RISK CHARACTERIZATION OF CONTAMINANTS IN PASSAIC RIVER SEDIMENTS, NEW JERSEY

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ABSTRACT: *Sediment data from the Passaic River collected in 1991, 1993, 1995, and 1999 were analyzed for selected metals (Cr, Pb, Hg, Ni, and Zn) and organic contaminants (TCDDs and total DDTs). In this study, we compared the concentrations of these selected contaminants with different sediment quality benchmark below which adverse effects are unlikely, to determine the hazard quotients (HQ) of the chemicals of concern. It was found that the contribution of TCDDs to the potential toxic risk in the Passaic River was over 99% in all the years and average concentrations ranging from 0.007 to 0.02 µg g^{-1}. For all the metals, Pb and Hg posses the highest risk, with HQ > 268 for Pb and HQ > 58 for Hg based on the sample analysis from the 1995 sampling. The degree and spatial extent of contaminant "hot spots" in this study is correlated well with proximity to anthropogenic sources, suggesting localized point source inputs. In this study, Harrison Reach is identified as the river segment posing the greatest potential risk for all chemicals analyzed while TCDDs and Hg are identified as the primary drivers of potential risk in all reaches along the lower Passaic River. Although a variety of chemicals of concern contaminated the Passaic River, we found good spatial correlations of TCDDs contamination with other chemical contaminations. Therefore, remediation of TCDDs contaminated sediments could address the issue to a great extent. Information derived from this study in identifying "hot spots" and localized areas of contamination are important for environmental remediation and restoration.*

Keywords: Contaminated sediments, Passaic River

INTRODUCTION

The Passaic River System is part of the New York-New Jersey Harbor Estuary System. The lower reach of the Passaic River consists of a 10 km (6 mile) stretch primarily located in Newark, New Jersey. The area has five navigational reaches, as defined by the United States Army Corps of Engineers (USACE), including (upriver from mouth) Point No Point Reach, Harrison Reach, Newark Reach, Kearny Reach, and Arlington Reach. The Passaic River was once a great river with numerous ecological systems, supporting enormous biological diversity, and providing the native people with critical environmental and human-use services. But like many urban rivers in the world's civilization history, urban expansion and industrial development have adversely impacted the Passaic River since the early nineteenth century (Cunningham, 1954; Brydon, 1974). Water quality deteriorated throughout the nineteenth century as raw sewage and industrial chemicals were discharged directly into the river through sewers, industrial outfalls, and surface run-off (Cunningham, 1966; Brydon, 1974; Galishoff, 1988). In 1894, as much as one-third of the total flow of the Passaic River was estimated to be raw sewage (Brydon, 1974). The industrial expansion in Newark, which accompanied both World War I and World War II, led to the rapid growth of many industries, including chemicals, paint and pigment, metal refining, ship building, textiles and leather, rubber, rope, paper products, plastics, perfumes, wood treatment, petroleum transport, and more recently, hazardous waste handling. These continue to operate in the region (Myers, 1945; Cunningham, 1954, 1966; Halle, 1984; MacRae's, 1986). The attendant urbanization and industrial development has drastically altered the shorelines of the Passaic River. The river has narrowed considerably due to shoreline development to create additional land for industrial sites. Bulkheading and riprapping the riverbank and wetland reclamation have caused a drastic change in the natural, land-shore interface (Iannuzzi et al., 2002). Along the lower 10 km of the Passaic River, at least 90% of the original wetland habitat no longer exists, and it has been replaced by landfills, bulkheads, and shoreline riprap. These wetlands were reclaimed with as much as 4 m of fill materials on the original marsh surface (Iannuzzi et al., 2002; Squires, 1992). Waste disposal, atmospheric deposition, industrial sewage, and toxic chemicals spills have greatly contaminated the Passaic River aquatic system including water and sediments. In 1970, the United States Environmental Protection

Agency (USEPA) declared the Passaic River the "second most polluted river in America".

Previous studies carried out to characterize and assess chemical contaminants in the Passaic River and Newark Bay have shown that sediments in the Passaic River contain elevated concentrations of numerous toxic substances including, but not limited to, arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), zinc (Zn), dichlorodiphenyltrichloroethane (DDT), petroleum hydrocarbons, TCDDs/PCDFs, and pesticides (Bonnevie et al., 1992, 1993, 1994; Gillis et al., 1993, 1995; Gunster et al., 1993; Huntley et al., 1993, 1995, 1997; Iannuzzi et al., 1995, 1997; Iannuzzi and Wenning, 1995; Wenning et al., 1993a, 1993b, 1994). The present study is part of the ongoing effort to characterize, assess, and remediate chemical contaminants in Passaic River. In this paper, we focus on the risk assessment of persistent chemical contaminants in the lower Passaic River using Geographic Information System (GIS). In 1991, the USEPA developed a guide for risk assessors, site engineers, and others in using risk information at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites to both evaluate remedial alternatives during the feasibility study and to evaluate ecological and human health risk associated with the selected remedial alternative during and after its implementation (USEPA, 1991). Also, deciding on the best management alternatives for dredged contaminated sediments is challenging for managers, as they must evaluate the human and ecological risks associated with the remediation project. This study will provide an understanding of the temporal and spatial variation, to a certain extent, of the potential risk posed by multiple chemical contaminants in the lower Passaic River, which is imperative in the establishment of preliminary remediation goals and alternatives for the Passaic River.

MATERIALS AND METHODS

Our study area is within the 10 km section of the lower Passaic River in New Jersey, which was under USEPA intensive investigation from 1990 to 2000 (Figure 1). For example, the USEPA conducted a remedial investigation of the lower Passaic River in 1995 to determine the horizontal and vertical distributions and concentrations of chemical contaminants in the river sediment. The study included taking 78 sediment core borings comprising of three borings taken along 26 equally spaced transects about 360 meters (1200 ft) apart, extending

downstream of the 10 kilometer (6 mile) study boundary (Figure 1). The dataset compiled for this research includes sediment surface data from the 1995 remedial investigation sampling program and other sediment sampling data collected by government agencies, Tierra Solutions Inc., industries and academia and compiled by Tierra Solutions Inc. from 1990-2000. There are 21 sampling events occurring between 1990 and 2000 with approximately 3,000 samples. The sampling dataset is stored as a non-relational database (i.e. all data in one table) in Microsoft® Access, where it can be queried to extract specific sets of data to be analyzed and used. Data for some chemicals of concern (Cr, Pb, Hg, Zn, TCDDs, and Total DDTs), which historically have been discharged into the Passaic River and are known to be toxic, were queried and analyzed for this study.
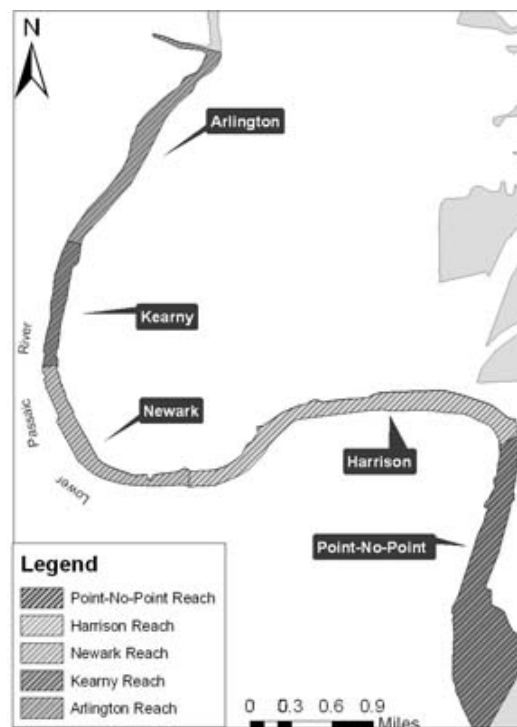

Figure 1. Map showing the study area in the lower Passaic River and locations of some associated industrial facilities along the Passaic River.

A variety of different types of sediment guidelines from multiple sources (e.g., Environment Canada, 1995; Ingersoll et al., 1996) were used in this study and are presented in Table 1. The Ingersoll et al. (1996) guidelines identify four levels of protection. These guidelines provide sediment concentrations where there is a low likelihood of effects (Effects Range Low [ERL] and Threshold Effect Levels [TEL]) as well as concentrations where effects are more likely to occur (Effects Range Median [ERM]

and Probable Effect Levels [PEL]). When a sediment concentration falls below ERL and TEL values, effects are rarely observed. In contrast, the probability of effects is more frequent (generally greater than 50%) when concentrations exceed ERM and PEL values (Ingersoll et al., 1996; Long et al., 1998a). It should be noted that an exceedance of any one of these sediment guidelines does not necessarily mean that aquatic or human life are at risk. This is because the sediment guidelines are not site-specific, are conservative, and do not always indicate that an effect will actually occur when effect levels are exceeded (Long et al., 1998a). Much of the toxicity data used to develop such guidelines are based on whether effects were observed in bioassays of field-collected samples. Accordingly, if effects were observed, the toxic effect level is assumed to be related to the concentration of an individual chemical in the sample when, in fact, it is likely that a variety of chemicals contributed to the observed toxicity. The toxicity of the Passaic River sediments was characterized by calculating the hazard quotients (HQs) of the selected chemical contaminants.

$$HQ = \frac{SCC}{SQG}$$

where, SCC is the sediment chemical concentration and SQG is the sediment quality guideline.

Multiple sediment guidelines for individual chemicals were used in this study when available. This provides a weight of evidence when evaluating sediment risks since site-specific factors can have substantial impacts on chemical bioavailability in sediment. The ability of these different types of guidelines to predict toxicity (or lack of toxicity) to benthic organisms was reviewed by Long et al. (1998a). They assessed the toxicity of hundreds of field-collected sediment samples using various laboratory bioassays. Based on the data provided in their paper, it is clearly evident that several ERL values, and even more TEL values, need to be exceeded before sediment toxicity is observed with any consistency. Sediment data collected in 1991, 1993, 1995, and 1999 were used respectively to assess potential risks to aquatic life. The 1995 sampling was more comprehensive and widespread than other sampling events, and also included the collection of core samples. The biological relevance of these data is uncertain since they reflect concentrations from depths greater than the usual bioturbation zone. While fewer samples were collected in 1999, the data could only reflect conditions in the biologically active top 15 cm of sediment. Accordingly, the 1999 data represent more recent and realistic exposure conditions. The

1991 and 1993 data sets had fewer and unevenly spread-sampling locations but also included the collection of core samples. None of the sediment data from these different studies were combined in the effect characterization, since they were temporally and spatially different (i.e., collected at different times and from a variety of different depths). In this study, we defined that sediment composited over a depth of 0-15 cm was considered as upper layer sediment, while sediment below 15 cm was considered as deep core sediment. Both upper layer and deep core sediments were screened and compared for the different years of data that were analyzed. The sediment guideline values used in this study are specific to estuarine and marine systems sediment. The PEL values were used in all the analysis except for TCDD analysis. The apparent effect threshold (AET) relates chemical concentrations in sediments to synoptic biological indicators of injury. AET represents the concentration above which adverse biological impact would always be expected and were used to analyze the TCDD chemical concentrations. The PEL and AET are concentrations where effects are more likely to occur in organisms. Using ArcView® software platform, a GIS spatial analysis was designed to map the temporal and spatial extent of the HQs of selected chemicals of concern in this study, for the different years. The HQ quotient expresses the potential for risk to ecological receptors. Risk characterization considered HQs greater than or equal to one to be a potential for adverse effect. In this study, contaminant concentrations in sediment were compared to sediment quality guidelines from various sources (e.g., Environment Canada, 1995; Ingersoll et al., 1996). Both upper layer and core sediments concentrations were mapped to interpret the variations in chemical HQ for the different years.

RESULTS AND DISCUSSION

Metal Contaminants (Cr, Ph, Hg, Ni, and Zn)

The mean concentrations of heavy metals in upper layer and deep core sediments were compiled for the different years (Table 2). As shown in Table 2, the concentrations ranged from 124 to 334 $\mu g\ g^{-1}$ for Cr, 224 to 581 $\mu g\ g^{-1}$ for Pb, 2 to 7 $\mu g\ g^{-1}$ for Hg, 39 to 58 $\mu g\ g^{-1}$ for Ni, and 523 to 788 $\mu g\ g^{-1}$ for Zn.

Historical Hg concentrations in the lower Passaic River on the average have been reported to vary from 0 to 13.2 $\mu g\ g^{-1}$ (Iannuzzi et al., 2002), and from non-detect (< 0.1$\mu g\ g^{-1}$) to 98 $\mu g\ g^{-1}$ (dry weight) (Gillis et al., 1993), depending on the study areas.

Table 1. Sediment Quality for Metals and Organics

Chemical	Ingersoll et al. (1996)				Environment Canada (1995)		Buchman (1999)marine				Buchman (1999)freshwater		
	ERL (ug/g)	ERM (ug/g)	TEL (ug/g)	PEL (ug/g)	TEL (ug/g)	PEL (ug/g)	ERL (ug/g)	ERM (ug/g)	PEL (ug/g)	AET (ug/g)	TEL (ug/g)	PEL (ug/g)	UET (ug/g)
Metals													
Chromium	39	270	36	120	37.3	90	80	370	160.4	62	36.3	90	95
Lead	55	99	37	82	35	91.3	46.7	218	112.2	400	35	91.3	127
Mercury	-	-	-	-	0.174	0.486	0.05	0.7	0.69	0.41	0.17	0.49	0.56
Nickel	24	45	20	33	18	35.9	20.9	51.6	42.8	110	18	35.9	43
Zinc	110	550	98	540	123	315	150	410	271	410	123.1	315	520
Organics													
TCDD 2,3,7,8-	-	-	-	-	-	-	-	-	-	0.0000036	-	-	0.0000088
DDT, total	-	-	-	-	-	-	0.0016	0.046	0.052	0.011	0.007	4.45	0.05

ERL = Effects range-low; ERM = Effects range-median; TEL = Threshold effect level; PEL = Probable effect level; AET = Apparent effect threshold; UET = Upper effect threshold; All sediment values are in dry weight.

Table 2. Maximum and Average Concentrations of Cr, Pb, Hg, Ni, and Zn in Passaic River Sediments

Year	Sediment	**Chromium**				**Lead**				**Mercury**				**Nickel**				**Zinc**			
		Max	Mean	SD	n	Max	Mean	SD	n	Max	Mean	SD	n	Max	Mean	SD	n	Max	Mean	SD	n
1991	Upper layer	402	152	98	33	2200	412	382	33	12.4	4.4	3.0	28	118	50.7	22.2	14	740	562	191	11
	Deep core	1230	188	215	142	3000	359	472	102	29.6	6.1	7.5	102	269	52.7	49.5	102	10200	553	982	142
1993	Upper layer	397	151	97	25	777	340	182	21	6.7	2.6	1.5	21	178	50.8	37.8	25	1800	568	381	25
	Deep core	1530	292	325	55	7860	581	1071	55	28.1	4.3	5.0	54	143	51.5	26.4	55	8630	802	1204	55
1995	Upper layer	589	153	100	95	751	334	147	90	10.7	3.3	1.9	92	369	47.7	42.9	64	1620	596	235	71
	Deep core	2160	334	314	490	22000	505	1286	490	28.3	6.5	5.4	490	309	58.2	35.8	490	3110	788	531	490
1999	Upper layer	202	124	38	58	515	224	98	58	5.8	2.3	1.2	58	57.7	39.2	7	30	680	523	69	30

SD is standard deviation; n is sample size; concentration in $\mu g\ g^{-1}$; upper layer sediment is $\leq$15 cm and deep core sediment is >15 cm.

Historical sources of Hg to the Passaic River include paint and dye manufacturers and combined sewer overflows (CSOs) located along the River and its tributaries (Wenning et al., 1994). Pb and Zn also have elevated concentration throughout the decade. Although the average concentrations of Pb and Zn in upper layer sediments and deep core sediments in the river varied from year to year or sampling to sampling, the highest mean concentrations were 580.7$\mu g\ g^{-1}$ for Pb and 802.3 $\mu g\ g^{-1}$ for Zn found in the deep core sediment from the 1993 sampling (Table 2). Historical Pb concentrations in the lower Passaic River on the average have been reported ranging from 280 $\mu g\ g^{-1}$ to 910 $\mu g\ g^{-1}$ (dry weight) (Bonnevie et al., 1992). Historical Zn concentrations in the lower Passaic River on the average were reported ranging from 30 $\mu g\ g^{-1}$ to 1910 $\mu g\ g^{-1}$ (Iannuzzi et al., 2002). Sources of Pb to the River include smelters, dye and paint manufacturers, and petroleum refineries (Wenning et al., 1994). Sources of Zn include dye and paint manufacturers, and electroplating industries (Wenning et al., 1994). In this study, we found that areas mostly impacted by Ni include Newark, Harrison, and Point-no-Point Reaches of the River. Highest mean concentrations averaged for upper layer sediments and deep core sediments, respectively, were 333.5 $\mu g\ g^{-1}$ for Cr and 58.2 $\mu g\ g^{-1}$ for Ni found in the deep core sediment from the 1993 sampling (Table 2).

With respect to risk assessment, HQ values for Cr, Pb, Hg, Ni, and Zn consistently exceeded 1.0, i.e. above benchmark values, for all of the years. However, deep core sediments (>15 cm) exhibited higher HQ values than upper layer sediments ($\leq$15 cm). For example, for all the metals, Pb and Hg posses the highest risk, with HQ > 268 for Pb and HQ > 58 for Hg in 1995. The trends of metal contaminants over the years show a fluctuating pattern from 1991 to 1999. This may be attributed to the tempo-spatial variation in the sediment sampling points coupled with hydrodynamics and sediment transport within the river system. In all the years in this study, the HQs for the mean concentrations of Cr, Pb, Hg, Ni, and Zn were generally greater than 1.0. Average HQ ranged from 1.1-1.4 for Cr, 2.4-6.3 for Pb, 4.7-13.4 for Hg, 1.4-1.7 for Ni, and 1.6-2.5 for Zn. Of the selected metals, Hg had the highest impact for all the years studied and Pb and Zn had moderate impact while Cr and Ni had the least impact on the Passaic River with respect to toxicity. Mercury (Hg) HQs in upper layer sediments were greater than 10 and up to 20 in all the years and extended to all reaches of the River. Comparably, the deeper core sediments exhibited similar trends for the years with HQs up to 60. Of note is that more than 70% sediment cores, from surface to bottom, in 1995 (Figure 2) were elevated in Hg concentration (10 $\leq$ HQ $\leq$ 60). Figure 3 shows the HQs of Pb in upper layer and deep core sediments. Lead (Pb) in upper layer sediments remained elevated for all the years with HQs up to 20, but declined in 1999 with HQs less than five except for a sample in the Arlington

Reach where HQ remained high. The decrease of HQs found in the 1999 sampling data analysis could be attributed to the outcomes of decades-long environmental management and restoration effort carried out by federal, state, and local agencies and organizations. Few exceptions may be due to continued local input from a metal industry proxy to the sampling location (NJDEP, 2003). The risk potentials of Pb increase in deeper core sediments, reaching a value of HQs ≥ 100 in some locations at Point-no-Point, Harrison, and Newark Reaches (Figure 3). This may be associated with previous industrial waste discharge to the River in an era of poor environmental regulations. The contributions of Cr, Ni, and Zn to the hazard potentials of the lower Passaic River sediments were relatively low compared to Hg and Pb. HQs of these metals (Cr, Ni, and Zn) were less than 20 for both upper layer and deep core sediments (Figures 4 – 6). There appears apparent relationships of "hot spot" from different years and may be due to localized urban sources and/or sediment depositional centers. Of significance is that the "hot spots" of Zn delineated in 1993 where upper layer

sediments were approximately taken from locations that bordered paint, metal tooling, and chemical industries in the Harrison Reach and metal plating industry in the Point-no-Point Reach (Figure 1) (NJDEP, 2003). Similar trends in contamination levels were also observed for other metals and the distinctive lower concentration of nearby sample cores to the "hot-spots" emphasizes the possible contribution of a localized input.

For metal contaminants, it is important to note the ongoing debate in scientific literature on how to evaluate the potential risks of sediment contaminants to aquatic organisms. In some opinion, bioavailability (i.e., contaminant uptake by organisms and subsequent toxicity) is controlled primarily by the dissolved metal concentration in the sediment porewater (e.g., Ingersoll et al., 2000). Proponents of this theory contend that using simultaneously extracted metals/acid-volatile sulfide (SEM/AVS) molar ratios to estimate sediment porewater concentrations for cadmium, copper, mercury, nickel, lead, and zinc (generally present as divalent species) provides a better indicator of sediment
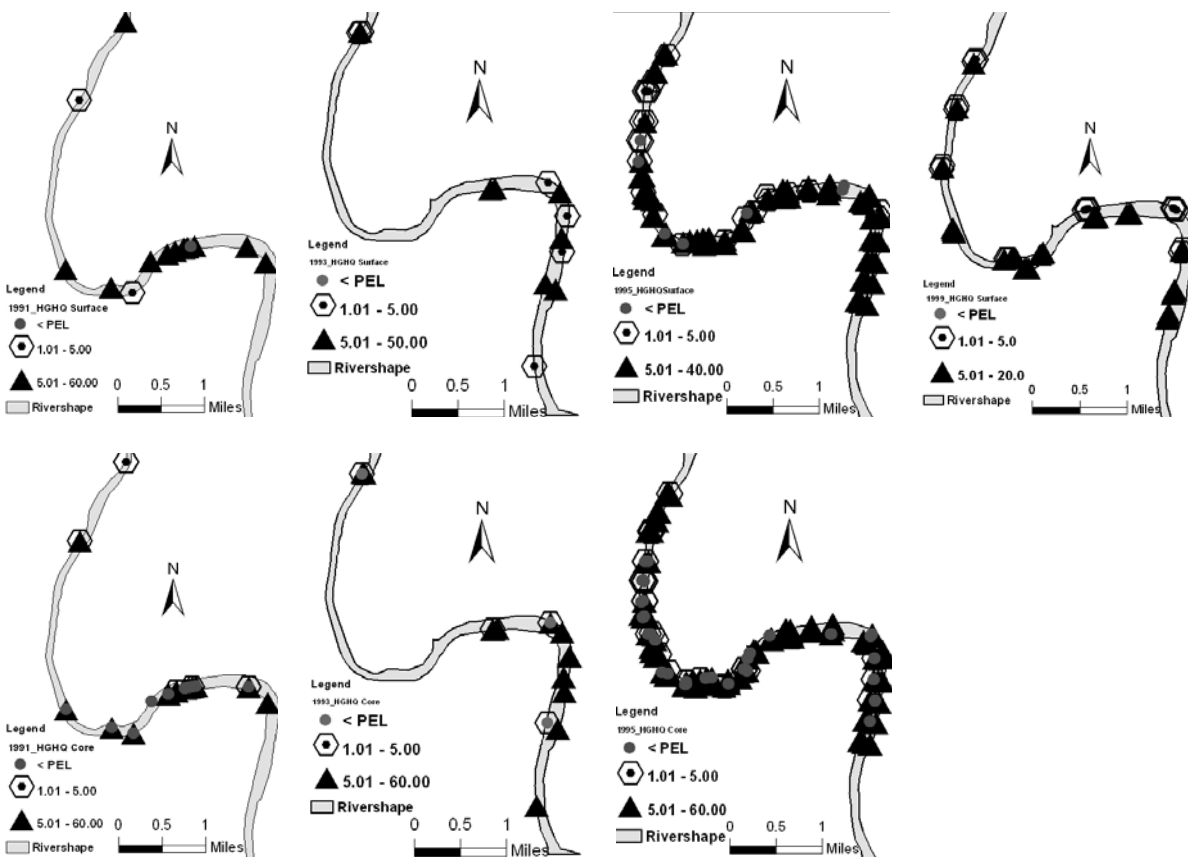

Figure 2. Hazard quotients of Hg. Mercury concentrations are normalized to Probable Effects Level (Environment Canada, 1995). From left to right: Top row 1991, 1993, 1995, and 1999 upper layer sediments (<15 cm) data and bottom row 1991, 1993, and 1995 deep core (>15 cm) data.
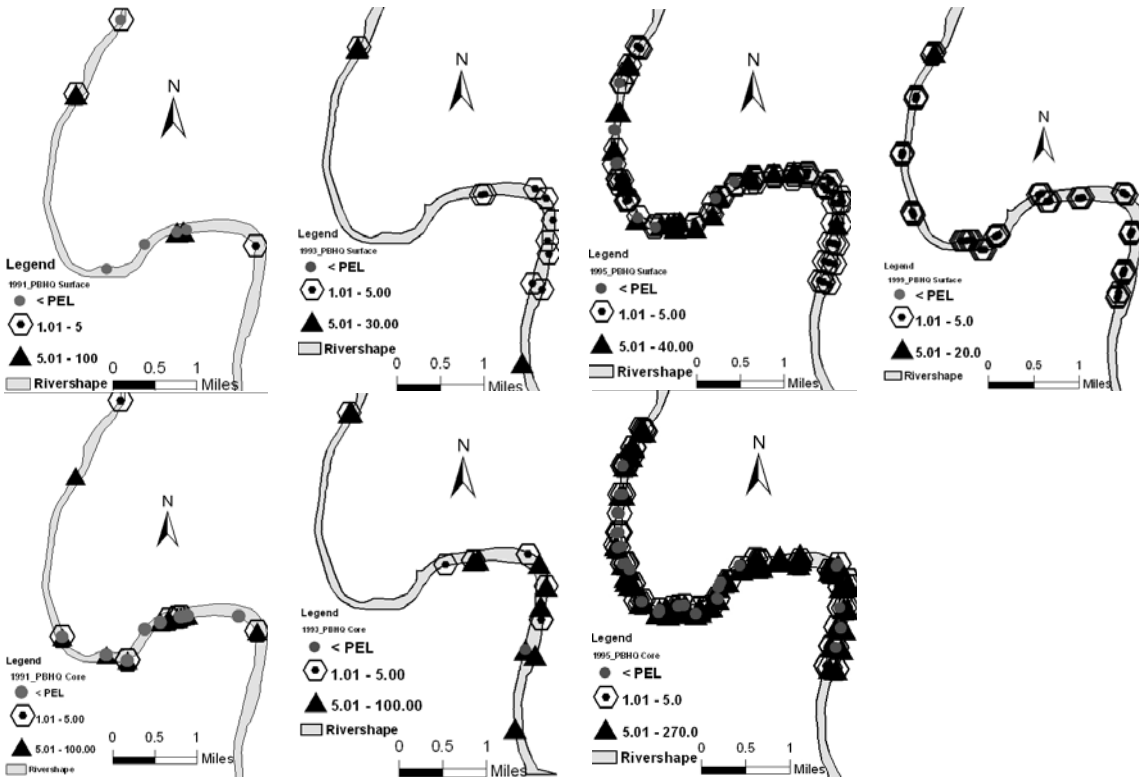
Figure 3. Hazard quotients of Pb. Lead concentrations are normalized to Probable Effects Level (Ingersoll et al., 1996). From left to right: Top row 1991, 1993, 1995, and 1999 upper layer sediments (<15 cm) data and bottom row 1991, 1993, and 1995 deep core (>15 cm) data.
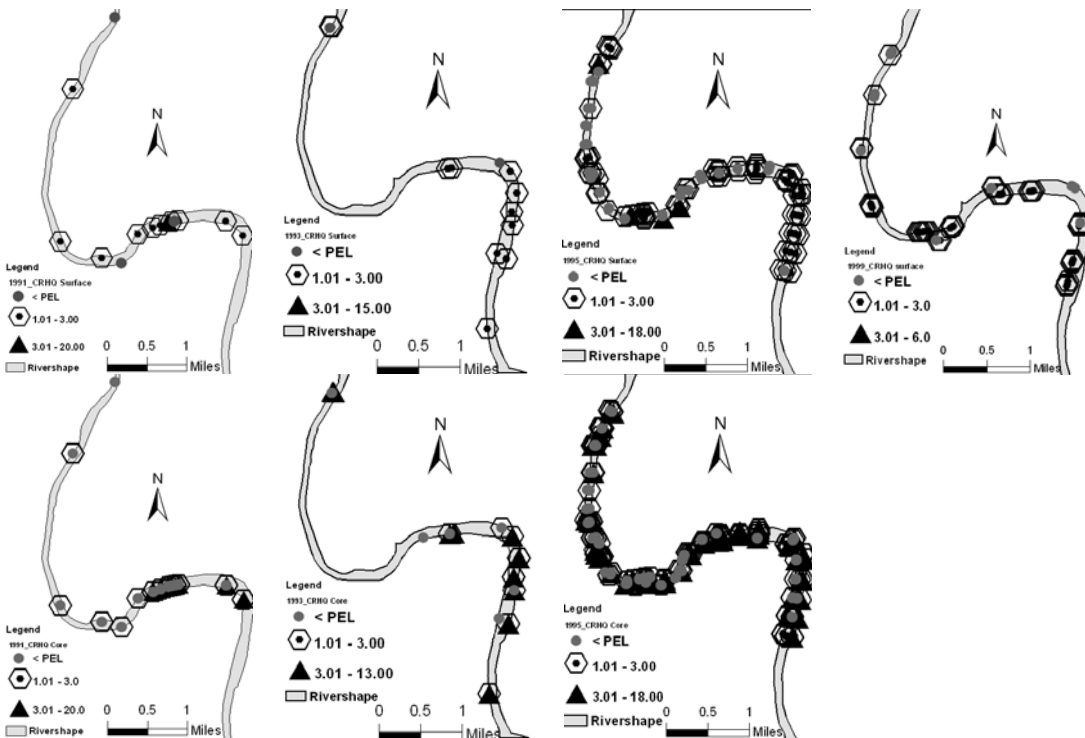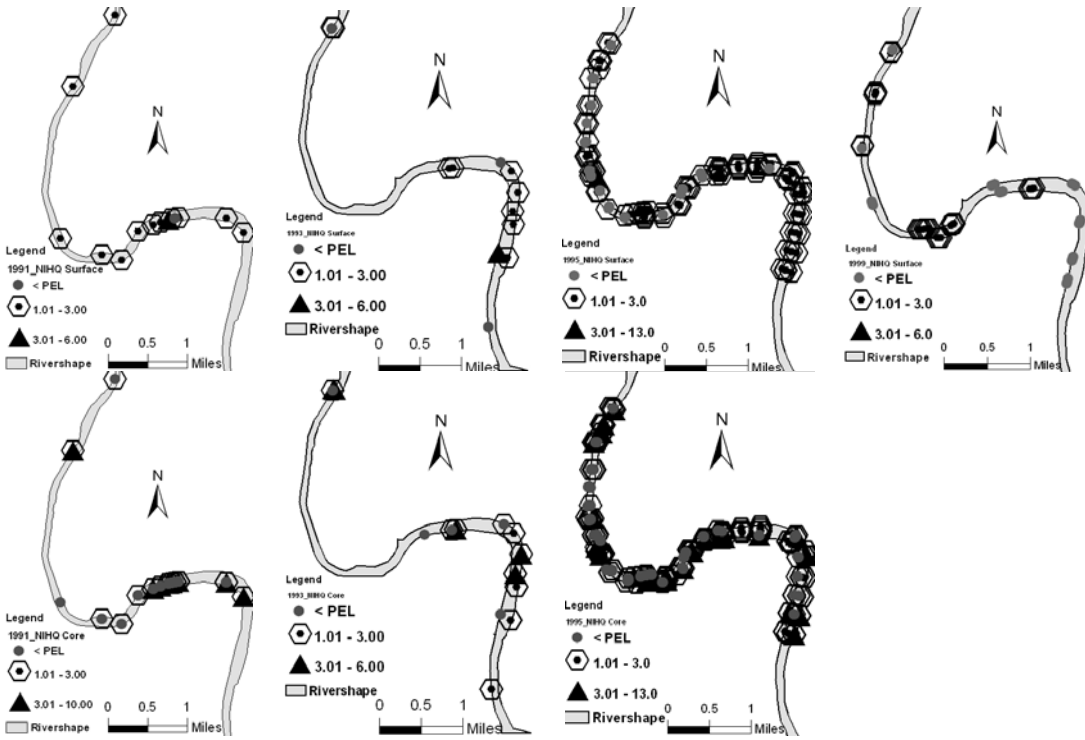
Figure 4. Hazard quotients of Cr. Chromium concentrations are normalized to Probable Effects Level (Ingersoll et al., 1996). From left to right: Top row 1991, 1993, 1995, and 1999 upper layer sediments (<15 cm) data and bottom row 1991, 1993, and 1995 deep core (>15 cm) data.

Figure 5. Hazard quotients of Ni. Nickel concentrations are normalized to Probable Effects Level (Ingersoll et al., 1996). From left to right: Top row 1991, 1993, 1995, and 1999 upper layer sediments (<15 cm) data and bottom row 1991, 1993, and 1995 deep core (>15 cm) data.
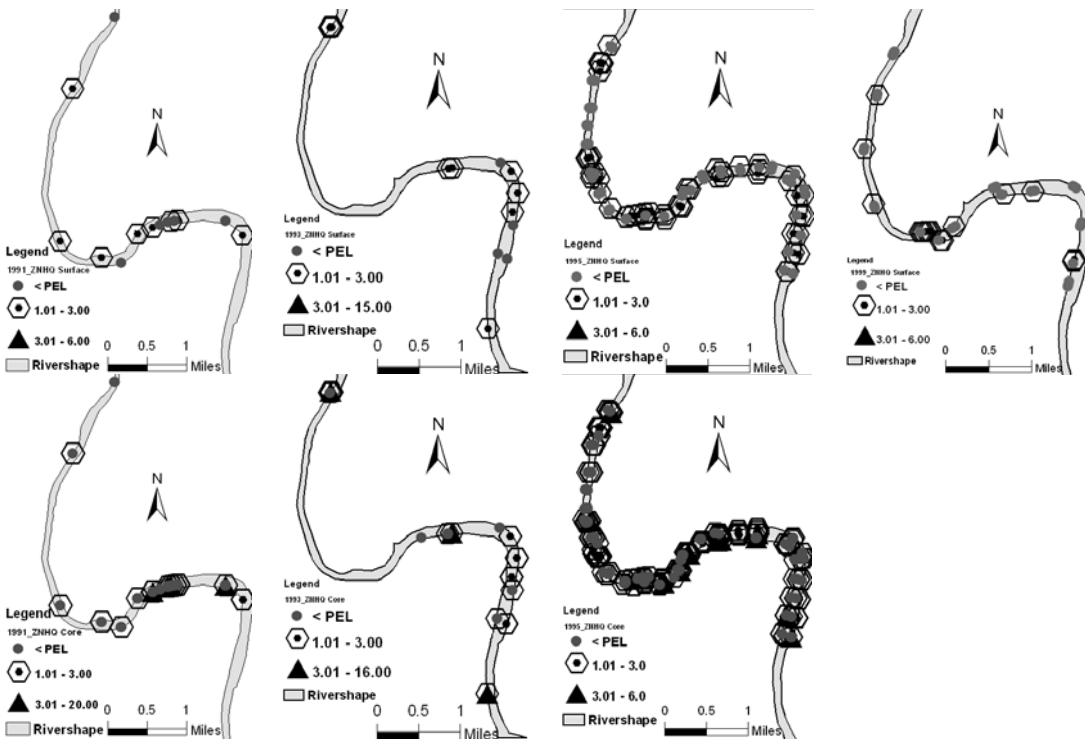

Figure 6. Hazard quotients of Zn. Zinc concentrations in sediments: Data are normalized to Probable Effects Level (Ingersoll et al., 1996). From left to right: Top row 1991, 1993, 1995, and 1999 upper layer sediments (<15 cm) data and bottom row 1991, 1993, and 1995 deep core (>15 cm) data.

toxicity than total metals concentrations on a dry weight basis (DeWitt et al., 1996; Hansen et al., 1996). AVS is usually the dominant-binding phase for divalent metals in sediment. Metal sulfide precipitates are typically very insoluble and this limits the amount of dissolved metal available in the sediment porewater. For an individual metal, when the amount of AVS exceeds the amount of the SEM metal (i.e., the SEM/AVS molar ratio is below one), the metal concentration in the sediment porewater will be low because of the limited solubility of the metal sulfide. For a suite of divalent metals, the sum of the SEM metals must be considered, with the assumption that the metal with the lowest solubility product constant (K_{sp}) value (least soluble) will form the most stable complex with the AVS (DiToro et al., 1992). The other propositions use an empirical approach that matches trace metal sediment chemistry to biological effect data to determine toxic effect levels (Long et al., 1998; Ingersoll et al., 1996; MacDonald et al., 1996). Dietary factors (i.e., sediment ingestion) are an important pathway of biotic uptake for the empirical approach (Lee et al., 2000). Recent articles have reported that although metal concentration in sediment porewater may be controlled by geochemical equilibration with metal sulfides, metal exposure and subsequent toxicity is most likely influenced by sediment ingestion (Long et al., 1998b; Lee et al., 2000).

Organic Contaminants (TCDD and DDT)

The mean concentration of organic contaminants in upper layer and deep core sediments of Passaic River were compiled for the four years: 1991, 1993, 1995, and 1999 (Table 3). Average concentrations varied from 0.003 to 0.02 $\mu g\ g^{-1}$ for TCDDs and 0.14 $\mu g\ g^{-1}$ to 59.4 $\mu g\ g^{-1}$ for total DDTs, showing significant spatial variations across all reaches of the River. The highest concentration of TCDDs was found within the Harrison Reach (Figure

7) and the highest concentration of DDTs was also found within the Harrison Reach (Figure 8). Organic contaminants also show significant variations as same as the metal contaminants. The average concentrations of TCDDs were mostly elevated in 1993 and 1995 samples while total DDT concentration were greatest in 1991 deep core data.

When the average concentration of the organics was compared to the sediment benchmarks, the contribution of TCDDs to the HQ in the Passaic River was over 99% in all the years with HQ values in the order of magnitude of 10^6. TCDDs exceedance in the river was mainly within the Harrison and Newark Reach. HQs of TCDD for upper layer sediments ranged from 5388 to 84444. There was a declining trend on the level of contamination from 1991 to 1999. This could be attributed to remediation actions carried out in the area or natural attenuation. The detail mechanisms are still not clear in this study. Deeper core samples revealed extreme hazard potentials of TCDDs with HQs in 10^6, indicating the exceedance of sediment quality benchmarks over a million times. All of the "hot-spots" for TCDDs were located almost at a single source within the Harrison Reach (Figure 7), which may be highly related to a superfund site on Lister Avenue, Newark City (Bopp et al., 1991). Total DDT HQs indicate a river wide low impact and were below the PEL except for localized "hot-spots" within the Harrison Reach for both upper layer and deep core sediment samples (Figure 8).

The presence of TCDDs in the lower Passaic River analyzed during the study period is considered as the greatest contributor to the potential hazard effects in the river. The spatial distribution of TCDDs in the lower Passaic River shows very high river-wide concentrations with minimum HQs 1000 times above benchmark in all the years of the study period. Maximum average HQ, which was computed as the mean of the HQs for each layer per chemical of concern, was 5555 for TCDDs and was recorded in

Table 3. Maximum and Average Concentrations of TCDD and Total DDT in Passaic River Sediments

Year	Sediment	TCDD				Total DDT			
		Max	Mean	SD	n	Max	Mean	SD	n
1991	Upper layer	0.028	0.007	0.006	33	2.51	0.38	0.58	27
	Deep core	0.095	0.003	0.009	218	16.8	0.4	2.1	109
1993	Upper layer	0.3	0.02	0.06	24	0.83	0.21	0.21	19
	Deep core	0.3	0.006	0.03	114	223	4.4	29.2	57
1995	Upper layer	0.072	0.011	0.01	96	5.98	0.31	0.75	93
	Deep core	5.3	0.02	0.2	955	18600	59.4	951	481
1999	Upper layer	0.019	0.008	0.004	58	1.21	0.14	0.19	43

SD is standard deviation; n is sample size; concentration in $\mu g g^{-1}$; upper layer sediment is ≤15 cm and deep core sediment is >15 cm.
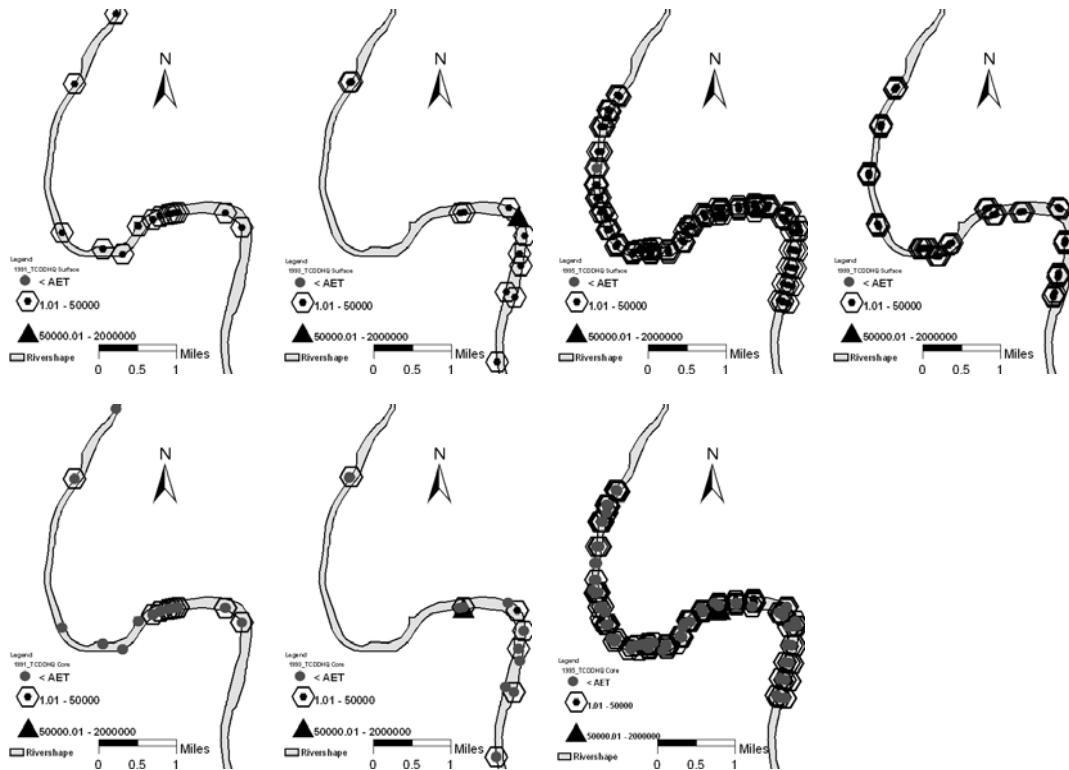
Figure 7. Hazard quotients of dioxin. TCDD 2,3,7,8- concentrations are normalized to Apparent Effects Threshold (Buchman, 1999). From left to right: Top row 1991, 1993, 1995, and 1999 upper layer sediments (<15 cm) data and bottom row 1991, 1993, and 1995 deep core (>15 cm) data.
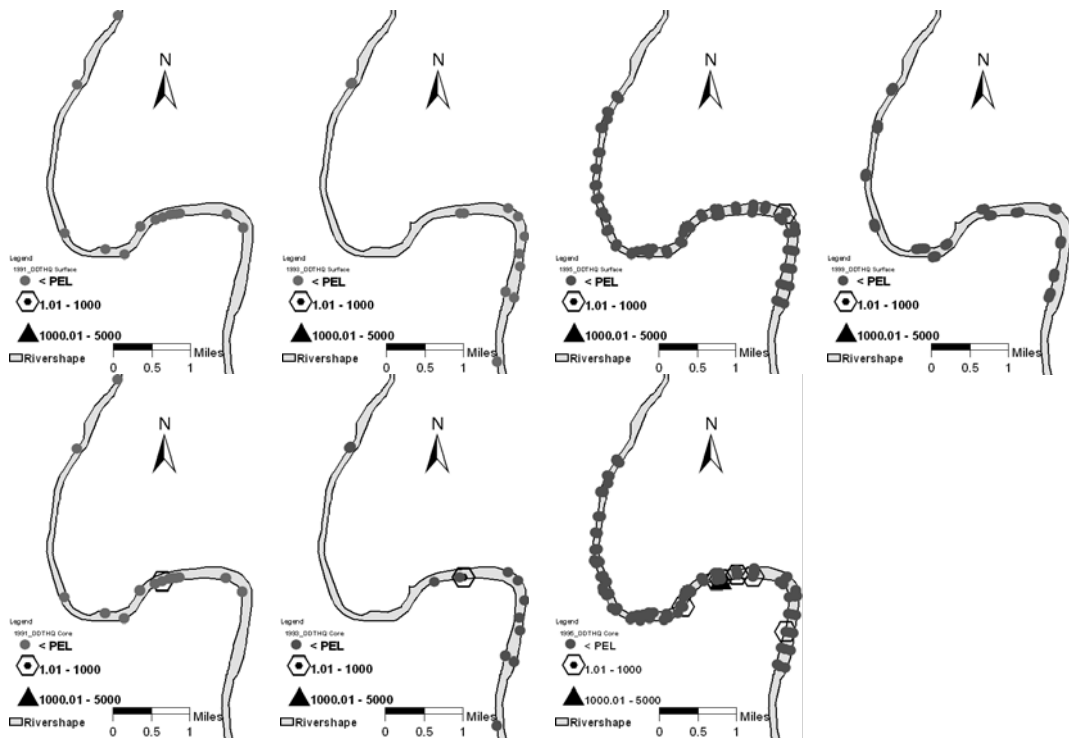

Figure 8. Hazard quotients of DDT. Total DDT concentrations are normalized to Probable Effects Level (Ingersoll et al., 1996). From left to right: Top row 1991, 1993, 1995, and 1999 upper layer sediments (<15 cm) data and bottom row 1991, 1993, and 1995 deep core (>15 cm) data.

the 1991 deep sediment, 1993 upper layer sediment, and 1995 deep core sediments with mean concentration of 0.02 µg g^{-1}. Historically, a TCDDs concentration in the lower Passaic River was reported to range from 0.0042 to 0.023 µg g^{-1} (Wenning et al., 1993b). Sources of dioxin in the environment include waste-burning incinerators and point source industrial discharges. The presence of TCDDs has drawn considerable attention and several researchers have reported that the spatial distribution of TCDDs in the Passaic River does not indicate any single source (Finley et al., 1990; Gills et al., 1995; Wenning et al., 1993a, 1993b). Total DDTs impact was limited to the Harrison Reach with HQs greater than 90 (HQ > 90). Average maximum HQ of 13.4 and average concentrations of 59.4 µg g^{-1} were recorded in 1995 deep core samples. Historical concentration of total DDTs ranged from 0.006 µg g^{-1} to over 300 µg g^{-1} (Iannuzzi et al., 2002). Sources of DDTs to the Passaic River include multiple pesticide manufacturing facilities (Gillis et al., 1995).

CONCLUSIONS

The results from this study indicate that organic and inorganic chemicals (such as TCDDs, total DDT, Cr, Pb, Hg, Ni, and Zn) heavily contaminated upper layer sediments of the lower Passaic River throughout the 1990s. There exist elevated and potential toxic substances in the River with highest concentrations in the 1993 and 1995 analysis. The concentrations of metals, total DDTs, and TCDDs showed a general decreasing trend by 1999; however, these chemicals were present in elevated concentrations compared to the sediment quality benchmarks. The variations in contaminant concentrations from year to year could be a reflection of spatial variability due to proximity to anthropogenic sources as well as various diverse arrays of land uses and river hydrodynamics. It could also be a result of data gaps with depth and different sampling station layout and density for each year sampling campaign. The spatial extent of the 1995 and 1999 sampling locations were far reaching with a better river-wide coverage, than the 1991 and 1993 sampling programs. More so, the depth of core recovery and sectioning was inconsistent from year to year, thus, limiting the accuracy of interpreting contaminant signatures in deep cores.

The results of this study also indicate that concentrations of contaminants of interest are above sediment quality guidelines, posing danger to the ecosystem. While the results should be interpreted with caution because of the conservative assumptions in sediment quality guidelines, they do allow a relative comparison of the potential risks by river reach, and they show contributions from the selected chemicals of concern. It is imperative to note that the resulting risk estimates from this study, are not toxicity thresholds i.e. there is no assurance that samples with HQ values greater than one (HQ > 1) will be toxic. In this study, the Harrison Reach in the lower Passaic River is identified as the river segment posing the greatest potential risk for all chemicals analyzed while TCDDs and Hg are identified as the primary drivers of potential risk in all reaches of the lower Passaic River. "Hot spots" and localized areas of contamination identified in this study can be applied in prioritizing areas for remediation and type of remediation. While the 1999 data had the lowest concentrations for all toxic chemicals analyzed, the chemicals of concern remain present at elevated concentrations indicating continued pollution sources like combined sewer overflows, urban runoff, and point source discharges. Further, this study demonstrates that GIS not only can be applied as an analytical tool, but also provides a means of communicating results in the simplest possible way to gain a better perspective and understanding of contamination in the Passaic River. It also supports information management tools needed for the strategic development of environmental management and restoration.

Based on the results from this study, it is recommended that further investigation should be focused on characterizing the present state of contamination in the river, in a spatially consistent manner. Also, investigation on the physical properties (e.g. grain size, organic carbon) that controls contaminant variability and sediment accumulation rates will improve the delineation of contaminant hot spot and source.

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