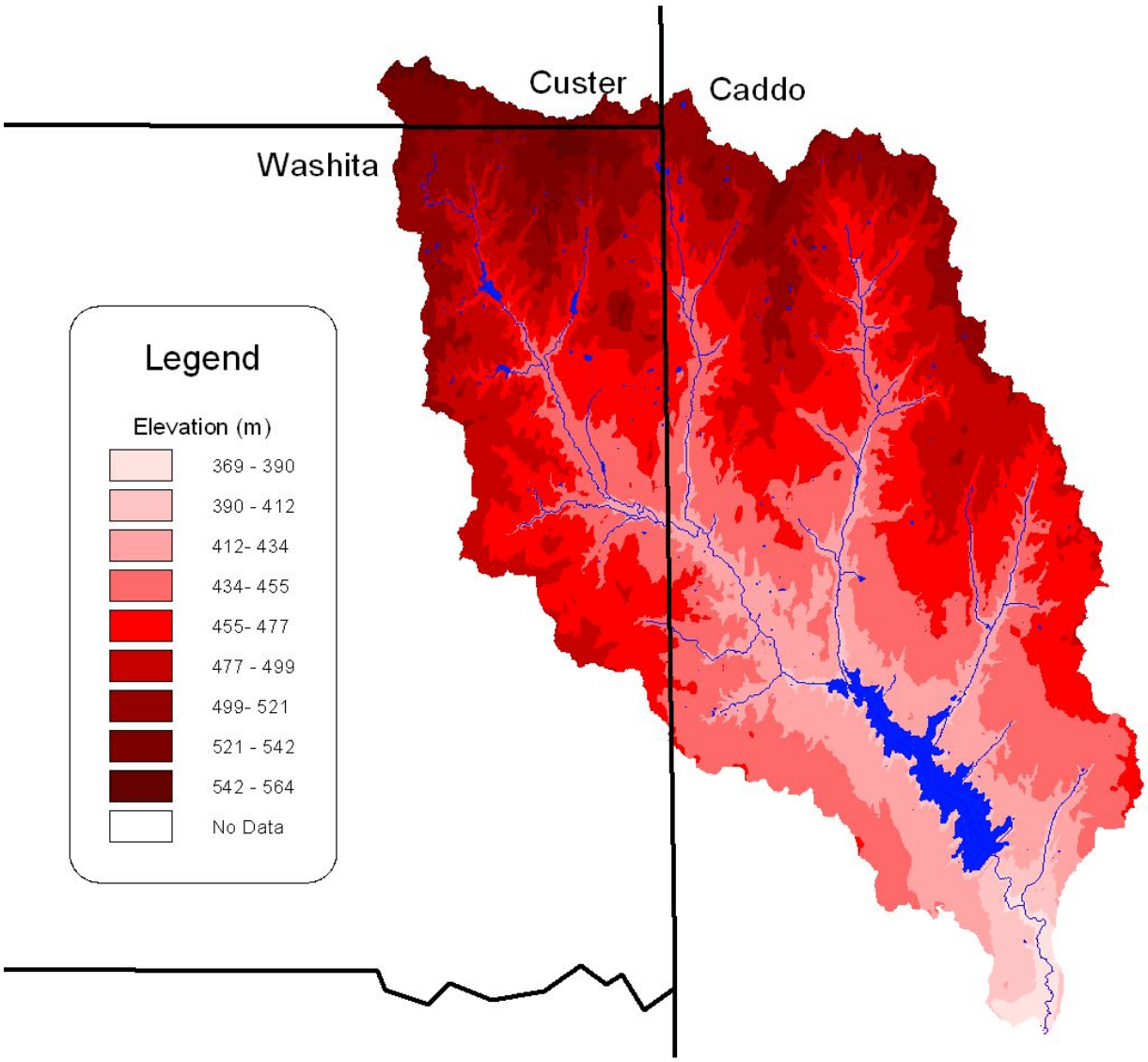

Figure 4 Ten meter USGS Digital Elevation Model (DEM) with county boundaries for the Fort Cobb Basin.

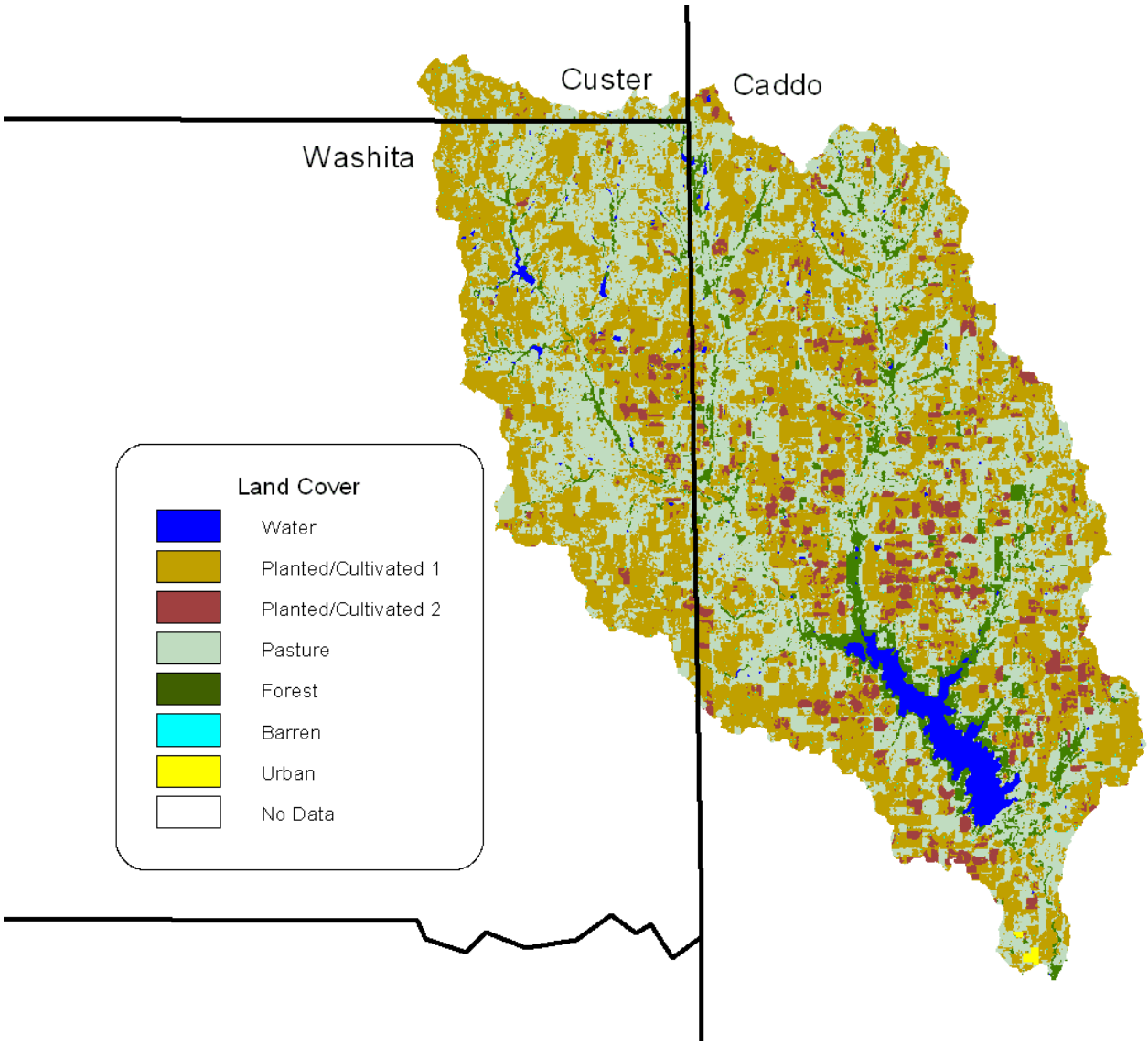

Figure 5 Thirty meter Applied Analysis Incorporated Landsat derived land cover with county boundaries for the Fort Cobb Basin.

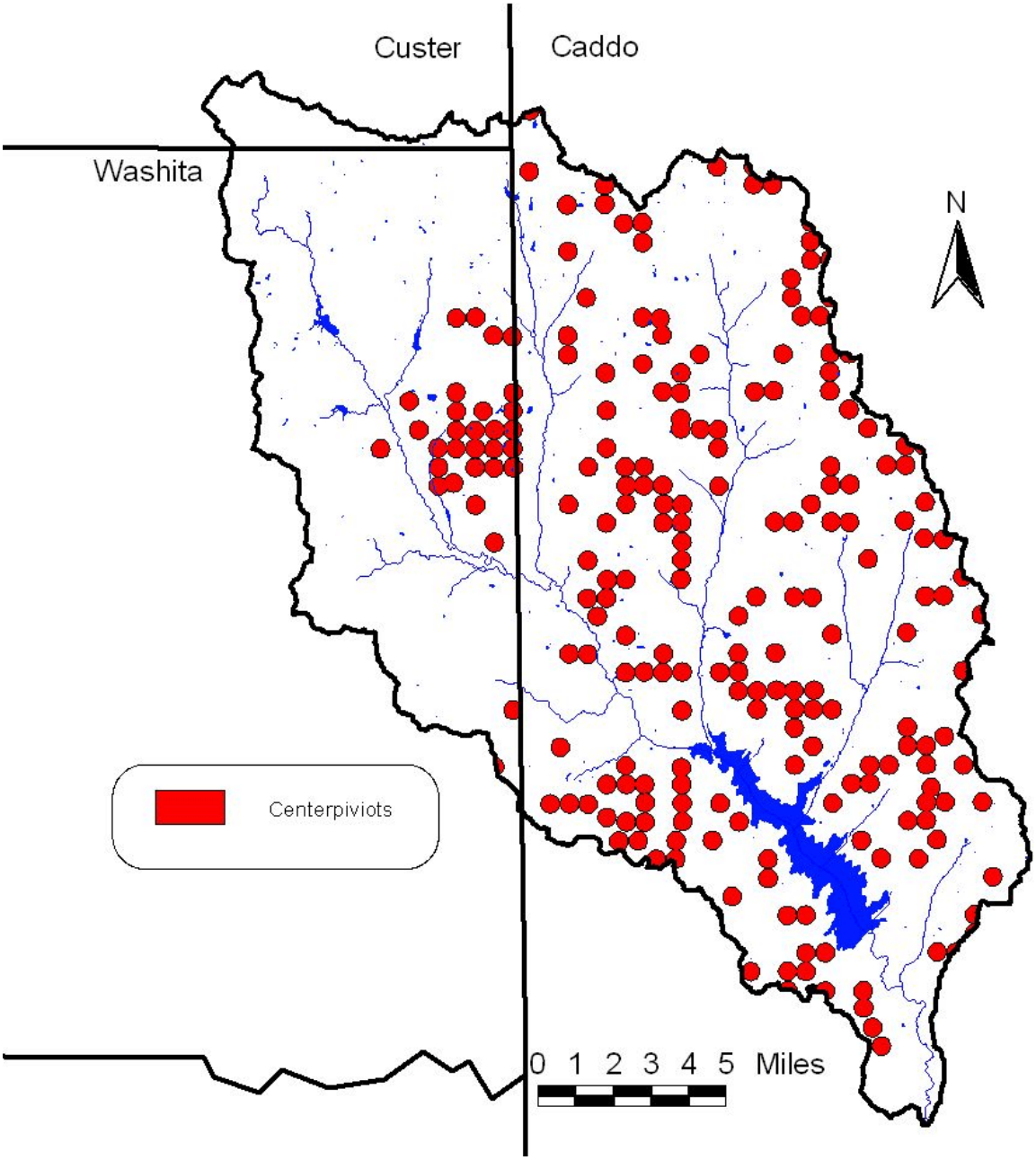

Figure 6 Center pivot irrigation systems tagged from 1 m digital aerial photography for the Fort Cobb Basin.

Table 5 Crop breakdown based on 1999-2001 National Agricultural Statistics Service data**.**

Irrigated Cropland	Peanuts	71%
	Sorguhm	29%
Non-Irrigated Cropland	Wheat for Grain	76%
	Wheat for Pasture	24%

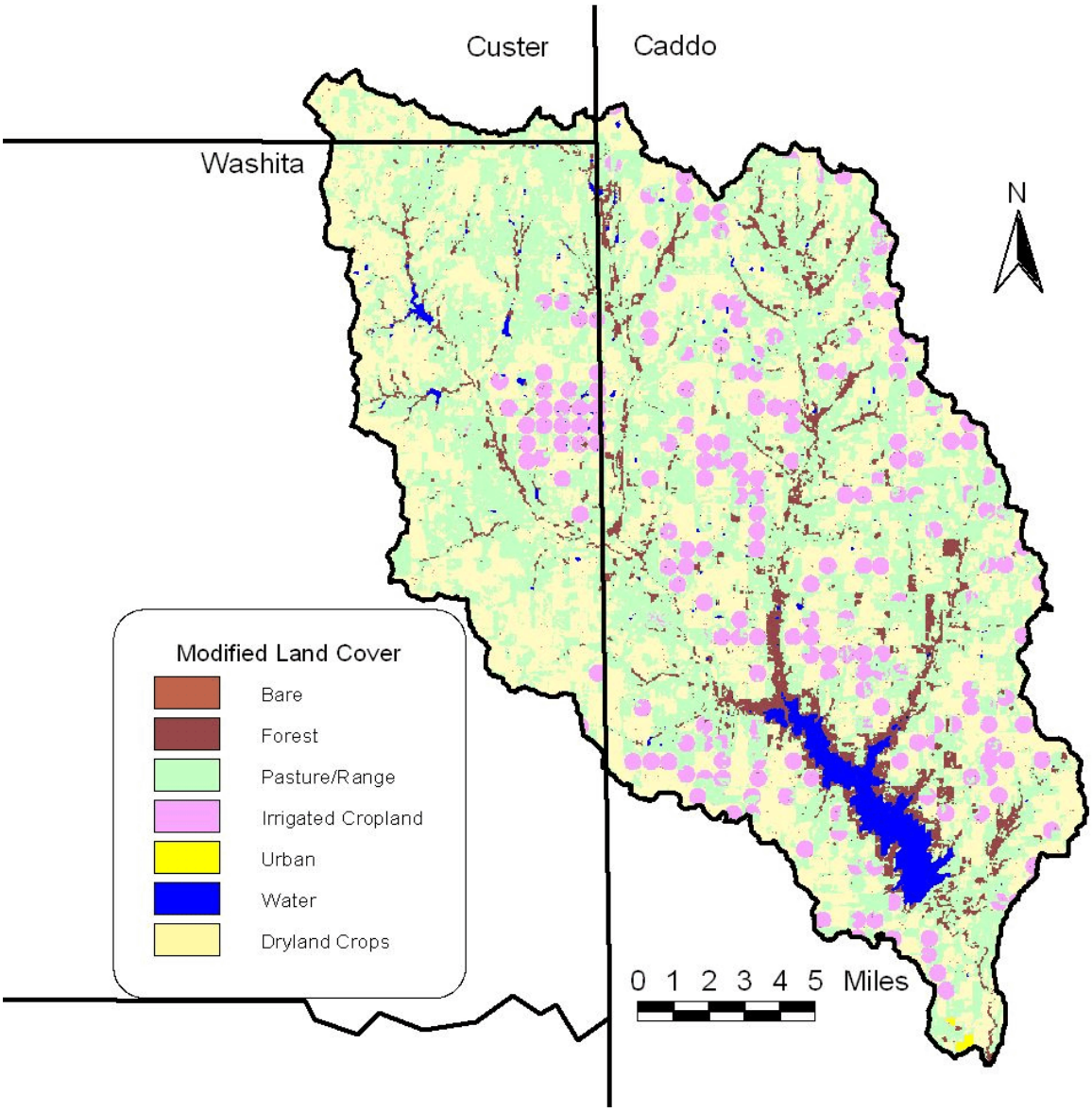

Figure 7 Land cover coverage incorporating Applied Analysis Incorporated land cover data, center pivot locations, and National Agricultural Statistics Service data.

Table 6 Management operations SWAT predicted sediment yields on a single Hydraulic Response Unit with identical properties other than management. Soil and subbasin properties are listed in the lower right section. *Peanut Only* and *Sorghum Only* were not used in the model and are listed for comparison purposes only.

Peanut/Wheat	Wheat for Grain	Wheat Graze out	Sorghum/Wheat
4.9 ton/ha Sediment	**7.0 ton/ha Sediment**	**7.3 ton/ha Sediment**	**7.9 ton/ha Sediment**
Kill Wheat April 15	Harvest Wheat June 1	Kill Wheat May 1	Harvest Wheat May 25
Fertilize 27 lb/acre N April 16	Fertilize 120 lb/acre N Sept 20	Fertilize 70 lb/acre N Aug 20	Fertilize 40 lb/acre N May 27
Fertilize 70 lb/acre P2O5 April 16	Fertilize 30 lb/acre P2O5 Sept 20	Fertilize 30 lb/acre P2O5 Aug 20	Fertilize 15lb/acre P2O5 May 27
Disk April 17	Disk Sept 22	Disk Aug 22	Disk May 28
Disk April 17	Disk Sept 22	Disk Aug 22	Disk May 28
Insecticide Temik 1 lb/acre ai April 17	Springtooth Sept 24	Springtooth Aug 24	Insecticide Temik 1 lb/acre ai May 28
Herbicide Lasso 3 lb/acre ai April 17	Plant Wheat Sept 25	Plant Wheat Aug 25	Herbicide Lasso 2.5 lb ai/acre May 28
Springtooth April 18	Grazing 1/3 au/acre for 90 days Dec 1	Grazing 1/3 au/acre for 150 days Nov 15	Springtooth May 29
Plant Peanuts April 19			Plant sorghum June 1
Auto irrigation April 20			Auto irrigate June 20
Harvest Peanuts Oct 15			Harvest sorghum Oct 15
Fertilize 40 lb/acre N Oct 17			Fertilize 82 lb/acre N Oct 17
Fertilize 15 lb/acre P2O5 Oct 17			Disk Oct 18
Disk Oct 18			Disk Oct 18
Disk Oct 18			Springtooth Oct 19
Springtooth Oct 19			Plant Wheat Oct 20
Plant Wheat Oct 20			
Grazing 1/3 au/acre for 130 days Dec 1			

Peanut Only	Sorghum Only
11.9 ton/ha Sediment	**17.5 ton/ha Sediment**
Fertilize 27 lb/acre N April 16	Fertilize 40 lb/acre N May 27
Fertilize 70 lb/acre P2O5 April 16	Fertilize 15lb/acre P2O5 May 27
Disk April 17	Disk May 28
Disk April 17	Disk May 28
Insecticide Temik 1 lb/acre ai April 17	Insecticide Temik 1 lb/acre ai May 28
Herbicide Lasso 3 lb/acre ai April 17	Herbicide Lasso 2.5 lb ai/acre May 28
Springtooth April 18	Springtooth May 29
Plant Peanuts April 19	Plant sorghum June 1
Auto irrigation April 20	Auto irrigate June 20
Harvest Peanuts Oct 15	Harvest sorghum Oct 15
Disk Oct 18	Disk Oct 18
Disk Oct 18	Disk Oct 18
Springtooth Oct 19	Springtooth Oct 19

Parameter	Value
Soil	Woodward
USLEK	0.37
Hydrologic Soil Group	B
Slope	3.60%
Slope Length	300 ft

Calibration

Few stream gage data were available to calibrate the Fort Cobb Basin SWAT Model for the period Jan 1990 - Oct 2001. The only suitable gage was Cobb Creek Near Eakley (USGS 07325800). The hydrologic calibration was performed predominantly with data from this gage. Another gage down stream of the Fort Cobb Reservoir was also utilized as a check of the calibration (Figure 8). Calibration parameters for ungaged areas were identical to the gaged area on Cobb Creek. Older USGS stream gage data indicated that runoff volume per unit area was similar in other parts of the basin (Table 7). Note that Cobb Creek Near Fort Cobb is downstream of the reservoir and is subject to additional water losses (evaporation, seepage etc.) that occur in reservoir, and therefore it is expected to have a much lower flow per unit area.

The results of the calibration are shown in Table 8 and Figures 9 and 10. Average relative errors were less than 2% at Cobb Creek near Eakley. Comparisons at the Fort Cobb near Fort Cobb gage, which is downstream the reservoir and outside the basin, were 1.78 CMS and 1.79 CMS for observed and simulated flow, respectively. Time-series of monthly flows indicated that the model over predicts peak flows and often underestimates flow during low flow conditions (Figure 9). We think this is the result of the ponds upstream of the gage on Cobb Creek. These ponds were not added to the model as reservoirs. Reservoirs have a filtering effect on stream flow, limiting peak flows by impounding water during storms and releasing water during low flow periods. Due to the way reservoirs are added to the SWAT model, it was not possible to add them during calibration. This limitation mainly effects short term stream flow and should not significantly impact long-term averages. Significant changes to the SWAT model were made during calibration. Table 9 contains all parameter modifications made to calibrate the model for both flow and nutrients.

Total phosphorus and total nitrogen were calibrated using water quality data collected throughout the basin. Insufficient data were available at any given location to accurately estimate nutrient loading. The model was calibrated by comparing individual water quality observations at the same location and time in the model as they were actually taken. The vast majority of these samples were taken under base flow conditions; thus their utility is limited. A total of 62 samples of total nitrogen and 60 samples of total phosphorus were used in the calibration. The results of the nutrient calibration are shown in Figures 11 and 12.

Results

The SWAT model was used to estimate the loading to the reservoir and how the loading varies spatially across the basin. Figures 13, 14, and15 illustrate how the load per unit area varies across the basin. Table 11 displays the load by landcover as predicated by SWAT. The total predicted sediment loading to the reservoir is 245,000 metric ton annually (Table 13).

High Resolution Erosion Mapping

Data from the SWAT model was applied to the original high resolution GIS data to create a map of relative sediment yield for the basin (Figure 17). There are several clusters of high relative erosion in the northern half of the basin. SWAT makes predictions for specific combinations of land cover and soils known as Hydrologic Response Units (HRUs). A database of unique soil and land cover combinations were generated from the HRU level data. If two HRUs had the same soil and land cover, an area weighted average was performed. Included in this database were the annual sediment yield and slope. This database was used to estimate erosion for each grid cell in the original GIS data. Sediment yield was adjusted proportionately based on the slope form the grid cell and the average slope in the database for that particular combination. If a particular land cover and soil combination was not an HRU in the model and therefore not in the database, the average

for the land cover was used.

Erosion Targeting

The high resolution erosion map was verified in field and appeared to be very accurate, however a few anomalies were found. In the northwestern portion of the basin several hot spots were discovered to be gypsum outcropings that were miss-classified as crop land in the land cover data. These outcrops are common in Cornick soil series. The Cornick series is characterized by its very shallow soil, with only 5-20 inches to gypsum bedrock. This series is rocky and seldom suitable for tillage. Areas listed in the MIADs soils data as *Rough Broken Land* were also considered unsuitable for tillage. When the land cover data listed one of these soils as crop land, it is likely that a miss-classification has occurred. Exposed rock and bare soil are spectrally similar. These areas were tagged as non-typical in the final product (Figure 18). Crop land areas with slopes greater than 15% were also tagged as non-typical. It is unlikely that tillage would be performed in an area so steep. Priority areas were tagged by ranking the grid cell erosion values and using a cutoff based on area (Figure 19). The final product was generated by dividing the basin into four categories:

- **High Priority** is 5% of the basin with the highest predicted erosion.
- **Medium Priority** includes the next highest eroding 5%.
- **Low Priority** covers the remainder.
- **Non-typical** areas are suspected missclassifications in land cover including agricultural fields with slopes greater than 15%, gypsum outcroppings, or rough broken land.

Summary

The WEPP roads model estimated that the annual sediment loading from roads in the Fort Cobb basin to be 6,030 metric tons per year (Table 13). This represents 2.2% of the 280,000 metric tons per year of sediment loading predicted by the SWAT Model for the entire basin. SWAT predicted sediment load to Fort Cobb Reservoir is 245,000 metric tons per year. The difference is due to the small portion of Cobb Creek between the Fort Cobb Reservoir and the Washita River, which is included in the entire basin estimate. SWAT model predictions combined with high resolution GIS data indicate several sediment “hot spots”. These areas contribute sediment loads more that ten times the basin average on a per hectare basis.

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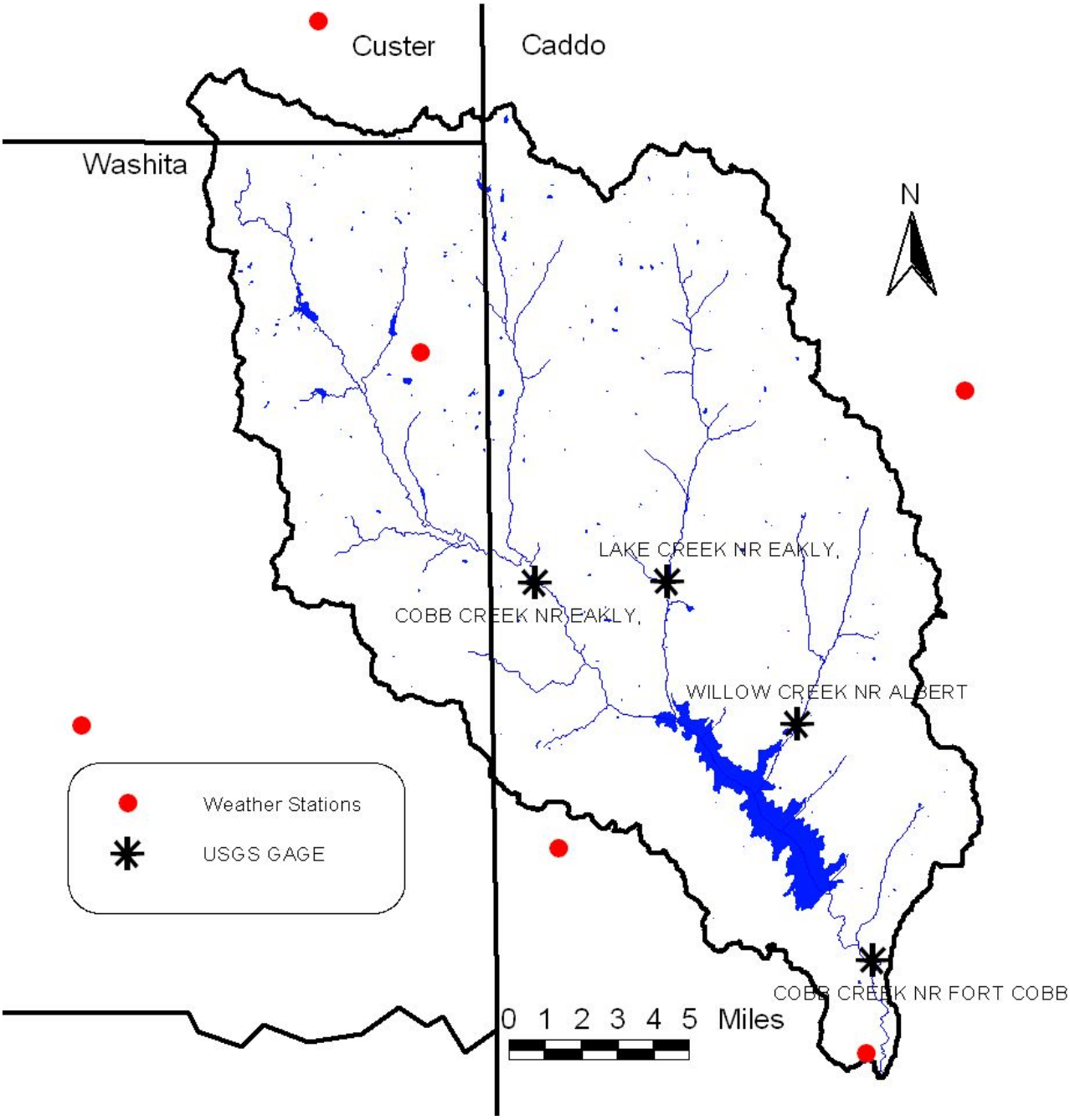

Figure 8 U.S. Geologic Survey (USGS) stream gage and Cooperative Observation Network (COOP) weather station locations in the Fort Cobb Basin.

Table 7 Flow per unit area from 10-1-70 to 6-30-78 for available USGS stations in the Fort Cobb Basin.

Station	Drainage Area (mi^2)	Flow/Area (cfs/mi^2)
Cobb Creek Near Eakley	132	0.18
Lake Creek Near Eakley	52	0.15
Willow Creek Near Albert	28	0.14
Cobb Creek Nr Fort Cobb	307	0.06

Table 8 Average SWAT Model hydrologic calibration results for stream flow at the Cobb Creek near Eakley gage for the period 1/1990-10/2001.

	Total	Surface	Baseflow
Observed	1.09	0.52	0.57
Predicted	1.10	0.53	0.58
Relative Error	-1.6%	-1.7%	-1.5%

Table 9 Parameter values use to calibrate the Fort Cobb SWAT model for both nutrients and flow.

Value	Variable	Description
15	GW_DELAY	Groundwater delay [days]
50	GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur
50	REVAPMN	Threshold depth of water in the shallow aquifer for "revap" to occur [mm]
0.2	RCHRG_DP	Deep aquifer percolation fraction
0.3	ESCO	Soil evaporation compensation factor
0.04	AWC	Soil maximum avalable water content
0.8	USLEP	Universal Soil Losss Equation conservation practive factor
1.5	GW_NO3	Concentration of nitrate in groundwater contribution to streamflow from subbasin
0.2	NPERCO	Nitrogen percolation coefficient
1	PPERCO	Phosphorus percolation coefficient
900	PHOSKD	Phosphorus soil partitioning coefficient
0.55	PSP	Phosphorus sorption coefficient
0.3	RES_K	Reservoir Permeability

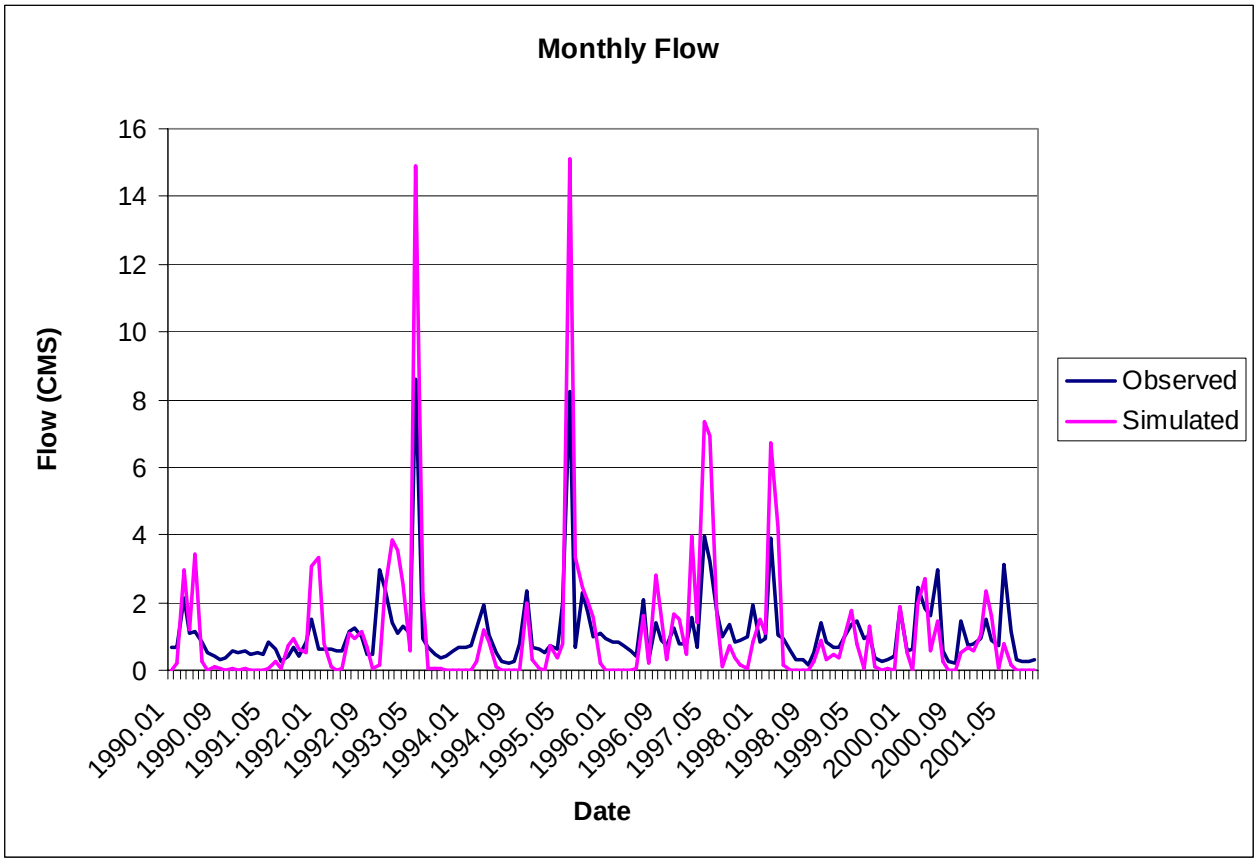

Figure 9 Time-series monthly average observed and SWAT simulated flow at Cobb Creek near Eakley.

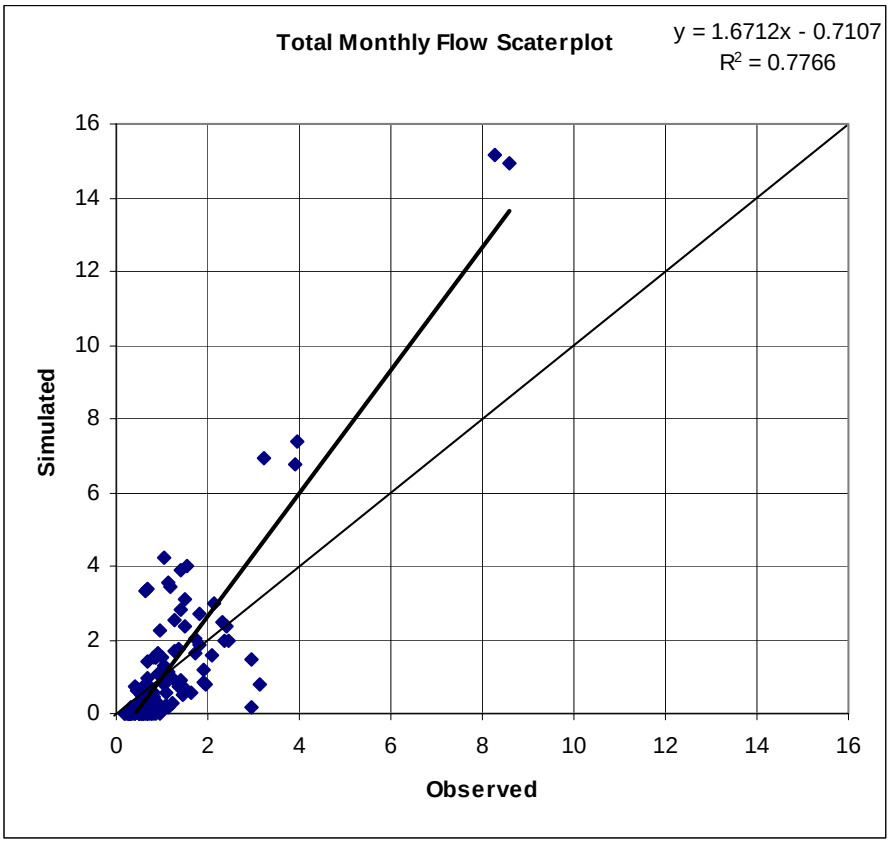

Figure 10 Scatter plot of monthly average observed and SWAT simulated flows at Cobb Creek near Eakley (Flow in CMS).

Table 10 Observed and SWAT model predictions using three different averages.

Type of Average Units	Total P (OBS) (mg/l)	Nitrate (OBS) (mg/l)	Total Nitrogen (OBS) (mg/l)	Total P (SIM) (mg/l)	Nitrate (SIM) (mg/l)	Total Nitrogen (SIM) (mg/l)
Average	**0.17**	**1.03**	**2.22**	**0.13**	**0.93**	**1.39**
Flow Weighted	**1.03**	**0.26**	**1.12**	**1.37**	**0.48**	**5.62**
Flow Weighted With Observed Flow Only	**0.23**	**0.28**	**1.06**	**0.01**	**0.85**	**0.89**

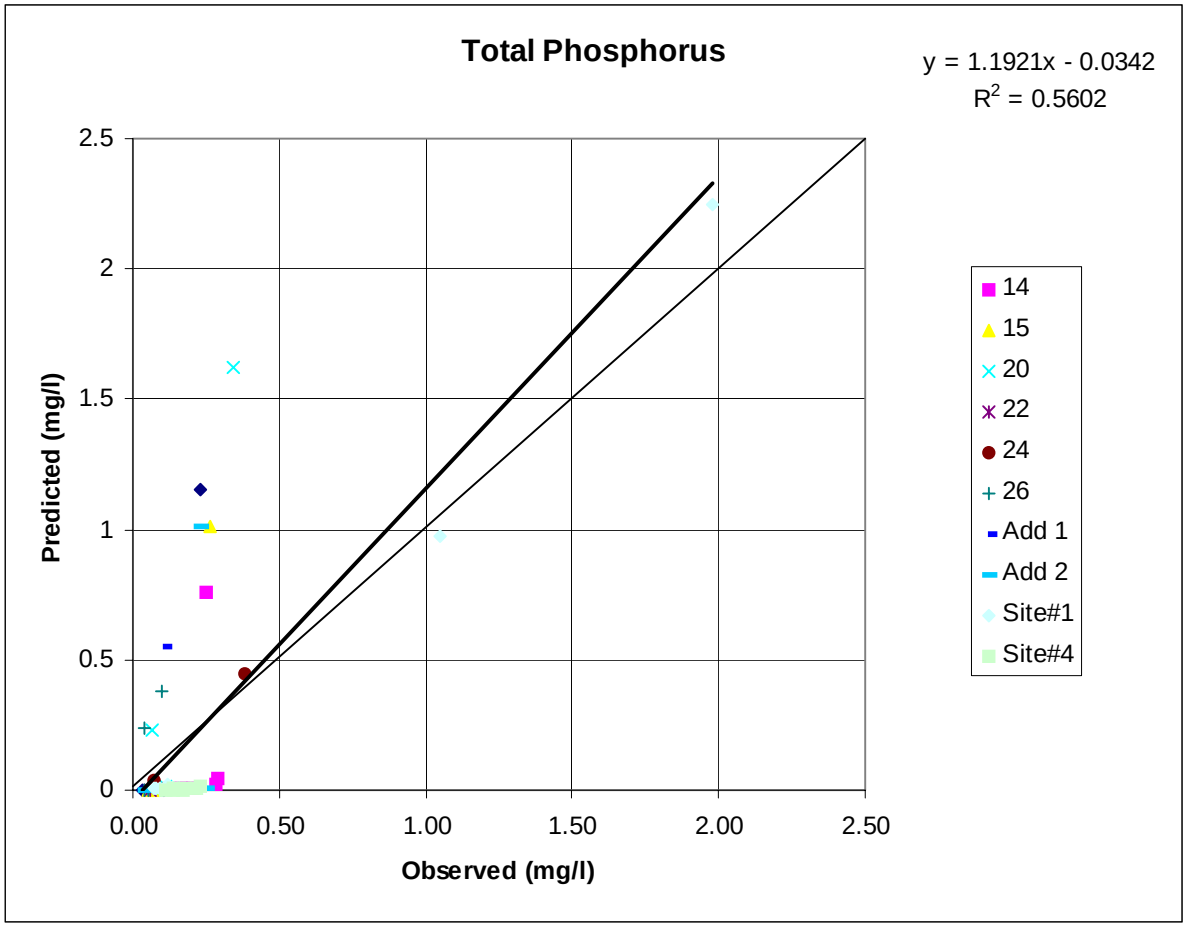

Figure 11 Observed total phosphorus concentrations vs SWAT model predictions for the Fort Cobb Basin. Each series is a different sampling site.

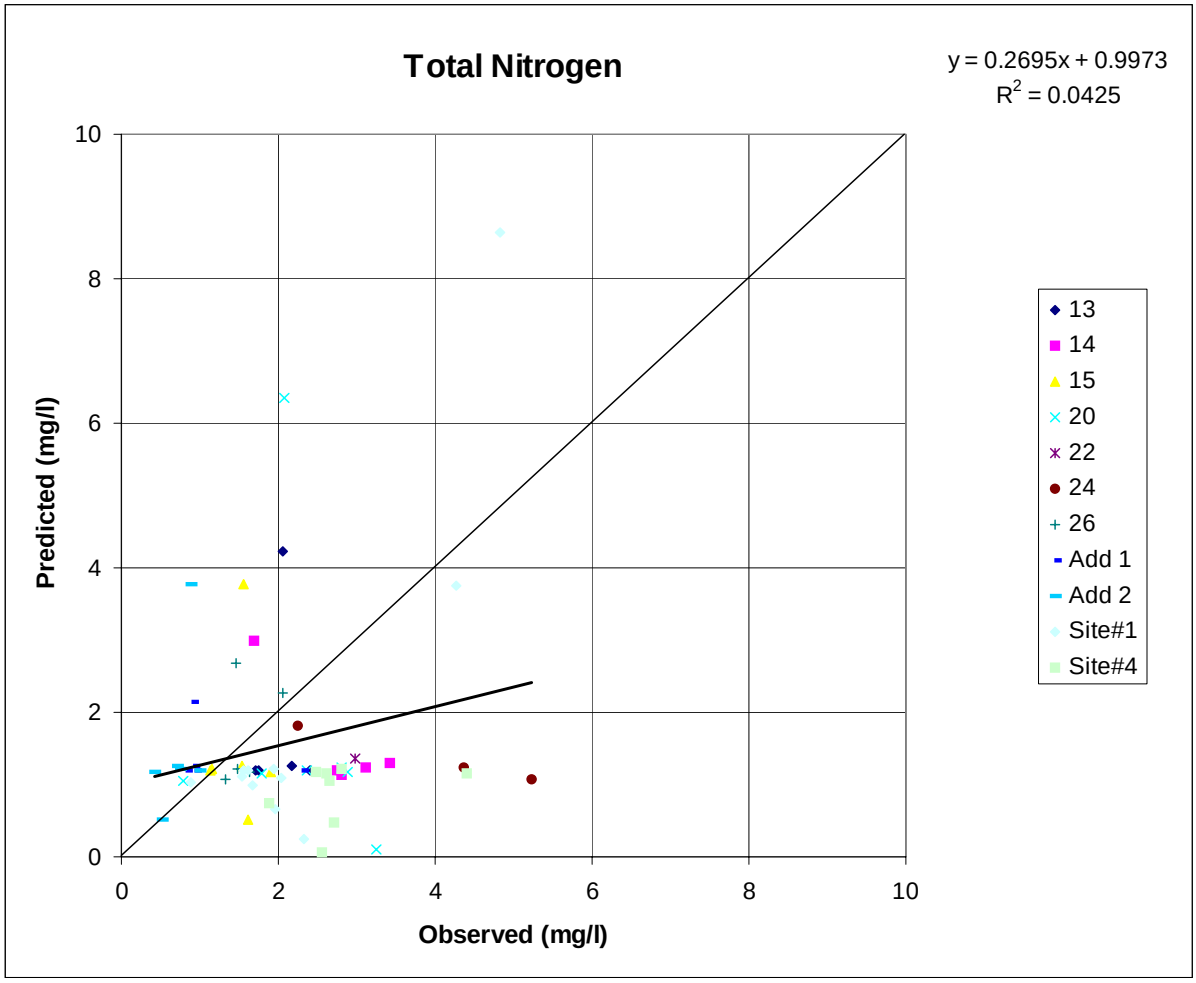

Figure 12 Observed total nitrogen concentrations vs SWAT model predictions for the Fort Cobb Basin. Each series is a different sampling site.

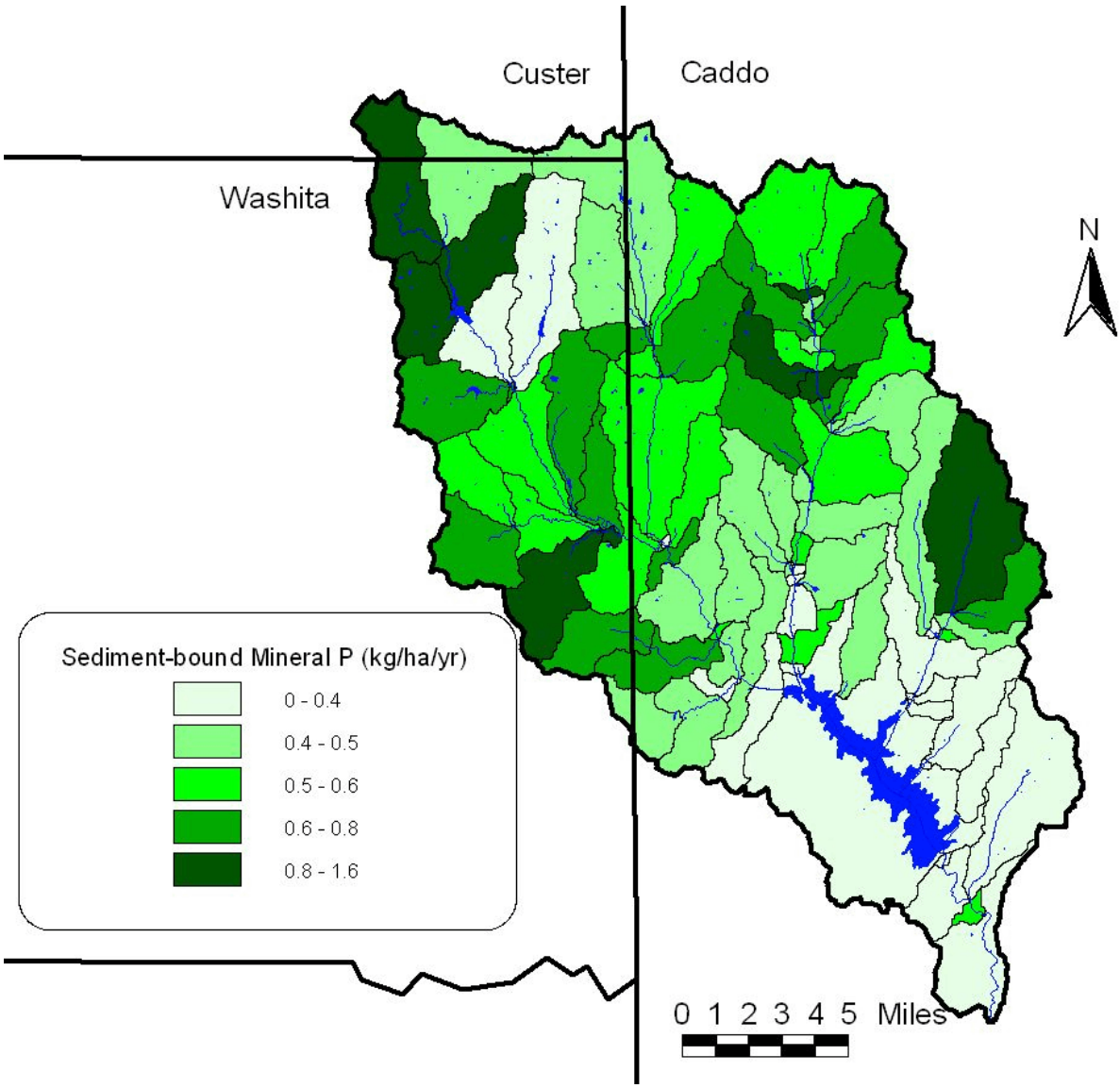

Figure 13 Sediment-bound mineral phosphorus loading across the Fort Cobb Basin as predicated by the Soil and Water Assessment Tool (SWAT) model. Does not include sediment-bound organic forms.

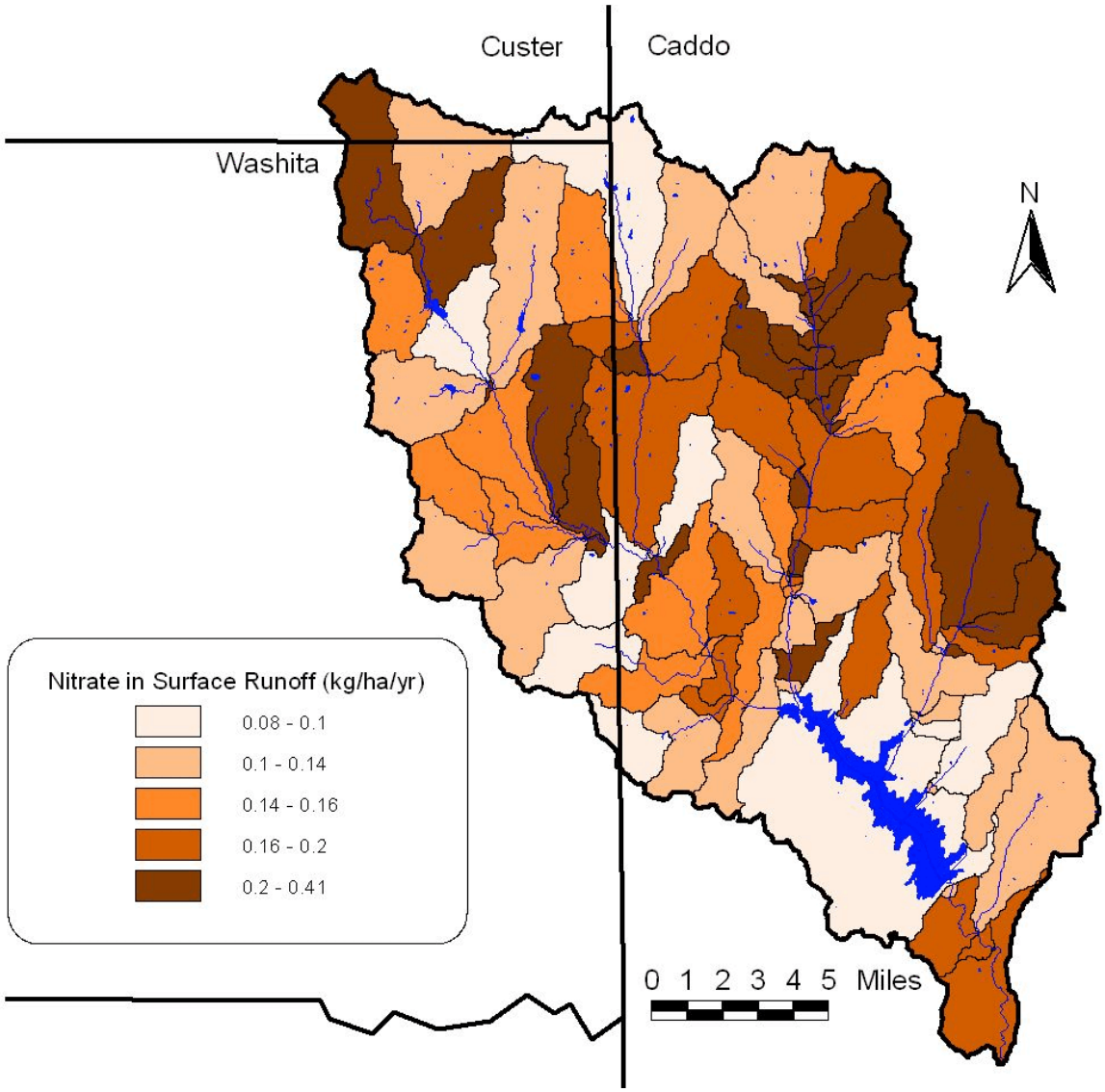

Figure 14 Nitrate in runoff across the Fort Cobb Basin as predicated by the Soil and Water Assessment Tool (SWAT) model.

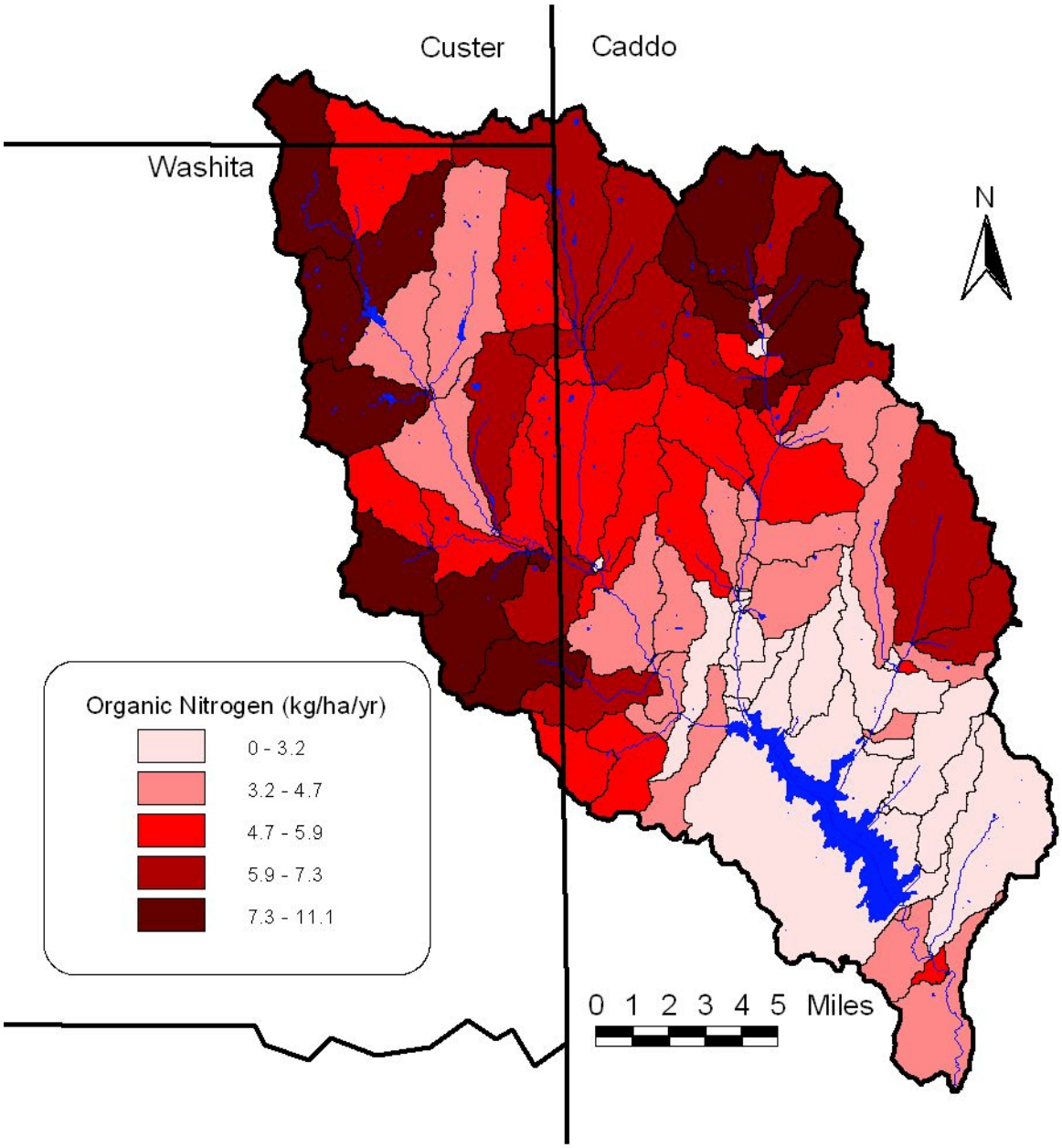

Figure 15 Organic nitrogen yield across the Fort Cobb Basin as predicated by the Soil and Water Assessment Tool (SWAT) model.

Table 11 SWAT simulated loads by land cover for the Fort Cobb Basin for the period 1/1990-10/2001.

Land Cover	Total Phosphorus (kg/ha)	Total Surface Nitrogen (kg/ha)	Total Surface Nitrogen (mg/l)	Total P (mg/l)	Soluble P (mg/l)	Surface NO3 (mg/l)	Sediment Yield (mt/ha)
Forest	0.01	2.12	1.18	0.00	0.00	0.20	0.01
Pasture/Range	0.54	3.16	3.00	0.51	0.01	0.27	1.29
Peanut	1.94	7.87	5.35	1.32	0.02	0.30	4.00
Sorghum	1.54	8.23	5.10	0.95	0.01	0.37	4.17
Urban	0.08	1.13	1.12	0.08	0.02	0.72	0.04
Water							
Wheat for Grain	2.12	10.62	8.73	1.74	0.02	0.38	6.38
Wheat for Other	1.99	9.29	7.82	1.67	0.02	0.29	5.57
Average	1.25	6.40	5.40	1.05	0.01	0.32	3.44

Table 12 Swat predict loads to the Fort Cobb Reservoir by tributary for the period 1/1990-10/2001.
Tributary locations are shown in Figure 17.

Area	Area (km^2)	Flow (cms)	Sediment (mt/yr)	Organic N (kg/yr)	Organic/Sediment-bound P (kg/yr)	Nitrate (kg/yr)	Soluble P (kg/yr)
83	430	1.42	128300	260800	56230	39580	3780
84	173	0.72	66190	103700	22510	20850	1614
85	9	0.06	1931	2091	619	2153	80
86	78	0.39	30230	40780	9401	12430	725
87	13	0.07	1561	2338	542.9	2733	45
88	8	0.04	1485	2066	493	1583	44
89	87	0.31	15031	242034	5746	661	26
Reservoir	**799**	**3.00**	**244728**	**653809**	**95542**	**79990**	**6314**

Table 13 Load summary for the Fort Cobb/Cobb creek Basin as predicted by the SWAT Model for the period 1/1990-10/2001.

Constituents	Total P	Total N	Sediment	Total Surface Nitrogen*
Units	(kg/yr)	(kg/yr)	(Mg/yr)	(kg/yr)
Fort Cobb Reservoir Load	102,000	734,000	245,000	N/A
Cobb Creek Basin Load	106,000	N/A	293,000	546,000

*Does not include nitrogen contributions from sub-surface flows.

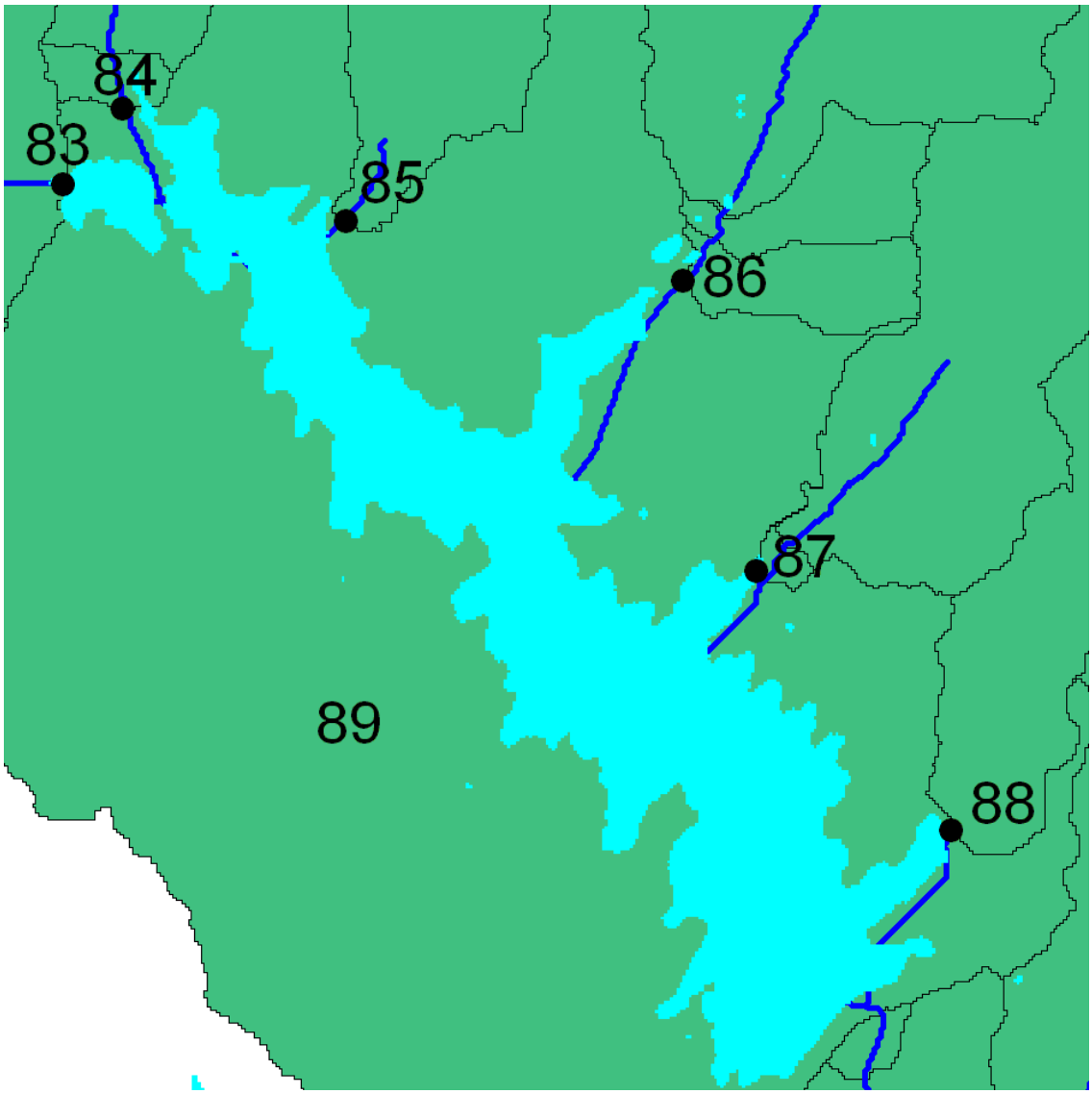

Figure 16 Tributaries flowing into the Fort Cobb Reservoir. Area 89 is the area adjacent to the reservoir.

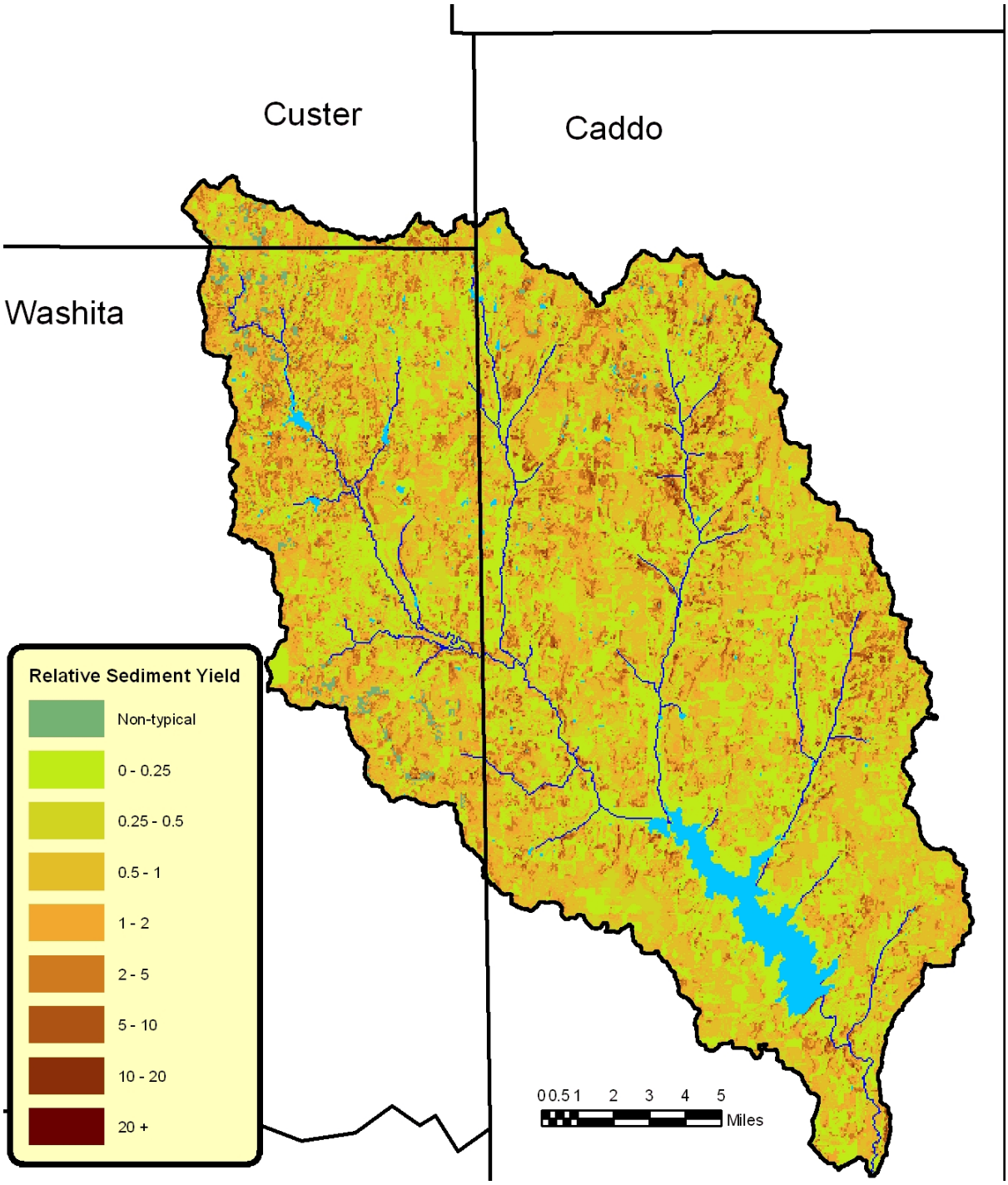

Figure 17 High resolution relative erosion in the Fort Cobb Basin. Based on SWAT model simulations.

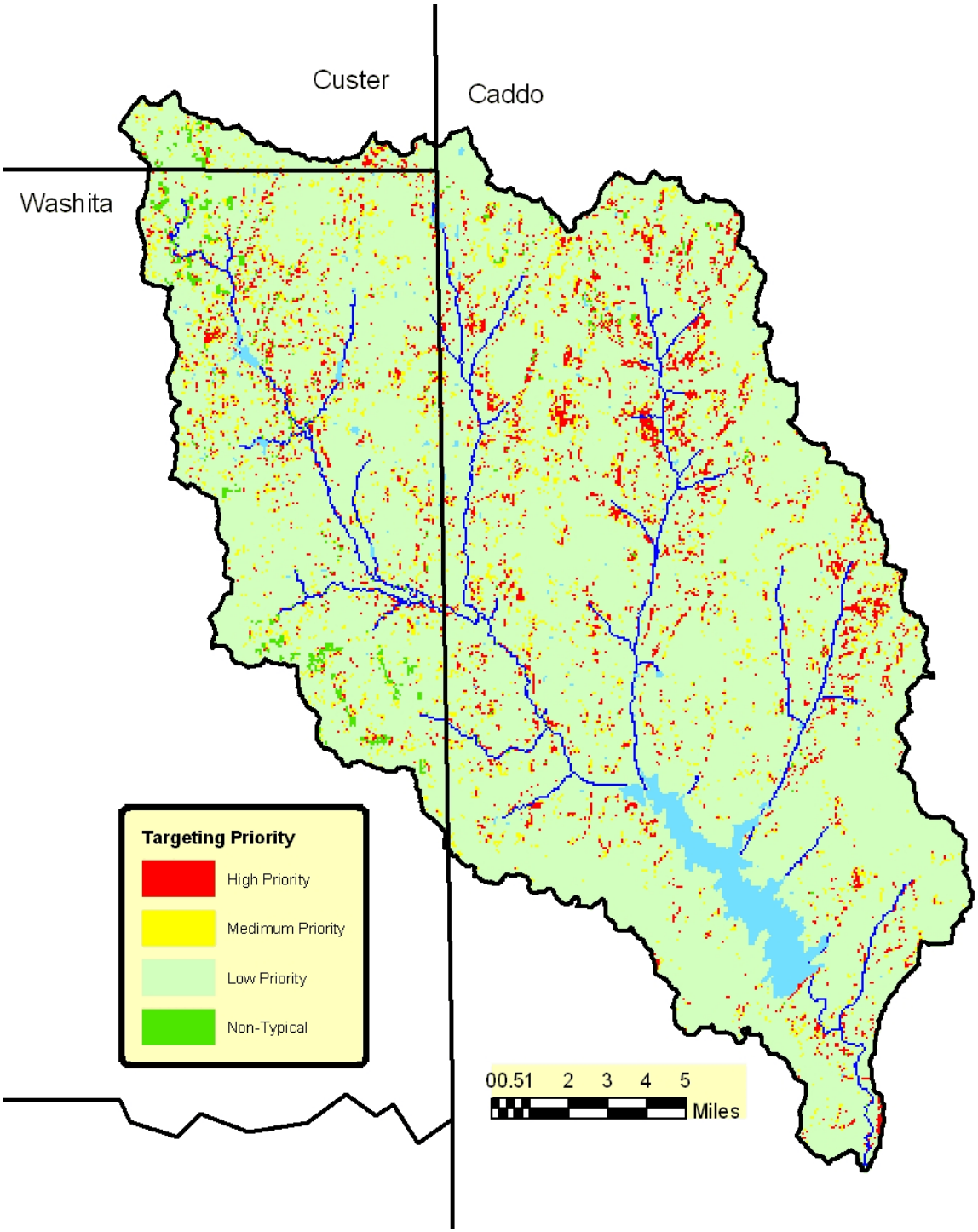

Figure 18 Erosion Targeting Map. High Priority is 5% of the basin with the highest predicted erosion. Medium Priority includes the next highest eroding 5%. Low Priority covers the remainder. Non-typical areas are suspected miss-classifications in land cover including agricultural fields with slopes greater than 15%, gypsum outcroppings, or rough broken land. Derived from Soil and Water Assessment Tool 2000.

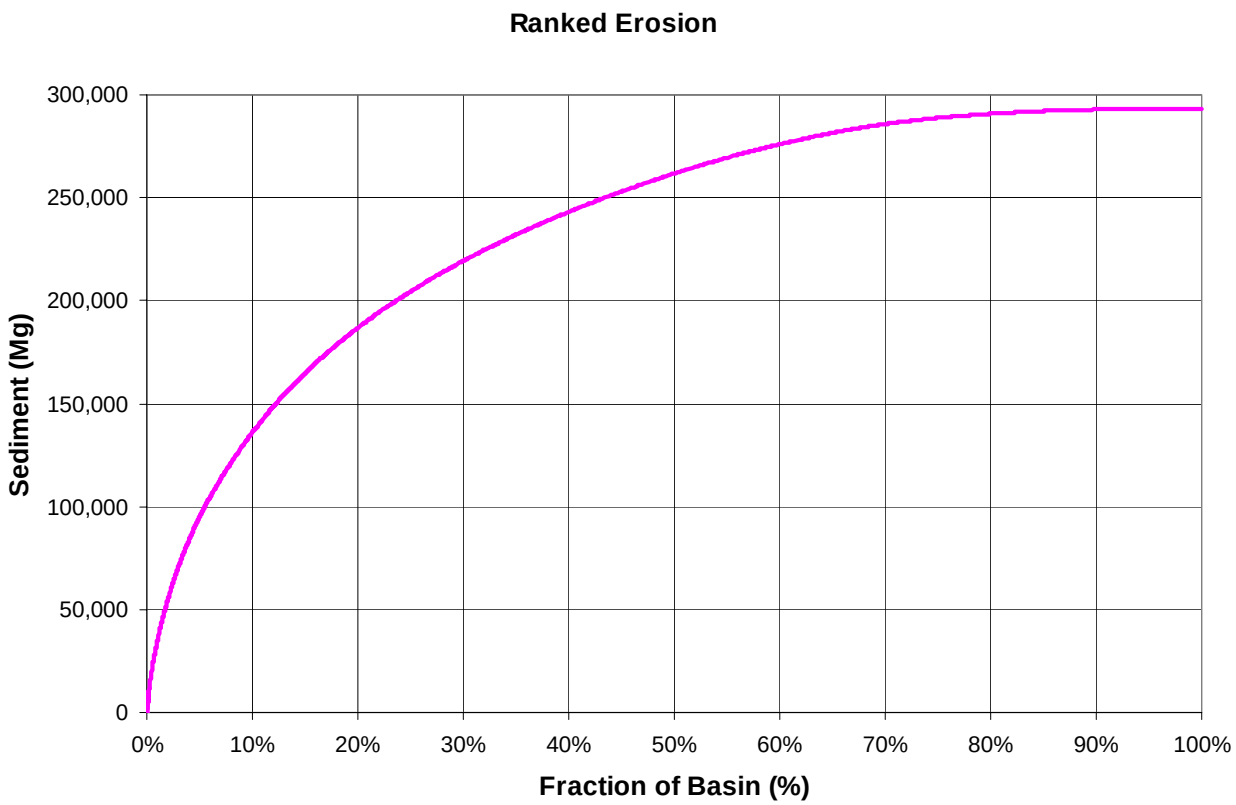

Figure 19 Cumulative ranked grid cell erosion for the Cobb Creek Basin. Based on Soil and Water Assessment Tool predictions.

Appendix A - AAI Land Cover Classification Report

Development of Current Digital Landcover Data Using 30 m TM (Landsat 7 ETM+) Imagery for the Fort Cobb Basin

Prepared for

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Dept. of Biosystems and Ag Engineering
Oklahoma State University

by

Applied Analysis Inc.
630 Boston Road, Suite 201
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01821

September 12, 2002

Fort Cobb Basin Project

Introduction

The purpose of this project was to develop a digital landcover data layer using recent (June 10, 2001) 30 m resolution Landsat TM imagery for the Fort Cobb Basin. Satellite imagery has been used since the 1970's as an accurate and cost effective tool for deriving vegetation and landcover information. Digital processing techniques involving the statistical analysis of image data representing various portions of the electromagnetic spectrum allows for definition of areas that reflect solar radiation in a similar manner. These areas may then be related to landcover or vegetation types through the use of ground truth information.

For this project, a traditional classification method was used where pixels are selected that represent patterns or landcover features that can be recognized or identified with help from other sources, such as ground data, aerial sources (photography, orthophoto quads) or maps. Knowledge of the types of information desired in the end product is required prior to the onset of classification. By identifying patterns, the software is trained to identify pixels with similar characteristics. Applied Analysis Inc. (AAI) relied on local sources to assist in collection of georeferenced ground truth data to ensure the accuracy of the final product. This type of landcover data can be used to conduct watershed assessments, resource inventories, and to detect change in ecosystems.

Ground Truth

Ground truth data and information was provided to Applied Analysis, Inc by Monty Ramming, Oklahoma Conservation Commission (OCC) and Dr. Daniel Storm, Oklahoma State University (OSU). The ground truth data included 1 meter resolution Digital Orthophoto Quarter Quads (DOQQ) from 1995 for the entire Fort Cobb Basin. This data is low altitude panchromatic photography and was registered to the June 10, 2001 Landsat 7 ETM+ scene. Additional ground truth information included a detailed ground survey of two 16 square mile quads located within the watershed. These quads were selected because they contained a representative sample of all the cover types of interest in the watershed and exhibited a high level of spectral variability in the Landsat image. AAI provided OCC copies of the DOQQ's for these quad areas. OCC conducted an extensive ground survey to locate and map large contiguous areas of each cover type. Additionally, OCC provided photographs of select fields of each cover type. These photos along with the field survey were the basis for labeling the spectral classes into the appropriate land cover categories.

Methods

This project mapped landcover types across the Fort Cobb Basin and used a whole pixel classification technique. In this study, we used an unsupervised iterative self-organizing data analysis (ISODATA) clustering algorithm. ISODATA is a widely used clustering algorithm that makes a large number of passes through an image using a minimum spectral distance routine to form clusters. It begins with an arbitrary cluster mean and each time the clustering repeats, the means of these clusters are shifted. The new cluster means are used for the next iteration. This iteration process continues until statistically distinct features emerge.

The methods used to generate the final cover type map across Fort Cobb Basin included a multi-step ISODATA analysis technique. Because of the complex nature of the landcover types across the watershed and the spectral similarity between these landcover categories, four iterations of ISODATA clustering were required to accurately map landcover types. Each iteration of classification generated 100 spectral classes. Spectral convergence threshold was set to 95 percent. The initial classification produced 100 classes which were displayed on top of the Landsat image and DOQQ's as a thematic layer. By visual interpretation of the Landsat imagery and DOQQ's, a set of spectral classes was identified as containing the majority of the forest cover types. The thematic layer was then recoded such that all identified forest classes were recoded to "0" and all other classes were recoded to "1". This layer was saved as a separate file and used as a mask. The mask was applied to the original Landsat image and all pixels that fell within the forest classes were removed. The output masked image was the original Landsat image with all forest pixels removed. This image was then used as the input for the second ISODATA clustering.

The second classification iteration generated 100 spectral classes using the same number of iterations and convergence threshold. This classification was used to extract water

from the Landsat imagery. The classification results were again displayed on the Landsat and DOQQ imagery. A set of spectral classes was identified for the category. The set of spectral classes were recoded and saved as a separate file. This file was used as a mask to remove water features from the original image. The output image was the original Landsat image with all forest and water pixels removed. This image (containing mainly pasture and cropland fields) was used as the input for the third classification.

The third classification iteration produced 100 spectral classes. This classification was used to identify and map pasture and planted/cultivated types across the Fort Cobb Basin. The cover type categories included pasture, planted/cultivated 1, planted/cultivated 2 and barren areas. There is tremendous temporal change within and between these cover types. For example, a typical field in the Fort Cobb Basin can be rotated amongst a wide variety of cultivated crops and pasture types. Because of this temporal change and lack of temporal coincidence between the imagery acquisition and ground truth data collection, the ground truth data could not be relied upon solely to guide the selection of spectral classes for the pasture and cultivated categories. A set of decision criteria was established to guide the labeling of spectral classes into landcover categories. The decision criteria are as follows:

1. *Pasture*
    a. Fields with a high to moderate vegetative biomass state;
    b. These fields were relatively homogeneous in their spectral response and in their apparent color in the Landsat imagery;
    c. These fields included cultivated pasture, native pasture and rangeland.

2. *Planted / Cultivated 1*
    a. Fields with a low vegetative biomass state;
    b. These fields were relatively heterogeneous in their apparent color in Landsat imagery;
    c. These fields contained some vegetative spectral response with a significant soil component;
    d. These fields included wheat, peanuts, cotton and other row crops.

3. *Planted / Cultivated 2*
    a. Fields with no vegetative spectral response;
    b. These fields were relatively homogeneous in their apparent color in Landsat imagery;
    c. Fields which have been recently tilled or have such a low vegetative biomass state as to not be spectrally of visually apparent;
    d. Contiguous fields > 1 acre.

4. *Barren*
    a. Fields with no vegetative biomass;
    b. Contiguous fields sized < 1 acre.

These decision criteria were used as a guide for labeling spectral classes into landcover types. The primary means for labeling these spectral classes was the apparent color of the pixels in the Landsat imagery. Each spectral class was analyzed to see what cover types it was detecting. The decision criteria were then used to label that class to an appropriate landcover type.

The third classification was also used to identify any additional forest or water pixels that may have been missed in the two previous classification iterations. Once all the spectral classes were labeled to the appropriate landcover category, the image was recoded such that each landcover category was given a unique identifier.

The June 10, 2001 Landsat imagery showed a significant amount of bare soil fields across the Fort Cobb Basin. The reason for this, according to the Oklahoma Conservation Commission, was that the wheat harvest was underway at that time. Recently harvested wheat fields exhibit an overwhelming soil spectral response in Landsat imagery. Additionally, standing dry wheat fields, due to their lack of chlorophyll, exhibit a similar spectral response as bare soil. Because of the large temporal difference between imagery and ground truth, we were unable to identify which of these spectrally bright fields were standing wheat fields or bare soil. It should be noted that this spectral similarity does not preclude detection of dry wheat fields in Landsat imagery. If temporally coincident ground truth and imagery are acquired, there are several spectral techniques which could be used to detect this crop condition. Because of the previously noted spectral response, many fields in the third classification fell into one or two spectral classes. As a means to further separate landcover categories in these recently tilled or dry fields, a fourth classification iteration was run.

The soil classes were subsetted from the Landsat image. The fourth classification iteration on these high soil areas produced 100 spectral classes. The decision criteria described above were used to separate these spectrally bright fields into the planted/cultivated and barren categories. The set of spectral classes for each category were recoded and saved as separate files.

An additional analysis of *Clump* and *Sieve* was used to separate these bare soil fields between the landcover types of planted/cultivation 2 and barren. *Clump* and *Sieve* are spatial analysis tools to analyze raster data based on class identity and spatial relationship. The fields classified as barren in the fourth classification were run through a clump and sieve routine. All contiguous bare soil fields larger than one acre were reclassified as planted/cultivation 2. All contiguous bare soil fields one acre or less were left in the barren category.

The urban category in the Fort Cobb Basin is underrepresented in this classification because the roads are too narrow to be detected in 30 meter Landsat data. The small town of Fort Cobb was classified as urban by using the roads vector layer to identify the town limits.

The final landcover map for the June 10, 2001 Landsat 7 ETM+ image was produced using standard image overlay techniques. The forest pixels from the first classification, the water pixels from the second classification, the pasture and cultivation types from the third and forth classification, and the clump and sieve and urban layers were added together and recoded to unique identifying numbers. Finally, the classes were color coded and output to a final thematic map.

A riparian habitat assessment was also performed in the Fort Cobb Basin. Hydrologic data layers for the basin were acquired from the USGS via the Oklahoma Digital Atlas. A 100 meter buffer was extended from these hydrologic features to create and assess the spatial distribution of landcover types in the riparian zone. The riparian assessment was unsmoothed, to retain a finer minimum mapping unit and thus increase the spatial utility of each landcover type for best management practice implementation targeting purposes.

Results

With image processing complete, the final results were grouped into 7 landcover classes. The final percentages for landcover in the Fort Cobb basin were calculated and are presented below.

Landcover (by percentage) within the Fort Cobb Basin

Urban – 0.5%
Pasture – 39.72%
Planted / Cultivated 1 – 46.44%
Planted / Cultivated 2 – 5.01%
Forest – 6.68%
Barren – 0.20%
Water – 1.89%

Total – 100%

The basin was dominated by planted/cultivated 1 (46.44%) followed by pasture (39.72%). The other classes exhibited smaller percentages. This was due to the coarse spatial resolution of the Landsat imagery, which allowed some of the narrower roads/urban features and water bodies (streams and creeks) to go undetected or classified with another neighboring landcover type.

In addition to classifying the entire Fort Cobb basin, a detailed riparian zone land cover classification was produced for 100 m buffer around hydrologic features in the watershed. The final results for this riparian zone were quantified and are presented below:

Landcover percentages within the riparian zone of Fort Cobb Basin

Urban – 0.00%

Pasture – 48.47%
Planted / Cultivated 1 – 18.47%
Planted / Cultivated 2 – 0.56%
Forest – 32.42%
Barren – 0.07%

Total – 100%

Discussion

The landcover classification for the watershed and riparian zone maps the spatial distribution of landcover throughout the Fort Cobb Basin. The classification categories planted/cultivated 1, planted/cultivated 2 and barren map the spatial distribution of high soil component fields across the watershed and within the riparian buffer. These classification categories are ranked in order of increasing bare soil reflectance.

As the bare soil component comprised such a large percentage of the individual pixels classified in these three landcover types throughout the watershed and there was not temporally coincident ground truth data, the whole pixel ISODATA procedure provides the most reliable, accurate results for landcover analysis. Subpixel analysis would have been an appropriate technical approach if temporally coincident ground truth data were available and if the image were selected in a more appropriate season. Subpixel analysis is able to detect materials that comprise as little as 20 percent of the pixel. Thus, utilizing the *Subpixel Classifier* process in areas with very low vegetative cover, less than 20 percent of a pixel, would have created many errors of commission.

The riparian zone classification offers a qualitative targeting method to spatially locate high risk landcover types within the riparian corridor. These highest risk landcover types would include bare soil/barren, planted/cultivated 1, and planted cultivated 2. When combined with estimates of nonpoint source loadings attributed to subwatersheds through SWAT modeling, it is anticipated that the combination will provide the watershed project coordinator with a mechanism to proactively identify and recruit landowners that are likely contributing to the overall degradation of water quality within the Fort Cobb Basin.

Appendix B - Water Quality Data

DATE	SITE NAME	FLOW CMS	TP mg/l	Nitrate mg/l	TKN + Nitrate mg/l	Soluble P mg/l
13-Aug-98	Lake Creek site #1	0.11	0.11	1.00	1.57	
13-Aug-98	Lake Creek site #4	0.07	0.15	2.04	2.70	
15-Sep-98	Lake Creek site #1	0.05	0.05	0.32	0.77	
15-Sep-98	Lake Creek site #4	0.03	0.10	2.00	2.66	
13-Oct-98	Lake Creek site #1	0.05	0.06	0.77	1.19	
13-Oct-98	Lake Creek site #4	0.05	0.15	2.33	2.76	
15-Dec-98	Lake Creek site #1	0.20	0.09	1.59	1.95	
15-Dec-98	Lake Creek site #4	0.13	0.14	2.24	2.81	
11-Jan-99	Lake Creek site #1	0.19	0.07	1.56	1.97	
11-Jan-99	Lake Creek site #4	0.11	0.14	2.18	2.72	
09-Feb-99	Lake Creek site #1	0.21	0.08	1.05	1.61	
09-Feb-99	Lake Creek site #4	0.11	0.22	3.30	4.41	
17-Mar-99	Lake Creek site #1		0.15	1.26	2.03	
17-Mar-99	Lake Creek site #4		0.23	1.88	2.66	
20-Apr-99	Lake Creek site #1		0.10	0.97	1.54	
20-Apr-99	Lake Creek site #4	0.09	0.12	2.12	2.61	
25-Apr-99	Lake Creek site #1		1.98	0.21	4.83	
20-May-99	Lake Creek site #1		0.16	1.23	1.55	
20-May-99	Lake Creek site #4		0.18	1.92	2.49	
13-Jun-99	Lake Creek site #1	0.15		1.14	1.68	
13-Jun-99	Lake Creek site #4	0.08		1.92	2.55	0.22
21-Jun-99	Lake Creek site #1	0.94	1.05	1.02	4.27	
20-Jul-99	Lake Creek site #1	0.10	0.12	0.45	0.88	
20-Jul-99	Lake Creek site #4	0.06	0.17	1.28	1.88	
17-Aug-99	Lake Creek site #1	0.06	0.08	0.25	0.77	
17-Aug-99	Lake Creek site #4	0.04	0.14	1.48	2.38	
31-Aug-99	Lake Creek site #1	0.05				
31-Aug-99	Lake Creek site #4	0.03				
20-Sep-99	Lake Creek site #1	0.05	0.07	1.03	1.60	
20-Sep-99	Lake Creek site #4	0.04	0.10	1.85	2.37	
19-Oct-99	Lake Creek site #1	0.06	0.07	0.59	46.19	
19-Oct-99	Lake Creek site #4	0.04	0.13	1.40	33.40	0.59
09-Nov-99	Lake Creek site #1		0.14	1.81	2.33	
09-Nov-99	Lake Creek site #4		0.15	2.27	2.83	
6/17/2000	22		0.31	0.98	2.57	0.25
6/17/2000	20		0.34	0.45	2.09	0.13
6/17/2000	24		0.38	0.70	2.25	0.20
6/17/2000	14		0.25	0.69	1.70	0.15
6/17/2000	13		0.23	0.90	2.05	0.19
6/17/2000	Add 2		0.23	0.01	0.89	0.07
6/17/2000	Add 1		0.10	0.39	0.90	0.20
6/17/2000	26		0.10	0.73	1.47	0.18
6/17/2000	15		0.26	0.48	1.55	0.15
7/13/2000	22		0.07	1.01	2.25	0.19
7/13/2000	20		0.11	0.94	2.37	0.21
7/13/2000	24		0.17	1.86	4.18	0.29
7/13/2000	14		0.29	1.17	3.43	0.35
7/13/2000	13		0.10	0.71	1.75	0.20
7/13/2000	Add 2		0.14	0.05	0.75	0.07
7/13/2000	Add 1		0.13	0.88	2.31	0.20
7/13/2000	26		0.10	0.37	1.33	0.09
7/13/2000	15		0.09	0.42	1.16	0.21

DATE	SITE NAME	FLOW CMS	TP mg/l	Nitrate mg/l	TKN + Nitrate mg/l	Soluble P mg/l
9/18/2000	22		0.06	0.79	1.98	0.18
9/18/2000	20		0.06	0.14	0.81	0.15
9/18/2000	24		0.09	1.83	4.07	0.21
9/18/2000	14		0.18	0.78	1.91	0.30
9/18/2000	13		0.04	0.24	0.82	0.17
9/18/2000	Add 2		0.00		0.00	0.00
9/18/2000	Add 1				0.00	0.00
9/18/2000	26		0.05	0.59	1.55	0.16
9/18/2000	15		0.07	0.01	0.41	0.19
11/29/2000	22		0.05	1.61	3.39	0.16
11/29/2000	20		0.07	1.27	2.80	0.16
11/29/2000	24		0.11	2.26	5.23	0.21
11/29/2000	14		0.16	1.49	3.11	0.31
11/29/2000	13		0.03	0.99	2.17	0.19
11/29/2000	Add 2		0.20	0.02	0.71	0.25
11/29/2000	Add 1		0.03	0.39	0.93	0.20
11/29/2000	26		0.04	0.62	1.49	0.15
11/29/2000	15		0.05	0.65	1.54	0.15
2/14/2001	22		0.06	1.31	2.99	0.16
2/14/2001	20		0.10	1.09	2.88	0.18
2/14/2001	24		0.07	1.96	4.37	0.19
2/14/2001	14		0.21	1.21	2.81	0.32
2/14/2001	13		0.05	1.01	2.41	0.16
2/14/2001	Add 2		0.04	0.01	0.43	0.13
2/14/2001	Add 1		0.04	0.31	0.83	0.13
2/14/2001	26		0.04	0.52	2.05	0.01
2/14/2001	15		0.07	0.73	1.90	0.18
4/23/2001	22	0.01	0.08	1.09	2.58	0.17
4/23/2001	20	0.22	0.14	1.12	3.25	0.19
4/23/2001	24	0.02	0.08	2.00	4.51	0.19
4/23/2001	14	0.02	0.15	0.95	2.20	0.27
4/23/2001	13	0.07	0.08	0.90	2.35	0.16
4/23/2001	Add 2		0.17	0.01	0.52	0.22
4/23/2001	Add 1	0.01	0.07	0.25	0.82	0.18
4/23/2001	26	0.10	0.08	0.91	2.24	0.17
4/23/2001	15	0.12	0.11	0.54	1.61	0.18
6/21/2001	22	0.01	0.08	1.01	2.26	0.18
6/21/2001	20	0.18	0.12	0.65	1.78	0.20
6/21/2001	24	0.02	0.13	1.99	4.27	0.28
6/21/2001	14	0.01	0.29	1.14	2.75	0.37
6/21/2001	13		0.10	0.69	1.72	0.20
6/21/2001	Add 2		0.25	0.01	1.01	0.15
6/21/2001	Add 1		0.15	0.10	0.95	0.20
6/21/2001	26	0.09	0.05	0.71	1.63	0.14
6/21/2001	15	0.07	0.09	0.41	1.13	0.20
9/16/2001	22	0.01	0.36	1.47	4.38	0.16
9/16/2001	20	0.05	0.06	0.10	0.78	0.13
9/16/2001	24	0.02	0.15	1.81	4.01	0.13
9/16/2001	14	0.01	0.20	0.85	1.97	0.25
9/16/2001	13	0.25	0.05	0.74	1.74	0.13
9/16/2001	Add 2		0.00		0.00	0.00
9/16/2001	Add 1		0.00		0.00	0.00
9/16/2001	26	0.07	0.04	0.63	1.53	0.12
9/16/2001	15	0.04	0.07	0.50	1.35	0.14

Appendix C - Quality Assurance Project Plan

Fort Cobb Basin - Modeling And Land Cover Classification Quality Assurance Project Plan

Submitted To The

Oklahoma Conservation Commission

For The

U.S. Environmental Protection Agency

Submitted by:

Dr. Daniel E. Storm, Professor
Michael J. White, Research Engineer,
Dr. Michael D. Smolen, Professor

Oklahoma State University
Department of
Biosystems and Agricultural Engineering
Stillwater, Oklahoma
May 7, 2002

Fort Cobb Basin - Modeling And Land Cover Classification
Quality Assurance Project Plan
Approval Page May 7, 2002

Plan Prepared by:

_____
Daniel E. Storm, Project Director Date

Investigator Approval:

_____
Michael D. Smolen, Professor, Biosystems and Agric. Engi. Date

Conservation Commission Approval:

_____
Lawrence R. Edmison, Director, Water Quality Division Date

_____
Dan Butler, Biologist, Water Quality Division Date

_____
Shannon Phillips, QAPP Officer, Water Quality Division Date

Office of the Secretary of Environment Approval:

_____
Jennifer Myers Wasinger, Environment Programs Manager Date

EPA Approval:

_____
USEPA Region VI Office of Water Quality Date

Project Objectives and Responsibilities

Objectives and Purpose

The purpose of this study is to use the hydrologic model Soil and Water Assessment Tool (SWAT) to evaluate erosion and nutrient loading to the Ft. Cobb Reservoir. In addition, riparian corridors will be characterized. These analysis will be used to target and implement cost share and technical assistance programs. The following objectives are required to meet that goal:

- **Collect Ground Truth Data.**
  Ground truth data are required to perform accurate land cover classifications. Additional data may be collected to verify existing maps or GIS data.

- **Land cover classification.**
  Lansat TM (30m) resolution imagery will be classified into a land cover map. In this process, pixels are selected that represent patterns or land-cover features that can be recognized or identified with help from other sources, such as ground truth data, aerial sources, or maps.

- **Riparian corridor characterization.**
  This process will utilize IMAGINE Subpixel Classifier software that has the ability to detect and report whole and subpixel occurrences of a specific material in multi-spectral imagery. IMAGINE Subpixel Classifier classifies all pixels that contain the material into classes based on how much of the material they contain.

- **Collect and process model input data.**
  Geographic Information System (GIS) data for topography, soils, land cover, and streams are required by the SWAT model. An ArcView GIS interface is available to summarize the GIS data and convert it to a form usable by the model.

- **Model Calibration.**
  Calibration is the process by which a model is adjusted to more closely match observed data. Calibration greatly improves the accuracy of a model. The SWAT model will be calibrated on observed streamflow from all suitable US Geologic Survey (USGS) gages.

- **Targeting High Erosion Areas.**
  Based on SWAT predicted erosion rates, problematic combinations of soils, land cover, and slope will be used to target critical areas. The final product will be a basin map showing highest erosion areas shaded by severity.

Project Participants

Biosystems and Agricultural Engineering Department, Oklahoma State University
Dr. Daniel E. Storm, Professor
Mr. Michael J. White, Research Engineer
Dr. Michael D. Smolen, Professor

Responsibilities:
- Collect and process model input data.
- Model Calibration.
- Targeting High Erosion Areas.

Applied Analysis Incorporated
Dr. Scott Stoodley, Director of Environmental Water Quality Programs

Responsibilities:
- Land cover classification.
- Riparian corridor characterization.

Oklahoma Conservation Commission
Dan Butler, Aquatic Biologist

Responsibilities:
- Collect Ground Truth Data.

Data Sources and Selection

Basin scale hydrologic modeling requires a vast amount of data. The modeling report will contain all data sources and references. These data come from a variety of sources:

Data Name	Data class	Data Type	Data Source
10 m DEM	GIS	Elevation	US Geological Survey
MIADS	GIS	Soils	Oklahoma Natural Resource Conservation Commission
Landsat imagery	Image	Multi-spectral	Satellite Imaging
Ground truth	Tabular		Oklahoma Conservation Commission Personnel
STATSGO database	Tabular	Soils	Soil and Water Assessment Tool
NEXRAD precipitation	Tabular	Weather	Arkansas-Red Basin Forecast Center
NOAA Cooperative Observer Network	Tabular	Weather	National Oceanic & Atmospheric Administration
Soil test phosphorous	Tabular	Soil test Phosphorus	Oklahoma State University Soil, Water & Forage Analytical Laboratory
Management operations	Tabular	Management	Cooperative Extension Publications
Stream gage	Tabular	Streamflow	US Geological Survey

Often there are several data sets available from which to choose for a particular modeling task. These data are evaluated based on the following criteria:

1. **GIS data detail.**
   GIS data come in a variety detail levels, the level of detail may be expressed as a resolution or map scale. White (2001) found that the detail of input GIS data has a significant impact on SWAT model output.

2. **Age of data set.**
   Some data used are more time sensitive than others. For example, land cover may change dramatically over the span of a decade, where as soils typically change only over geologic time.

3. **Accuracy.**
   Accuracy information is seldom available. In these cases the accuracy is assessed by professional judgement.

4. **Temporal continuity.**
   Temporal continuity is of great importance when selecting weather, streamflow, or water quality data. Weather and streamflow should ideally be continuous on a daily basis, although it is possible to estimate missing days based on other data. These data are seldom continuous for long period of time.

5. **Spatial Consistency.**
   Spatial consistency is often sacrificed to use the most current data available. Most data sets cover only a limited area such as a state or county. A basin is typically not limited to those same boundaries, and often cross both state and county lines. This leads to the use of multiple GIS data sets to define a single model input layer and may create a lack of consistency across the basin.

Quality and Limitations of SWAT Model Data

It is not currently possible to comprehensively quantify the error in SWAT model predictions, thus there are no quantitative data quality requirements. It is, however, possible to list limitations. Model limitations may be the result of data used in the model, inadequacies in the model, or using the model to simulate situations for which it was not designed. Hydrologic models will always have limitations, because the science behind the model is neither perfect nor complete. A model by definition is a simplification of the real world. The following is a list of notable SWAT model limitations:

- **Weather**
  Weather is the driving force for any hydrologic model. Data collected at a few points is applied to an area of thousands of square miles. Rainfall can be quite variable, especially in the spring when convective thunderstorms produce precipitation with a high degree of spatial variability. It may rain heavily at a weather station, but may be dry a short distance away. On an average annual or average monthly basis, these errors have may cancel. This limitation among others, caution us against using model output on a daily or monthly basis.

- **Radical Parameter Changes**
  Scenarios involving radical changes to the basin result in greater uncertainty. The SWAT model is calibrated using estimates of what is presently occurring in the basin. Large departures from calibration conditions raise the level of uncertainty in model predictions.

- **Small Land Covers**
  Land uses that cover very small areas are not represented in the SWAT model. Land uses that occupy limited areas such as unpaved roads, bare areas, construction sites, and some row crops may not be simulated. In addition, most of these features may not be depicted in the available land cover. Some of these small areas may contribute many times more sediment on a per unit area basis than rangeland. Although significant, they may not be able to be simulated with the currently available data.

- **Hydrologic Response Unit (HRU) Characteristics**
  Each HRU in a particular subbasin is assumed to have the same characteristics by the SWAT model. For instance, the same slope is used for all rangeland and agricultural HRUs in a single subbasin. Agricultural land is generally located in valleys or other flat areas. Rangeland generally occupies land that is unsuitable for row crop production.

- **Management Uncertainty**
  There is a great deal of uncertainty associated with management. In reality, management varies significantly from field to field. It is not possible to easily determine what is happening where, or to simulate all these activities in the

model. Therefore, categories are created to cover reasonable managements choices only.

- **Unidentified Point Sources**
  There are many point sources in the basin; these could be significant. Potential point sources include household septic systems, CAFOs, and municipalities.

- **Instream Process**
  SWAT models in-stream processes based, in large part, on unvalidated assumptions of channel and stream-bank properties. Therefore these process will be turned off and not utilized.

Data Reporting, Reduction, and Validation

Reporting.

A final report will be prepared for this project. The report will include sufficient information to meet the project objectives.

Data Reduction.

Models, such as SWAT, may generate a vast amount of data that must be summarized. A great deal of these data are of no interest to the user and are discarded. These data are so varied in type, format, and resolution, that summarizing techniques are selected on a case by case basis using best professional judgement.

Validation

Validation is the process of verifying the ability of a calibrated model to make predictions outside the calibration period. A portion of the available stream flow record is withheld during calibration and later used to validate the model. The SWAT model may be validated depending on the amount of available stream flow data. If little observed stream flow are available, no model validation will be performed.