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Effects of Conservation Reserve Program on Runoff and Lake Water Quality in an Oxbow Lake Watershed

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Abstract: A case study of Beasley Lake Watershed, located in the Mississippi Delta region of the U.S., was used to evaluate runoff from edge-of-field sites under either row crop management practices or planted in trees under the Conservation Reserve Program (CRP). Beasley Lake Watershed, with a history of long-term ARS natural resource research, was selected as one of fourteen watersheds for participation in the Conservation Effects Assessment Program (CEAP), a nationwide assessment by USDA-Agriculture Research Service (ARS) and USDA-Natural Resources Conservation Service (NRCS) regarding the effectiveness of USDA conservation programs. Approximately one-third of the Beasley Lake watershed (ca. 280 ha) was converted from cropped land to CRP beginning in 2003, and the remainder of the cropland is managed for soybean, cotton, or corn production. Sub-drainage areas (1.2 to 6 ha) with similar topography and soil types were either cropped (three reduced tillage sites) or placed in CRP (three CRP sites) and were instrumented in 2005 to collect water samples from field drainage slotted-inlet pipes during all surface runoff events. Runoff samples were analyzed for sediments and nutrients. This paper reports on runoff, sediment, and nutrient losses from each sub-drainage area. Establishing trees within areas adjacent to the oxbow lake reduced the total sediments by 85% and nutrients by greater than 28% leaving the watershed as compared to reduced-till crop management techniques. The impact of converting the cropped area into trees has reduced the sediment load entering the lake by an order of magnitude resulting in improved water quality in Beasley Lake based on reductions in nutrient and sediment losses and increases in water visibility.

Keywords: Runoff, Sediment Yield, Water Quality, Conservation Reserve Program (CRP), Reduced-Till.

Introduction

Soil erosion has long been recognized as a threat to the productivity of U. S. farms and the quality of surface waters. Excessive amounts of sediment cause taste and odor problems for drinking water, block water supply intakes, foul treatment systems, and fill reservoirs. A high level of sediment adversely impacts aquatic life, reduces water clarity, and affects recreation. Even in relatively flat areas, such as the Mississippi Delta, considerable soil erosion can occur. Murphree and Mutchler (1981) reported a 5-year average sediment yield as high as 17.7 t ha^{-1} from a flat watershed in the Mississippi Delta. Cooper and Knight (1990) found that suspended sediment loads generally exceeded 80 to 100 mg L^{-1} (maximum for optimal fish growth) during and immediately following storm events in two upland streams in Mississippi. Ritchie *et al.* (1979) found that 2.5 to 7.5 cm of fine sediments accumulated per year in natural lakes along Bear Creek, a drainage system in the Mississippi Delta where 75% of the land was in cultivation. Accumulated sediment has covered the bottoms of many lakes and stream sections with fine silt (Ritchie *et al.*, 1986).

Fertilizers are extensively used in the United States to increase crop production. The wide spread use of fertilizer continues to be a major public concern because of possible human health risks and the eutrophication of surface water (Novotny & Olem, 1994). Nitrate concentration is a parameter of

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particular concern because of its link to the "blue baby" syndrome and formation of carcinogenic compounds.

Improvement of water resources has been an issue of significant societal and environmental concern for many years. Off-site transport of sediment and its associated pollutants from agricultural cropland has been classified as one of the major sources of water quality impairment, and water quality would directly benefit if the amount of soil loss was reduced (Natural Resource Conservation Service, 1997). Impairment to surface water quality due to sediment and nutrient transport from agricultural cropland has been estimated to be about $9 billion per year (Ribaudo, 1992). Although more than $500 billion has been spent on water pollution control since the implementation of the Clean Water Act in 1972, the quality of the U.S. water still remains largely unknown (Akobundu & Riggs, 2000). Also, the Mississippi River system has been cited as a leading contributor to conveying sediments and other pollutants into the Gulf of Mexico resulting in hypoxia issues (Scavia, *et al.* 2003).

In reducing soil erosion and solving nonpoint source (NPS) water quality problems, regulatory agencies promote Best Management Practices (BMPs), as defined by Natural Resources Conservation Service, adoption on areas most susceptible to NPS pollution. Under the USDA Environment Quality Incentive Program (EQIP), cost sharing is available from government agencies to agricultural producers who voluntarily implement BMPs (Natural Resource Conservation Service, 2001). Depending on local priorities and funding availability, the cost-sharing rate is up to 50 percent and may be more. Therefore, a significant amount of research has been conducted to identify management options for minimizing sediment yield and NPS pollution from agricultural land areas. Examples of such management options include conservational tillage (Loehr *et al.*, 1979; Mueller *et al.*, 1984), grass filter strips (Dillaha *et al.*, 1989; Line, 1991; Cooper and Lipe, 1992; Robinson *et al.*, 1996), and impoundments that retard flow and allow suspended sediment transported in runoff sufficient time to drop out of suspension (Laflen *et al.*, 1978). However, the impact of a particular BMP on water quality is still a challenge to estimate before any actual implementation (Parker *et al.*, 1994; Walker, 1994) at a particular location since data from one location may not be applicable to other locations. It is even more difficult to predict integrated effects of implementation of several BMPs.

Various national initiatives and programs have focused on assessing the impact agricultural BMPs have on water conservation and quality over the past two decades. The 1989 Presidential Initiative on Water Quality established water quality objectives and a framework for a national research and assessment endeavor called the Management Systems Evaluation Areas (MSEA) as part of the United States Department of Agriculture Water Quality Program (USDA, 1994). The multi-agency National MSEA program initially focused on five Midwestern states and then expanded to other areas, including Mississippi (Locke, 2004). The Mississippi MSEA (MD-MSEA) project was located in the Mississippi Delta (Figure 1) and was comprised of three oxbow lake watersheds, including Beasley Lake Watershed.

Changes in US farm policy redirected USDA conservation programs to address natural resource issues such as water quality and ecosystem protection as high priorities. This commitment to environmental stewardship extended to the 2002 Farm Bill, with significant increases in funding for conservation programs. The USDA-Agriculture Research Service (ARS) partnered with USDA-Natural Resources Conservation Service (NRCS) in a nationwide assessment regarding the effectiveness of USDA conservation programs that was termed the Conservation Effects Assessment Program (CEAP). Fourteen watersheds, including Beasley Lake Watershed, with a history of long-term ARS natural resource research were selected as benchmark locations for participation in CEAP. A significant database from Beasley Lake Watershed spanning from 1994 to 2003 (MD-MSEA research) and into the present (CEAP) serves as an important tool for supporting CEAP goals (Locke *et al.*, 2008).

As part of the CEAP assessments, this paper reports and compares the runoff and water quality from 2005 to 2008 from edge-of-field drainage sites with row crop management practices to drainage sites with Conservation Reserve Program (CRP). Also, this paper assesses the water quality of the lake by analyzing lake water samples for sediments and nutrients.

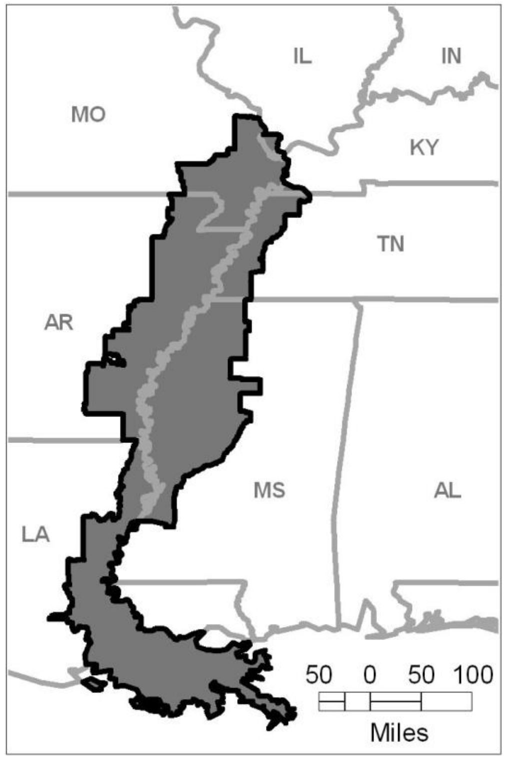

Figure 1. Map of area of United States that represents a sub region of the Lower Mississippi River Basin, an alluvial plain known as the Mississippi Delta.

Materials and Method

A case study of Beasley Lake Watershed, typical of topography and cropping systems in the Mississippi Delta region, was used to evaluate water quality from various BMPs placed throughout the watershed. The Mississippi Delta region (Figure 1) comprises 11 million hectares of the southern portion of the Mississippi River Alluvial Plain. This alluvial plain region is a narrow strip on both sides of the Mississippi River, widening in some places to approximately 160 kilometers, that extends over 1100 kilometers from southeastern Missouri to the Gulf of Mexico. Historically, cotton (*Gossypium hirsutum* L.) production dominated the rural and intensively agricultural region, but in recent decades, agriculture has diversified to soybeans [*Glycine max* (L.) Merr.], rice (*Oryza sativa*), catfish (*Ictalurus punctatus*), and corn (*Zea mays* L.). The climate is classified as humid subtropical with an annual rainfall ranging from 1140 to 1520 mm and temperatures averaging 18^{o}C. Although the Delta region topography averages less than 1% slope, significant quantities of sediment are lost in runoff from the high rainfall events common during winter and spring months.

Beasley Lake Watershed (latitude 33^{o}24’15”, longitude 90^{o}40’05”) is located in Sunflower County, Mississippi, and part of the Big Sunflower River watershed (hydrologic unit code 08030207) within the Yazoo River Basin (Locke, *et al*., 2008). Beasley Lake (Figure 2) is a 25-ha oxbow lake resulting from a course shift by the nearby Sunflower River. The total drainage area of this watershed is approximately 850 ha. The Sunflower River levee defines the northern part of the watershed boundary. Soils are generally loam to heavy clay, with part of the watershed being forested. Further watershed details, description of soil survey, data and management decisions with respect to time can be found in Locke, *et al.*, 2008. Drainage of the watershed is dependent on man-made ditches with water draining into Beasley Lake. The predominant watershed crop is soybean, but corn and cotton are rotationally grown.

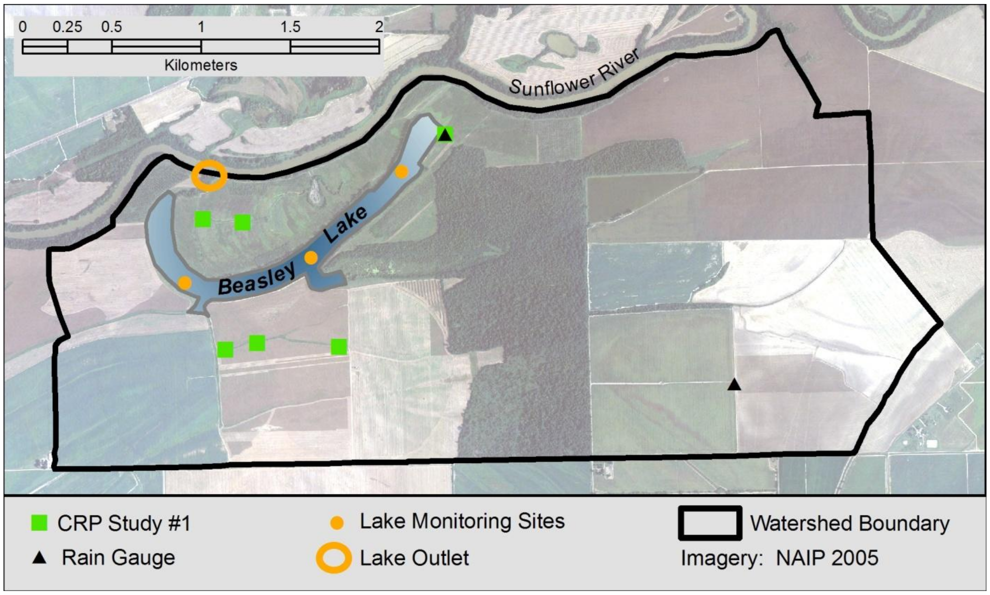

Figure 2. Map of Beasley Lake Watershed that shows the location for gauging the runoff (green squares) and the location for lake monitoring (yellow dots).

Beasley Lake Watershed has evolved from row crop agriculture dominated by cotton production to a mixture of row crop and non-cropped areas from 1995 through 2008 (Figure 3). Approximately 12% (113 ha) of the Beasley Lake Watershed was converted from cropped land to CRP beginning in 2003, and the remainder of the cropland was still managed for soybean, cotton, or corn production. Beginning in 2005, research was initiated involving monitoring runoff from edge of field slotted-inlet drainage pipe sites on both CRP and cropped land. Six sub-drainage areas (1.2 to 6 ha) (denoted by green squares in Figure 2) of similar topography and soil types were selected from areas either cropped in reduced tillage soybean (three sites) or planted in eastern cottonwood (*Populus deltoids*), oak (*Quercus sp.*) and hickory (*Carya sp.*) trees and set aside as Conservation Reserve (CRP) (three sites). These trees, planted on a 2 m by 2 m grid, are some of the largest North American hardwood trees and are grown in riparian areas. Global positioning system (GPS) surveys were used to establish/delineate drainage acreages (4-6 ha) for each site. Bermed borders were created to delineate sub-drainage areas for measuring surface runoff. Rain and runoff from rain events producing runoff were measured and sampled. Rain was measured using 1-mm tipping buckets connected to area-velocity flow logger/meters within the study area (denoted in Figure 2 by black triangles). Runoff was determined from flow measurements using area-velocity flow logger/meters and acoustic Doppler devices mounted in slotted-inlet pipes positioned at the outlets of the sub-drainage areas. Runoff from these rain events was collected starting in April 2005 from these sub-drainage areas instrumented with these relatively simple and compact area-velocity flow logger/meters and automated composite water samplers. Water samplers automatically collected runoff samples from field drainage slotted-inlet pipes on a flow proportional basis via acoustic Doppler technique during all surface runoff events. Within 24 h of rainfall events, runoff samples were collected, transported to the National Sedimentation Laboratory in Oxford, MS, and stored at 4°C (usually <24 h) for analysis. Runoff, sediment yield or soil loss, and nutrient loss were determined for each site. Water samples were filtered through 0.45 µm nitrocellulose membranes to produce the filterable and nonfilterable nutrient components of total kjeldahl nitrogen (TKN) and total phosphorus (TP). Analytical and chemical methods were based on procedures from APHA (1992). Calculation of means and statistical analysis were completed using SAS STAT software (SAS Institute, Inc., 2006).

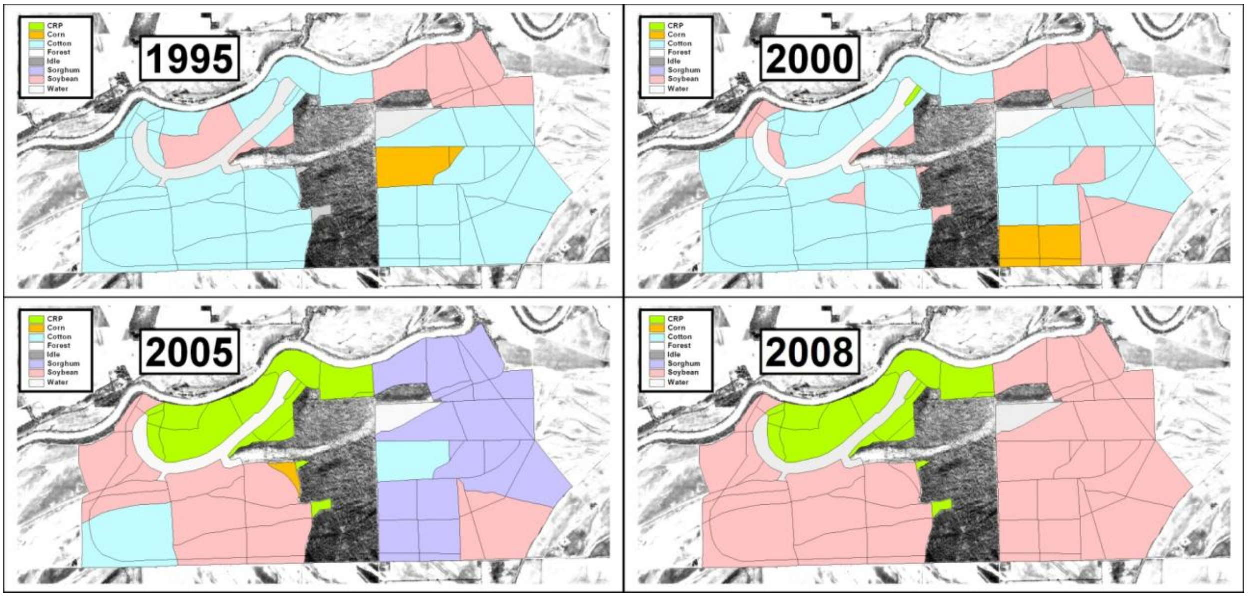

Figure 3. Map of Beasley Lake Watershed displaying crop changes to watershed from 1995 through 2008.

Three lake water sampling sites (denoted by yellow dots in Figure 2) were selected for water quality monitoring with locations at one-third distance from inlet, mid-point of lake, and one-third distance from outlet. At these locations, water was collected in sample bottles within 5 cm of the lake's surface on a biweekly basis from May 1995 through December 2008 and analyzed for total, suspended, and dissolved sediments, TP, filterable orthophosphate, ammonium nitrogen and nitrate nitrogen, chlorophyll, coliform and enterococci bacterial counts. A Secchi visibility determination was made at each site by placing a Secchi disc into the water column and measuring the distance to where it initially disappeared. Results from this data from May 1995 to December 1999 are found in Cullum et al. (2006). This paper extends the use of the total, suspended, and dissolved sediments, the Secchi visibility, and some of the chemical data of ammonium nitrogen, nitrate nitrogen, orthophosphate, and total phosphorus to assess the land management effects on the receiving water body.

The hypothesis being tested is that improvement in edge-of-field water quality can be demonstrated via land placed in CRP. Improvement in edge-of-field water quality was primarily based on the reduction of sediments, since many of the contaminants of interest entering water bodies are associated with these particles. Improvement in edge-of-field water quality consists of evaluating differences in sediment and nutrients in runoff resulting from converting cropped land to CRP. Selected fields (three cropped or tillage sites and three CRP sites) in the Beasley watershed were automated to collect surface water samples from field drainage slotted-inlet pipes during all surface runoff events. Runoff samples were analyzed for sediments and nutrients. Both soil and chemical loss and runoff data were analyzed on a quarterly, annual, and total basis. Statistical analysis was conducted by comparing CRP sites to row crop sites to determine effectiveness of CRP to improve water quality, chiefly by reducing sediments. Data were collected from April 2005 to July 2008.

Results and Discussion

When lake data collection began in 1995, 718 ha of the watershed were cropped with cotton (63.3% of cropped area), corn, and soybeans. Typically, farming practices in the watershed included disking the soil in the fall, preparing the seedbeds just prior to planting, and cultivating during the growing season. During the period from 1995 to 2006, implementation of government sponsored conservation programs resulted in dramatic changes within the Beasley watershed (Figure 3). In 2001 and 2002, reduced-till cotton and soybeans occupied most of the cultivated area, and from 2003 to 2006, reduced-till soybeans were the dominant crop. In 2007 these cultivated areas were rotated out of soybeans into corn. In 2008, all the cropped area of the Beasley watershed was rotated to reduced-till soybeans. In fall 2002, 113 ha were removed from row crop production and planted to hardwood trees under the CRP.

Physical water quality data for the six drainage sites are shown in Table 1. Analysis of variance showed significant differences in the means (p=0.05) between the total average runoff and total soil loss from crop areas as compared to CRP areas over the time of study. Differences in runoff and soil loss means among the four years were found within both the crop areas and CRP areas probably due to the annual rainfall quantity differences during this study. The analysis of variance tests also showed a significant difference in means of the quarterly data with the January through March period producing the most runoff (Figure 4) and soil loss (Figure 5) especially in the crop areas.

Table 1. Annual rain, runoff, and sediment yield from crop and CRP sites.

Year	Rain (mm)	Runoff (mm)		Sediment Yield (kg/ha)	
		Crop	CRP	Crop	CRP
2005	298	202	56	320	54
2006	632	219	262	2071	789
2007	631	355	130	1810	213
2008	487	158	147	4161	234
Total	**2048**	**934**	**595**	**8361**	**1290**

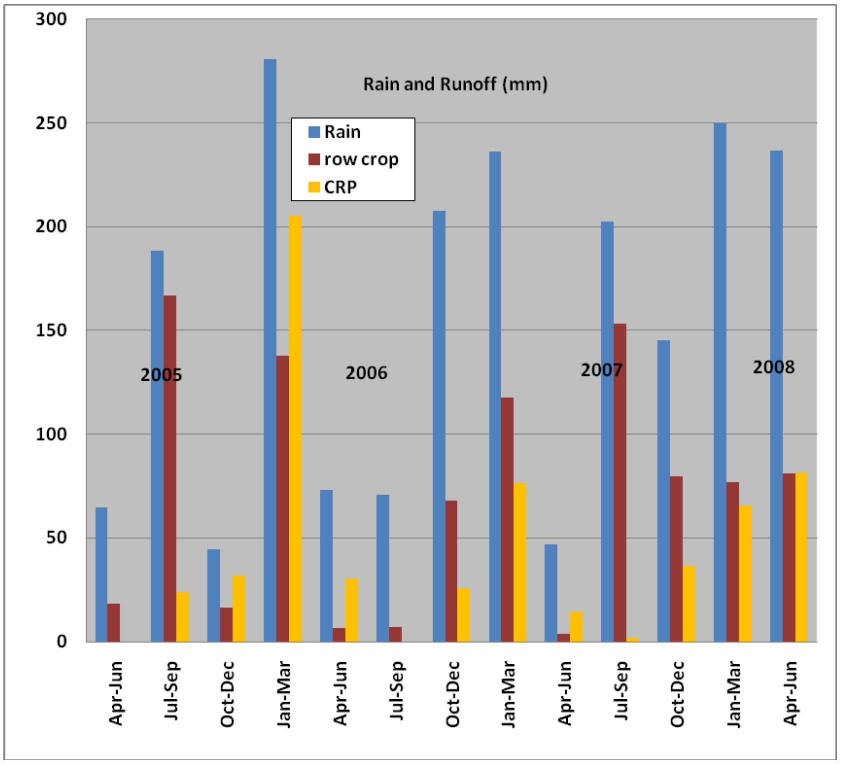

Figure 4. Quarterly rain and runoff from the three row crop sites and the three CRP sites.

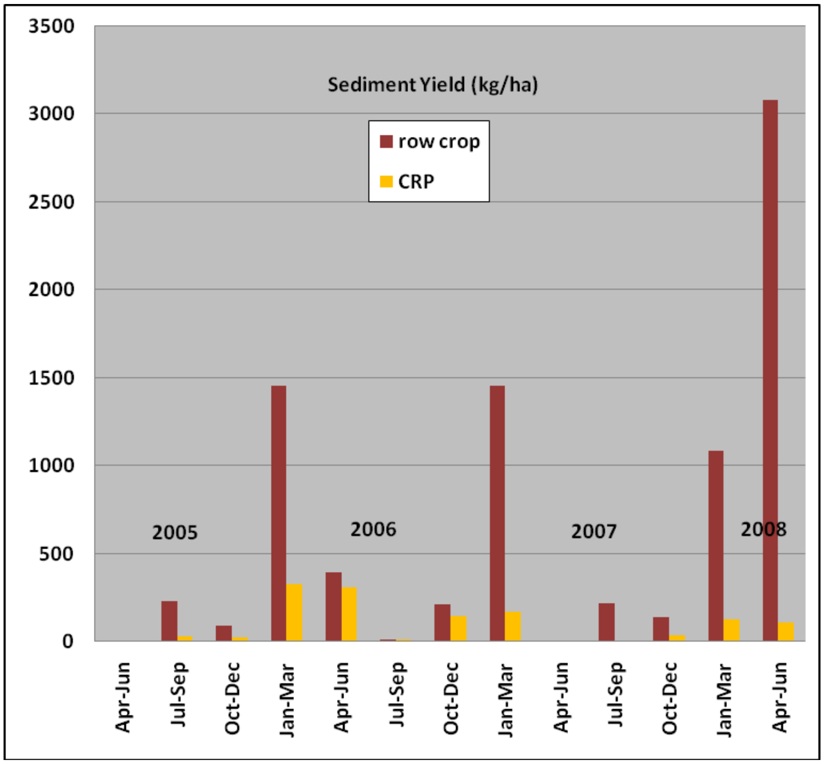

Figure 5. Quarterly sediment yield (kg/ha) from the three row crop sites and the three CRP sites.

Of the total rainfall producing runoff events in the watershed, approximately 45 percent was in runoff from land cultivated in row crops while 29 percent was in runoff from CRP areas. These results are shown in Table 1 when comparing the total runoff of 934 mm and 595 mm from crop and CRP, respectively to the 2048 mm of rain producing runoff over the testing period. Annual soil loss from the crop area was 2.1 t ha^{-1} as compared to the annual soil loss from the CRP area of 0.3 t ha^{-1}. Total runoff and total soil loss were 36% and 85% lower from the CRP areas than from the cropped areas. Both areas produced lower annual soil loss than the NRCS tolerance level of 3 t ha^{-1}; thus, these two best management practices would be considered appropriate for this agricultural watershed.

The annual chemical losses from runoff collected from the six drainage sites are shown in Table 2. Similar to observations made concerning total runoff and sediment loss, loss of chemicals was reduced in CRP areas. The total chemical losses for the study (Table 2) within the CRP areas as compared to the cropped areas were 83%, 71%, 35%, 36%, and 28% for NO_2-N, NO_3-N, NH_4-N, PO_4-P, and TOC, respectively. More of TKN was in the filterable component (fine fraction, including soluble) (F) of the sample than in the TKN non-filterable (NF) component (larger sized constituents) for the CRP areas (Table 2). TKN losses within the filterable component of the runoff were reduced by 45% for the study within the CRP areas as compared to that in the cropped areas. The total phosphorus (TP) losses for the study were 969 gm ha^{-1} and 628 gm ha^{-1} for the filterable component of the runoff for cropped areas and CRP areas, respectively, and 712 gm ha^{-1} and 20 gm ha^{-1} for the NF fraction of the runoff for cropped areas and CRP areas, respectively. TP losses were reduced by 35% and 97% for the F and NF fractions of runoff, respectively, when comparing the CRP areas to the cropped areas.

The lake data indicated reduction of sediments over time when assessing the sediment data from the surface water samples of the lake and the Secchi visibility measurements. The biweekly data was summarized into monthly means for all three sampling points within the lake. The suspended sediments and Secchi visibility data showed significant differences among the months and among the years as shown in Figure 6. Filterable sediments, which are the fine solids and soluble materials, remained relatively stable over time at around 60 mg L^{-1}. Variation among the suspended sediments was three orders of magnitude from 1071 mg L^{-1} in April 1996 to 4 mg L^{-1} in 2008. Secchi visibility was from 4 cm in May 1995 to 83 cm in September 2008. An indirect relationship of declining suspended solids with increasing Secchi visibility was observed (Figure 6).

Table 2. Mean annual chemical loads from runoff of row crop and CRP sites.

Year	Drainage Type	NO_2-N (gm/ha)	NO_3-N (gm/ha)	NH_4-N (gm/ha)	PO_4-P (gm/ha)	TOC (gm/ha)	TKN (gm/ha) (NF*)	TKN (gm/ha) (F*)	TP (gm/ha) (NF)	TP (gm/ha) (F)
2005	row crop	154	3633	269	1251	54909	1947	1594	750	304
	CRP	6	46	52	694	4732	436	689	319	248
2006	row crop	56	5213	740	713	45879	3514	4044	1513	870
	CRP	27	3105	805	1053	60165	2363	3773	1199	1200
2007	row crop	75	3204	659	2575	46649	7155	7370	2451	988
	CRP	12	881	222	909	23699	1693	2556	656	542
2008	row crop	63	5342	272	2791	52348	3492	2963	2011	1716
	CRP	14	988	181	2000	55474	1591	1767	419	522

** Water samples filtered through 0.45 μm nitrocellulose membranes to produce the filterable (F) and nonfilterable (NF) nutrient components of TKN and TP.*

The sediment data and Secchi visibility data (Table 3) were also presented as annual summaries and further divided into three time steps. The first time step was when the edge-of-field conservation practices were first implemented (but with few in-field conservation row crop practices) from 1995 through 1998. The second time step was when some in-field conservation practices were included and the use of transgenic crops was increased from 1999 thru 2003. The third time step was after CRP practices were implemented in a major portion of the watershed from 2004 through 2008. Lake water samples resulted in over 55% reduction of suspended sediments during the third time step or post-CRP implementation period when comparing the second time step of 112 mg L^{-1} suspended sediments from 1999 through 2003 to the third time step of 50 mg L^{-1} suspended sediments from 2004 through 2008. Also, the average Secchi disc depth visibility increased from 21 cm during the second time step from 1999 through 2003 to 44 cm during the third time step or post-CRP implementation period. These data indicate that reduced sediment runoff due to conservation measures in the watershed was positively impacting the lake water quality.

Improvements in edge-of-field water quality were observed when evaluating differences in sediments and nutrients in runoff resulting from converting cropped land to CRP. All physical and chemical water quality data from the runoff from these drainage ditches provided support for the hypothesis that improvement in edge-of-field water quality can be demonstrated via land placed in the Conservation Reserve Program. Reductions of soil loss and reduction of nutrients were found from each storm event, each quarterly, annual, and total data. The impact of converting one third of the cropped area into trees reduced the sediments leaving the watershed and entering the lake by an order of magnitude, resulting in improved water quality in Beasley Lake.

While lake nutrients had declined due to installation of structural conservation practices and implementation of conservation tillage within the watershed, conversion to CRP continued to contribute to decreasing concentrations of nutrients and improvement of water quality (Table 4). Comparing the mean concentrations of ammonium-nitrogen, nitrate-nitrogen, orthophosphate, and total phosphorus in lake water for the period following implementation of conservation tillage with the period following CRP conversion indicates a decrease in all four nutrients by 85%, 19%, 18% and 18%, respectively.

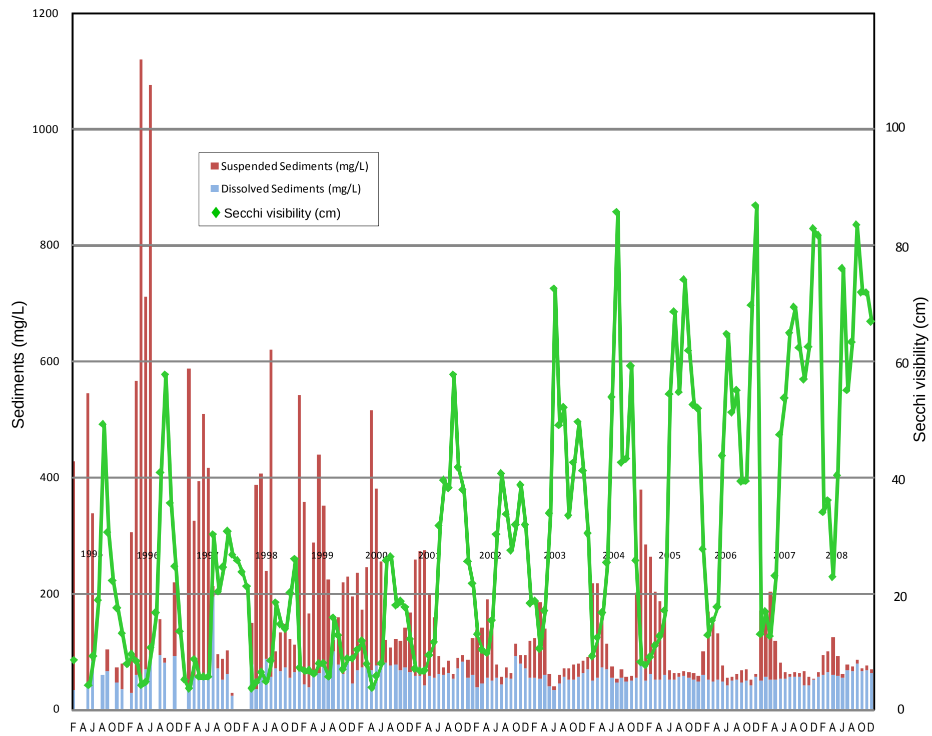

Figure 6. Average monthly Secchi visibility or depth measurements (cm), suspended sediments (SS), and dissolved or filterable sediments (DS) from surface water samples taken from three sites on Beasley Lake from 1995 thru 2008.

Table 3. Secchi visibility and sediment data from water samples from three sites on Beasley Lake.

Year	Secchi Visibility (cm)	Total Sediments (mg/L)	Suspended Sediments (mg/L)	Filterable Sediments (mg/L)
1995	18	232	179	52
1996	18	603	535	68
1997	16	270	203	67
1998	14	238	173	64
Average from 1995-1998	**16**	**333**	**273**	**63**
1999	8	286	227	64
2000	14	215	142	73
2001	26	149	90	59
2002	24	112	55	55
2003	35	95	45	50
Average from 1999-2003	**21**	**171**	**112**	**60**
2004	35	132	75	57
2005	40	126	72	54
2006	42	86	38	49
2007	45	97	47	50
2008	59	82	18	63
Average from 2004-2008	**44**	**105**	**50**	**54**
Average from 1995-2008	**26**	**180**	**120**	**60**

Table 4. Mean concentration of chemicals from all water samples of Beasley Lake from 2001 thru 2008 from before and after CRP.

Years	Status of Watershed	NH_4-N (mg/L)	NO_3-N (mg/L)	ortho P (mg/L)	TP (mg/L)
2001-2003	before CRP	0.058	0.141	0.698	0.227
2004-2008	after CRP	0.009	0.114	0.573	0.187
	% diff	-85	-19	-18	-18

Summary and Conclusions

This study of Beasley Lake Watershed was used to evaluate runoff from edge-of-field sites with various row crop management practices, and quantify effects of areas in the watershed that were shifted to forest (CRP). Approximately one-third of the Beasley Lake watershed (ca. 280 ha) was converted from cropped land to CRP beginning in 2003, and the remainder of the cropland is still managed for soybean, cotton, or corn production. Sub-drainage areas (1.2 to 6 ha) with similar topography and soil types were either cropped (three sites under reduced tillage crop production) or CRP (three CRP sites) and were instrumented in 2005 to collect water samples from field drainage slotted-inlet pipes during all surface runoff events. These runoff samples were analyzed for sediments, nutrients, and pesticides. Reducing soil loss and nutrient loads in runoff from edge-of-field through the use of BMPs results in lower sediments and agrichemicals entering Beasley Lake. Establishing trees within CRP adjacent to oxbow lakes reduces the quantities of sediments and nutrients leaving the watershed as compared to reduced-till crop management techniques. The impact of converting one third of the cropped area into trees has reduced the sediments leaving the watershed by an order of magnitude resulting in improved water quality in Beasley Lake by July 2008.

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