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Review Article

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A Spatial Scale Assessment of Depositional Areas in Mid-West Water Bodies: Implications for Ecological Risk of Hydrophobic Organic Compounds

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Abstract
This study was designed to summarize grain size data (% sand, % silt and % clay) from mid-west United States water bodies to determine the percent of sites where sediment samples are primarily depositional sediment (more than 50% silt/clay) or non-depositional (less than 50% silt/clay). Sediment sampling protocols were reviewed for all the grain size measurements to determine if non-random or random sampling was conducted. Based on four studies with a total of 269 sites, the mean percent of sites dominated by the silt/clay fraction was approximately 5%. This value is very low and certainly shows that depositional areas are spatially limited in mid-west water bodies. The ecological relevance of this result is that silt/clay areas where Hydrophobic Organic Compounds (HOCs) may be found are spatially limited for mid-west water bodies. Before judging HOC ecological risk it is critical to know how sites for sediment collection were selected, using either a non- random or random approach, and this information also needs to be carefully considered when assessing potential ecological risk of HOCs in ambient mid-west sediment. A random sampling design on a watershed scale that includes spatially extensive sediment mapping is recommended in areas where HOC ecological risk is suspected.

Keywords: Mid-West Streams, Depositional Areas, Hydrophobic Organic Compounds, Grain Size

Introduction
Human activities in catchments have resulted in increased delivery of fine grain sediments to flowing water bodies such that loading of fine sediments to many lotic systems now exceeds background conditions [1, 2]. Loading for fine grain material has important ecological risk implications because the grain size of sediment particles (i.e., gravel, sand, silt and clay) can impact the sorptive behavior of hydrophobic organic compounds (HOCs) such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and synthetic pyrethroids [3-5]. If sources exist, HOCs are known to accumulate in fine grain silt/clay depositional areas in sediment [5-8]. A key to determining the environmental fate and possible ecological effects of HOCs lies in an understanding of the spatial extent of fine grain depositional areas in water bodies that may be impacted by these chemicals [9].

Five spatially extensive sediment mapping studies have been conducted where the percent depositional area in wadeable streams has been reported [10-12]. Results from four of these extensive sediment mapping studies conducted in California streams showed that depositional areas ranged from from 4 to 24 % of the wetted stream bed with a mean value of 12 % across all streams [10, 11]. Another spatially extensive sediment mapping study was also conducted in an agricultural mid-west stream in 2017 (Big Bureau Creek, Illinois) and the results from this study showed that the mean percent depositional area was only 3.5% of the stream bed [12]. In addition to the 5 detailed sediment mapping studies reported above, a recent historical review study was also conducted where grain size data from 1993 to 2016 from California water bodies was summarized and percent of sites where sediment samples are primarily depositional sediment (more than 50% silt/clay) or non-depositional sediment (less than 50% silt/clay) was reported [9]. Based on 23 years of data from 685 sites (1,859 observations) in all 9 California Regions, the summary analysis showed that only 58% of the sites were considered depositional areas even when targeted sampling for depositional areas was used [9]. Since only slightly more than half the sites were reported as depositional areas based on sampling that targets depositional areas, these results would certainly suggest that depositional areas are not dominant. In fact, for the one protocol where random sampling was used depositional areas were not reported to be dominant. From an ecological risk perspective, the implication of this finding is that HOCs would not be expected to accumulate in the dominant type of sediment found in most California water bodies [9].

It is unknown if the results from the above California studies would apply to other areas of the United States, such as the mid-west, although we do have at least one creek-specific detailed mapping study for this geographic area that would suggest depositional areas are spatially limited [12]. Therefore, this open question provides a compelling reason for conducting a comprehensive mid-west grain size study to access the spatial scale of depositional areas where HOCs could accumulate if sources exist.

The objective of this study was to obtain and summarize the grain size data (% sand, % silt and % clay) from the United States Geological Survey (USGS), the United States Environmental Protection Agency (USEPA), other mid-west state organizations and our data (University of Maryland) from mid-west studies to determine the number and percent of sites where sediment samples are primarily depositional sediment (more than 50% silt/clay) or non-depositional (less than 50% silt/clay or primarily sand or larger grain material). Sediment sampling protocols were reviewed for all the grain size measurements to determine if non-random sampling based on various criteria or random sampling was conducted. Data were organized in a tabular format and presented using maps by appropriate geographic region for mid-west sites.

Methods

Depositional areas were generally defined as grain size with < 63 µm fraction that would represent both silt and clay as defined by Gordon et al. [13]. Therefore, for this study sediment samples were considered depositional sediment (more than 50% silt/clay) or non-depositional (less than 50% silt/clay or primarily sand or larger grain material). The < 63µm fraction of the suspended sediment bed load has been documented to have an increased importance in biogeochemical fluxes within a water body because this is the chemically active component of the solid load and many Hydrophobic Organic Compounds (HOCs) are transported with this fraction [14].

The general sources used to obtain grain size data from mid-west states were as follows: USGS; USEPA; mid-west State Regulatory and Resource Agencies; and the University of Maryland. Based on an extensive review of historical grain size literature, four specific studies were identified in mid-west states that were useful for completing the goals of this study. These four studies were the Ohio Fluvial Study, the Ohio Bank full study, USGS 2013 mid-west study and the Big Bureau Creek Illinois sediment mapping study [12, 15-17]. A brief description of these studies along with the specific methods used to obtain grain size data from each of these studies is described below.

Ohio Fluvial Study

In October 1969, the U.S. Geological Survey, in cooperation with the Ohio Department of Natural Resources, established a fluvial sediment inventory network to provide sufficient data so that quantities and characteristics of fluvial sediment could be defined on a statewide basis [15]. Fluvial sediment includes sediment that has been deposited in beds by water. The network consisted of streamflow stations that met the following criteria: wide geographical distribution, representation of major soil associations, and unregulated flow conditions. Sediment and related data were collected at sites on an intermittent basis in early fall at each station for the 5-year period from 1969 to 1974.

Bed material was sampled for particle-size analysis by the dry-sieve method. Material larger than very coarse gravel was not sampled so a field approximation was made of the representativeness of the unsampled material. At a given cross section, the number of samples varied with the lateral distribution of the bed material size. Stations with a uniform lateral distribution of bed material size were sampled only once. Average grain size of the streambed at a station was evaluated by incorporating particle-size distributions from samples, field approximations of coarser material, and the percentage of bedrock. Percent of silt/clay (<63 µm) in surface sediment from 48 selected Ohio stream sites in Figure 1was calculated.

Ohio Bank full Study

In August 2000, the U.S. Geological Survey (USGS), in cooperation with the Ohio Department of Transportation (ODOT) and the U.S. Department of Transportation, Federal Highway Administration (FHWA), began a study to collect geomorphic data at 50 unregulated natural alluvial streams in Ohio [16]. Criteria were developed to guide the site-selection process. Some of the following characteristics were considered desirable for this study: active gaging station; relatively small drainage area (0 to 50 mi2) for most sites; unregulated streamflow at flows near bank full discharge; predominantly rural land use in the drainage basin; alluvial sediments at the sample sites (no bedrock channels); natural channel at the study site (not affected by human influences such as dredging, channelization, straightening, or restoration); and an equal distribution of the 50 selected sites in Figure 1 throughout Ohio as well as equal distribution among physiographic provinces and sections.

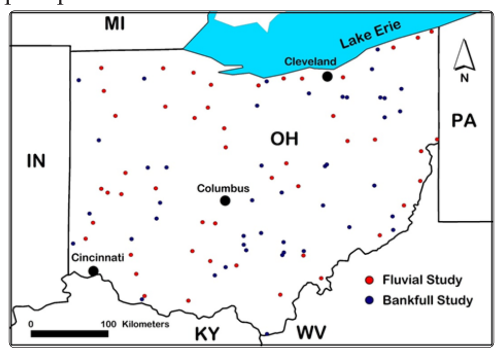

Figure 1: Map showing grain size locations for Ohio Fluvial Study and Ohio Bankfull Study

Five cross sections that were representative of the general physical characteristics of the stream were surveyed at most of the 50 study sites throughout the state of Ohio. Fewer than five cross sections were surveyed at some study sites where conditions for the surveying of five cross sections were unsuitable. Bed-material particle size was sampled at each cross section by means of Wolman pebble counts [18]. Bed material was sampled in a random grid pattern so that samples were equally distributed within the sample area. Sampling was conducted between June-September of 2002 and although the study was not specifically designed to be representative of sediment grain size (deep pools and bedrock avoided) the predominate geophysical aspects of the stream site was represented in the cross sections. Percent of silt/clay (<63 µm) in surface sediment from 50 selected Ohio streams was calculated.

USGS 2013 Midwest Study

Grain size data was obtained from the Midwest Regional Stream Quality Assessment Program (MSQA) [19]. This study of about 100 sites was conducted in collaboration with the USEPA National Rivers and Streams Assessment Program (NRSA). Methods for the study are described in Garrett et al. [20].

The MSQA design focused on effects from the widespread agriculture in the region and urban development because of their importance as ecological stressors of particular concern to Midwest region resource managers. A combined random stratified selection and a targeted non-random selection based on land-use data were used to identify and select sites representing gradients in agricultural intensity across the region. The MSQA region overlies the Midwestern agricultural region dominated by corn and soybean cultivated crops and comprises parts of 12 States, with an area of about 600,000 km2. The area covers large parts of Illinois, Indiana, Iowa, southern Minnesota, northern Missouri, and western Ohio, plus portions of northeastern Kansas, western Kentucky, eastern Nebraska, southeastern South Dakota, southeastern Wisconsin, and a small extension into southern Michigan (although no sampling sites were in Michigan). During a 14-week period from May through September 2013, sites were selected and sampled for contaminants, nutrients, and sediment.

One of the USEPA responsibilities from the study was to assess the stream sediment surface for grain size in the field (21 transects per site) such that the % of the stream bed that was composed of fines (defined as sand/silt/clay) was determined as well as all larger particle sizes (gravel/boulders/logs etc.). These data were available online [17, 21]. Though the % of the stream that was just silt/clay could not be directly determined there was grain size data available for sediment samples from the same sites during the same study that targeted sand/silt/clay as well. These grain size samples were representative of all the fine sediment (sand/silt/clay) and the USEPA analysis provided the mean % of the site surface that was sand/silt/clay. Therefore, a correction factor (ratio of surface sediment composed of fines) was used to multiply by the % grain size that was just silt/clay to determine an approximate % of the stream bed that was composed of silt/clay sediment.

For example, a USEPA crew might have established that a particular stream segment had a mean % of the sediment surface that was 50% sand/silt/clay. A USGS crew draws multiple sediment samples from the same sand/silt/clay portion of the same segment because the crew is purposely trying to pull a representative sample from the sand/silt/clay portion of the segment. Grain size analyses of the USGS composite sample from that same segment shows that 40% of it is silt/clay (<63 µm). If 50% of the segment area was sampled using a representative approach by USGS because it is sand/silt/clay and 40% of that sample is silt/clay, then 0.50 (segment area) x 40% (silt/clay grain size) = 20% of the segment surface area that is approximately silt/clay. This calculation was recommended by USGS for calculating the silt/clay portion. Although 100 stream sites were included in the MSQA sample regime only 96 of the sites with % fines sediment surface overlapped with the % silt/clay grain size data. The location of these sites is presented in Figure 2.

Big Bureau Creek Illinois Sediment Mapping Study

Unlike the other three studies described above, the Big Bureau Creek Sediment Mapping Study was an intensive creek-specific mapping investigation in one representative mid-west agricultural creek. Big Bureau Creek is located in Bureau County Illinois. Big Bureau Creek discharges into the Illinois River which in turn discharges into the Mississippi River. The dominant land use surrounding this water body is agriculture. Approximately 48 km of this stream was sampled from 12 sites during a bioassessment multiple stressor study described in Hall et al. Therefore, the sediment mapping work described in the Hall et al. a report used for this study included this 48 km reach [22].

The % of depositional (fine grain material) and non-depositional (larger grain material such as sand) areas in Big Bureau Creek was determined using a coarse wetted stream mapping approach as described in detail in Hall et al. The entire wetted stream length (~48 km) was mapped from areas that were accessible by the field crew based on landowner permissions, by using a stratified random mapping design [10]. Big Bureau Creek was separated into three approximately equal segments – lower, middle and upper – and 25 samples from transects were randomly collected from each segment to ensure equal distribution of sample sites (total of 75 transects). A grid tool (1 x 1 m) described in Hall et al. was used to visually determine the predominant substrate type (depositional versus non-depositional areas) in the wetted stream bed of the study sites [23]. The cut point used for the mapping work was 50% as used for other stream mapping as described in Hall et al. [10]. Transects with > 50% depositional area (silt and clay) were defined as depositional areas. Areas less than 50% fine grain material and dominated by sand, gravel or larger grain material were classified as non-depositional areas. Transects ranged in width from 3.4 to 24. 8 m. The percent silt/clay for the 75 transects was calculated and the location of Big Bureau Creek is presented in Figure 2.

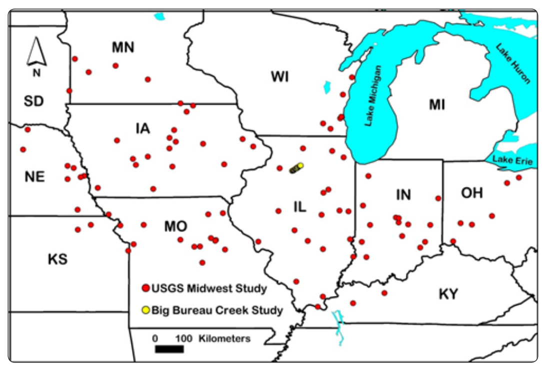

Figure 2: Map showing grain size locations for USGS 2013 Midwest study and the Big Bureau Creek, IL mapping study

Results And Discussion

Ohio Fluvial Study

The percent silt/clay data from 48 Ohio sites in Figure 1 sampled from early fall from 1969 to 1974 is presented in Table 1 [15]. The percent silt/clay based on non-random sampling for the various sites ranged from 0 to 42% with a mean value of 3.96 % for all the sites. There were no sites where the 50% silt/clay cut point was exceeded and for 24 sites the % silt/clay value was zero. These data clearly show that depositional areas are spatially limited in all areas sampled for this study within the state of Ohio.

Table 1: Mean percent silt/clay in surface sediment from 48 selected Ohio stream sites from the Ohio Fluvial Study (Anttila and Tobin [15] 1978). Sites were sampled in early fall of 1969-1974

Site Name	% Silt/Clay (<63 µm)	Latitude	Longitude
Ashtabula River near Ashtabula OH	1[a]	41.85561	-80.76203
Auglaize River near Defiance OH	0	41.23755	-84.39911
Auglaize River near Fort Jennings OH	1[a]	40.94866	-84.26606
Big Darby Creek at Darbyville OH	2	39.70062	-83.11019
Black River at Elyria OH	0	41.38032	-82.10459
Blanchard River near Findlay OH	0	41.05589	-83.68799
Captina Creek at Armstrongs Mills OH	0	39.90868	-80.92398
Chippewa Creek at Easton OH	16	40.94644	-81.74291
Conneaut Creek at Conneaut OH	0	41.92700	-80.60397
Cuyahoga River at Independence OH	1[a]	41.39533	-81.62985
Deer Creek at Mount Sterling OH	0	39.71506	-83.25714
East Fork Little Miami River near Marathon OH	0	39.11451	-84.02465
Grand River near Madison OH	1[a]	41.74061	-81.04649
Great Miami River at Sidney OH	1	40.28699	-84.14994
Great Miami River at Troy OH	14	40.04033	-84.19772
Greenville Creek near Bradford OH	23	40.10227	-84.42995
Hocking River at Athens OH	0	39.32896	-82.08764
Huron River at Milan OH	1[a]	41.30089	-82.60823
Kokosing River at Millwood OH	0	40.39756	-82.28571
Little Beaver Creek near East Liverpool OH	0	40.67590	-80.54062
Little Muskingum River at Bloomfield OH	12	39.56313	-81.20372
Mad River near Urbana OH	0	40.10756	-83.79910
Maumee River at Waterville OH	0	41.50005	-83.71271
North Fork Licking River at Utica OH	10	40.22979	-82.45488
Ohio Brush Creek near West Union OH	0	38.80368	-83.42102
Olentangy River at Claridon OH	36	40.58284	-82.98880
Paint Creek near Bourneville OH	4	39.26368	-83.16685
Paint Creek near Greenfield OH	0	39.37923	-83.37547
Portage River at Woodville OH	1[a]	41.44950	-83.36132
Raccoon Creek at Adamsville OH	2	38.87361	-82.35583
Sandusky River near Bucyrus OH	0	40.80367	-83.00574
Sandusky River near Fremont OH	0	41.30783	-83.15881
Sandusky River near Mexico OH	0	41.04422	-83.19492
Sandy Creek at Waynesburg OH	0	40.67256	-81.25983
Scioto River at Higby OH	6	39.21229	-82.86379
Sevenmile Creek at Collinsville OH	0	39.52311	-84.61078
Shade River near Chester OH	2	39.06369	-81.88180
Short Creek near Dillonvale OH	9	40.19340	-80.73425
Stillwater River at Pleasant Hill OH	1	40.05783	-84.35606
Sugar Creek above Beach City Dam at Beach City OH	2	40.65673	-81.57679
Tiffin River at Stryker OH	42	41.50450	-84.42967
Todd Fork near Roachester OH	0	39.33534	-84.08660
Twin Creek near Ingomar OH	0	39.70783	-84.52495
Tymochtee Creek at Crawford OH	0	40.92283	-83.34881

Vermilion River near Vermilion OH	1[a]	41.38199	-82.31683
Wakatomika Creek near Frazeysburg OH	0	40.13257	-82.14792
White Oak Creek near Georgetown OH	0	38.85812	-83.92854
Yellow Creek near Hammondsville OH	1a	40.53784	-80.72508
Mean of all Sites	3.96		
[a] Original data point listed as <1 but converted to 1 for mean calculation.			

Ohio Bank full Study

The percent silt/clay data from 50 Ohio sites in Figure 1 sampled from 2000 to 2005 are presented in Table 2 [16]. The percent silt/clay based on non-random sampling for the various sites ranged from 0 to 54.2% with a mean value of 5.2% for all sites. There was only one site where the 50% silt/clay cutoff was exceeded and for 12 sites the % silt/clay value was 1% or less. These data are very similar to the data presented above for the Ohio Fluvial Study thus demonstrating that silt/clay areas sampled during this study are spatially limited within the State of Ohio.

Table 2: Mean percent silt/clay in surface sediment from 50 selected Ohio stream sites from the Ohio Bankfull Study (Sherwood and Huitger [16] (2005). Sites were sampled in 2000-2005

Station Name	% Silt/Clay (<63 µm)	Latitude	Longitude
Beaver Creek near Springfield	7.1	39.94056	-83.74889
Beech Creek near Bolton	3.8	40.93056	-81.14722
Big Creek at McClure	9.8	41.38111	-83.93250
Big Four Hollow Creek near Lake Hope	0.0	39.36333	-82.31417
Blake Run near Reily	8.2	39.46639	-84.75611
Bokengehalas Creek near De Graff	2.5	40.34722	-83.89111
Bull Creek near Adelphi	0.5	39.45306	-82.77944
Chagrin River at Fullertown	0.3	41.49056	-81.29444
Clear Creek near Rockbridge	2.3	39.58833	-82.57861
Crooked Creek at Alma	1.0	39.19194	-82.99028
Dry Run near Bangs	0.6	40.37139	-82.57333
Eagle Creek at Phalanx Station	1.5	41.26111	-80.95444
Etna Creek at Etna	9.8	39.96889	-82.68194
Gallman Creek near Monticello	15.6	40.66528	-84.45833
Grand River near Painesville	1.0	41.71889	-81.22806
Greenville Creek near Bradford	1.6	40.10222	-84.43000
Hayden Run near Haydenville	1.0	39.48250	-82.31833
Higgins Run near Higginsport	3.3	38.81944	-83.95778
Hinkley Creek at Charlestown	1.2	41.15444	-81.14750
Keith Fork at Keith	4.2	39.65694	-81.55611
Licking River near Newark	1.0	40.05917	-82.33972
Little Mill Creek near Coshocton	3.6	40.38417	-81.81778
Little Mill Creek near Coshocton	3.2	40.36417	-81.83889
Mad River at Zanesfield	5.2	40.35028	-83.67444
Mill Creek near Berlin Center	0.0	41.00028	-80.96861
Mill Creek near Chauncey	0.4	39.37944	-82.08444
Neff Run near Litchfield	18.5	41.20917	-82.02389
No Name Creek at No Name	0.0	39.09778	-83.11528
North Fork at Bath Center	3.7	41.16889	-81.63444
North Fork Massie Creek at Cedarville	8.7	39.75694	-83.79028
Ohio Brush Creek near West Union	3.2	38.80361	-83.42111
Old Woman Creek at Berlin Road near	12.2	41.34833	-82.51389

Price Creek near Brennersville	0.0	39.81389	-84.56694
Salt Creek at Tarlton	1.6	39.55556	-82.78083
Salt Creek near Chandlersville	2.2	39.90861	-81.86056
Sandusky Creek near Burlington	1.4	38.41750	-82.51000
Sandusky River near Bucyrus	1.4	40.80361	-83.00583
Sandy Run near Lake Hope	1.0	39.33361	-82.33222
Shade River near Chester	7.5	39.06361	-81.88194
Skull Fork near Londonderry	54.2	40.13944	-81.26667
Tar Hollow Creek at Tar Hollow State Park	4.6	39.38944	-82.75083
Tiffin River at Stryker	27.1	41.50444	-84.42972
Trail Run near Antioch	1.7	39.62472	-81.04833
Unnamed tributary to Lost Creek near	6.3	41.36167	-84.69111
Walnut Creek near Boughtonville	5.1	41.06722	-82.62556
Wayne Creek at Waynesville	1.4	39.51889	-84.07972
West Branch Mahoning River near Ravenna	3.2	41.16139	-81.19722
Wood Run near Woodsfield	0.8	39.78222	-81.05583
Yellow Creek at Botzum	4.7	41.16306	-81.58389
Yellow Creek near Hammondsville	1.0	40.53778	-80.72528
Mean of all Sites	5.20		

USGS 2013 Mid-west Study

The percent silt/clay data from 96 mid-west sites shown in Figure 2 from 12 states sampled using combined stratified random and targeted non-random criteria based approach in the late summer of 2013 is presented in Table 3 [17]. This study provided a more robust spatial scale covering 12 states than the two Ohio studies discussed above. The percent silt/clay ranged from 0.06 to 43 % with a mean value of 8.01% for all 96 sites. There were no sites where the 50% silt/clay cutoff was exceeded and for 22 sites the % silt/clay value was 2% or less. The mean percent silt/clay reported from this study is slightly higher than values reported above for Ohio but the 8.01% mean value would still be considered low and support the finding from the Ohio studies that depositional areas are spatially limited throughout mid-west states.

Table 3: Mean percent silt/clay values from 96 sites throughout the Midwest from the USGS 2013 Midwest Study. Percent silt/clay was calculated from percent of stream surface that has fine sediment and percent of particle sizes < 63 µm [17]. Sites were sampled in late summer of 2013

Site Name	% Silt/Clay	Latitude	Longitude
Allison Ditch near Vincennes, IN	2.00	38.71778	-87.59436
Bear Creek nr Gilliam, MO	2.28	39.25114	-93.00928
Beaver Creek at Bouton, IA	6.40	41.84925	-94.02828
Beaver Creek at Glendon, IA	2.97	41.58925	-94.40161
Beck Creek at Herrick, IL	10.8	39.21556	-89.02056
Bell Creek near Arlington, NE	25.9	41.49312	-96.34804
Big Darby Creek at Prairie Oaks nr Lake Darby, OH	4.20	39.99507	-83.25379
Big Pine Cr at Co Rd N125E nr Williamsport, IN	2.10	40.31744	-87.29176
Big Raccoon Creek at Ferndale, IN	2.48	39.71117	-87.07128
Brushy Creek near Cameron, MO	19.3	39.71513	-94.15640
Cedar River at 100th St. near Lyle, MN	3.76	43.51422	-93.00286
Cedar River at Lancer Avenue at Osage, IA	1.50	43.25372	-92.81203
Clear Creek near Jeisyville, IL	13.1	39.54639	-89.43500
Cole Creek near Hardin, IL	14.0	39.19333	-90.56972
Contrary Creek nr St. Joseph, MO	36.6	39.69756	-94.88753
Eagle Creek at Zionsville, IN	2.66	39.94643	-86.26027

Elkhorn River near Oakdale, NE	6.00	42.06927	-97.93312
Fall Creek at 16th Street at Indianapolis, IN	0.61	39.78878	-86.17747
Fish Branch near Mexico, MO	1.43	39.24537	-91.89452
Florida Creek at 171st Ave near Marietta, MN	8.55	44.90222	-96.30928
French C at Parallel Rd, Onaga, KS	4.44	39.56611	-96.21669
Galum Creek near Pyatts, IL	8.00	37.94444	-89.37972
Goodwater Creek nr Centralia, MO	3.19	39.30429	-92.05239
Green River near Hooppole, IL	9.00	41.48639	-89.90028
Herget Drainage Ditch near Kilbourne, IL	19.0	40.14889	-89.93889
Hodge Ditch Stream at Cord N400W nr Wheatfield, IN	1.00	41.24278	-87.12154
Honey Creek at Ct Highway DD near Burlington, WI	1.84	42.71950	-88.30944
Honey Creek at Wauwatosa, WI	0.06	43.04383	-88.00511
Howe Creek near Lindy, NE	0.32	42.69596	-97.78838
Indian Creek near Fairbury, IL	1.11	40.72278	-88.53000
Johns Creek near Worthington, IA	8.32	42.39717	-91.06225
Lick Cr at N Cord 250W near Harrisburg, IN	2.34	39.71435	-85.18515
Limberlost Creek at Cord N 250 E near Bryant, IN	4.30	40.54527	-84.93408
Lincoln Creek @ Sherman Boulevard at Milwaukee, WI	0.70	43.09714	-87.96725
Little Fabius River nr Fabius, MO	9.60	40.04456	-92.13672
Little Papillion Cr at Ak-Sar-Ben at Omaha, NE	9.12	41.24528	-96.02057
Little Wabash River near Mason, IL	1.98	38.95833	-88.54556
Long Creek at 137th Street near Van Wert, IA	18.0	40.83814	-93.85717
Loutre River near Montgomery City, MO	5.33	38.94376	-91.61281
Lusk Creek near Eddyville, IL	1.02	37.47258	-88.54769
Maple Creek near Nickerson, NE	0.92	41.56117	-96.54083
Massac Creek at Metropolis, IL	0.21	37.15667	-88.70806
Massies Creek at Wilberforce, OH	1.04	39.72239	-83.88231
Maynes Creek near Hampton, IA	3.24	42.68083	-93.20325
Middle Fork Vermilion River above Oakwood, IL	0.90	40.13698	-87.74586
Middle Raccoon River near Bayard, IA	12.6	41.77908	-94.49286
Mill Creek at Carthage, OH	0.52	39.20197	-84.47128
Mill Creek near Choctaw, IL	18.2	39.26694	-87.69667
Moniteau Creek near Rocheport, MO	23.5	39.03325	-92.57111
Muddy C at 145h St nr Wetmore, KS	8.40	39.71835	-95.81182
Nineveh Cr at Stone Arch Rd nr Nineveh, IN	9.86	39.36611	-86.06641
North Fabius River nr Monticello, MO	16.6	40.08376	-91.67599
North Fork Maquoketa River near Fulton, IA	25.8	42.16433	-90.72933
North Fork Vermilion River near Wing	3.63	40.82139	-88.37417
North Moreau Creek nr Jefferson City, MO	8.40	38.53564	-92.31892
North Raccoon River near Sac City, IA	6.38	42.35475	-94.99033
Old Mans Creek at Kansas Ave SW near Iowa City, IA	20.0	41.60839	-91.63844
Otter Cr at N Cord 560E nr Butlerville, IN	0.28	39.00915	-85.50075
Otter Creek at W Country Rd 750N nr Napoleon, IN	6.00	39.18431	-85.35087
Otter Creek at Willow Road near Plymouth, WI	2.73	43.78889	-87.92139
Perche Creek near Columbia, MO	17.1	39.04128	-92.39483
Pipestone Creek nr SD/MN State Line, SD	7.98	43.90556	-96.48472

Pond Run at Highway 110 near Falls of Rough, KY	3.75	37.58501	-86.61873
Poplar Creek at Elgin, IL	1.60	42.02611	-88.25556
Prairie Cr at Co Rd N100W nr Capehart, IN	10.0	38.70952	-87.18541
Richland Creek at Carbondale Rd near Richland, KY	13.0	37.26634	-87.60116
Rock Creek at Kentucky road in Independence, MO	12.9	39.11194	-94.47222
Salt Creek at Western Springs, IL	2.24	41.82583	-87.90028
Sangamon River at Monticello, IL	3.00	40.03087	-88.58895
Scuppernong River near Palmyra, WI	7.40	42.88611	-88.54139
Sevenmile Ck blw Footbridge in Park nr Kasota, MN	0.93	44.26217	-94.02903
Skull Lick Creek nr Mexico, MO	8.30	39.21886	-91.91906
South Fork Iowa River at H Avenue near Buckeye, IA	6.65	42.43617	-93.34675
South Fork Iowa River NE of New Providence, IA	6.88	42.31508	-93.15206
Spoon River near St. Joseph, IL	8.80	40.16417	-88.02750
Squaw Cr Ditch near Squaw Creek Wildlife Area, MO	37.0	40.04087	-95.25416
Stillman Creek at Stillman Valley, IL	4.42	42.10722	-89.17000
Sugar Creek at Co Rd 400S at New Palestine, IN	2.40	39.72782	-85.87942
Threemile Creek at 210th Ave near Ghent, MN	9.02	44.49025	-95.87744
Tisch Mills Creek at Tisch Mills, WI	0.70	44.32754	-87.63675
Tomahawk C nr Overland Park, KS	3.04	38.90611	-94.64000
Turkey Creek near Steinauer, NE	1.20	40.18944	-96.22398
Unnamed Trib to East Br Indian Cr near Zearing, IA	5.84	42.10661	-93.35081
Unnamed Trib to Honey Creek near Willard, OH	6.00	41.02586	-82.78153
Unnamed Trib to W Nishnabotna Riv nr Randolph, IA	43.0	40.87350	-95.59458
Vermilion River at SR18 near Clarksfield, OH	1.56	41.19604	-82.41104
W Fk Busseron Cr at St Rt 48 nr Wilfred, IN	12.7	39.18633	-87.32920
Wahoo Creek at Ithaca, NE	29.8	41.14750	-96.53778
Walnut Creek near Vandalia, IA	11.2	41.53703	-93.25897
Wapsipinicon River at McIntire, IA	1.68	43.44328	-92.61125
West Fork Beaver Creek at 320 St. near Bechyn, MN	8.20	44.69042	-95.03531
West Papillion Creek at Millard, NE	22.4	41.20736	-96.12761
Williams Creek at 96th Street, Indianapolis, IN	0.60	39.92698	-86.17221
Wolf Creek at Dayton, OH	0.36	39.76673	-84.23661
Wolf Creek near Dysart, IA	2.91	42.25153	-92.29889
Yellow River at Knox, IN	10.1	41.30282	-86.62057
Mean of all Sites	8.01		

Reporting the occurrence of a limited spatial scale of depositional areas where HOCs may accumulate for these 12 mid-west stream is valuable information for assessing potential ecological risk. For example, a study by Moran et al. reported that an HOC, the insecticide bifenthrin, is impacting benthic communities throughout mid-west streams [24]. However, the results from our study showing that depositional areas where bifenthrin could accumulate is so spatially limited in mid-west streams that the finding of widespread impacts from bifenthrin on benthic communities by Moran et al. would seem to be questionable [24].

Big Bureau Creek Sediment Mapping Study

The percent silt/clay from 75 sites within Big Bureau Creek, Illinois is shown Figure 2 with the detailed data in Table 4 [12]. This creek-specific study involved detailed sediment mapping of a 48 km section of Big Bureau Creek using a stratified random design that included 75 transects with an equal distribution in the upper, middle and lower section of the creek. The percent silt/clay ranged from 0 to 37% with a mean value of 3.47% for all sites. The limited spatial scale of depositional areas in Big Bureau Creek was similar to results reported from the three studies discussed above and also similar to results from sediment mapping studies conducted in four California streams [10, 11].

Table 4: Mean percent silt/clay in surface sediment from 75 Big Bureau Creek stream sites from the Big Bureau Creek, IL Mapping Study (Hall et al. [12] (2017b). Sites were sampled in August of 2017

Site ID	Meter Mark (m)[a]	% Silt/Clay	Latitude	Longitude
Lower-1	120	2.00	41.40545	-89.51010
Lower-2	183	0.00	41.40602	-89.51007
Lower-3	330	5.28	41.40712	-89.50912
Lower-4	632	0.00	41.40759	-89.50637
Lower-5	706	0.00	41.40802	-89.50573
Lower-6	874	0.00	41.40866	-89.50392
Lower-7	934	1.20	41.40869	-89.50321
Lower-8	1011	0.00	41.40855	-89.50232
Lower-9	1202	0.27	41.40759	-89.50051
Lower-10	1288	0.34	41.41588	-89.47992
Lower-11	1668	0.00	41.41674	-89.47636
Lower-12	1720	0.00	41.41648	-89.47584
Lower-13	1816	0.47	41.41605	-89.47486
Lower-14	1867	2.20	41.41567	-89.47450
Lower-15	1939	2.44	41.41527	-89.47397
Lower-16	2648	0.00	41.41893	-89.47012
Lower-17	2807	0.00	41.42020	-89.46939
Lower-18	3585	10.0	41.43208	-89.45684
Lower-19	3850	9.33	41.43251	-89.45376
Lower-20	4342	0.00	41.43571	-89.44996
Lower-21	4652	3.91	41.43736	-89.45231
Lower-22	5204	1.27	41.45268	-89.43118
Lower-23	5270	15.9	41.45264	-89.43041
Lower-24	5322	0.00	41.45286	-89.42992
Lower-25	5395	1.81	41.45310	-89.42913
Middle-26	5641	0.33	41.46600	-89.40971
Middle-27	5707	0.00	41.46611	-89.40893
Middle-28	6058	0.00	41.46806	-89.40573
Middle-29	6347	0.00	41.46973	-89.40435
Middle-30	6504	10.0	41.47088	-89.40400
Middle-31	6623	0.00	41.47191	-89.40417
Middle-32	6704	0.00	41.47253	-89.40389
Middle-33	6946	0.31	41.47425	-89.39210
Middle-34	7008	0.34	41.47453	-89.39147
Middle-35	7405	0.00	41.47785	-89.39166
Middle-36	7490	5.92	41.47855	-89.39126
Middle-37	7584	0.40	41.47936	-89.39100
Middle-38	7694	0.00	41.48029	-89.39087
Middle-39	7742	3.98	41.48075	-89.39095
Middle-40	7813	1.12	41.48646	-89.36815
Middle-41	8052	0.00	41.48528	-89.36684
Middle-42	8185	0.00	41.48482	-89.36550
Middle-43	8450	0.00	41.48306	-89.36363
Middle-44	8542	0.00	41.51157	-89.35331

Middle-45	8643	0.71	41.51199	-89.35226
Middle-46	8760	0.34	41.51287	-89.35157
Middle-47	8901	2.97	41.51288	-89.34992
Middle-48	9096	12.5	41.51281	-89.34761
Middle-49	9210	0.46	41.51242	-89.34637
Middle-50	9260	0.00	41.51227	-89.34582
Upper-51	9729	0.00	41.51214	-89.33196
Upper-52	9880	0.00	41.51298	-89.33082
Upper-53	10069	0.41	41.51445	-89.33039
Upper-54	10149	2.82	41.51504	-89.33048
Upper-55	10343	21.3	41.53769	-89.30384
Upper-56	10413	7.54	41.53727	-89.30324
Upper-57	10495	37.0	41.53729	-89.30229
Upper-58	10877	0.00	41.53702	-89.29890
Upper-59	11306	19.8	41.53871	-89.29694
Upper-60	11384	0.00	41.53921	-89.29754
Upper-61	11485	18.4	41.53998	-89.29816
Upper-62	11715	0.00	41.55556	-89.27610
Upper-63	11895	12.8	41.55589	-89.27413
Upper-64	11967	3.78	41.55589	-89.27327
Upper-65	12169	0.00	41.55613	-89.27100
Upper-66	12346	0.00	41.57108	-89.26330
Upper-67	12555	0.00	41.57222	-89.26136
Upper-68	12709	7.35	41.57163	-89.25980
Upper-69	12869	13.6	41.57065	-89.25841
Upper-70	13331	4.05	41.56966	-89.25342
Upper-71	13484	3.01	41.56863	-89.25223
Upper-72	13652	2.63	41.56739	-89.25114
Upper-73	13778	9.46	41.56629	-89.25083
Upper-74	14800	0.00	41.56830	-89.24395
Upper-75	15008	0.77	41.56950	-89.24559
Mean of all Sites	3.47			

The importance of grain size data for assessing potential HOC risk, where depositional and non-depositional areas were sampled along with concurrent measurements of a HOC (bifenthrin), is illustrated in the Hall et al. study [12]. As an example, bifenthrin was reported at 14x times lower concentrations in non-depositional areas (mean across sites of 0.1 ng/g) compared with a mean across depositional sites of 1.4 ng/g. However as reported above, depositional areas are spatially limited so the risk to benthic communities is clearly lower in the most dominant type of sediment (non-depositional areas).

Conclusions

The mean percent of mid-west sites dominated by the silt/clay fraction within sediment based on four studies with a total of 269 sites sampled from 1969 to 2017 was approximately 5%. This value is very low and certainly shows that depositional or silt/clay areas are spatially limited in mid-west water bodies based on the data summarized in this study. The ecological relevance value of this finding is that silt/clay areas where HOCs may be found are highly spatially limited for mid-west water bodies. Therefore, this finding needs to be carefully considered with assessing the potential ecological risk of HOCs in mid-west water bodies.

The approach used to select sediment sites for both grain size and HOC measurements is also critical when assessing the ecological risk of HOCs in mid-west water bodies. It is important to know if sediment sampling sites were selected based on random or stratified random sampling (e.x., USGS 2013 Mid-west study and Big Bureau Creek Illinois Sediment Mapping study), targeted sampling for fine grain areas or non-random sampling based on other criteria (e.x.,Ohio Fluvial Study, Ohio Bank full Study, and USGS 2013 Mid-west study). Random sampling has advantages as this type of sampling is the basis of many statistical tests and removes bias from the sample collection process. However, practical constraints such as lack of access to property near stream sites (due to landowner refusing access) can be a problem. Targeted sampling for fine grain areas can also be problematic and lead to misleading conclusions particularly if fine grain areas are spatially limited as reported in this mid-west study and another similar study conducted in California [9]. Non-random sampling based on other criteria such as proximity to gauging stations, required unregulated flow, or specific type of land use may also introduce bias associated with the various criteria. In summary, it is critical to know how sites for sediment collection were selected and depending on the sediment collection approach used this information needs to be carefully considered as a component of uncertainty analysis when assessing the potential ecological risk of HOCs in ambient sediment. Watershed scale sediment mapping studies based on random or stratified random sampling with an extensive spatial scale are recommended in areas where HOC ecological risk is suspected.

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