International Journal of Ecology and Environmental Sciences 33(1): 61-71, 2007

Pesticides in Lake Water in the Beasley Lake Watershed, 1998-2005

S. SMITH, JR.*, C.M. COOPER, R.E. LIZOTTE, JR., M.A. LOCKE, AND S.S. KNIGHT
Water Quality and Ecology Research Unit, UDSA-ARS, National Sedimentation Laboratory (NSL), 598 McElroy Drive, P.O. Box 1157, Oxford, MS 38655-1157, USA
* Author for Correspondence: *Email: ssmith@ars.usda.gov*

ABSTRACT

Oxbow lakes are remnants of meandering floodplain rivers, which have been cut off and physically isolated from their respective main river channels. They usually capture only small relic drainages. Beasley Lake Watershed, a Conservation Effects Assessment Project (CEAP) benchmark watershed, is one of three oxbow lake watersheds in the original Mississippi Delta Management Systems Evaluation Area (MDMSEA) project begun in 1994. Best Management Practices (BMPs) originally established in the Beasley Lake Watershed consisted of grade stabilization and water control structures, including slotted-board risers and slotted-inlet pipes, accompanied by numerous grass filter strips along major drainages into the lake. A large forested wetland adjoining Beasley Lake provided additional natural water treatment. Conventional cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), and soybeans [*Glycine max* (L.) Merr.], totaling about 660 ha, were the predominant crops from 1995-2000 in the Beasley Lake Watershed. In 2001-2002, reduced-till cotton and soybeans occupied most of the Watershed, and from 2003 to the present time, reduced-till soybeans has been the dominant crop along with 91 ha (north side of the Lake) planted to hardwoods under the Conservation Reserve Program (CRP). BMP modifications over the last several years include: 1) additional slotted-board risers and slotted-inlet pipes (with and without stiff grass hedges and with and without tile drains) instrumented to automatically collect edge-of-field runoff on a flow proportional basis from both cropped and CRP land, 2) conservation tillage, and 3) constructed wetlands. On a monthly basis since 1998, water has been collected from Beasley Lake and analyzed for a suite of 17 current and past-use (residual) pesticides (and/or metabolites). Of the 80 pesticide detections ≥0.1ppb in surface water, herbicides accounted for 68, equivalent to 85%. With regard to the 80 detections ≥0.1ppb, 44 (55%) occurred in the years 1998-2000, 21 (26%) occurred in the years 2001-2002, and 15 (19%) occurred in the years 2003-2005. As previously mentioned, prior to the year 2001, conventional tillage was employed throughout the Beasley Lake Watershed. In 2001-2002, reduced-till cotton and soybeans occupied most of the watershed. From 2003-present, the north side of Beasley lake was in trees under CRP, with the balance of the watershed in predominantly reduced-till soybeans. Thus, the number of lake water pesticide detections≥0.1ppb was progressively and significantly reduced by moving from conventional tillage to reduced-tillage to reduced-tillage+CRP.

Key Words: Insecticide, Herbicide, Lake Water, Agricultural land use, Tillage, CRP

INTRODUCTION

The Mississippi Delta Management Systems Evaluation Area (MDMSEA) project, begun in 1994, had as its major objective the development of region-specific alternative farming systems, composed of combinations of selected Best Management Practices, BMPs (Locke 2004). This was and still is crucial to protecting the surface and ground water resources and improving the ecological and environmental quality of the entire Mississippi Delta region. Research was needed on the alluvial soils of this region because the significance of agrichemical percolation (leaching) to relatively shallow water tables, which are hydraulically connected to nearby lakes and rivers, was poorly understood. The effectiveness of adjacent riparian zones to trap sediment and to trap and process agrichemicals in runoff was also poorly defined. Essentially nothing was known about the ability of the Delta lakes to recover and/or to sustain fisheries production after sediment and agri-chemical inputs were permanently reduced.

The hot, humid climatic conditions and long growing season make the Mississippi Delta ideal for intensive row crop production, primarily cotton (*Gossypium hirsutum* L.), soybeans [*Glycine max* (L.) Merr.], rice (*Oryza sativa* L.), and corn (*Zea mays* L.). However, these same conditions also provide for enhanced weed growth and high insect infestations, resulting in the need for intense agrichemical pest control measures. Because of the level topography and high annual rainfall, numerous streams, wetlands, and lakes are present. Many of the lakes are known as “oxbow lakes” because of their shape. Oxbow lakes are remnants of meandering floodplain rivers, which have been cut off and physically isolated from their respec-tive main river channels and usually capture only small relic drainages. Isolation resulted in physical and chemical changes in the lake basin and in the floral/ faunal assemblages present at the time of separation. Over time, organic materials introduced from elsewhere were processed and energetically depleted, resulting in the lakes having become less heterotrophic and more autotrophic. If suspended sediment concentrations are low enough to provide suitable light penetration, isolated oxbow lakes provide conditions conducive to photosynthesis, primarily via phytoplankton, and may support sustainable fisheries production. However, decades of traditional agricultural practices including clean tillage and no winter cover on land surrounding these oxbow lakes resulted in continuous high lake turbidity from fine sediment transport in runoff. Thus, light penetration in water was reduced, photosynthesis inhibited, and productivity lost. In addition, runoff often transported agrochemicals into the lakes causing further reductions in water quality. Consequently, many Delta oxbow lakes, long known for their fish productivity and recreational value, became unattrac-tive (Knight et al. 2001).

Potential benefits from conducting this research include: 1) an increased knowledge of how the various physical, chemical, and biological properties of soils affect water and agrichemical movement, 2) the development of improved agrichemical transport models that allow for management, edaphic (inherent in the soil), and environmental variables, 3) new knowledge of agrichemical filter/processing system design and effec-tiveness, 4) improvements in crop residue and agri-chemical management, 5) a reduction in agrichemical application with a concomitant reduction in sediment as well as surface and subsurface agrichemical transport, and 6) ecologically healthy lakes and streams with sustainable fisheries.

The Beasley Lake Watershed (one of the original MDMSEA watersheds) is now one of the benchmark watersheds in what is known as the Conservation Effects Assessment Project (CEAP), a national watershed research project jointly conducted by the USDA Agricultural Research Service (ARS) and the USDA Natural Resources Conservation Service (NRCS). This paper discusses monthly pesticide concentrations determined in Beasley Lake water over the period of 1998-2005 during which time farm management practices in the watershed progressively changed from predominantly conventional tillage cotton and soybeans to reduced tillage to inclusion of the NRCS Conservation Reserve Program (CRP).

Site Description

Beasley Lake Watershed (total drainage=about 850 ha, lake surface=about 25 ha) is one of three oxbow lake watersheds in the original MDMSEA project (Figure 1). The MDMSEA project design involved a hierarchy of BMPs in three research watersheds located in Sunflower and Leflore counties in west-central Mississippi (Smith et al. 2001, Locke 2004). The watersheds are “closed systems” each with drainage into an oxbow lake. Thighman Lake watershed (south of Moorehead also in Sunflower County) served as a control with no BMPs initially. Beasley Lake watershed (south of Indianola) received nominal BMP treatment consisting of grade stabilization and water control structures including slotted-board risers, slotted-inlet pipes, overfall pipes, and culverts. Numerous grass filter strips were established along major drainages into the lake and in selected fields. Advantage was taken of a large forested wetland (about 125 ha) adjacent to Beasley Lake for natural processing of receiving water. Deep Hollow Lake watershed (near Sidon in adjacent Leflore County to the east) received an intense BMP effort consisting of winter wheat cover crop and all conservation-till cotton and soybeans in addition to drainage control structures.

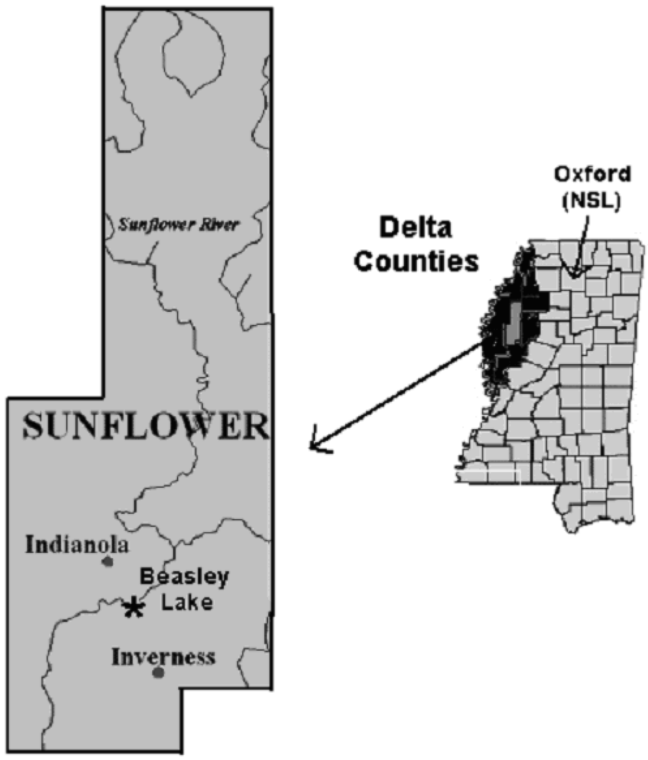

Figure 1. Location map of Beasley Lake watershed

Conventional cotton, corn, and soybeans (about 660 ha) were the predominant crops from 1995-2000 in the Beasley Lake Watershed. In 2001-2002, no-till cotton and soybeans occupied most of the watershed and from 2003 to the present time, no-till soybeans has been the dominant crop along with 91 ha (north side of the Lake) planted to hardwoods under CRP. BMP modifications over the last several years include a constructed wetland, conservation tillage, and addi-tional slotted-board risers and slotted-inlet pipes (with and without stiff grass hedges and with and without tile drains) instrumented to automatically collect edge-of-field runoff on a flow proportional basis from both cropped and CRP land.

MATERIALS AND METHODS

Monthly, 4-L water samples were collected in a 10-L glass jar, fitted with a Teflon-lined screw cap, from Beasley Lake. Samples were taken from about the middle of the lake and from about the middle of the water column. Samples were extracted onsite by adding 4 g KCl and 400 mL pesticide grade EtOAc and shaking vigorously by hand for about 1 min. The lake water sample was immediately placed on ice, transported to the NSL, and stored at 4˚C (usually <24 h) for pesticide analyses via GC using a modified method similar to that of Bennett et al., (2000) and Smith and Cooper (2004). Briefly, sample preparation involved partitioning in a separatory funnel, and discarding the water phase. The EtOAc phase was dried over anhydrous Na_2SO_4 and concentrated by rotary evaporation to near dryness. The extract was taken up in about 5 mL pesticide-grade hexane, cleaned up by silica gel column chromatography, and concentrated to 1 mL under dry nitrogen for GC analysis. Mean extraction efficiencies, based on fortified samples, were >90% for all pesticides.

Two Hewlett Packard (now Agilent) model 6890 gas chromatographs each equipped with dual HP 7683 ALS autoinjectors, dual split-splitless inlets, dual capillary columns, a HP Kayak XA Chemstation were used to conduct all pesticide analyses (Smith and Cooper 2004). One HP 6890 was equipped with two HP micro electron capture detectors (µECDs) and the other 6890 with one HP µECD, one HP nitrogen phosphorus detector (NPD), and a HP 5973 mass selective detector (MSD).

Present and past pesticide usage in the contri-buting watershed area resulted in 17 pesticides (and/or metabolites) being targeted for analysis (Table 1). The main analytical column was a HP 5MS capillary column (30 m x 0.25 mm i.d. x 0.25 µm film thick-ness). Column oven temperatures were as follows: initial at 85˚C for 1 min, ramp at 25˚C min^{-1} to 190˚C, hold at 190˚C for 25 min, ramp at 25˚C to 230˚C, and hold for 30 min. The carrier gas was UHP helium at 28 cm sec^{-1} average velocity with the inlet pressure at 8.64 psi

Table 1. Presently Targeted Pesticides

Pesticide	Retention time (min)	LOD (ng L^{-1})	LOQ (ng L^{-1})
Trifluralin	10.63	1	0.1
Atrazine 12.31	10	1.0	
Methyl parathion	16.78	10	1.0
Alachlor 17.35	5	0.5	
Metolachlor	20.68	10	1.0
Cyanazine	20.96	1	0.1
Chloropyrifos	21.17	5	0.5
Pendimethalin	25.06	5	0.5
Fipronil	26.78	1	0.1
p,p'-DDE	32.17	1	0.1
Dieldrin 32.29	1	0.1	
Fipronil sulfone	33.28	1	0.1
Chlorfenapyr	34.13	5	0.5
p,p'-DDD	34.95	10	1.0
p,p'-DDT	37.70	10	1.0
Bifenthrin	43.36	1	0.1
l-Cyhalothrin	51.01	1	0.1

and inlet temperature at 250˚C. The µECD tempera-ture was 325˚C with a constant make up gas flow of 40 mL min^{-1} UHP nitrogen. The autoinjector was set at 1.0-µL injection volume in the fast mode. Under these GC conditions, all 17 pesticides were analyzed in a single run of 61.80 min. When deemed necessary, pesticide residues were confirmed with a HP 1MS capillary column (30 m x .25 mm i.d. x 0.25-µm film thickness) and/or with the MSD. The MSD was used only when there was a question as to the identity of a particular pesticide. Online HP Pesticide and NIST search libraries were used when needed.

RESULTS AND DISCUSSION

It is important here to mention some important factors that affect pesticide transport. The physicochemical properties of the pesticides themselves are very important. For example, the herbicides generally have relatively high water solubilities (S_w) and low organic carbon partitioning coefficients (K_{oc}) compared to the insecticides as pesticide classes. Thus, the herbicides tend to be transported in runoff in the soluble phase as opposed to the insecticides which tend to be trans-ported in runoff attached to soil particles. However, many common herbicides besides being somewhat water soluble also have a significant affinity for soil particles and are also transported in runoff attached to such particles. Other factors such as application method (ground versus aerial), incorpo-ration techniques, tillage, time between pesticide application and runoff, field persistence of the pesticide, and crop residue cover are also very important and affect pesticide transport and fate. These factors have been discussed in more detail by others (Smith 1993, Smith et al. 1994, Smith et al. 1995). According to Cooper et al. (2003), inexpensive ways to reduce pesticide movement from agricultural fields to receiving water bodies such as streams and lakes include "edge-of-field vegetation, ranging from grass buffers to vegetated ditches or forested wetlands".

Of the 17 targeted pesticides, trifluralin, atrazine, alachlor, metolachlor, cyanazine, and pendimethalin are all recent/current-use herbicides and represent three chemical classes of herbicides. Trifluralin and pendi-methalin are dinitroanilines. Atrazine and cyanazine are chlorotriazines. Alachlor and metolachlor are chloro-acetanilides. Methylparathion, chlorpyrifos, fipronil, chlorfenapyr, bifenthrin, and lambda-cyhalothrin are all current-use insecticides. Methyl-parathion and chlor-pyrifos are organophosphates. Bifenthrin and lambda-cyhalothrin are synthetic pyrethroids. Fipronil and its commonly occurring metabolite, fipronil sulfone, are pyrazoles. Chlorfenapyr is a pyrrole. Dieldrin, p,p'-DDT, and its commonly occurring metabolites, p,p'-DDD and p,p'-DDE, are past-use persistent (residual) organochlorine insecti-cides whose registered uses were discontinued in the early to middle 1970s, but whose persistence in soil is such that their residues are still usually detectable in receiving waters because of transport in suspended sediment.

As previously mentioned, the 17 targeted pesti-cides were chosen for analysis based on agricultural row crop production in the drainage contributing area. These compounds are either present-use, past-use, or meta-bolites of present-use or past-use pesticides (Delta Agricultural Digest 2004). For example, cotton pro-duction herbicides include trifluralin, pendimethalin, and metolachlor; and insecticides include methyl-parathion, chlorpyrifos, lambda-cyhalothrin, bifenthrin and chlorfenapyr (Section 18 emergency exemption only, 2001). Herbicides for corn include atrazine, alachlor, metolachlor, and pendimethalin. Insecticides for corn include bifenthrin, chlorpyrifos, and fipronil. Among the herbicides used for soybeans are metola-chlor, alachlor, and pendimethalin. Insect management in soybeans includes lambda-cyhalothrin, chlorpyrifos, and methylparathion. Registered uses of cyanazine were discontinued after 2002.

During the sampling period, 85 lake water samples were collected from Beasley Lake approximately monthly (Table 2). Each sample was analyzed for 17 pesticides (and/or pesticide metabolites) resulting in 1445 possibilities of detection. There were 80 pesticide detections $\geq$ 0.1 µg L^{-1} (ppb), equivalent to 5.5% of the possible pesticide detections. [Note: The value of 0.1 µg L^{-1} was chosen because LC50 (96-h) values for the most aquatically toxic of the targeted pesticides, the pyrethroid insecticides (bifenthrin and lambda-cyhalothrin), are in the range of 0.15-0.35 µg L^{-1} for common indicator fish species such as bluegill sunfish (*Lepomis macrochirus*) and rainbow trout (*Oncorhynchus mykiss*) (EXTOXNET 2001; U.S. EPA 1988a, 1988b; The Agrochemicals Handbook 1991)]. These pesticides are also acutely toxic to and cause growth impairment to other aquatic organisms such as the benthic amphipod *Hyalella azteca*, commonly used to assess sediment toxicity (Amweg et al. 2005). These researchers further stated that in the Central Valley of California, pyrethroid concentrations are exceeding the values acutely toxic to sensitive species in many agriculture-dominated water bodies.

The synthetic pyrethroid

Table 2. Pesticide detections in Beasley Lake Water.

Date	Trifluralin	Atrazine	Methyl	Alachlor	Metola-chlor	Chlor-pyrifos	Cyanazine	Pendi-methalin	Fipronil	Dieldrin	pp'-DDE	Fipronil-sulfone	Chlor-fenapyr	pp'-DDD	pp'-DDT	Bifenthrin	λ-Cyhalo-thrin
	Pesticide Concentration---ppb																
6/2/1997	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
1/8/1998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
2/13/1998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
3/10/1998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
5/20/1998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
6/24/1998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
7/22/1998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
8/18/1998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
9/10/1998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
10/9/1998	0.013	**0.275**	0.000	0.000	**0.314**	0.000	**0.757**	0.000	0.004	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
11/28/1998	0.003	**0.121**	0.000	0.000	0.048	0.000	**0.506**	0.000	0.004	0.000	0.000	0.004	0.000	0.001	0.000	0.000	0.000
1/6/1999	0.000	0.000	0.000	0.000	0.000	0.000	**0.100**	0.000	0.004	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
2/9/1999	0.000	0.000	0.000	0.000	0.000	0.000	0.031	0.000	0.004	0.000	0.002	0.004	0.000	0.005	0.000	0.000	0.000
3/23/1999	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.012	0.004	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
4/21/1999	0.000	**3.054**	0.000	0.000	**3.010**	0.000	0.007	0.000	0.004	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
6/22/1999	0.005	**0.388**	0.000	0.000	**10.046**	0.000	0.006	0.000	0.004	0.000	0.001	0.004	0.000	0.000	0.000	0.000	0.000
7/29/1999	0.020	**0.648**	0.000	0.000	0.000	0.000	0.005	0.000	0.004	0.000	0.070	0.004	0.000	0.000	0.000	0.000	0.043
8/24/1999	0.011	**0.258**	0.000	0.000	**1.293**	0.000	0.069	0.000	0.004	0.008	0.000	0.004	0.000	0.002	0.000	0.000	0.033
9/22/1999	0.069	**0.298**	0.018	0.005	**1.060**	0.007	**0.100**	0.009	0.004	0.001	0.007	0.004	0.000	0.013	0.000	0.037	0.022
10/20/1999	0.013	0.000	0.008	0.001	**0.279**	0.006	0.057	0.000	0.004	0.004	0.003	0.004	0.025	0.015	0.000	0.040	0.025
10/29/1999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
11/8/1999	0.021	**2.433**	0.025	0.000	**0.216**	0.013	0.036	**0.108**	0.004	0.018	0.007	0.004	0.015	0.009	0.000	0.000	0.020
12/16/1999	0.011	0.085	0.011	0.000	**0.355**	0.000	0.076	0.007	0.004	0.009	0.002	0.004	0.021	0.006	0.000	0.038	0.023
1/13/2000	0.006	0.050	0.006	0.000	0.079	0.000	0.028	0.005	0.004	0.007	0.001	0.004	0.005	0.005	0.000	0.018	0.008
2/9/2000	0.016	0.059	0.010	0.007	**0.228**	0.003	0.072	0.009	0.004	0.002	0.002	0.004	0.001	0.009	0.000	0.029	0.021
3/9/2000	0.013	0.000	0.008	0.000	**0.187**	0.004	0.048	0.011	0.004	0.008	0.004	0.004	0.008	0.007	0.000	0.035	0.032
4/4/2000	0.003	0.005	0.031	0.014	0.069	0.003	0.006	0.010	0.004	0.003	0.007	0.005	0.013	0.030	0.000	0.004	0.004
5/3/2000	0.006	0.025	0.038	0.016	0.094	0.006	0.011	0.010	0.000	0.003	0.002	0.003	0.006	0.019	0.000	0.007	0.004
5/31/2000	0.012	**1.357**	0.000	0.000	**0.276**	0.000	**0.112**	0.000	0.004	0.003	0.005	0.002	0.007	0.032	0.000	0.000	0.003
6/22/2000	0.013	**0.928**	0.035	0.009	**0.156**	0.003	**0.281**	0.006	0.004	0.003	0.008	0.002	0.004	0.032	0.000	0.000	0.003
7/21/2000	0.015	**0.760**	0.038	0.011	**0.100**	0.000	**0.585**	0.000	0.000	0.002	0.004	0.003	0.005	0.020	0.000	0.019	0.004
8/18/2000	0.012	**0.591**	0.045	0.009	0.082	0.001	**0.536**	0.005	0.006	0.003	0.006	0.003	0.010	0.015	0.000	0.042	0.004
9/20/2000	0.017	**0.712**	0.033	0.014	0.015	0.009	**0.549**	0.005	0.008	0.003	0.010	0.008	0.009	0.016	0.000	0.076	0.042
10/18/2000	0.011	**0.493**	0.035	0.013	0.015	0.008	**0.371**	0.005	0.005	0.003	0.007	0.003	0.010	0.012	0.000	0.021	0.012
11/8/2000	0.016	**0.245**	0.051	**0.110**	**0.138**	0.032	**0.211**	0.010	0.007	0.008	0.004	0.000	0.000	0.008	0.000	0.009	0.002

Table 2. continued

	Pesticide Concentration---ppb																
Date	Trifluralin	Atrazine	Methyl	Alachlor	Metola-chlor	Chlor-pyrifos	Cyanazine	Pendi-methalin	Fipronil	Dieldrin	pp'-DDE	Fipronil-sulfone	Chlor-fenapyr	pp'-DDD	pp'-DDT	Bifenthrin	λ-Cyhalo-thrin
12/6/2000	0.005	**0.154**	0.090	0.012	0.013	0.004	**0.137**	0.006	0.000	0.002	0.004	0.003	0.005	0.015	0.000	0.018	0.012
1/30/2001	0.001	0.002	0.029	0.010	0.059	0.001	**0.100**	0.008	0.003	0.003	0.009	0.000	0.006	0.034	0.000	0.002	0.005
2/12/2001	0.001	0.003	0.029	0.012	0.049	0.001	0.021	0.006	0.004	0.003	0.004	0.003	0.003	0.015	0.000	0.016	0.002
9/27/2001	0.046	**0.888**	0.026	0.000	0.084	0.000	**0.619**	0.000	0.000	0.029	0.034	0.014	0.029	0.021	**0.265**	0.016	0.065
10/31/2001	0.000	0.041	0.030	0.000	0.000	0.000	0.007	0.000	0.000	0.006	0.008	0.003	0.011	0.028	0.050	0.000	0.000
11/5/2001	0.005	**0.303**	0.081	0.050	**0.184**	0.000	**1.339**	0.005	0.005	0.006	0.019	0.038	0.043	0.030	0.017	0.036	0.010
12/3/2001	0.003	**0.178**	0.067	0.044	0.028	0.000	**0.333**	0.004	0.005	0.008	0.043	0.019	0.019	0.013	0.090	0.004	0.030
1/30/2002	0.001	0.091	0.071	0.024	0.036	0.023	0.067	0.012	0.007	0.008	0.021	0.027	0.033	0.044	**0.113**	0.041	0.023
3/11/2002	0.003	**0.180**	0.080	0.025	0.038	0.027	0.000	0.004	0.006	0.018	0.015	0.023	0.033	0.031	0.022	0.059	**0.119**
4/29/2002	0.000	0.063	0.010	0.000	0.044	0.000	0.000	0.000	0.000	0.008	0.000	0.023	0.006	0.006	**0.115**	0.003	0.002
5/31/2002	0.000	**0.223**	0.015	0.000	0.075	0.000	0.025	0.000	0.000	0.003	0.005	0.000	0.011	0.011	0.088	0.000	0.003
6/17/2002	0.000	**0.537**	0.000	0.000	0.057	0.000	0.030	0.004	0.000	0.010	0.008	0.001	0.005	0.013	**0.112**	0.063	0.000
7/16/2002	0.011	**0.237**	0.021	0.000	0.038	0.000	0.047	0.000	0.007	0.010	0.013	0.001	0.028	0.015	**0.256**	0.007	0.031
8/12/2002	0.002	**0.154**	0.014	0.000	0.015	0.000	0.044	0.000	0.000	0.003	0.011	0.008	0.018	0.015	**0.123**	0.059	0.030
9/23/2002	0.001	**0.123**	0.000	0.000	0.000	0.000	0.022	0.000	0.000	0.014	0.010	0.003	0.009	0.008	0.065	0.005	0.000
10/21/2002	0.000	0.092	0.000	0.000	0.022	0.003	0.000	0.000	0.005	0.012	0.008	0.002	0.014	0.009	0.070	0.033	0.009
12/2/2002	0.001	0.035	0.000	0.000	0.028	0.011	0.000	0.000	0.012	0.009	0.000	0.007	0.009	0.005	0.053	0.061	0.037
2/10/2003	0.006	**0.423**	0.015	0.017	0.094	0.014	0.002	0.000	0.008	0.021	0.007	0.006	0.017	0.013	0.075	0.051	0.027
3/21/2003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.001	0.003	0.000	0.003	0.008	0.049	0.029	0.000
4/30/2003	0.000	**0.206**	0.015	0.000	0.020	0.000	0.006	0.000	0.010	0.002	0.004	0.002	0.008	0.006	0.024	0.015	0.005
5/19/2003	0.000	**0.227**	0.015	0.000	0.011	0.000	0.002	0.000	0.011	0.001	0.002	0.001	0.004	0.003	0.014	0.006	0.002
6/16/2003	0.000	**0.289**	0.000	0.000	0.000	0.004	0.000	0.000	0.005	0.000	0.001	0.000	0.000	0.002	0.008	0.003	0.000
7/15/2003	0.000	**0.133**	0.000	0.000	0.000	0.008	0.000	0.000	0.005	0.000	0.004	0.000	0.004	0.003	0.008	0.008	0.004
8/25/2003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.000	0.000	0.001	0.010	0.000	0.000
9/23/2003	0.000	0.052	0.000	0.000	0.000	0.028	0.000	0.000	0.000	0.002	0.002	0.081	0.004	0.002	0.017	0.000	0.000
10/20/2003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.001	0.001	0.008	0.001	0.000
11/3/2003	0.000	0.000	0.000	0.000	0.000	0.030	0.000	0.000	0.008	0.000	0.001	0.000	0.006	0.004	0.015	0.005	0.000
12/8/2003	0.000	0.000	0.000	0.000	0.000	0.029	0.000	0.000	0.007	0.000	0.000	0.000	0.001	0.004	0.019	0.000	0.000
1/26/2004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.012	0.006	0.005
2/27/2004	0.000	0.013	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.001	0.001
3/23/2004	0.007	0.098	0.010	0.000	0.000	0.045	0.000	0.000	0.002	0.001	0.006	0.003	0.001	0.006	0.030	0.001	0.005
4/29/2004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.010	0.000	0.000
5/26/2004	0.006	0.035	0.013	0.000	0.000	0.043	0.000	0.008	0.005	0.001	0.004	0.003	0.005	0.007	**0.374**	0.000	0.000
6/29/2004	0.000	0.085	0.011	0.000	**0.563**	0.039	0.000	0.000	0.005	0.002	0.003	0.001	0.001	0.004	**0.249**	0.021	0.037

Table 2. continued

Date	Trifluralin	Atrazine	Methyl	Alachlor	Metola-chlor	Chlor-pyrifos	Cyanazine	Pendi-methalin	Fipronil	Dieldrin	pp'-DDE	Fipronil-sulfone	Chlor-fenapyr	pp'-DDD	pp'-DDT	Bifenthrin	λ-Cyhalo-thrin
	Pesticide Concentration---ppb																
7/26/2004	0.000	0.000	0.000	0.000	**0.134**	0.000	0.000	0.000	0.003	0.000	0.002	0.001	0.000	0.003	**0.128**	0.000	0.005
8/25/2004	0.000	0.072	0.015	0.000	0.099	0.000	0.000	0.000	0.005	0.004	0.007	0.005	0.002	0.007	**0.288**	0.013	0.009
9/20/2004	0.000	0.017	0.011	0.000	**0.102**	0.000	0.000	0.000	0.003	0.002	0.004	0.005	0.010	0.008	**0.238**	0.000	0.004
10/4/2004	0.009	**1.762**	0.000	0.000	0.025	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.002	0.002	0.025	0.000	0.002
11/27/2004	0.000	0.000	0.000	0.000	0.000	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.011	0.029
12/10/2004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000
12/20/2004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000
1/24/2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000
2/22/2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3/21/2005	0.000	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.007	0.000	0.000
5/31/2005	0.001	0.068	0.000	0.000	0.027	0.038	0.002	0.002	0.000	0.002	0.003	0.004	0.003	0.006	0.042	0.000	0.000
6/27/2005	0.000	0.036	0.015	0.000	0.010	0.039	0.000	0.000	0.004	0.001	0.002	0.004	0.003	0.005	0.025	0.000	0.003
8/23/2005	0.006	**0.125**	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.001	0.001	0.004	0.002	0.004	0.037	0.000	0.000
9/19/2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.004	0.002	0.005	0.026	0.013	0.013
10/17/2005	0.000	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.001	0.002	0.002	0.000	0.002	0.025	0.000	0.010
12/12/2005	0.000	0.022	0.000	0.000	0.000	0.026	0.000	0.000	0.000	0.003	0.003	0.002	0.002	0.000	0.042	0.000	0.000
85	0	**32**	0	**1**	**18**	0	**16**	**1**	0	0	0	0	0	0	**11**	0	**1**
mean (all 85 samples)	0.005	0.233	0.013	0.005	0.234	0.006	0.087	0.003	0.004	0.003	0.005	0.005	0.006	0.008	0.039	0.012	0.010
std dev	0.010	0.498	0.021	0.014	1.140	0.012	0.212	0.012	0.003	0.005	0.010	0.010	0.009	0.010	0.075	0.018	0.018
max	0.069	3.054	0.090	0.110	10.046	0.045	1.339	0.108	0.012	0.029	0.070	0.081	0.043	0.044	0.374	0.076	0.119
mean (detections ≥0.1ppb)		0.584			1.036		0.415										
std dev		0.683			2.357		0.328										

Note: Detections ≥0.1 ppb shown in bold

Table 3. Summary of pesticide detections ≥0.1 ppb.

Pesticide	Pesticide Detections (Year) 1998	1999	2000	2001	2002	2003	2004	2005	Totals
Trifluralin	0	0	0	0	0	0	0	0	0
Atrazine 2	6	8	3	6	5	1	1	32	
Methyl parathion	0	0	0	0	0	0	0	0	0
Alachlor 0	0	1	0	0	0	0	0	1	
Metolachlor	1	7	6	1	0	0	3	0	18
Chlorpyrifos	0	0	0	0	0	0	0	0	0
Cyanazine	2	2	8	4	0	0	0	0	16
Pendimethalin	0	1	0	0	0	0	0	0	1
Fipronil 0	0	0	0	0	0	0	0	0	
Dieldrin 0	0	0	0	0	0	0	0	0	
pp'-DDE 0	0	0	0	0	0	0	0	0	
Fipronil sulfone	0	0	0	0	0	0	0	0	0
Chlorfenapyr	0	0	0	0	0	0	0	0	0
pp' -DDD	0	0	0	0	0	0	0	0	0
pp' -DDT	0	0	0	1	5	0	5	0	11
Bifenthrin	0	0	0	0	0	0	0	0	0
l-Cyhalothrin	0	0	0	0	1	0	0	0	1
Totals	5	16	23	9	12	5	9	1	80

insecticides as a group are generally considered to be "highly toxic to fish and aquatic invertebrates" (WHO 1999).

Of the 80 pesticide detections ≥0.1ppb in Beasley Lake water, the herbicides accounted for 68, equivalent to 85% (Table 3). Herbicide detections were as follows: atrazine=32, metolachlor=18, cyanazine=16, alachlor=1, and pendimethalin=1. [Note: atrazine detections are likely associated with the small acreages of corn or milo (grain sorghum, *S. bicolor*) production or from atmospheric deposition. While atrazine is residual in soils, it is also widely distributed by prevailing winds. It is often detected in reservoirs that have had forest as the only land use for decades (personal communication C.M. Cooper, 2006)]. The detections of the herbicides in lake water generally occurred within a few weeks after application whenever runoff events occurred within a week or two after application. Because the herbicides generally have water solubilities that are several orders of magnitude higher and organic carbon partition coefficients that are several orders of magnitude lower than those of insecticides and because the herbicides were applied in the watersheds using ground equipment, the presence of the herbicides in lake water is likely the result of transport during runoff events. The three most frequently detected herbicides had means (±standard deviation) for all 85 lake water samples collected of 0.233±0.498, 0.234±1.140, and 0.087±0.212 ppb for atrazine, metolachlor, and cyanazine, respectively. For the detections ≥0.1ppb, means (±standard deviation) were 0.584±0.683, 1.036±2.357, and 0.415±0.328 ppb, respectively. Maxima were 3.054, 10.046, and 1.339 ppb, respec-tively, and well below herbicide LC50 (96 hour) values, in the range of 2.4-18 mg L^{-1} (ppm), for several fish species (EXTOXNET 2001).

The other 12 detections ≥0.1ppb in Beasley Lake water were the insecticides p,p'-DDT (11 detections) and lambda-cyhalothrin (1 detection). The p,p'-DDT detections appeared to be associated with large runoff events. Because the pyrethroids were applied by airplane and because the single detection in lake water could not be correlated with a runoff event, the likely cause for detection was drift during application.

With regard to the 80 detections ≥0.1ppb, 44 (55%) occurred in the years 1998-2000, 21 (26%) occurred in the years 2001-2002, and 15 (19%) occurred in the years 2003-2005. As previously mentioned, prior to the year 2001, conventional tillage was employed throughout the Beasley Lake Watershed. In 2001-2002, reduced-till cotton and soybeans occupied most of the watershed. From 2003-present, the north side of Beasley lake was in trees under CRP, with the balance of the watershed in predominantly reduced-till soybeans. Thus, numbers of lake water pesticide detections ≥0.1ppb were progressively and significantly reduced by moving from conventional tillage to reduced-tillage to reduced-tillage+CRP.

Supporting the above conclusions is the fact that analysis of surface water from Beasley Lake over about the same time period indicates that implementation of conservation tillage and CRP enrollment reduced sediment, resulting in improved water clarity, plankton growth, and fish stocks. High sediment concentrations in lake water limit light availability which in turn suppresses phytoplankton production. Water quality improvements included: a 41% decrease in total phosphorus, an increase of 97% in Secchi visibility, and a 70% decrease in suspended sediment. Chlorophyll a, an indicator of primary productivity increased 23%. This improvement in primary productivity resulted in an improved sports fishery and represents one of the few times that BMPs installed throughout an agri-cultural landscape have been directly linked to eco-logical benefits (Knight et al. 2006).

ENDING NOTE

The above discussion concerns some general obser-vations about changes in pesticide occurrence and con-centrations in Beasley Lake water over about 8 years that parallel changes in watershed management, particularly crops grown and tillage. To get a more complete understanding of watershed management effects on pesticide dynamics, pesticide lake water data need to be combined with data from current studies in the Beasley Lake Watershed concerned with pesticide reduction from edge-of-field structural and cultural (vegetative) management strategies. By combining watershed pesticide dynamics information with other Beasley Lake Watershed water quality information (e.g., nutrients, dissolved oxygen, turbidity, chlorophyll, suspended sediments, etc.), the goal of quantifying the beneficial effects of watershed conservation manage-ment practices on the ecological integrity of the water-shed should be attainable.

ACKNOWLEDGEMENTS

We wish to thank the following for much needed and appreciated technical assistance: Jennifer Swint, Michelle Johnson, Charlie Bryant, Toyal Flemmons, Lisa Williams, and Sam Testa. We also especially thank the farmers/landowners for their patient cooperation.

REFERENCES

Amweg, E.L., Weston, D.P., and Ureda, N.M. 2005. Use and toxicity of pyrethroid pesticides in the Central Valley, California, USA. Environmental Toxicology and Chemistry. 24(5): 966-972.

Bennett, E.R., Moore, M.T., Cooper, C.M., and Smith, S. Jr. 2000. Simultaneous method for the extraction and analysis of two current use pesticides, atrazine and lambda-cyhalothrin, in sediment and aquatic plants. Bulletin of Environmental Contamination and Toxicology, 64: 825-833.

Cooper, C.M., Smith, Jr., S., and Moore, M.T. 2003. Surface water, ground water and sediment quality in three oxbow lake watersheds in the Mississippi Delta agricultural region: pesticides. International Journal of Ecology and Environmental Sciences. 29: 171-184.

Delta Agricultural Digest 2004. Forrest Laws (Editor). Published by Farm Press, a PRIMEDIA Business, Clarksdale, Mississippi.

EXTOXNET. 2001. Pesticide Information Profiles. The Extension Toxicology Network. http://ace.ace.orst.edu/info/extoxnet/.

Knight, S.S., Cooper, C.M. and Cash, B. 2001. pages 128-138, In: Rebich, R.A. and Knight, S. (Editors) The Mississippi Delta Management Systems Evaluation Areas Project, 1995-1999. Mississippi State University Information Bulletin #377, Mississippi State, MS,

Knight, S.S., Lizotte, Jr., R.E., Smith, Jr., S., Cooper, C.M., and Locke, M.A. 2006. Effects of watershed conser-vation practices on Beasley Lake water quality. 2006 ARS CEAP Annual Meeting. Agricultural Research Service. Abstracts.

Locke, M.A. 2004. Mississippi Delta Management Systems Evaluation Area: Overview of water quality issues on a watershed scale. Chapter 1, pages 1-15. In: Water Quality Assessments in the Mississippi Delta, Regional Solutions, National Scope. Mary Nett, Martin Locke, and Dean Pennington (Editors), ACS Symposium Series 877, American Chemical Society, Chicago, IL. Oxford University Press.

Smith, Jr., S. 1993. Effects of tillage on pesticide concen-trations in shallow ground water and surface runoff from fragipan soils in north Mississippi, USA. 2nd USA/CIS Joint International Conference on Environmental Hydrology & Hydrogeology. Yoram Eckstein and Alexander Zaporozec (Editors). WEF, Alexandria, VA. Pages 79-91.

Smith, Jr., S. and Cooper, C. M. 2004. Pesticides in shallow groundwater and lake water in the Mississippi Delta MSEA. Chapter 7, pages 91-103. In: Water Quality Assessments in the Mississippi Delta, Regional Solutions, National Scope. Mary Nett, Martin Locke, and Dean Pennington (Editors), ACS Symposium Series 877, American Chemical Society, Chicago, IL. Oxford University Press, U.K.

Smith, Jr., S., Cullum, R.F., and Schreiber, J.D. 1994. Pesticides in runoff and shallow groundwater from upland corn production in north Mississippi, USA. Second International Conference on Groundwater Ecology. TSP94-1. Jack Stanford & Maurice Vallett (Eds.). AWRA, Herdon, VA. Pags. 247-258.

Smith, Jr., S., Schreiber, J. D., Cooper, C. M., Knight, S. S. and Rodrigue, P. Water Quality Research in the Beasley Lake forested wetland/riparian area of the Mississippi Delta MSEA. Pp. 193-201. In Richard A. Rebich and S. S. Knight, (Eds). The Mississippi Delta Management Systems Evaluation Area Project 1995 – 1999. MAFES Information Bulletin 377, Mississippi State University. 222 pages. October, 2001.

Smith, Jr., S., Schreiber, J.D., and Cullum, R.F. 1995. Upland soybean production: Surface and shallow groundwater quality as affected by tillage and herbicide use. Transactions of the American Society of Agricultural Engineers 38(4): 1061-1068.

The Agrochemicals Handbook, Third Edition. 1991. Kidd, H. and James, D.R. (Editors) Royal Society of Chemistry Information Services, Cambridge, UK, (as updated). Pages 2-13.

U.S. Environmental Protection Agency (USEPA). 1988a. Office of Pesticides and Toxic Substances. Fact Sheet No. 171: Karate (PP321). USEPA. Washington, DC.

U.S. Environmental Protection Agency. 1988b. Office of Pesticides and Toxic Substances. Fact Sheet No.177: Bifenthrin. USEPA. Washington, DC.

World Health Organization (WHO). 1999. International Programme on Chemical Safety. http://www.inchem.org/documents/ehc/ehc/ehc99.htm#SubSectionNumber:6.2.2

APPENDIX

Chemical names of pesticides mentioned in this paper

alachlor	(2-chloro-2',6'-diethyl-*N*-methoxymethylacetanilide)
atrazine	(2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine)
bifenthrin	[2-methylbiphenyl-3-ylmethyl (*Z*)-(1*RS*,3*RS*)-3-(2-chloro-3,3,3-trifluoroprop-1-enyl)-2,2-dimethylcyclopropanecarboxylate]
chlorfenapyr	[4-bromo-2-(4-chlorophenyl)-1-(ethoxymethyl)-5-(trifluoromethyl)-1H-pyrrole-3-carbonitrile]
chlorpyrifos	(*O*,*O*-diethyl *O*-3,5,6-trichloro-2-pyridyl phosphorothioate)
cyanazine	[2-(4-chloro-6-ethylamino-1,3,5-triazin-2-ylamino)-2-methylpropionitrile]
lambda-cyhalothrin	{[1α(S*),3α(Z)]-cyano(3-phenoxyphenyl)methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate]}
p,p'-DDD	[1,1-dichloro-2,2-bis (*p*-chlorophenyl) ethane]
p,p'-DDE	[1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethylene]
p,p'-DDT	[1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane]
dieldrin	(1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a,octahydro-1,4,5,8-dimethanonaphthalene)
fipronil	[(RS)-5-amino-1-(2,6-dichloro-α,α,α-trifluoro-*p*-tolyl)-4-trifluoromethylsulfinylpyrazole-3-carbonitrile]
fipronil sulfone	[(RS)-5-amino-1-(2,6-dichloro-α,α,α-trifluoro-*p*-tolyl)-4-trifluoromethylsulfonylpyrazole-3-carbonitrile]
methylparathion	(*O*,*O*-dimethyl-*O*-*p*-nitrophenyl phosphorothioate)
metolachlor	[2-chloro-6'-ethyl-*N*-(2-methoxy-1-methylethyl)acet-*o*-toluidide]
pendimethalin	[N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine]
trifluralin	(α,α,α-trifluro-2,6-dinitro-*N*,*N*-dipropyl-*p*-toluidine)