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PRESENCE AND DISTRIBUTION OF CHLORINATED ORGANIC COMPOUNDS IN STREAMBED SEDIMENTS, NEW JERSEY[1]

Paul E. Stackelberg[2]

Newark Bay Study Area
NBSA-00090

ABSTRACT: Concentrations of 18 hydrophobic chlorinated organic compounds in streambed sediments from 100 sites throughout New Jersey were examined to determine (1) which compounds were detected most frequently, (2) whether detection frequencies differed among selected drainage basins, and (3) whether concentrations differed significantly among selected drainage basins. Twelve drainage basins across New Jersey that contain a range of land-use patterns and population densities were selected to represent various types and degrees of development. To ensure an adequate number of samples for statistical comparison among drainage basins, the 12 selected basins were consolidated into seven drainage areas on the basis of similarities in land-use patterns and population densities. Additionally, data for three classes of chlorinated organic compounds in streambed sediments from 255 sites throughout New Jersey were examined to determine whether the presence of these compounds in streambed sediments is related to the type and degree of development within the drainage area of each sampling site.

Chlorinated organic compounds detected most frequently within the seven representative drainage areas were DDT, DDE, DDD, chlordane, dieldrin, and PCBs. DDT, DDE, and DDD, which were the most widely distributed organic compounds, were detected in about 60 to 100 percent of the samples from all drainage areas but one (where the detection rate for these compounds was about 20 to 40 percent). Chlordane and dieldrin were detected in about 80 to 100 percent of samples from highly urbanized and populated drainage areas; detection frequencies for these compounds tended to be smaller in less developed and populated areas. PCBs were detected in about 40 to 85 percent of samples from all drainage areas; detection frequencies were highest in the most heavily developed and populated areas.

Analysis of variance on rank-transformed organic compound concentrations normalized to sediment organic carbon content was used to evaluate differences in concentrations among the seven representative drainage areas. Chlordane and PCBs were the chlorinated organic compounds with the most highly elevated concentrations in streambed sediments across the State. Median normalized concentrations of all six of the most frequently detected chlorinated organic compounds were highest in the most heavily urbanized and populated drainage area and lowest in the less populated, predominantly agricultural or forested areas. Concentrations of DDT and DDE, however, did not differ significantly among most of the drainage areas. Concentrations of DDD, chlordane, dieldrin, and PCBs differed significantly among drainage areas. The highest median normalized concentrations were found in samples from the most heavily urbanized and populated areas, and the lowest were in samples from the least developed, most heavily forested area.

Logistic regression was used to examine relations between the presence of hydrophobic chlorinated organic compounds in streambed sediments at specified concentrations and variables that characterize the type and degree of development within the drainage areas of 255 sites across New Jersey. The explanatory variables found most useful for predicting the presence of chlorinated organic compounds in streambed sediments include total population and amounts (in square kilometers) of various land-use categories. Logistic regression equations were developed to identify significant relations between population and amounts of specific land-use categories within drainage areas and the probability of detecting chlorinated organic contaminants in streambed sediments. These relations can be used to assist in the identification of geographic regions of primary concern for contamination of bed sediments by chlorinated organic compounds across the State.
(KEY TERMS: modeling/statistics; nonpoint source pollution; urban hydrology; streambed sediments.)

INTRODUCTION

The U. S. Geological Survey (USGS), in cooperation with the New Jersey Department of Environmental Protection (NJDEP), has established a water quality monitoring network that provides data used to describe surface-water quality (Robinson *et al.*, 1988), estimate nutrient loads (Smith *et al.*, 1993), and evaluate trends in water quality (Hay and Campbell, 1990). In the late 1970s, the scope of sampling was expanded to include annual collection of streambed sediments at one-third of the surface water quality sites. Streambed sediment samples were analyzed for organic compounds and trace elements. The NJDEP has recently expanded its sampling efforts to include the monitoring of benthic invertebrate communities in streams across the State, and two studies similar

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[2]Hydrologist, U.S. Geological Survey, 810 Bear Tavern Road, Suite 206, West Trenton, New Jersey 08628

to this investigation are currently being conducted to evaluate (1) the presence and distribution of trace elements in bed sediments and (2) benthic invertebrate communities in streams across the State.

In 1991, the USGS began full implementation of the National Water Quality Assessment (NAWQA) program to address similar issues on a national scale. The program is designed to: (1) provide a consistent description of current water-quality conditions for a large part of the Nation's water resources; (2) define long term trends (or lack of trends) in water quality; and (3) identify, describe, and explain, to the extent possible, the major natural and human factors that affect observed water-quality conditions and trends (Leahy *et al.*, 1990). The program (as currently planned) will be conducted in 60 study units across the Nation, which account for 60 to 70 percent of the Nation's water use as measured by total withdrawals and population served by public water supply (Leahy *et al.*, 1990). In each study unit, long term, multiscale, interdisciplinary investigations designed to integrate surface water, ground water, and biological conditions and to assess overall effects on these resources will be undertaken.

One objective of the surface water component of the NAWQA program is to evaluate the presence and distribution of organic and inorganic compounds in water, suspended and bed sediments, and biota (vegetation, aquatic insects, benthic invertebrates, and fish). This evaluation will be accomplished through (1) review and analyses of available data and (2) fixed site monitoring and intensive synoptic surveys of organic and inorganic compounds identified as being important within each study unit. This investigation addressed one part of this objective for the Long Island-New Jersey (LINJ) NAWQA study by evaluating an extensive data base on chlorinated organic compounds in streambed sediments. Results of this analysis will aid in the design of future surveys of chlorinated organic contaminants in streambed sediments and fish tissues by identifying localities and organic contaminants within the study unit that are of greatest concern.

The chemical composition of streambed sediments is important because bed sediments (1) supply nutrients to plants; (2) can be toxic to biota, particularly benthic invertebrates; (3) can be a sink for various compounds; and (4) can transmit contaminants through the food chain (Rinella *et al.*, 1993; Colman and Sanzolone, 1991). The chlorinated organic compounds discussed in this paper are hydrophobic; they tend to sorb to organic carbon in suspended and bed sediments rather than to be dissolved in the water column. Because of this behavior, these compounds can be present in sediments in concentrations that are orders of magnitude higher than those in the water column. Therefore, sediments can provide a mechanism by which environmentally persistent hydrophobic chlorinated organic compounds remain in a surface water system many years after their initial input (Smith *et al.*, 1988). Thus, bed sediments can provide a time integrated sample of overall water quality conditions at a site and a means of evaluating the presence and distribution of hydrophobic chlorinated organic compounds over a wide geographical area.

Concentrations of 18 chlorinated organic compounds in streambed sediments collected from the late 1970s to 1993 throughout New Jersey were examined to determine (1) which compounds are most frequently detected, (2) whether detection frequencies differed among drainage basins, and (3) whether concentrations differed significantly among drainage basins. Twelve drainage basins that contain a range of land-use patterns and population densities were selected to represent various types and degrees of development across the state (Figure 1A). To ensure an adequate number of samples for statistical comparison, the 12 selected basins were consolidated into seven drainage areas on the basis of similarities in land-use patterns and population densities. The seven drainage areas, in order of decreasing urbanization, are the (1) Rahway River (RAWA); (2) Big Timber Creek and Cooper River (BTCR); (3) Passaic River (PSSC); (4) Raritan River (RRTN); (5) Great Egg Harbor and Mullica Rivers (GEMU); (6) Salem River and Raccoon Creek (SRRC); and (7) Pequest River, Paulins Kill, and Pohatcong Creek (PPP). Additionally, data for three classes of chlorinated organic compounds in bed sediments were examined to determine whether the presence of these compounds in streambed sediments is related to the type and degree of development within the drainage areas of 255 sampling sites across New Jersey (Figure 1B).

Purpose and Scope

This paper describes the results of the study, the major objective of which was to evaluate the presence and distribution of chlorinated organic compounds in streambed sediments throughout New Jersey. Data from bed sediment samples collected from the late 1970s to 1993 are examined to determine (1) which compounds were detected most frequently, (2) whether detection frequencies differed among selected drainage basins, and (3) whether concentrations differed significantly among selected drainage basins. Additionally, data for three classes of chlorinated organic compounds in bed sediments are examined to determine whether the presence of these compounds in streambed sediments is related to the

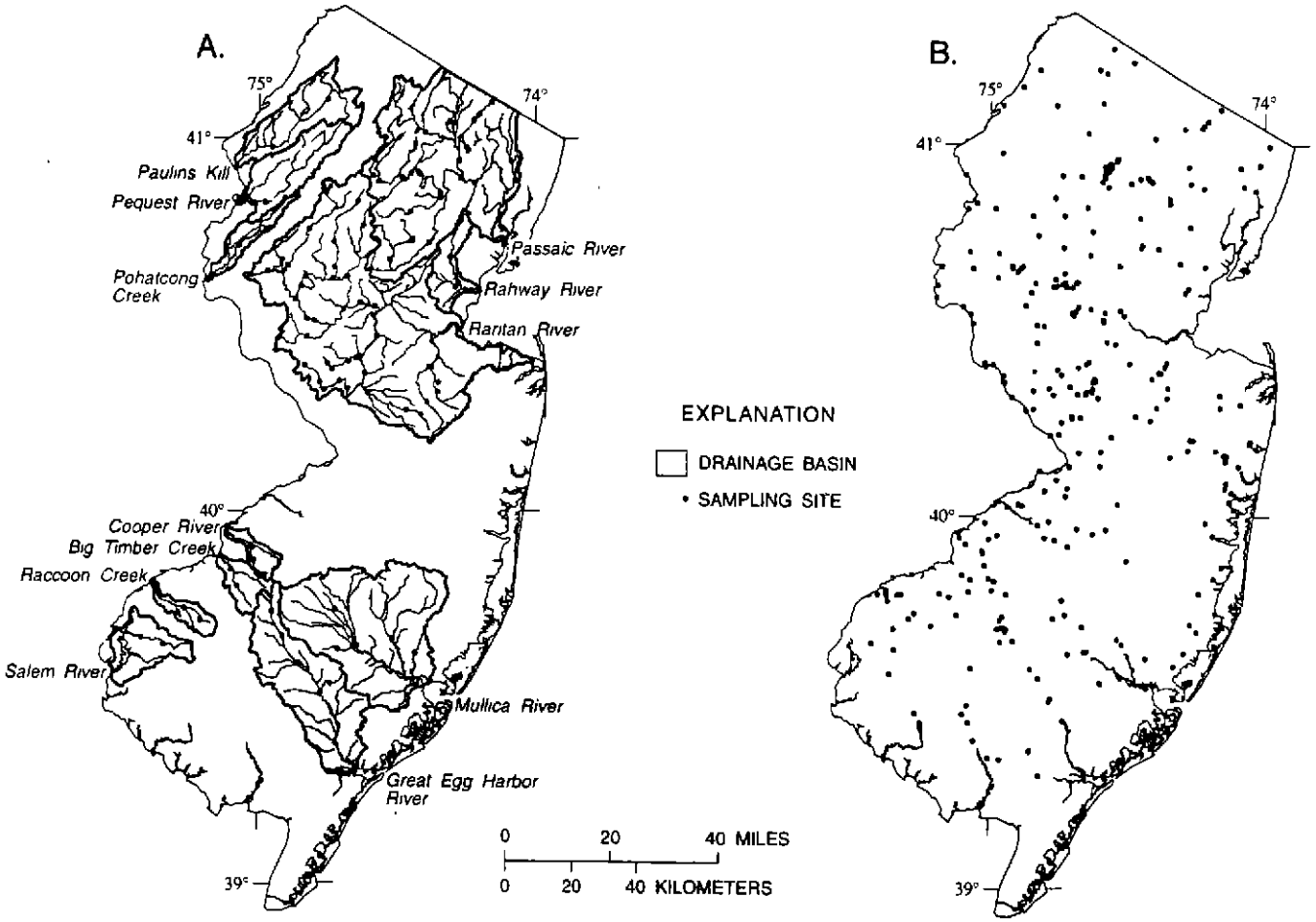


Figure 1. Location of (A) Streambed Sediment Sampling Sites in Selected Drainage Basins and (B) Streambed Sediment Sites Throughout New Jersey.

type and degree of development within the drainage areas of 255 sampling sites.

Literature Review

Many investigators have examined the presence of organic compounds in the sediments of estuaries and tidal reaches of streams in New Jersey and adjacent states (Bopp *et al.*, 1981; Bopp *et al.*, 1991; Johnson *et al.*, 1992; Johnson *et al.*, 1993; O'Conner and Huggett, 1988; O'Keefe *et al.*, 1984; Stainken and Rollwagen, 1979; Tong *et al.*, 1990; Wenning *et al.*, 1992; Wenning *et al.*, 1993; and Zdanowicz and Gadbois, 1990); however, relatively few investigators have examined the presence and distribution of organic compounds in bed sediments of freshwater streams in New Jersey. Notable exceptions include Smith *et al.*, (1987), who examined the presence and distribution of organic compounds in bed sediments of the upper Rockaway River in northern New Jersey. These authors found that reaches of the stream that drained industrial, commercial, and residential areas contained significantly higher concentrations of several organic compounds than reaches that drained forested areas. Hochreiter (1982) and Hochreiter and Kozinski (1985) examined the presence of organic compounds in bed sediments of the Delaware River estuary and adjacent tidal and non-tidal reaches of New Jersey tributaries. Sediment from almost every sampling site in these studies contained measurable concentrations of DDT, DDE, DDD, chlordane, and PCBs. Although a regionally extensive data base for chlorinated organic compounds in bed sediments of New Jersey streams exists as a result of a cooperative program between the USGS and the NJDEP, these data have not yet been examined for the purpose of describing the presence and distribution of these compounds in streambed sediments across the state.

DESCRIPTION OF SELECTED DRAINAGE BASINS

Twelve drainage basins throughout New Jersey were selected to represent various types and degrees of development (Figure 1A). The basins contain a range of land uses and population densities (Table 1). To ensure the availability of an appropriate number of bed-sediment samples for statistical analyses, several drainage basins in close proximity to each other and with similar land use patterns and population densities were combined, resulting in seven drainage areas representative of the various types and degrees of development throughout New Jersey.

Land use and population information for the seven drainage areas is summarized in Table 1. The seven drainage areas represent a range of land uses; the Rahway River drainage area is predominantly urban, the Salem River and Raccoon Creek drainage area is predominantly agricultural, and the Great Egg Harbor and Mullica Rivers drainage area is predominantly forested (Table 1). The Raritan River drainage area is the largest (1,157 mi^2) and represents the most diverse assemblage of land use categories; urban, agricultural, and forested land comprise 26, 40, and 30 percent of the drainage area, respectively.

Population density in the seven drainage areas was derived from U.S. Bureau of the Census data compiled for 1990 (U.S. Bureau of the Census, 1991). Population density values reflect the amounts of land classified as residential within the drainage areas (Table 1). The highest population density is within the Rahway River drainage area (7.21 people per acre), and the lowest is within the Great Egg Harbor and Mullica Rivers drainage area (0.38 people per acre) (Table 1).

METHODS OF DATA COLLECTION AND ANALYSIS

Bed sediment data examined for this paper are results of analyses of sediment samples collected from stations located throughout New Jersey by the USGS and NJDEP from the late 1970s to 1993. Samples were collected by following guidelines described in Ward and Harr (1990) and included cross-sectional samples collected by either ponar dredge or a hand held scoop to 3 cm or less below the bottom surface. Samples were composited, wet sieved to 2 mm in either a stainless steel or a brass sieve, placed in oven fired glass jars, and chilled on ice prior to being sent to a laboratory (Jacob Gibs, U.S. Geological Survey, oral communication, 1995). Bed sediment analyses were conducted by the National Water Quality Laboratory of the USGS in Arvada, Colorado, using dual column gas chromatography with an electron capture detector (Wershaw *et al.*, 1987). For comparison among drainage areas, concentrations of chlorinated

TABLE 1. Land Use and Population Density in Selected Drainage Areas, New Jersey.
[mi^2, square miles; Anderson level I and II land use data from Fegeas *et al.*, 1983; population data from U.S. Bureau of the Census (1991).]

	Percent of Drainage Area						
Land Use Category	Rahway River (RAWA) (83 mi^2)	Big Timber Creek and Cooper River (BTCR) (100 mi^2)	Passaic River (PSSC) (784 mi^2)	Raritan River (RRTN) (1,157 mi^2)	Great Egg Harbor and Mullica Rivers (GEMU) (915 mi^2)	Salem River and Raccoon Creek (SRRC) (161 mi^2)	Pequest River, Paulins Kill, and Pohatcong Creek (PPP) (390 mi^2)
Urban Nonresidential	27.98	16.59	12.39	8.52	1.96	2.79	1.80
Urban Residential	57.21	45.19	35.28	17.19	5.82	5.63	4.21
Agricultural	0.65	15.61	3.26	40.00	11.93	64.08	42.88
Forest	10.24	17.18	40.65	30.22	54.30	11.41	46.65
Water	0.60	1.96	3.12	1.29	2.07	4.51	1.83
Wetland	2.89	1.46	4.06	1.74	22.55	11.29	1.99
Barren	0.44	2.01	1.24	1.04	1.38	0.28	0.64
	Average Population						
People Per Acre	7.21	5.71	3.47	1.66	0.38	0.5	0.43

organic compounds in bed sediment samples were normalized to the organic carbon content of the sediment sample. Because the chlorinated organic compounds discussed in this paper are hydrophobic they tend to sorb to organic carbon in suspended and bed sediments. Thus, sediment samples with greater amounts of organic carbon can sorb higher concentrations of hydrophobic organic compounds. Normalization accounts for differences in concentrations of hydrophobic organic compounds caused by natural variation in the organic carbon content of sediment samples. Therefore, differences observed in normalized concentrations can be attributed to anthropogenic influences rather than natural variations in the organic carbon content of the sediment samples (Witkowski *et al.*, 1987; Smith *et al.*, 1988). Organic carbon content was calculated as the difference between the total carbon content and inorganic carbon content of the sediment. Organic compound concentrations could not be normalized for samples for which one of these values was missing. Therefore, these samples were excluded from the comparison of organic compound concentrations among drainage areas. Analyses of samples from some sites were censored at more than one reporting limit. Samples censored at reporting limits above the analytical reporting limit were excluded from statistical analyses to avoid the loss of data below these high reporting limits. The number of samples excluded did not exceed 5 percent of the total number of analyses for any chlorinated organic compound in any drainage area, except for DDE in the Big Timber Creek and Cooper River drainage area, where 3 of 20 samples were excluded from the calculations. Summary statistics for bed sediment data containing censored values were calculated by using a log probability regression technique (Helsel and Hirsch, 1992), a robust procedure that minimizes rates of root mean square error.

Analysis of variance (ANOVA) on rank transformed bed sediment data was used to evaluate differences in normalized chlorinated organic compound concentrations among drainage areas. ANOVA on rank transformed data is a robust, nonparametric statistical procedure designed to be insensitive to outlying values and assumptions of equal variance and normality (Helsel and Hirsch, 1992; Iman and Conover, 1983). The null hypothesis evaluated is that the mean normalized concentration rank for the organic constituent is equal among all drainage areas. Rejection of the null hypothesis indicates that at least one mean normalized concentration rank value differs from another. If the null hypothesis was rejected, Tukey's Honest Significant Difference test (Tukey's test) was performed to determine which mean normalized concentration ranks differed (Helsel and Hirsch, 1992). Results of Tukey's test are presented as letters for each drainage area. Drainage areas with at least one letter in common do not differ significantly from one another.

Maximum likelihood logistic regression was used to explore relations between the presence or absence of chlorinated organic compounds in bed sediment samples and explanatory variables that characterize the type and degree of development within drainage areas. Variables used to characterize the type and degree of development within drainage areas include land use categories, population, total flow of municipal effluent, total flow from known point sources, and measures of biochemical oxygen demand. Logistic regression theory and application are discussed in Walker and Duncan (1967), Harrell *et al.* (1980), Hosmer and Lemeshow (1989), Helsel and Hirsch (1992), and Eckhardt and Stackelberg (1995). Explanatory variables were obtained from a spatial model designed to aggregate distance weighted attributes that describe sources of point and nonpoint contaminants within drainage areas (White *et al.*, 1992). Each variable was aggregated by using 10 factors that represent the rate of loss or decay of contaminants downstream from sources. Factors ranged from -1 to 0, with -1 representing maximum net loss and 0 representing no net loss (conservative substance). The factors were distance weighted and, thus, distinguished sources of contamination near sampling sites from those further upstream. Development and application of the spatial model are discussed in White *et al.* (1992) and Smith *et al.*, (1993). Land use categories for the spatial model were determined through classification of Landsat Thematic Mapper data for August 1985 and level I and II Anderson classifications of 1:250,000 scale land use data compiled from high altitude aerial photographs taken in the early 1970s (Fegeas *et al.*, 1983; Anderson *et al.*, 1976); population estimates were obtained from the 1980 Census of Population and Housing (Lanfear, 1993).

Maximum likelihood estimates computed by using the iteratively reweighted least squares algorithm were used to define the best linear fit between the response variable (presence or absence of specific chlorinated organic compounds at a specified concentration) and explanatory variables. The maximum likelihood procedure optimizes the likelihood that the observed presence or absence of specific chlorinated organic compounds in bed sediments would be produced from a given set of explanatory variable slopes (Helsel and Hirsch, 1992). The resulting regression parameters differ significantly from 0 at a 95 percent confidence level ($\alpha = 0.05$) with the exception of one explanatory variable, which differed significantly from 0 at a 90 percent confidence level ($\alpha = 0.10$). Three measures of goodness of fit were used to assess the predictive ability of the logistic regression

equations: (1) the chi-square statistic (χ^2) for the joint significance of the explanatory variables, which was maximized through iterative stepwise procedures (Helsel and Hirsch, 1992) by forward selection and backward elimination of explanatory variables; (2) the Akaike Information Criterion (AIC), which is a form of the log likelihood statistic adjusted for the number of explanatory variables in a model; and (3) the rank correlation between predicted probabilities and observed responses (C). Equations with the greatest values for the χ^2 and C statistics and lowest values for the AIC statistic represent optimal model fits.

PRESENCE AND DISTRIBUTION OF CHLORINATED ORGANIC COMPOUNDS

Detection frequencies and concentrations of chlorinated organic compounds in bed sediment samples, normalized to organic carbon content, were compared among seven drainage areas in New Jersey. Included in the analysis were 397 samples collected from 100 sites during 1978-1993 (Figure 1A). Detection frequencies for selected chlorinated organic compounds are illustrated in Figure 2; summary statistics and results of Tukey's test for organic carbon and selected chlorinated organic compounds are provided in Table 2. Results of Tukey's test indicate that organic carbon concentrations in bed sediment samples were statistically similar in six of the seven drainage areas; however, concentrations in samples from the Great Egg Harbor and Mullica Rivers drainage area were lowest and concentrations in bed sediment samples from this area differed significantly from concentrations in bed sediment samples from three other drainage areas (Table 2). Therefore, for comparison among drainage areas, concentrations of chlorinated organic compounds in bed sediment samples were normalized to the organic carbon content of the sediment sample.

Chlorinated Insecticides

Chlorinated insecticides account for less than 10 percent of the insecticides currently in use in the United States, and their use is declining in favor of less persistent, more selective insecticides. The production and use of chlorinated insecticides has been greatly curtailed over the last 15 years because of their environmental persistence, toxic effects, and lipophilic nature (Sandstrom, 1992; Smith *et al.*, 1988). As a group, chlorinated insecticides are among the most persistent anthropogenic compounds introduced into the environment. Most have low vapor pressures and are nonvolatile. Their high octanol water partitioning coefficients cause them to have low volatility in water; therefore, they strongly partition to organic matter dissolved in the water column or in bed sediments (Sandstrom, 1992). Despite low vapor pressures, the highly insoluble nature of chlorinated insecticides allows for relatively high loss rates to the atmosphere; thus, atmospheric deposition results in widespread distribution of some chlorinated insecticides and accounts for their detection in remote regions of the globe (Smith *et al.*, 1988).

After the discovery of its tremendous insecticidal properties in the 1940s, DDT was used heavily in agriculture to control the Colorado potato beetle and other crop pests. DDT also was used extensively in residential settings to control mosquito populations and in forested areas to control gypsy moths and spruce budworms. The production, distribution, and sale of DDT were banned by the USEPA in 1972 (Ware, 1994). DDT was detected with high frequency in sediment samples from all seven drainage areas (Figure 2). Detections were most frequent in the RAWA drainage area (89 percent), BTCR drainage area (86 percent), and SRRC drainage area (87 percent). The RAWA drainage area had the highest median normalized concentration; however, Tukey's test results indicate that mean normalized DDT concentrations were statistically similar in five of the seven drainage areas (Table 2).

Elevated concentrations of DDT in the RAWA, BTCR, and SRRC drainage areas (Table 2) reflect the use of DDT in residential and agricultural areas. Of the seven drainage areas, the RAWA and BTCR drainage areas have the highest percentage of land classified as residential, as well as the highest population densities, whereas the SRRC drainage area has the highest percentage of land classified as agricultural (Table 1). Detection frequencies and concentrations of DDT were relatively low in the PPP drainage area despite the fact that 43 percent of it is classified as agricultural. Agricultural activities within this drainage area are predominantly associated with livestock production. Thus, a large percentage of agricultural land is used for pasture and fodder production, whereas agricultural activities in other parts of the State (such as within the SRRC drainage area) are primarily associated with row-crop production.

Two DDT metabolites, DDE and DDD, also had high detection frequencies in the seven drainage areas (Figure 2). DDE was detected in 42 to 80 percent of samples from all drainage areas (Figure 2). Although the RAWA drainage area had the highest median normalized concentration, and the PPP drainage area had the lowest, Tukey's test results indicate that mean normalized DDE concentrations were statistically similar in six of the seven drainage

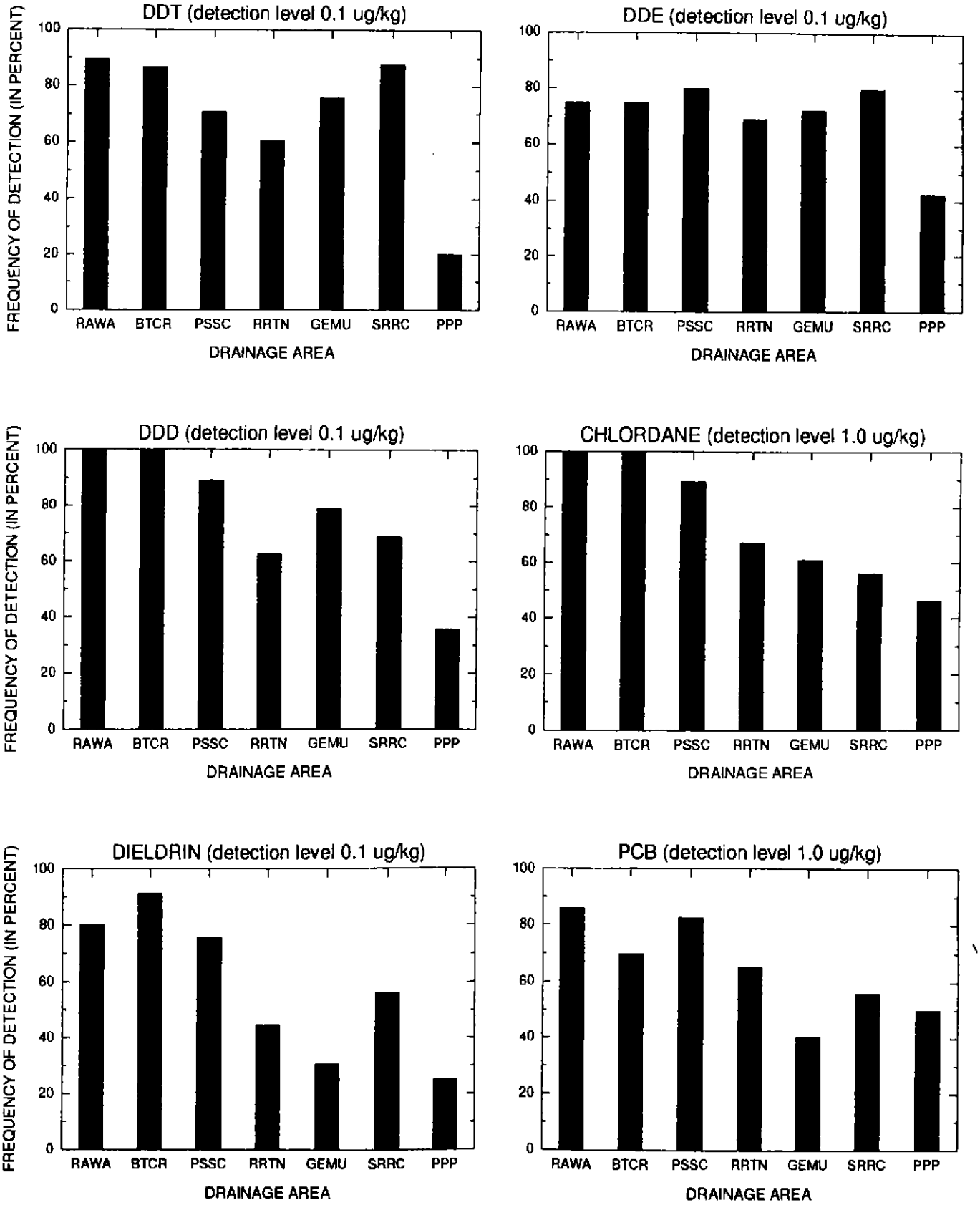


Figure 2. Frequency of Detection for Selected Organic Compounds in Selected Drainage Areas, New Jersey (RAWA: Rahway River; BTCR: Big Timber Creek and Cooper River; PSSC: Passaic River; RRTN: Raritan River; GEMU: Great Egg Harbor and Mullica Rivers; SRRC: Salem River and Raccoon Creek; PPP: Pequest River, Paulins Kill, and Pohatcong Creek).

TABLE 2. Summary Statistics for Organic Carbon Concentrations (kilograms of organic carbon per kilogram of sediment) and Selected Organic Compounds in Bed Sediments with Concentrations Normalized to Organic Carbon Content (micrograms of organic constitute per microgram sediment organic carbon), New Jersey (Tukey's test: drainage areas with at least one letter in common do not differ significantly from one another).

	Drainage Area						
Statistic	Rahway River (RAWA)	Big Timber Creek and Cooper River (BTCR)	Passaic River (PSSC)	Raritan River (RRTN)	Great Egg Harbor and Mullica Rivers (GEMU)	Salem River and Raccoon Creek (SRRC)	Pequest River, Paulins Kill, and Pohatcong Creek (PPP)
Organic Carbon (kg/kg sediment)							
n	21	23	93	180	38	16	28
Median	0.0049	0.0042	0.0048	0.0036	0.0018	0.0028	0.0065
25th-75th Percentile	0.0037-0.0098	0.0022-0.0069	0.0025-0.0119	0.0018-0.007	0.001-0.0038	0.0021-0.0063	0.0034-0.0096
Tukey's Test	A	AB	A	AB	B	AB	A
DDT ($x10^5$ (µg/µg sediment organic carbon)							
n	20	22	89	172	37	16	25
Median	0.17	0.05	0.027	0.0054	0.012	0.03	0.00008
25th-75th Percentile	0.04-0.08	0.007-0.12	0.00085-0.28	.0003-.057	0.0003-0.06	0.005-0.07	.00008-.0002
Tukey's Test	A	AB	AB	BC	BC	AB	C
DDE ($x10^5$) (µg/µg sediment organic carbon)							
n	20	20	88	167	36	15	26
Median	0.07	0.03	0.03	0.0084	0.005	0.034	0.0003
25th-75th Percentile	0.02-0.2	0.004-0.11	0.0015-0.19	.0003-.067	0.0002-0.04	0.002-0.08	.0003-.01
Tukey's Test	A	AB	AB	AB	B	AB	B
DDD ($x10^5$) (µg/µg sediment organic carbon)							
n	21	23	91	178	38	16	28
Median	0.41	0.17	0.097	0.0048	0.01	0.02	0.0004
25th-75th Percentile	0.14-0.15	0.07-0.37	0.01-0.57	.00024-.08	0.0005-0 1	0.0005-0.05	0.0004-0.01
Tukey's Test	A	A	AB	C	BC	BC	C
CHLORDANE ($x10^5$) (µg/µg sediment organic carbon)							
n	21	23	93	179	37	16	28
Median	2.7	0.5	0.42	0.04	0.02	0.01	0.02
25th-75th Percentile	1.1-5.1	0.2-1.2	0.1-2.4	0.0027-0.3	0.0007-0.08	0.002-0.17	0.01-0.14
Tukey's Test	A	AB	B	C	C	C	C
DIELDRIN ($x10^5$) (µg/µg sediment organic carbon)							
n	21	23	86	174	36	16	28
Median	0.04	0.03	0.02	0.00036	0.00003	0.0015	0.0002
25th-75th Percentile	0.007-0.1	0.01-0.046	0.001-0.06	.00014-.012	.00003-.006	.0003-.006	.0002-.0017
Tukey's Test	A	A	AB	BC	C	BC	C
Total PCBs ($x10^5$) (µg/µg sediment organic carbon)							
n	21	23	91	179	38	16	28
Median	1.6	0.3	0.36	0.061	0.0015	0.10	0.05
25th-75th Percentile	0.3-5	0.02-1.0	0.034-5.5	.0038-.67	0.0006-0.05	0.013-0.42	0.012-0.21
Tukey's Test	A	AB	AB	BC	C	BC	BC

areas (Table 2). DDD was detected in 89 to 100 percent of samples from the three most urbanized drainage areas (RAWA, BTCR, and PSSC) and in only 36 percent of samples from the PPP drainage area (Figure 2). Although the RAWA drainage area had the highest median normalized concentration, Tukey's test results indicate that the mean normalized concentration rank in this area does not differ significantly from those in other highly urbanized and populated drainage areas such as the BTCR and PSSC (Table 2). The PPP drainage area had the lowest median normalized concentration. However, Tukey's test results indicate that the mean normalized concentration in this area does not differ significantly from those in other drainage areas with large amounts of forested and agricultural land (Table 2).

Chlordane and dieldrin were detected with high frequency in sediment samples from all seven drainage areas (Figure 2). Chlordane was detected in every bed sediment sample from the RAWA and BTCR drainage areas; dieldrin was detected in 91 percent of the samples from the BTCR drainage area and 80 percent of the samples from the RAWA drainage area (Figure 2). Concentrations of both compounds were elevated in the urbanized drainage areas and tended to decrease with decreasing percentages of land classified as urban-residential and decreasing population densities (Table 2). This pattern reflects the historical use of these compounds primarily for the control of termites in residential areas and, to a lesser extent, the control of soil borne insects in agricultural areas. Agricultural uses of chlordane and dieldrin were banned by the USEPA in the late 1970s and use of these compounds to control termites was banned in the mid-1980s (Ware, 1994).

The following chlorinated insecticides were detected infrequently, and at low concentrations, in bed sediment samples throughout New Jersey: aldrin, endosulfan, endrin, heptachlor, heptachlor epoxide, lindane, methoxychlor, mirex, perthane, and toxaphene.

Polychlorinated Biphenyls and Related Compounds

Polychlorinated biphenyls (PCBs) are chlorinated compounds synthetically produced by the catalyzed chlorination of biphenyl. They are complex mixtures containing from 1 to 10 chlorine atoms in 209 possible structures (congeners). Because of their chemical and thermal stability, PCBs historically have been used as plasticizers, heat resistant oils in electrical transformers and capacitors, hydraulic lubricants, and additives to paints and coatings (Foreman, 1993; Smith *et al.*, 1988); however, because of their environmental persistence and toxicity, the manufacture, processing, distribution, and use of PCBs was banned by Congress as of 1979. Although the properties of PCBs vary, they are generally characterized by relatively low aqueous solubilities and high octanol water partition coefficients (Smith *et al.*, 1988). Thus, PCBs strongly partition to organic matter dissolved in the water column and are associated with bed sediments. Despite low vapor pressures, the highly insoluble nature of PCBs allows for relatively high rates of loss to the atmosphere. Thus, atmospheric deposition results in widespread distribution of PCBs and accounts for their detection in remote regions of the globe (Smith *et al.*, 1988).

PCBs were detected frequently in all seven drainage areas (Figure 2). The RAWA drainage area had the highest detection rate (86 percent) and the highest median concentration, whereas the GEMU drainage area had the lowest detection rate (40 percent) and the lowest median concentration (Figure 2, Table 2). Detection frequencies and concentrations of PCBs were elevated in urbanized drainage areas and tended to decrease with decreasing population density and the percentage of land classified as urban, reflecting their association with industrial applications.

Polychlorinated naphthalenes (PCNs), chlorinated organic compounds used primarily as a component of capacitors and as an engine oil additive (Verschueren, 1983), were not detected in any bed sediment samples within New Jersey above a detection level of 1.0 µg/kg.

RELATION BETWEEN CHLORINATED ORGANIC COMPOUNDS AND BASIN CHARACTERISTICS

Maximum likelihood logistic regression was used to further examine relations between the presence of selected chlorinated organic compounds at or above specified concentrations and explanatory variables that characterize the type and degree of development within drainage areas. Median concentrations were calculated for samples from 255 sites across New Jersey (Figure 1B) for three classes of chlorinated organic compounds, and a binary response variable was set equal to 0 or 1 depending on whether the median concentration was below, or was equal to or exceeded, a specified concentration. Descriptions of, and summary statistics for, binary response variables for the three classes of chlorinated organic compounds are provided in Table 3.

Explanatory variables examined during the course of this investigation, which were designed to characterize the type and degree of development within the drainage area of each sampling site, included total population, land use categories, total flow of

TABLE 3. Statistics for Binary Response Variables and Continuous Explanatory Variables (km^2: square kilometers; µg/kg: micrograms per kilogram).

Binary Response Variables

Constituent Name	Binary Code and Description	Percentage of Sites at Which Median Constituent Concentration Exceeded Specified Concentration
DDT-T	1 Median concentration of sum of DDT, DDE, and DDD greater than or equal to 10 µg/kg. 0 Median concentration of sum of DDT, DDE, and DDD less than 10 µg/kg.	34
CHLDIEL	1 Median concentration of sum of chlordane and dieldrin greater than or equal to 5 µg/kg. 0 Median concentration of sum of chlordane and dieldrin less than 5 µg/kg.	42
PCB	1 Median concentration of total PCBs greater than or equal to 5 µg/kg. 0 Median concentration of total PCBs less than 5 µg/kg.	40

Continuous Explanatory Variables

Variable Name	Description, Unit of Measurement, and Source of Data	Minimum	Median	Maximum
POP-1	Total population aggregated upstream with a decay factor of -1.0 (Lanfear, 1993).	0	270.4	12,325
RES-3	Area of residential land (km^2) aggregated upstream with a decay factor of -0.1 (Fegeas *et al.*, 1983).	0	3.3	58.1
AGG-3	Area of Landsat Thematic Mapper data for August 1985 classified as agricultural land (km^2) aggregated upstream with a decay factor of -0.1.	0	.7.4	56.3
AGG-7	Area of Landsat Thematic Mapper data for August 1985 classified as agricultural land (km^2) aggregated upstream with a decay factor of -0.007.	0	15.9	1,123.7
URB-3	Area of urban land (km^2) aggregated upstream with a decay factor of -0.1 (Fegeas *et al.*, 1983).	0	1.4	30.2
FOR-9	Area of forested and undeveloped land (km^2) aggregated upstream with a decay factor of -0.001 (Fegeas *et al.*, 1983).	0	27.5	921.2

municipal effluent, total flow from known point sources, and measures of biochemical oxygen demand. Statistically significant equations were developed from various combinations of these explanatory variables; however, best fit equations consistently included only population and land-use categories. Descriptions of, and summary statistics for, continuous explanatory variables from these best fit equations are provided in Table 3.

Example logistic regression equations relating the presence of the three classes of chlorinated organic compounds to population and land use categories aggregated within the drainage area of each sampling site are presented in Table 4. Additional equations that use the alternative explanatory variables described above are possible, but the equations presented in Table 4 represent optimal model fits, as indicated by various goodness-of-fit statistics.

Chlorinated Insecticides

To examine relations between the presence of DDT, and its metabolites DDE and DDD, in bed sediments and variables that characterize the type and degree of development within drainage areas, the concentrations of DDT, DDE, and DDD in each sample were summed (DDT-T). Three equations are presented in Table 4 that relate the presence of DDT-T at a median concentration of at least 10 µg/kg to variables that reflect sources of these compounds. A median concentration of 10 µg/kg was used to distinguish those sites

TABLE 4. Logistic Regression Equations and Goodness-of-Fit Statistics (names of variables are described in Table 3; χ^2: chi-square statistic; C: rank correlation coefficient of predicted probabilities and observed responses; AIC: Akaike Information Criterion).

Explanatory Variables	Equations Coefficient Value, β_i	p-Value	Goodness-of-Fit Statistics χ^2	C	AIC
DDT-T (SUM OF DDT, DDE, AND DDD)					
RES-3	0.09	0.0001	26.7	0.70	305.3
AGG-7	-0.01	0.0006			
INTERCEPT	-0.77	0.0001			
RES-3	0.09	0.0002	26.3	0.70	307.6
FOR-9	-0.004	0.012			
AGG-3	-0.05	0.01			
INTERCEPT	-0.48	0.018			
POP-1	0.0003	0.001	19.0	0.66	313.0
AGG-3	-0.05	0.005			
INTERCEPT	-0.45	0.026			
CHLDIEL (sum of chlordane and dieldrin)					
POP-1	0.0005	0.01	65.2	0.78	289.7
RES-3	0.12	0.001			
AGG-3	-0.07	0.0001			
INTERCEPT	-0.67	0.002			
RES-3	0.18	0.0001	58.3	0.77	294.5
AGG-3	-0.08	0.0001			
INTERCEPT	-0.55	0.009			
POP-1	0.0009	0.0001	38.9	0.71	311.9
INTERCEPT	-0.95	0.0001			
PCBs					
POP-1	0.0003	0.08	38.3	0.71	316.5
URB-3	0.25	0.001			
AGG-7	-0.009	0.0002			
INTERCEPT	-0.79	0.0001			
URB-3	0.33	0.0001	35.0	0.71	317.8
AGG-7	-0.01	0.0001			
INTERCEPT	-0.71	0.0001			
POP-1	0.0004	0.001	14.7	0.64	336.2
INTERCEPT	-0.71	0.0001			

at which DDT-T concentrations were most highly elevated; 34 percent of the sampling sites exceeded this median concentration. DDT-T compounds were detected frequently in all drainage areas (Figure 2), reflecting the historical widespread application of these compounds. Concentrations were highest, however, in the most heavily urbanized and residential drainage areas (Table 2). Explanatory variables that describe DDT-T source terms include total population (POP-1) and the amount (in square kilometers) of land classified as residential (RES-3) in close proximity to sampling sites (Table 3). DDT-T was inversely related to the amount of land classified as agricultural (AGG-3) within close proximity to sampling sites and to the amount of agricultural (AGG-7) or forested (FOR-9) land aggregated over relatively large parts of the drainage areas because DDT-T compounds were not typically detected in agricultural or forested areas at concentrations of 10 µg/kg or greater.

Chlordane and dieldrin are structurally similar organic compounds that belong to the cyclodiene group. Both compounds are stable in soils and, thus, were used for similar purposes, primarily to control soil borne insects such as termites. To examine

relations between the presence of these compounds in bed sediments and variables that characterize the type and degree of development within drainage areas, the concentrations of chlordane and dieldrin in each sample were summed (CHLDIEL). Three equations that relate the presence of CHLDIEL at a median concentration of at least 5 µg/kg to variables that reflect sources of these compounds are presented in Table 4. A median concentration of 5 µg/kg was used to distinguish those sites at which chlordane and dieldrin concentrations were most highly elevated; 42 percent of the sampling sites exceeded this median concentration. Chlordane and dieldrin concentrations were elevated in drainage areas dominated by urban and residential development (Table 2), reflecting their primary use for the control of termite populations. Explanatory variables found useful for describing chlordane and dieldrin source terms include total population (POP-1) and the amount of land classified as residential (RES-3) in close proximity to sampling sites. CHLDIEL was inversely related to the amount of land classified as agricultural (AGG-3) within close proximity to sampling sites because CHLDIEL compounds were not typically detected in agricultural areas at concentrations of 5 µg/kg or greater.

Polychlorinated Biphenyls

Three equations that relate the presence of total PCBs at a median concentration of at least 5 µg/kg to variables that reflect sources of PCBs are presented in Table 4. A median concentration of 5 µg/kg was used to distinguish those sites at which PCB concentrations were most highly elevated; 40 percent of the sampling sites exceeded this median concentration. PCBs were detected most frequently, and concentrations were highest, in drainage areas dominated by urban land use (Figure 2, Table 2), reflecting the association of PCBs with industrial applications. Explanatory variables found useful for describing PCB source terms include total population (POP-1) and the amount of land classified as urban (URB-3) in close proximity to sampling sites (Table 3). The presence of PCBs was found to be inversely related to the amount of land classified as agricultural (AGG-7) aggregated over relatively large parts of the drainage areas because PCBs were not typically detected in agricultural areas at concentrations of 5 µg/kg or greater.

SUMMARY

Data on 18 chlorinated organic compounds in bed-sediment samples collected from surface water sites across New Jersey were evaluated. The data include concentrations of these compounds in sediment samples collected by the U.S. Geological Survey and the New Jersey Department of Environmental Protection from the late 1970s to 1993. Data from 100 sites within 12 basins across New Jersey were evaluated to determine (1) which compounds were detected most frequently, (2) whether detection frequencies differed among selected drainage basins, and (3) whether concentrations differed significantly among selected drainage basins. The 12 drainage basins selected represent a variety of land uses and a range of population densities for comparison of detection frequencies and concentrations. To ensure an adequate number of samples for statistical comparisons, the 12 drainage basins were consolidated into seven drainage areas on the basis of their proximity to each other and similarities in land-use composition and population densities. Additionally, bed sediment data for three classes of chlorinated organic compounds from 255 sites across New Jersey were examined to determine whether the presence of these compounds in streambed sediments is related to the type and degree of development within the drainage area of each sampling site. Analysis of these data provides insight relevant to the design of future surveys of bed sediments and fish tissues that will be conducted as part of the U.S. Geological Survey's National Water-Quality Assessment program in the Long Island-New Jersey Coastal Drainages study unit by identifying organic contaminants of primary concern and geographic areas of highest risk for contamination.

The six most frequently detected chlorinated organic compounds in bed-sediment samples were DDT, DDE, DDD, chlordane, dieldrin, and total PCBs. Chlorinated insecticides, which were detected infrequently and at low concentrations, include aldrin, endrin, heptachlor, heptachlor epoxide, methoxychlor, perthane, endosulfane, lindane, mirex, and toxaphene. Polychlorinated naphthalenes were not detected in any bed sediment samples above a detection level of 1.0 µg/kg.

The six most frequently detected chlorinated organic compounds tended to be widely distributed in bed sediments across the state. The most widely distributed compounds, DDT and its metabolites DDE and DDD, were detected in about 60 to 100 percent of samples from six of the seven representative drainage areas. This high detection rate across drainage areas with various land use patterns and population densities reflects the widespread application of these

compounds. Historically, these compounds were applied in residential areas to control mosquito populations, in agricultural areas to control crop pests, and in undeveloped and forested areas to control gypsy moths and spruce budworms. The median normalized concentrations of DDT, DDE, and DDD were highest in the most highly urbanized and populated drainage areas. However, concentrations of DDT and DDE were statistically similar in most of the drainage areas.

Chlordane and dieldrin were detected in about 80 to 100 percent of the bed sediment samples from the three most heavily urbanized and populated drainage areas; detection frequencies tended to be smaller in less heavily developed areas. Normalized concentrations of chlordane and dieldrin were significantly higher in the more heavily urbanized and populated areas such as the Rahway River and Big Timber Creek and Cooper River drainages, and lowest in the agricultural and forested areas such as the Great Egg Harbor and Mullica Rivers; the Salem River and Raccoon Creek; and the Pequest River, Paulins Kill, and Pohatcong Creek drainage areas. PCBs also were widely distributed; they were detected in about 40 to 85 percent of bed-sediment samples from all seven drainage areas. The most frequent detections and the highest normalized concentrations were in samples from the most heavily urbanized and populated drainage area, and the least frequent detections and lowest normalized concentrations were in samples from the most heavily forested and undeveloped drainage area.

Relations between the presence of chlorinated organic compounds in bed sediments and explanatory variables that characterize the type and degree of development within drainage areas were determined through logistic regression. The presence of these compounds in bed sediments was found to correlate significantly with population totals and amounts (in square kilometers) of various land use categories within the drainage area of each sampling site. These results indicate that the total number of people and amount of land classified as urban, residential, agricultural, or forested upstream from sampling sites are reliable predictors of the presence of specific groups of chlorinated organic compounds in bed sediments. These results can be used to identify areas where bed sediment contamination by specific organic compounds is most likely to occur and, thus, can help focus the design of future surveys aimed at assessing the effects of these compounds on stream ecology.

LITERATURE CITED

Anderson, James R., Ernest E. Hardy, John T. Roach, and Richard E. Witmer, 1976. A Land Use and Land Cover Classification System for Use with Remote Sensor Data. U.S. Geological Survey Professional Paper 964, 28 pp.

Bopp, R. F., M. L. Gross, H. Tong, H. J. Simpson, S. J. Monson, B. L. Deck, and F. C. Moser, 1991. A Major Incident of Dioxin Contamination: Sediments of New Jersey Estuaries. Environmental Science and Technology 25(5):951-956.

Bopp, R. F., H. James Simpson, Curtis R. Olsen, and Nadia Kostyk, 1981. Polychlorinated Biphenyls in Sediments of the Tidal Hudson River, New York. Environmental Science and Technology 15(2):210-216.

Colman, John A. and Richard F. Sanzolone, 1991. Surface-Water-Quality Assessment of the Upper Illinois River Basin in Illinois, Indiana, and Wisconsin: Geochemical Data for Fine-Fraction Streambed Sediment from High- and Low-Order Streams, 1987. U.S. Geological Survey Open-File Report 90-571, 108 pp.

Eckhardt, David A.V. and Paul E. Stackelberg, 1995. Relation of Ground-Water Quality to Land Use on Long Island, New York. Ground Water 33(6):1019-1033.

Fegeas, R. G., R. W. Claire, S. C. Guptill, K. E. Anderson, and C. A. Hallam, 1983. Land Use and Land Cover Digital Data. U.S. Geological Survey Circular 895-E, 21 pp.

Foreman, William, 1993. Complex Organochlorine Mixtures: Polychlorinated Biphenyls, Technical Chlordane, and Toxaphene. Unpublished notes from training course on Environmental Processing of Organic Chemicals given at U.S. Geological Survey's National Training Center, Lakewood, Colorado, Jan. 27 to Feb. 7, 1995.

Harrell, F. E., K. L. Lee, and R. A. McKinnis, 1980. Procedures for Large Regression Problems Requiring Maximum Likelihood Estimation. Proceedings of the Fifth Annual SAS Users Group International Conference, Cary, North Carolina, SAS Inst., Inc., pp. 199-202.

Hay, Lauren E. and Jean P. Campbell, 1990. Water-Quality Trends in New Jersey Streams. U.S. Geological Survey Water-Resources Investigations Report 90-4046, 297 pp.

Helsel, D. R. and R. M. Hirsch, 1992. Statistical Methods in Water Resources. Studies in Environmental Science, No. 49. Elsevier Publishers, Inc., New York, New York, 522 pp.

Hochreiter, Joseph J., Jr. and Jane Kozinski, 1985. Quality of Water and Bed Material in Streams of Logan Township, Gloucester County, New Jersey, 1984. U.S. Geological Survey Water-Resources Investigations Report 85-4300, 39 pp.

Hochreiter, Jr., Joseph J., 1982. Chemical-Quality Reconnaissance of the Water and Surficial Bed Material in the Delaware River Estuary and Adjacent New Jersey Tributaries, 1980-81. U.S. Geological Survey Water-Resources Investigations 82-36, 41 pp.

Hosmer, D.W., and Stanley Lemeshow, 1989. Applied Logistic Regression. John Wiley and Sons, Inc., New York, New York, 307 pp.

Iman, Ronald L. and W. J. Conover, 1983. A Modern Approach to Statistics. John Wiley and Sons, Inc., New York, New York, 497 pp.

Johnson, L. L., C. M. Stehr, O. P. Olson, M. S. Myers, S. M. Pierce, B. B. McCain, and U. Varanasi, 1992. National Benthic Surveillance Project: Northeast Coast, Fish Histopathology and Relationships Between Lesions and Chemical Contaminants (1987-89). National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Center, Seattle, Washington, NOAA Technical Memorandum NMFS-NWFSC-4, December 1992, Seattle, Washington.

Johnson, L.L., C. M. Stehr, O. P. Olson, M. S. Myers, S. M. Pierce, C. A. Wilgren, B. B. McCain, and U. Varanasi, 1993. Chemical Contaminants and Hepatic Lesions in Winter Flounder (*Pleuronectes americanus*) from the Northeast Coast of the United States. Environmental Science and Technology 27(13):2759-2771.

Leahy, P. P., J. S. Rosenshein, and D. S. Knopman, 1990. Implementation Plan for the National Water-Quality Assessment Program. U.S. Geological Survey Open-File Report 90-174, 10 pp.

Lanfear, K. J., 1993. 1980 Point Population Coverages for the Conterminous United States. From U.S. Bureau of the Census, 1980 Master Area Reference File for 1980 Census (United States) [Arc/Info format data file].

O'Conner, J. M. and R. J. Huggett, 1988. Aquatic Pollution Problems, North Atlantic Coast, Including Chesapeake Bay. Aquatic Toxicology 11:163-190.

O'Keefe, P., D. Hilker, C. Myer, K. Aldous, L. Shane, R. Donnelly, and R. Smith, 1984. Tetrachlorodibenzo-p-dioxins and Tetrachlorodibenzofurans in Atlantic Coast Striped Bass and in Selected Hudson River Fish, Waterfowl and Sediments. Chemosphere 13(8):849-860.

Rinella, J. K., P. A. Hamilton, and S. W. McKenzie, 1993. Persistence of the DDT Pesticide in the Yakima River Basin, Washington. U.S. Geological Survey Circular 1090, 24 pp.

Robinson, K., K. Berry, B. Miller, L. Semple, and B. McLendon, 1988. New Jersey 1988 State Water Quality Inventory Report: A Report on the Status of Water Quality in New Jersey Pursuant to the New Jersey Water Pollution Control Act and Section 305(b) of the Federal Clean Water Act. State of New Jersey Department of Environmental Protection, Trenton, New Jersey, May 1988.

Sandstrom, Mark W., 1992. Insecticides: General Chemistry, Environmental Fate and Transport. Unpublished notes from training course on Environmental Processing of Organic Chemicals given at U.S. Geological Survey National Training Center, Lakewood, Colorado, January 27 to February 7, 1995.

Smith, James A., Philip T. Harte, and Mark A. Hardy, 1987. Trace-Metal and Organochlorine Residues in Sediments of the Upper Rockaway River, New Jersey. Bulletin of Environmental Contamination and Toxicology 39:465-473.

Smith, James A., Patrick J. Witkowski, and Thomas V. Fusillo, 1988. Manmade Organic Compounds in the Surface Waters of the United States – A Review of Current Understanding. U.S. Geological Survey Circular 1007, 92 pp.

Smith, Richard A., Richard B. Alexander, Gary D. Tasker, Curtis V. Price, Keith W. Robinson, and Dale A. White, 1993. Statistical Modeling of Water Quality in Regional Watersheds. *In:* Proceedings WATERSHED '93, A National Conference on Watershed Management, March 21-24, 1993, Alexandria, Virginia, EPA 840-R-94-002, pp. 751-754.

Stainken, D. and J. Rollwagen, 1979. PCB Residues in Bivalves and Sediments of Raritan Bay. Bulletin of Environmental Contamination and Toxicology 23:690-697.

Tong, H. Y., S. J. Monson, M. L. Gross, R. F. Bopp, H. J. Simpson, B. L. Deck, and F. C. Moser, 1990. Analysis of Dated Sediment Samples from the Newark Bay Area for Selected PCDD/Fs. Chemosphere 20(10-12):1497-1502.

U.S. Bureau of the Census, 1991. Census of Population and Housing, 1990: Public Law 94-171 Data for New Jersey. U.S. Bureau of the Census, Washington, D.C., Machine-Readable Data Files (CD-ROM).

Verschueren, Karel, 1983. Handbook of Environmental Data on Organic Chemicals (2nd Edition). Van Nostrand Reinhold Company, New York, New York, 1310 pp.

Walker, S. H. and D. B. Duncan, 1967. Estimation of the Probability of an Event as a Function of Several Independent Variables. Biometrika 54:167-179.

Ward, J. R. and A. C. Harr (Editors), 1990. Methods for Collection and Processing of Surface-Water and Bed-Sediment Samples for Physical and Chemical Analyses. U.S. Geological Survey Open-File Report 90-140, 71 pp.

Ware, George W., 1994. The Pesticide Book (4th Edition). Thomson Publications, Fresno, California, 384 pp.

Wenning, R. J., M. A. Harris, M. J. Unga, D. J. Paustenbach, and H. Bedbury, 1992. Chemometric Comparisons of Polychlorinated Dibenzo-p-dioxin and Dibenzofuran Residues in Surficial Sediments from Newark Bay, New Jersey and Other Industrialized Waterways. Archives of Environmental Contamination and Toxicology 22(4):397-413.

Wenning, R. J., D. J. Paustenbach, M. Harris, and H. Bedbury, 1993. Principal Components Analysis of Potential Sources of Polychlorinated Dibenzo-p-dioxin and Dibenzofuran Residues in Surficial Sediments from Newark Bay, New Jersey. Archives of Environmental Contamination and Toxicology 24(3):271-289.

Wershaw, R. L., M. J. Fishman, R. R. Grabbe, and L. E. Lowe, 1987. Methods for the Determination of Organic Substances in Water and Fluvial Sediments. Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 5, Chapter A3, 80 pp.

White, Dale A., Richard A. Smith, Curtis V. Price, Richard B. Alexander, and Keith W. Robinson, 1992. A Spatial Model to Aggregate Point-Source and Nonpoint-Source Water-Quality Data for Large Areas. Computers and Geosciences 18(8):1055-1073.

Witkowski, P. J., J. A. Smith, T. V. Fusillo, and C. J. Chiou, 1987. A Review of Surface-Water Sediment Fractions and Their Interactions with Persistent Manmade Organic Compounds. U. S. Geological Survey Circular 993, 39 pp.

Zdanowicz, V. S. and D. Gadbois, 1990. Contaminants in Sediment and Fish Tissue from Estuarine and Coastal Sites of the Northeastern United States. U.S. Department of Commerce, National Oceanic and Atmospheric Administration.