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Storm Pesticide Concentrations in Little Topashaw Creek, USA

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ABSTRACT

A suite of 17 current and past-use pesticides (and/or metabolites) was measured in the Little Topashaw Creek channel, Mississippi, USA, during high flow storm events throughout the period, 2000-2004, in order to determine seasonal patterns of pesticide occurrence and concentrations. During the sampling period, 1176 storm water samples were collected from 58 high flow storm events. There were 2038 pesticide detections greater than or equal to 0.1 ug L^{-1}, equivalent to 10.2% of the possible 19,992 detections. On a quarter year basis, detections per storm event were highest for the second quarter of 2001 (with 111), followed by the fourth quarter of 2001 (with 81). Of the 58 storm events, 22 (38%) occurred in the second quarter, followed by 14 (24%), 13 (22%), and 9 (16%) in the first, third, and fourth quarters, respectively. Overall, most detections were for *p,p'*-DDT (542) and metabolites (129), totaling 671, followed by methylparathion (366), atrazine (277), and metolachlor (198). Primary agricultural land use in the near drainage contributing area upstream of the experimental LTC site includes cotton (*Gossypium* sp.), sweet potato (*Ipomoea batatas*), corn (*Zea* sp.), sorghum (*Sorghum* pp.), wheat (*Triticum* sp.), and soybeans (*Glycine* sp.). Of the herbicides detected, atrazine and metolachlor had the highest mean concentrations in high flow storm runoff in the second quarter of 2001 with values of 2.50±7.53 and 1.28±3.13 μg L^{-1}, respectively. Among the current-use insecticides in high flow storm water in the second quarter of 2001, bifenthrin and 8-cyhalothrin had the highest mean concentrations with values of 0.70±2.88 and 0.40±0.52 μg L^{-1}, respectively. However, the most frequently detected current-use insecticides were methylparathion and chlorfenapyr, with 53 and 49 detections, respectively, followed closely by bifenthrin with 41 detections. The annual seasonal "spring flush" in many US stream and river systems likely accounts for these phenomena.

Key Words: Insecticide, Herbicide, Runoff, Water, Agricultural land use, Drainage, Stream

INTRODUCTION

The Little Topashaw Creek (LTC) project emphasizes the use of large woody debris and biotechnical techniques for stream corridor restoration/rehabilitation (Shields 2004). Research on water quality, fish, macroinvertebrates, vascular plants, geomorphology, and hydrology is being conducted as part of the LTC project and is part of a much larger project known as the Demonstration Erosion Control (DEC) project. DEC is a cooperative effort among the U.S. Army Corps of Engineers, the USDA-NRCS, and the USDA-ARS National Sedimentation Laboratory, as well as cooperating landowners and scientists from other institutions. LTC research is designed to build upon two major findings of the DEC project. Firstly, low-cost, environmentally-friendly methods to stabilize incised stream channels are badly needed because DEC methods featuring combinations of grade-control drop structures, stone channel stabilization structures, drop pipes, small reservoirs (floodwater retarding structures), and land treatment are effective but costly [as much as \$1235 USD (U.S. dollars) ha^{-1} for treating an entire watershed and \$164 USD m^{-1} for channel stabilization]. Secondly, stabilization of incising channels and their stream corridors can have major, positive ecological effects, particularly when stabilization works are designed to address habitat-limiting factors. Three specific LTC project objectives are 1) to test and demonstrate an approach for channel stabilization that will cost less than \$82 USD m^{-1} of bank treated when implemented on a wider scale, 2) to test and demonstrate a low-cost approach for stabilizing gullies caused by overbank drainage into an incised channel, and 3) to quantify ecological effects of the proposed low-cost measures, particularly water quality as affected by agricultural nonpoint source pollution.

Water quality parameters being measured in the LTC project include NH_4^+-N, PO_4^{3-}-P, NO_3^--N, NO_2^--N, Total P (TP), Total Kjeldahl N (TKN), Total N (TN), chlorophyll *a*, temperature, conductivity, pH, dissolved oxygen, total solids, dissolved solids, suspended solids, fecal coliforms, and enterococci. (Lizotte et al. 2001, Lizotte 2004). In addition, a suite of 17 current and past use pesticides (and/or metabolites) are being measured in the creek channel during high flow storm events (Lizotte et al. 2002). Pesticide use is an integral part of agriculture in the United States and streams are often the first aquatic systems to receive pesticide-laden effluent from agricultural fields during storm events (Cooper 2004). Determining pesticide runoff from nonpoint sources during high flow is an important part of understanding the extent of potential contamination in streams and allows for 1) the overall assessment of water quality impairment due to current agricultural practices, 2) the assessment of impacts on and degradation of aquatic habitats, 3) addressing the limited availability of seasonal pesticide contamination data during high flows in streams, and 4) the establishment of appropriate TMDLs (Total Maximum Daily Loads) for streams.

The purpose of the present study was to examine and report seasonal patterns of pesticide occurrence and concentrations in LTC during high flow storm events during 2000-2004.

MATERIALS AND METHODS

Sample Collection

The pesticide storm sampling site was located in LTC within the Yalobusha River watershed, approximately 100-200m upstream (south) from the Dry Creek and LTC confluence in southwestern Chickasaw County, Mississippi, USA (**Figure 1**). A more complete description (with map) of the Yalobusha River system can be found elsewhere (Simon and Thomas 2002). Shields et al. (submitted 2005) provides a detailed description of the LTC channel conditions and cropped areas immediately adjacent to the sampling site.

During high flow storm events (fall 2000-summer 2004) water samples were collected hourly up to 24 h using ISCO 2700 or 3700 automated samplers. Sampling was initiated during storm events when ensuing rising water levels within the creek channel triggered ISCO liquid level actuators (water level sensors). Liquid level actuators were adjusted seasonally based upon changes in base flow, e.g., winter and spring (rainy season) had increased base flow and summer and fall (dry season) had decreased base flow. Liquid level actuators were set 2-4 cm above the water line during seasonal base flow. Collected water samples were preserved via chilling and transported immediately to the USDA-ARS National Sedimentation Laboratory, Oxford, Mississippi for pesticide analysis.

Analytical

Chilled storm water samples (aqueous plus suspended sediment) were prepared for pesticide analysis (consistently within 1h after being received) by a method similar to that reported by Bennett et al. (2000) and modified by Smith and Cooper (2004). This involved extraction with pesticide-grade ethyl acetate, silica gel column chromatography cleanup, and concentration to 1 mL volume under high purity dry nitrogen. Pesticide recoveries based on fortified samples were >89% for all pesticides in storm water.

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 contributing watershed areas resulted in 17 pesticides (and/or metabolites) being targeted for analysis (**Table 1**). LOD is limit of detection and LOQ is limit of quantitation for LTC storm water. The main analytical column was a HP 5MS capillary column (30 m x 0.25 mm i.d. x 0.25 μm film thickness). 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 and inlet temperature at 250/C. The μECD temperature 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

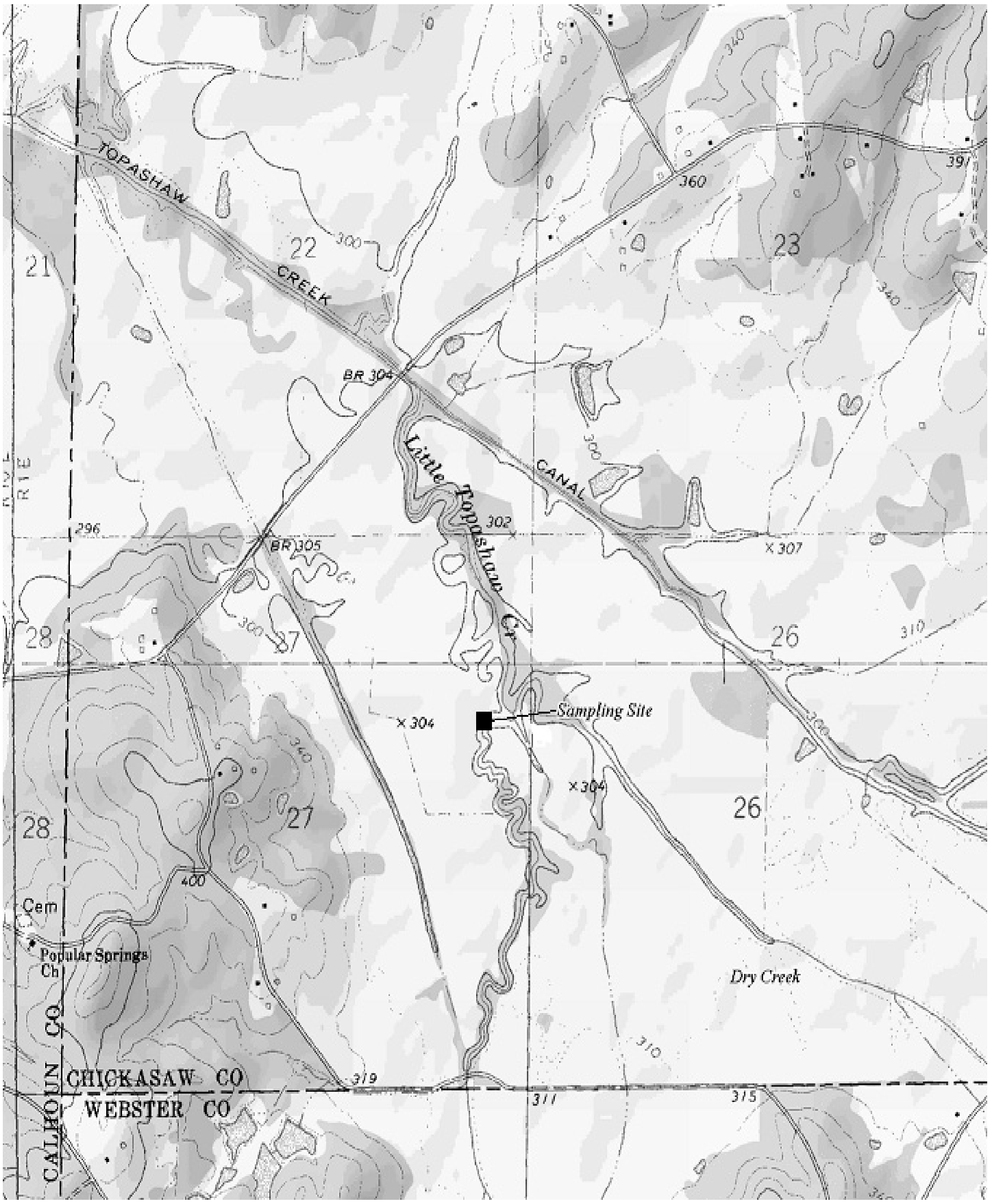

Figure 1. Storm runoff sampling site in Little Topashaw Creek (Chickasaw Co., Mississippi, USA).

volume in the fast mode. Under these GC conditions, all 17 pesticides on the list in **Table 1** 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-: m 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. **Figure 2** illustrates a typical chromatogram for an analytical pesticide standard and a randomly-selected LTC storm sample.

Table 1. Presently targeted pesticides.

Pesticide	Retention time (min)	LOD (ng L!1)	LOQ (ng L!1)
Trifluralin	10.63	1	10
Atrazine	12.31	10	100
Methyl parathion	16.78	10	100
Alachlor	17.35	5	50
Metolachlor	20.68	10	100
Cyanazine	20.96	1	10
Chlorpyrofos	21.17	5	50
pendimethalin	25.06	5	50
Fipronil	26.78	1	10
p,p'-DDE	32.17	1	10
Dieldrin	32.29	1	10
Fipronil sulphone	33.28	1	10
chlorfenapyr	34.13	5	50
p,p/-DDD	34.95	10	100
p,p'-DDT	37.70	10	100
Bifenthrin	43.36	1	10
8-Cyhalothrin	51.01	1	10

RESULTS AND DISCUSSION

During the sampling period (fall 2000-summer 2004), 1176 storm water samples were collected from 58 high flow storm events (**Table 2**). Each sample was analyzed for 17 pesticides (and/or pesticide metabolites) resulting in 19,992 possibilities of detection. Over the sampling period, there were 2038 pesticide detections greater than or equal to 0.1 μg L^{-1}, equivalent to 10.2% 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 8-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*) (EXTONET 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 amphi-pod *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 insecticides as a group are generally considered to be "highly toxic to fish and aquatic invertebrates" (WHO 1999).

The year 2001 had the most detections (966 from 16 storm events) followed by 2004 (551 from 14 storm events), equivalent to about 60 and 39 detections per storm event, respectively. Detections per storm event for the other three years, 2000, 2002, and 2003, were 44, 24, and 11, respectively. On a quarter year basis, detections per storm event (**Table 2**) were highest for the second quarter of 2001 (with 111), followed by the fourth quarter of 2001 (with 81). The overall quarter year mean was 35 detections per storm event. **Table 2** also shows total rainfall per quarter year throughout the study period. Mean rainfall for quarters 1, 2, 3, and 4 were 43.2, 40.9, 33.3, and 41.4 cm. Of the 58 storm events, 22 (38%) occurred in the second quarter, followed by 14 (24%), 13 (22%), and 9 (16%) in the first, third, and fourth quarters, respectively. In reviewing the daily rainfall records for the duration of the study, it was observed that the second quarter of each year tended to have more intense storms resulting in higher stream discharges.

Table 2. LTC quarter year storm collections and pesticide detections

Year	Storms	Samples collected	Pesticides detections	Detections per storm	Rainfall cm
2000	3	72	1224	132	39.6
2001	16	304	5168	966	167.4
2002	9	178	3026	216	124.5
2003	16	306	5202	173	163.3
2004	14	316	5372	551	95.5
Total	58	1176	19992	2038	590.6

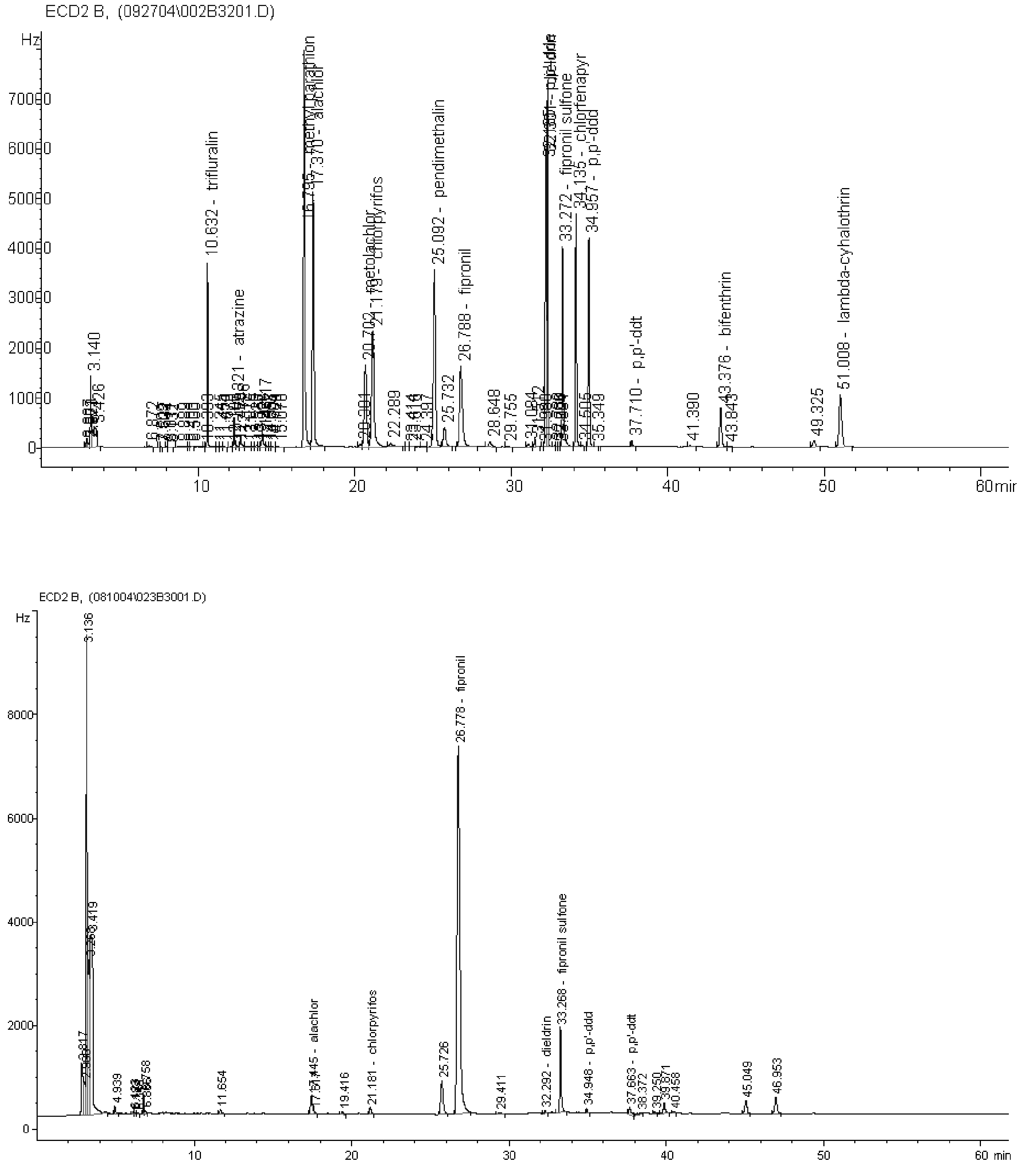

Figure 2. Typical gas chromatogram for pesticide standard and LTC storm water.

Table 3. LTC individual pesticide detections by quarter year for each year

Pesticide	2000	2001				2002			2003				2004			Total
quarter	4	1	2	3	4	2	3	4	1	2	3	4	1	2	3	
Trifluralin	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	4
Atrazine	4	0	57	28	51	10	31	0	12	23	19	0	7	33	2	277
Methyl parathion	49	23	53	26	21	6	20	0	6	2	0	0	1	157	2	366
Alachlor	1	0	21	8	28	0	0	0	1	2	3	0	0	5	1	70
Metolachlor	34	11	74	15	8	3	3	0	0	1	0	0	0	49	0	198
Cyanazine	0	0	11	1	2	4	0	0	0	2	4	0	22	23	1	70
Chlorpyrofos	10	0	44	4	3	1	0	0	2	0	0	0	0	0	1	65
pendimethalin	1	0	1	0	0	0	0	0	0	12	0	0	0	1	0	15
Fipronil	0	0	4	0	1	0	2	0	2	0	0	0	0	1	0	10
p,p'-DDE	0	0	6	0	14	0	0	0	0	0	0	0	0	0	0	20
Dieldrin	0	0	11	0	4	1	0	0	1	1	0	0	0	3	0	21
Fipronil sulphone	0	0	30	3	3	0	1	0	0	1	7	0	0	2	0	47
chlorfenapyr	0	0	49	5	2	1	1	0	2	3	0	0	0	1	0	64
p,p'-DDD	5	2	55	5	30	6	3	0	1	0	0	0	0	1	0	108
p,p'-DDT	11	19	94	8	40	20	88	3	15	12	6	0	40	167	19	542
Bifenthrin	13	1	41	3	3	1	4	4	4	0	2	6	1	5	1	89
8-Cyhalothrin	4	0	6	5	31	0	1	1	2	17	2	0	0	2	1	72

Of the 17 targeted pesticides, trifluralin, atrazine, alachlor, metolachlor, cyanazine, and pendimethalin are current-use herbicides and represent three chemical classes of herbicides. Trifluralin and pendimethalin are dinitroanilines. Atrazine and cyanazine are chloro-triazines. Alachlor and metolachlor are chloro-acetanilides. Methylparathion, chlorpyrifos, fipronil, chlorfenapyr, bifenthrin, and 8-cyhalothrin are all current-use insecticides. Methylparathion and chlorpyrifos are organophosphates. Bifenthrin and 8-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 insecticides whose registered uses were discontinued in the early to middle 1970s, but whose persistence in soil is such that their residues are still detectable.

Individual pesticide detections by year are shown in **Table 3**. Most detections were for *p,p'*-DDT (542) and metabolites (129), totaling 671, followed by methylparathion with 366, atrazine with 277, and metolachlor with 198. Primary agricultural land use in the near drainage contributing area upstream of the experimental LTC sites is for cotton (*Gossypium* spp.) and sweet potato (*Ipomoea batatas*) production, usually in annual rotation. Other crop production in the upstream drainage contributing area includes corn (*Zea* sp.), sorghum (*Sorghum* sp.), wheat (*Triticum* sp.), and soybeans (*Glycine* sp.) (USDA-NASS 1997). As previously mentioned, the 17 targeted pesticides were chosen for analysis based on agricultural row crop production in the drainage contributing area. These compounds are either present-use, past-use, or metabolites of present-use or past-use pesticides (Delta Agricultural Digest 2004). For example, cotton production herbicides include trifluralin, pendimethalin, and metolachlor; and insecticides include methylparathion, chlorpyrifos, 8-cyhalothrin, bifenthrin and chlorfenapyr (Section 18 emergency exemption only, 2001). Sweet potato insecticides include chlorpyrifos and bifenthrin. Herbicides for corn include atrazine, alachlor, metolachlor, and pendimethalin. Insecticides for corn include bifenthrin, chlorpyrifos, and fipronil. Among the herbicides used for soybeans are metolachlor, alachlor, and pendimethalin. Insect management in soybeans includes 8-cyhalothrin, chlorpyrifos, and methylparathion. Registered uses of cyanazine were discontinued after 2002.

Of the 542 *p,p'*-DDT detections, the year 2004 had the most (226) followed by the year 2001 (161). This number of detections is not unusual because residues of this compound and its metabolites in agricultural crop production areas in Mississippi and other parts of the US are still frequently reported if analytical capabilities of researchers are at sub-ppb (μg L^{-1}) levels (Cooper et al. 2002, 2003; Smith and Cooper 2004). Methylparathion detections were 160 in 2004 and 123 in 2001. For atrazine and metola-chlor, the most detections occurred in 2001 (136 and 108), respectively.

On a quarter year basis (**Table 3**), most pesticide detections occurred in the second quarter of 2001 (557, equivalent to 58% of the 2001 detections or 27% of all detections) followed by the second quarter of 2004 (451, equivalent to 82% of the 2004 detections or 22% of all detections). Of the 557 detections in the second quarter of 2001, 197 were herbicides (trifluralin, atrazine, alachlor, metolachlor, cyanazine, and pendimethalin) and 164 were current-use insecti-cides (methylparathion, chlorpyrifos, fipronil, chlor-fenapyr, bifenthrin, and 8-cyhalothrin) with mean concentrations of 0.89±1.02 and 0.31±0.21 μg L^{-1}, respectively. Of the herbicides, atrazine and metolachlor had the highest mean concentrations in high flow storm runoff in the second quarter of 2001 with values of 2.50±7.53 and 1.28±3.13 μg L^{-1}, respectively. The 197 herbicide detections were not unexpected as these herbicides are generally applied broadcast, preplant and/or preemergence in the spring of the year. They would thus be detected in central U.S. river systems in what is called the annual seasonal "spring flush" (Clark et al. 1999). The single detection of each of the two dinitroaniline herbicides, trifluralin and pendimethalin, is likely due to the two compounds being soil incorporated immediately after surface broadcast application because of their high volatility and susceptibility to photodegradation.

Among the current-use insecticides in high flow storm water in the second quarter of 2001, bifenthrin and 8-cyhalothrin had the highest mean concentrations with values of 0.70±2.88 and 0.40±0.52 μg L^{-1}, respectively. However, the most detected current-use insecticides were methylparathion and chlorfenapyr (53 and 49 detections, respectively), followed closely by bifenthrin (41 detections). Methylparathion detections were unexpected, as this insecticide is typically used for stink bug (Pentatomidae) control in cotton and soybeans later in the growing season. Chlorfenapyr [no longer registered for use on cotton because of field persistence and toxicity to birds (USGS 2002)] had been applied for beet armyworm (*Spodoptera exigua*) control in early cotton. Bifenthrin is often applied for cutworm (*Agrotis*, *Amathes*, *Peridroma*, *Prodenia* spp.) control in cotton early in the growing season.

Of the 451 detections in the second quarter of 2004, 89 were the 6 herbicides and 189 were the 6 current-use insecticides with mean concentrations of 2.61±3.73 and 0.20±0.06 μg L^{-1}, respectively. Of the herbicides, atrazine and metolachlor had the most detections (33 and 49, respectively), and the highest mean concentrations in high flow storm water in the second quarter of 2004 with values of 3.23±4.23 and 1.30±2.45 μg L^{-1}, respectively. There was, however, a single anomalous detection of pendimethalin at a concentration of 9.86 μg L^{-1} in early April of 2004. For the same reason as in the second quarter of 2001, the 86 herbicide detections were not unexpected as these herbicides are generally applied broadcast, preplant and/or preemergence in the spring of the year. There was also a single detection of trifluralin at a concen-tration of 0.34 μg L^{-1} in early May of 2004. As previously stated, the two dinitroaniline herbicides, trifluralin and pendimethalin, are soil incorporated immediately after surface broadcast application because of their high volatility and susceptibility to photo-degradation, and thus are less likely to be transported in surface runoff.

Among the current-use insecticides in high flow storm runoff in the second quarter of 2004, methyl-parathion and chlorpyrifos had the most detections (157 and 23, respectively). They also had the highest mean concentrations with values of 0.20±0.42 and 0.30±0.27 μg L^{-1}, respectively. Again the methyl-parathion detections are totally unexpected. There were no detections in the previous two quarters, i.e. the first quarter of 2004 and the fourth quarter of 2003. On a monthly basis in the second quarter of 2004, there were 47 methylparathion detections in April (from 3 storm events), 45 in May (from 3 storm events), and 65 in June (from 3 storm events). The chlorpyrifos detections in the second quarter of 2004 can likely be attributed to chlorpyrifos applications (as Lorsban™) for control of cutworms in cotton and corn, lesser cornstalk borers (*Elasmopalpus lignosellus*) in soybeans and corn, and several soil insects in corn including seed corn maggots (*Delia platura*), southern corn rootworms (*Diabrotica undecimpunctata howardi*), and wireworms (*Melanotus communis*).

There are several other anomalies worth mentioning in **Table 3**. These include the atrazine detections in the third quarter of 2001, 2002, and 2003, as well as the fourth quarter of 2001. These indicate atrazine persistence, i.e. half-life in soil of 60 to >100 d (EXTOXNET 2001). Although applied in late March or April, field runoff continued to transport atrazine. No detections in most fourth quarters simply reflected a lack of runoff. Also, there are the cyanazine detections in the first quarter of 2003 and the third quarter of 2004. As previously stated, registered uses of cyanazine were discontinued after 2002. The soil half-life of cyanazine is 2-10 wk, depending on soil texture (EXTOXNET 2001). And finally, there are the 12 pendimethalin detections in the second quarter of 2003. Perhaps this is the result of poor soil incorporation of this herbicide at the time of application.

Of the 2038 pesticide detections during the collection period of this study, 1138 occurred in the second quarter of the study years (**Table 3**). The fourth, third, and first quarters followed with 388, 336, and 176, respectively. The six current-use herbicides account for 339 (30%) and the six current-use insecticides account for 389 (34%) of all the second quarter detections. For all the current-use pesticides over all study years, methylparathion had the most detections with 366 (18%), followed by atrazine with 277 (14%), and metolachlor with 198 (10%). In their 1991-1997 study of herbicides in rivers in the Mississippi River Basin, Clark et al. (1999) reported that atrazine and metolachlor were the most frequently detected herbicides in the Mississippi River at Baton Rouge, LA, USA along with a metabolite of alachlor. For all the current-use pesticides over all study years, the six herbicides accounted for 629 (31%) of the 2038 detections, and the six insecticides (including the fipronil metabolite, fipronil sulfone) accounted for 718 (35%) of all of the detections. The past-use residual insecticides, dieldrin and *p,p'*-DDT (and its two metabolites), accounted for 691 (34%) of all detections.

These results are comparable to those of Cooper et al. (2002), who examined water quality (pesticides and metals) in the Yalobusha and Skuna Rivers, which contribute inflow to the Grenada Lake Reservoir (Mississippi, USA). They also examined water and sediment quality in the Grenada Reservoir. LTC is a tributary of the Yalobusha River. These researchers found that "In spite of long-term historical use of residual pesticides in the watershed and widespread use of currently applied agricultural compounds, concentrations in stream or reservoir sediments and overlying water were generally low and sporadic or not detectable". They did, however, detect all 17 of the pesticides reported in LTC in the present paper. Most pesticide detections in the river (stream) water were seasonal and in low concentrations (0.01-2.05 μg L^{-1}). Atrazine was very commonly found in stream and reservoir water and sediment. The higher mean concentration in stream water compared with reservoir water was attributed to higher atrazine concentrations in detections from high flow storm water.

In concluding this discussion of pesticides in high flow storm water in the LTC, it is important to mention some important factors that affect pesticide transport in runoff to streams such as the LTC. 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 transported 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 incorporation 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".

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Mention of a pesticide in this paper does not constitute a recommendation for use by the U. S. Department of Agriculture nor does it imply registration under FIFRA as amended. Names of commercial products are included for the benefit of the reader and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture. All programs and services of the U. S. Department of Agriculture are offered on a nondiscriminatory basis without regard to race, color, national origin, religion, sex, marital status, or handicap

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APPENDIX: Chemical names of pesticides mentioned in this paper

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