PCB Mass Loading
from Hazardous Substance Release Sites
to Surface Waters of New Castle, Kent, and Sussex Counties

Watershed Remediation (DE-1525)

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1.0 INTRODUCTION

BrightFields, Inc. (BrightFields) was retained by the Delaware Department of Natural Resources and Environmental Control – Site Investigation and Restoration Section (DNREC-SIRS) to assess the mass loading of polychlorinated biphenyls (PCBs) from various Delaware Hazardous Substance Control Act (HSCA) sites to the surface water of New Castle, Kent, and Sussex Counties. The project falls within DNREC's Watershed Remediation Program (DE-1525). The purpose of this assessment was to evaluate existing information from a total of 29 currently known PCB-contaminated Delaware HSCA sites pre-identified by DNREC-SIRS, in order to evaluate the relative impact of PCBs transported from these sites by overland flow of surface water and through the discharge of PCB-contaminated groundwater into the surface water bodies.

In June 2009, BrightFields completed *PCB Mass Loading from Hazardous Substance Release Sites to Surface Waters of the Christina Basin*. A total of 32 PCB-contaminated Delaware HSCA sites in New Castle County were evaluated with similar methodologies. This following project summary discusses the methods that were used during the second phase of the project and identifies modifications in assessment methodologies from the first to the second phase.

1.1 Project Background

The Watershed Remediation Project (DE-1525) is a part of DNREC's Watershed Approach to Toxics Assessment and Restoration (WATAR). WATAR is a 5-year plan that was finalized in 2012 with the goal of restoring watersheds that have been affected by toxic pollutants. Contaminants of potential concern are nutrients and persistent, bioaccumulative, and toxic (PBT) pollutants including PCBs, PAHs (polycyclic aromatic hydrocarbons), chlorinated pesticides, mercury, dioxins, and furans. Parts of the plan include reviewing and analyzing contaminant data, developing Total Maximum Daily Loads (TMDL) and regulations, providing guidance for evaluation and cleanup of contaminated sediment, and prioritizing remediation for different sites across Delaware.

The State of Delaware contains numerous sites where previous or current operations have impacted the soil and/or groundwater with PCBs. Some of these sites are located in the vicinity of surface water bodies. Rain falling on exposed surfaces at these sites can cause erosion of soil containing contaminants and/or dissolve site contaminants, resulting in discharge of impacted runoff to a surface water body. In addition to overland flow, contaminated groundwater can also discharge into a surface water body. The specific objective of this project was to develop PCB mass loading estimates for PCBs released from several Delaware HSCA sites to surface waters of New Castle, Kent, and Sussex Counties. By evaluating all of the sites consistently, the relative contribution from each site can be estimated and compared.

1.2 Background of Polychlorinated Biphenyls (PCBs)

PCBs are synthetic chlorinated biphenyls. They were first produced in the United States in 1929. The biphenyl structure consists of two connected benzene rings with up to 10 chlorines. PCBs are not a single chemical compound but, based on the number of chlorines and their placement, comprise 209 related chemicals known as congeners. The congeners can be subdivided into groups that contain the same number of chlorine atoms, with each of the 10 groups (e.g., the trichlorinated biphenyls) referred to as homologs. Because the analyses quantify the mass of the individual components, when samples are analyzed for congeners (e.g., using EPA Method 1668A), the sum of the congeners equals the "total PCB" content. The same situation also applies to samples analyzed for the 10 homologs.

The most common commercial PCB mixtures manufactured in the U.S. had the trade name Aroclor, of which there were different formulations based upon the overall percent chlorine in the mixture. Between 1957 and 1971, 12 different Aroclors were produced in the U.S., with chlorine contents ranging from 21% to 68% (ATSDR, 2000).

With the exception of Aroclor 1016, the first two digits refer to the number of carbon atoms, and the last two digits refer to the percentage of chlorine (for example Aroclor 1260 has 12 carbon atoms and contains 60% chlorine by mass). PCBs can be analyzed for Aroclor content through pattern matching to standards (e.g., using EPA Method 8082 or earlier methods such as 8080A).

Because Aroclors are multi-component mixtures, a higher level of analyst expertise is required to attain acceptable qualitative and quantitative analysis when samples contain more than one Aroclor. The same is also true of Aroclors that have been weathered or degraded by long exposure in the environment. Such weathered mixtures may have significant differences in peak patterns than those of Aroclor standards. In addition, due to this uncertainty and other factors, a summation of the detected Aroclors does not necessarily equal the "total PCBs" present.

Based upon evidence that PCBs bioaccumulate in food chains and can cause harmful effects in animals, they have not been produced commercially in the United States since October 1977. They are considered to be probable human carcinogens by the EPA (Class B2).

The environmental fate of PCBs is generally related to the degree of chlorination. Each of the 209 possible PCB congeners has their own physical and chemical properties and potential for biodegradation. In general, those with fewer chlorine atoms tend to be more readily subject to microbial degradation under aerobic conditions and the higher chlorinated congeners are more subject to dechlorination under anaerobic conditions. The potential for biodegradation is a function of the number of chlorine atoms on a PCB congener and also the structural placement of the chlorines. PCB congeners with the chlorine atoms on the ortho carbons (the ring position closest to the bond connecting the two rings) tend to be more difficult to biotransform than those with the chlorine atom in the meta or para positions, the positions farther away from the connecting bond. Aerobic processes oxidize PCBs, breaking open the carbon ring and destroying the compounds, but can only degrade less chlorinated congeners. Anaerobic processes leave the biphenyl rings intact while removing the chlorines. This anaerobic dechlorination degrades highly chlorinated compounds into less chlorinated derivatives (Erickson, 1997).

If released to soil, PCBs sorb strongly to soil particles and the sorption generally increases with the degree of chlorination of the PCB. The log of the sorption coefficients (Log Koc) values for the various Aroclors range from approximately 2.44 for Aroclor 1221 to 6.42 for Aroclor 1260 (Montgomery, 1991). Due to sorption, PCBs generally do not leach significantly in aqueous soil systems and, due to lower solubility, the higher chlorinated congeners have a lower tendency to leach than the lesser chlorinated congeners. However, in the presence of organic solvents (such as petroleum hydrocarbons), PCBs may leach quite rapidly through soil, due to co-solvency.

If released to water, sorption to sediment and suspended matter is an important process. Although sorption can immobilize PCBs (especially the higher chlorinated congeners) for relatively long periods of time, eventual re-solution into the water column has been shown to occur. The PCB composition in the water will be enriched by lower chlorinated PCBs because of their greater water solubility while the higher chlorinated PCBs will remain adsorbed to sediment and suspended particles.

Once the contaminated media is exposed to receptors (people and animals) the PCBs will tend to bind to fatty tissues. PCBs are stored in the fatty tissue and then released into the bloodstream slowly. Even at low exposure levels, the concentration of PCBs in fatty tissue can accumulate to a high level. In addition, PCBs accumulate in the fatty tissue of organisms low in the food chain and then become bioaccumulated or "magnified" when consumed by animals at a higher level of the chain.

PCBs continue to be a major environmental problem in the U.S. and abroad based upon their persistence. Their tendency to persist in the environment, bioaccumulate in food chains, and their toxicity, places them in a group of chemicals referred to as Persistent Bioaccumulative and Toxic substances (PBTs).

1.3 Objective

The specific objective of this project was to develop PCB mass loading estimates for a pre-identified list of 29 Delaware HSCA sites (Figure 1) to surface water of New Castle, Kent, and Sussex Counties. Mass loading was assessed through two transport mechanisms:

1. Erosion and overland flow of surface water contaminated by PCB-impacted surface soil; and

2. Subsurface (groundwater) flow and transport of dissolved phase PCBs.

2.0 PROCEDURES

This section describes the procedures that were developed to estimate the quantity of PCBs currently being released to surface waters through overland flow and groundwater transport. A site specific appendix was developed for each of the 29 sites. Each appendix includes a summary of the site location, site historical usage, previous investigations, PCB remediation (if performed), current regulatory status, concentrations of PCBs remaining on site, summary of overland flow and/or groundwater transport variables for the site, uncertainty evaluation, and estimated mass loading to surface waters. Supporting tables and figures are included in each site specific appendix.

2.1 Data Compilation

Each individual site was researched using the DNREC Environmental Navigator database. In lieu of submitting a "Freedom of Information Act" (FOIA) request, BrightFields requested missing files and data from DNREC directly. Once the requests were processed, BrightFields personnel examined the files and identified which files had information pertaining to this study. In some instances where files were missing data, BrightFields contacted the DNREC project manager to request individual files.

We also submitted FOIA requests to the United States Environmental Protection Agency Region 3 for Governor Bacon Health Center/Fort DuPont and the Harvey & Knott Drum Site Property.

BrightFields developed a master geodatabase to document pertinent information for each individual sites. The database is in Microsoft Access and is compatible with ESRI ArcGIS. Data was collected from all existing reports that could be found in DNREC's files pertaining to the site soil and groundwater PCB contamination. Information was also collected on sediment and surface water data although it was not specifically evaluated. The parameters recorded included: sample identification, sample depth, sampling company, report date, figure names, presence of descriptive logs, sample type, sample date, type of sample (e.g. surface, subsurface, or both), total concentration of PCBs, individual Aroclor concentrations, depth to groundwater, saturation definition, sample method, and result type (e.g. laboratory result or screening result). Once the data was entered into the geodatabase, it was reviewed for errors, any adjustments made, and moved on to the mapping phase.

The PCB analytical results tables presented in the site specific appendices are compared to the January 2014 DNREC Screening Levels for Aroclor concentrations. Some previous investigation summaries mention alternative screening levels, but all data across all the sites was compared to the January 2014 screening levels for consistency purposes.

2.2 Mapping Protocol

Once the data was compiled, a series of six or seven maps were created for each site as listed below:

1. Historic Sample Locations and Aerial Photograph
2. PCB Distribution in Surface Soil
3. PCB Distribution in Subsurface Unsaturated Soil
4. PCB Distribution in Subsurface Saturated Soil
5. PCB Distribution in Groundwater
6. Soil Loss Estimates (may not be present for some sites), and/or
7. Groundwater Discharge Map (may not be present for some sites).

For each site, all existing report figures that showed sample locations were georeferenced using the georeferencing tool in ArcGIS 10.0. Each sample on the map was then digitized and stored as a location in the geodatabase. In some instances sample location information was obtained from georeferencing CAD files and/or GIS shapefiles. In these cases, the sample location was directly digitized and stored into the geodatabase.

Each sample was assigned a status based on any known site remedial activities conducted since the sample was collected and categorized as to whether it was covered by at least 2 feet of fill, removed (e.g., excavated), or unchanged. Samples that were given a status of filled were treated as subsurface samples even if the original sampling depth was less than 2 feet (i.e., a surface sample). Samples in areas that had been remediated are still shown on the appropriate map; however, the total PCB concentration and the depth were not posted on the map and the concentrations of the removed samples were not included in the estimated PCB distribution area. The individual legend shown on each map explains where these samples are located for each site.

The Historic Sample Locations and Aerial Photograph shows the locations of all samples as well as a 2012 aerial photograph underlay from the Delaware DataMIL. The PCB Distribution in Surface Soil map shows those locations that have PCB data from depths of 0 to 2 feet below ground surface (bgs) (surface soil). The PCB Distribution in Subsurface Unsaturated Soil map shows sample locations that have that have PCB data at depths greater than 2 feet bgs but are also located above the water table. The PCB Distribution in Subsurface Saturated Soil map shows sample locations that have PCB data at depths greater than 2 feet bgs and are also located below the water table (saturated). Samples that spanned above and below 2 feet bgs were considered to be both surface and subsurface, and therefore were shown on two maps. The PCB Distribution in Groundwater map shows the locations where groundwater samples were analyzed for PCBs.

The PCB Distribution Maps depict the concentrations of total PCBs. Concentrations derived from commercial laboratory analysis are shown in plain text with the sample depth in parentheses. PCB concentrations measured using screening methods (e.g., immunoassay) are italicized and shown in parentheses. All maps also show existing and historic buildings, water bodies, and roads.

The PCB Distribution in Surface Soil, PCB Distribution in Subsurface Unsaturated Soil, PCB Distribution in Subsurface Saturated Soil, and PCB Distribution in Groundwater maps include a polygon showing estimated PCB distribution areas. The boundary of this polygon for each map was typically drawn using the midway point between samples that have PCB concentrations above the detection limit and those samples where PCB concentrations were not detected. The polygon encompassing those samples with concentrations above the detection limit is considered the estimated PCB distribution area.

The Soil Loss Estimates Map shows erodible surface soil (for overland flow calculations), overland flow direction to the nearest water body, and approximate distance to the water body. The estimated PCB distribution area for the Soil Loss Estimates Map is the same as the PCB Distribution in Surface Soil map; however, it has been modified to exclude all impervious surfaces such as buildings and parking lots based on the State of Delaware 2007 Impervious Surface Data files in ArcGIS. When assessing direction and distance to surface water bodies, the PCB distribution areas on the Soil Loss Estimates Map were grouped together based on the Surface Soil map. The overland flow direction on the Soil Loss Estimates map was assessed by drawing the shortest downhill path from the approximate centroid (the geometric center of the polygon) of each PCB distribution area to the nearest surface water body. Observations from site visits and previous reports were used to confirm the most likely overland flow paths. Modifications were made to the figure based on field conditions. The approximate distance noted on the figure is based on the closest edge of the erodible surface soil boundary to the surface water body. For sites with multiple estimated PCB distribution areas and therefore multiple distances to discharge points, the distances were averaged to assess the level of uncertainty associated with overland flow PCB mass loading.

The Groundwater Discharge map shows the width of the projected PCB-impacted groundwater discharge in feet. The Groundwater Discharge distance(s) was calculated by assessing the groundwater flow direction and drawing a line perpendicular to the flow direction across the PCB distribution area. At some sites with limited groundwater elevation data, the groundwater flow direction was estimated from the topography (shallow groundwater flow frequently mimics topography).

In cases where none of the available data met the criteria for a specific map, that map was excluded from the figure series for that site. For example, if no surface soil samples were present, the Soil Loss Estimates Map was not created. If all the soil samples that had a depth greater than 2 feet were located above the water table and no PCBs were detected in the groundwater, then the Groundwater Discharge map was not created.

2.3 Site Inspections

Site inspections were begun after the first set of maps was completed. Access to some sites was restricted, and therefore, estimates regarding site cover and topography had to be made using aerial photographs and observations from outside the property boundaries. BrightFields personnel inspected and evaluated the sites for specific features. These features included: presence of identifiable slopes; drainageways and stormwater discharge areas; types and thickness of ground cover; presence of buffer zones and sediment control features; and locations of impermeable surfaces and discharge points (e.g., stormwater drains). All site inspections were performed by the same individual in order to maintain consistency throughout the project. Observations were documented with photographs that are included in the site specific appendices.

2.4 Mass Loading Calculations

After the figures were completed for each individual site, BrightFields reviewed the data and the concentrations associated with each zone of interest, primarily the surface soil and subsurface soil where PCBs were in contact with the groundwater table (saturated).

The analytical protocol used for the available data varied from immunoassay screening to GC/MS screening at the DNREC-SIRS laboratory, to EPA Method 8082, to PCB Congener

(EPA Method 1668a) in order of least to most precise. In order to compare the screening data in a consistent and quantitative manner to the quantitative lab data, it was necessary to use a single result instead of a range. In this case BrightFields utilized half of the detected range in the calculations. For example, if the screening data reported a value of greater than 0.5 mg/kg but less than 1 mg/kg, a quantitative concentration of 0.75 mg/kg was assigned to the sample point. This was necessary in order to evaluate the detection in a manner consistent with the quantitative laboratory data. In cases where screening data was presented but no range of detection was provided (such as "PCBs present"), the data could not be used in the calculations. For areas where both laboratory data and screening data were available, the laboratory data was used.

The concentrations observed in each zone of interest were then evaluated using statistical methods to develop estimated site "average" concentrations to be used in the loading calculations.

The statistical method used for the surface soil for overland flow calculations was the 95% upper confidence limit (UCL) of the mean of the total PCBs concentrations. Only surface soil with detections that were still remaining on the site (indicated in the status column of the geodatabase) were utilized in the 95% UCL calculation. Surface soil detections were not included if the sample location was remediated after the sample was collected or if the surface soil was capped by an impervious surface or clean fill.

The EPA has issued guidance for calculating the UCL of an unknown population mean for hazardous waste sites and has developed software (ProUCL Version 4.1.00) that computes an appropriate 95% UCL of the unknown population mean. ProUCL tests the distribution of the data set to assess whether or not it fits a defined distribution (normal, log-normal, or gamma) and computes a conservative and stable 95% UCL of the unknown population mean using various methods developed for that distribution.

Where PCBs were detected in a sufficient number of samples at concentrations above the laboratory detection limit, the 95% UCL was calculated for that site using the EPA software ProUCL Version 4.1.00. If the number of detections was insufficient for the software to calculate the 95% UCL (normally four or less detections) or the calculated 95% UCL was higher than the maximum detected concentration due to a large range between the minimum and maximum detections, the maximum concentration was used.

The number of detections in the subsurface saturated soil and in the groundwater was low, generally less than five. Because of the low number of detections, more sophisticated statistical analysis was not possible. Therefore, simple arithmetic means were normally used to assess the estimated site "average" concentration.

For some sites, multiple areas of concern were identified. This occurred when high PCB concentrations were concentrated in one or more small areas surrounded by considerably lower PCB concentrations or non-detects. The overall site contribution was then the sum of each individual area.

Once the site contribution concentration(s) were calculated, the mass loading of PCBs to surface waters was evaluated for erosion and overland flow, and for subsurface (groundwater) contaminant transport and discharge of dissolved phase PCB into a surface water body, where applicable.

2.4.1 Overland Flow

Based on research conducted at the Soil Loss Data Center at Purdue University and prior studies, Wischmeier, Smith, and others (Wischmeier and Smith, 1978) developed the empirical Universal Soil Loss Equation (USLE). An Agriculture Handbook (No. 537) describing USLE was originally published in 1965 and was revised in 1978. The USLE estimates soil loss from erosion caused by rainfall. It does this by accounting for specific soil types, rainfall patterns, topography, vegetative ground cover and canopy, and sediment and erosion control practices. With a widespread acceptance, the USLE became the major soil conservation planning tool and is used in the United States and other countries. This equation follows the general form:

A = (R)(K)(L)(S)(C)(P), where:

A = annual soil loss

R = rainfall/erodibility index

K = soil erodibility

L = slope length factor

S = slope steepness factor

C = cover/management factor

P = support practice factor

As additional research, experiments, data, and resources became available, research scientists continued to improve the USLE, which led to the development of the Revised Universal Soil Loss Equation (RUSLE). The RUSLE retains the same general factors as USLE.

The main difference established for RUSLE is that each factor has been either updated with recent information, or new factor relationships have been derived based on modern erosion theory and data. RUSLE also has several improvements in assessing factors. These include revised isoerodent maps and erodibility index (R) distributions for some areas; a time-varying approach for the soil erodibility (K) that reflects freeze-thaw; new equations to reflect slope length and steepness; a subfactor approach for evaluating the cover-management factor (C); and new conservation-practice values (P) (Renard, et al., 1997). A new Agriculture Handbook (No. 703) describing RUSLE was published in 1997 by the U.S. Department of Agriculture.

CHANGES TO METHODOLOGY FROM 2009 STUDY

The previous mass loading evaluation, *PCB Mass Loading from Hazardous Substance Release Sites to Surface Waters of the Christina River Basin*, completed in July 2009, utilized RUSLE2 (version 1.26.6.4, November 2006) for overland flow calculations. RUSLE2 is a windows based program that allows the user to input specific parameters about the site. This program provides estimates of long-term average annual soil erosion for use in conservation planning based on the RUSLE equation.

Based on new publicly available data, including higher resolution elevation models and more detailed databases, BrightFields utilized ArcGIS to assess all of the overland flow runoff parameters instead of the RUSLE2 program. The methods for the determination of the "K" factor and the calculation of the LS factor in the RUSLE equation were improved for this phase of the PCB Mass Loading study and are discussed in the sections that follow. At the beginning of this project, BrightFields calculated the PCB mass loading via overland flow for one site using both the prior methodology and the improved methodology, and found the results to be comparable.

For sites that had inconsistent soil types or coverage types throughout the area of concern, rasters were utilized in ArcGIS to create a weighted average and determine the "K" and/or "C" factors. A raster is defined as "a spatial data model that defines space as an array of equally sized cells arranged in rows and columns, and composed of single or multiple bands" (ESRI, 2014). Each cell is associated with a geographic coordinate and has a value, which allows gridded spatial data to be analyzed and modeled.

The equation evaluated utilizing ArcGIS remained essentially the same as the original RUSLE equation:

A = (R)(K)(LS)(C)(P), where:

A = average annual soil loss (ton/acre-year) – calculated through ArcGIS

R = rainfall-runoff erosivity (100 foot-ton force-inch/acre-hour-year) – based on Isoerodent Map

K = soil erodibility (0.01 ton-acre-hour/acre-foot-ton force-inch) – based on SSURGO

LS = slope length and steepness factors (unitless) – grid based on elevation data

C = cover/management factor (unitless) – grid based on site specific data

P = support practice factor (unitless) – grid based on engineering controls

The RUSLE equation was used in ArcGIS to estimate mass loading of each site in terms of tons/acre of soil lost per year. The factors used in the RUSLE are based on long-term averages. The following is a brief description of each of the factors used in the RUSLE equation compiled from the Field Office Technical Guide (USDA NRCS, 2001) and how it was estimated in this study.

RAINFALL-RUNOFF INTENSITY EROSIVITY INDEX (R)

A long gentle rain may have the same total energy as a short intense rain. Although raindrop erosion increases with the intensity of the rain, total energy of the rainfall alone is not a good indicator of erosive potential. However, when energy is combined with rainfall intensity the result (EI-Energy/lntensity) is a good predictor of erosive potential. The term includes particle detachment combined with transport capacity (the soil erosion process). The sum of EI's for an average year for a particular locality is the Rainfall Erosion Index - “R” for that location. The higher the “R” value, the higher the erosion potential. An “R” value of 175 was chosen for all sites evaluated based on the Isoerodent Map published for the Eastern U.S. by the USEPA in March 2012 (USEPA, March 2012).

SOIL ERODIBILITY (K)

Soil erodibility is a function of chemical and physical properties of the soil within the erodible area. Soil erodibility is the ease with which soil is detached by raindrop splash during rainfall and/or surface flow. Soil erodibility is a combination of the effect of rainfall, runoff, and infiltration and the soil erodibility factor (K) is the soil loss rate for a specified soil. The "K" represents both the susceptibility of the soil to erode and the rate of runoff. Soil generally becomes easier to erode with an increase in the silt fraction regardless of the clay or sand fraction. In sandy soil, infiltration rates are much higher and there is less surface runoff than in clay. In addition to these factors, an increase in organic matter produces an increased resistance to detachment due to aggregation and the resultant larger particle size.

When available, “K” factors were extracted directly from the National Resource Conservation Soil Survey Geographic Database (SSURGO) and rasters were created for the individual sites based on the shapefiles for soil erosivity. The Raster Calculator in the Spatial Analyst extension of ArcMap was used to calculate the RUSLE model grid to determine soil erosion potential. This evaluation is derived based on a study conducted by Saint Mary’s University of Minnesota in Winona, MN, *Assessment of Soil Erosion Risk within a Subwatershed using GIS and RUSLE with a Comparative Analysis of the use of STATSGO and SSURGO Soil Databases (Breiby, 2006).*

For sites that did not have “K” factors in the database, the methods used during the 2009 study were utilized. “K” factors were assigned using surface soil descriptions from soil logs to assess the soil composition and equate them to a corresponding generic soil type and organic material content. This was completed by looking at the borehole logs for the boring with the detected concentration, borings on the property, or borings that were located on a neighboring parcel. The top two feet of the log (“surface soil”) was reviewed to make an assessment of the soil description. Once the soil description was made, it was compared to the RUSLE generic soil types and a soil type closest to the observed soil matrix was selected.

<u>LENGTH AND SLOPE FACTORS (LS)</u>

The length and slope factors used in RUSLE account for the effect of topography on erosion. Erosion increases as the slope angle and length increase. The slope-length factor (L) is defined as the horizontal distance from the origin of flow to the point where either the slope decreases enough to allow deposition to begin or the runoff becomes concentrated in a defined channel. The slope steepness factor (S) reflects the influence of the slope angle on erosion. Erosion potential increases with the steepness of the slope.

The combined LS factor in RUSLE represents the ratio of soil loss on a given slope length and steepness referenced to a value of 1.0 (derived from a 72.6 foot slope length with a 9% steepness). The shape and makeup of a slope must be accounted for when assigning its LS value. Uniform slopes are slopes that are generally uniform over the entire length. Irregular or complex slopes have slope changes along the measured slope length.

In the 2009 PCB study, the slope length and steepness were assessed solely by evaluating the Delaware DataMIL elevation contours across the area of concern (a polygon developed based on the concentrations of PCBs). For this 2014 phase of the project, the elevation data was evaluated more thoroughly including determining valleys (settlement areas) and peaks (detachment areas) across the line of runoff.

Evaluating the LS factor in ArcGIS required generating a slope grid and a flow accumulation grid from the Digital Elevation Model (DEM; a raster image created from elevation data). To create the slope grid, the Slope function feature in ArcGIS was used. The output slope grid was generated at a cell size of one foot. The flow accumulation grid was constructed using the ArcGIS extension, ArcHydro Tools, from the University of Texas at Austin Center for Research in Water Resources (available on their website).

The Fill Sink feature under Terrain Preprocessing was used to remove depressions within the DEM. This feature produces a smoothed over DEM in the form of an output grid. The resulting output grid was used to determine flow direction using the ArcHydro Flow Direction feature. Utilizing the ArcHydro Flow Accumulation feature, the flow direction output grid was used to identify areas where flow would collect within the raster based on site topography. The output flow accumulation grid was generated at a cell size of one foot.

The remaining factor of LS (slope length and slope steepness) was calculated using the slope and flow accumulation grids. Longer slope lengths have a higher amount of cumulative runoff and steeper slopes have higher runoff velocity, both which contribute to erosion. The original equation to calculate the LS factor was an empirical equation published in the USDA Agriculture Handbook No. 537 (Wischmeier and Smith, 1978). The equation has undergone some minor changes including the equation published by Moore and Burch in 1986 (Moore and Burch, 1986).

The LS empirical equation that was used for this project is:

$$LS = (\text{Flow Accumulation grid x cell size} / 22.13)^{0.4} \text{ x } [\text{Sin(Slope grid x 0.01745)} / 0.0896]^{1.4} \text{ x } 1.4$$

The Raster Calculator in the Spatial Analyst extension of ArcMap was used to calculate the LS grid. The Raster Calculator expression of the equation above is:

LS = Pow([Flow Accumulation grid] x10 / 22.1, 0.4) x Pow(Sin[Slope grid]x0.01745) / 0.0896, 1.4) x 1.4

The output LS grid was generated at a cell size of 1 foot.

COVER MANAGEMENT FACTOR (C)

The cover-management factor (C) reflects the effect of management practices on erosion rates. The "C" Factor measures how soil loss potential will be distributed in time during management schemes. The "C" factor represents the effect of plants, soil cover, soil biomass (roots and other organic residue), and soil-disturbing activities within the erodible area on soil loss.

When possible, BrightFields assigned a cover management factor based on a peripheral site visit to evaluate the current site conditions. Once on site, a BrightFields field scientist evaluated the site cover for percentage of vegetation, vegetation type, impervious surfaces, gravel thickness, etc. For consistency, the same BrightFields field scientist performed all peripheral site visits. After the cover management was described, BrightFields assigned a “C” factor to the site from a tabulated set of values from Section I-C of the Water Erosion Prediction and Control Technical Guide (USDA NRCS, 1995).

If the site access was restricted and we could not directly inspect the site cover, BrightFields used aerial photography to assess the cover for the same characteristics. The profile was then created utilizing the information obtained from the aerial photography.

Two sites (CitiSteel Area A and Donovan Salvage Works Property) had varying cover management throughout the area of concern, so a raster approach was utilized to distribute cover management factors across these sites. The individual “C” factors and the weighted average are presented in the individual site specific appendices.

SUPPORT PRACTICE FACTOR (P)

The support practice factor "P" in RUSLE assesses the soil loss with specific support practices. The support practices principally affect erosion by modifying the flow pattern, grade, or direction of surface runoff. The P factor accounts for control practices that reduce the erosion potential of the runoff by their influence on drainage patterns, runoff concentration, runoff velocity, and hydraulic forces exerted by runoff on soil. A P factor of one represents a surface condition with no control practices whereas a factor closer to zero represents complete containment.

Recognizing that RUSLE was developed for agricultural practices rather than environmental remediation, the agricultural approaches to erosion approach are described below. There are two major approaches to erosion control. One approach is through on-site protection of the soil so that the long-term productivity of the land is maintained. The supporting mechanical practices include tillage (furrowing, soil replacement, seeding, etc.), strips of close-growing vegetation, deep ripping, terraces, diversions, and other soil-management practices. The other approach is sediment control so that off-site resources are protected. These practices include buffer strips of close-growing vegetation, stiff grass hedges, straw-bale barriers, gravel filters, sand bags, silt fences, continuous berms, and rock check-dams. Sediment-control barriers and structures cause ponding of water and sediment deposition on the upslope side. The effectiveness of a barrier or basin is directly related to the length and volume of ponded water. This length and volume increases as hillslope gradients increase, unless the sediment control fails or is overwhelmed.

For these environmentally contaminated sites, erosion control approaches may include silt fencing, seeding with vegetation, slope modification, berms, sedimentation basins, and capping with soil or impervious surfaces.

BrightFields used site visits, aerial photographs and site reports to determine the extent of sediment and erosion controls. There were four sites (Chicago Bridge & Iron, Former Dagsboro Substation, 1600 Bowers Street, and Jablow) which were observed to have sediment and erosion controls, including retention basin(s), drainage swales, a vegetative berm, and/or silt fence. Information on installation process and ongoing maintenance were not available to be utilized in the development of the P factor. In an effort to be conservative, the overland flow calculations were performed using a P factor of 1 for Chicago Bridge & Iron and Former Dagsboro Substation to calculate the maximum potential PCB mass loading via overland flow if all engineering controls were to fail. At Chicago Bridge & Iron and Former Dagsboro Substation, the actual amount of PCB mass loading via overland flow for the sites is expected to be lower than the presented values due to the sediment and erosion controls instituted onsite.

For the 1600 Bowers Street and Jablow sites the P factor was calculated using the RUSLE2 program. At 1600 Bowers Street, a berm that discharges into a lined retention basin at the base of the slope below the yard operations area was constructed to trap contaminated sediment runoff. Since the majority of the runoff from the PCB-impacted erodible area of the site is captured by the berm and flows into the retention basin, a site specific P factor was calculated for the site using the RUSLE2 program. At Jablow there is a swale which leads to a riprap sediment trap. The majority of runoff from the site is directed to the sediment trap, which allows sediment to settle out before reaching the Christina River. A site specific P factor was calculated for Jablow using the RUSLE2 program.

OVERLAND FLOW MASS LOADING CALCULATIONS

The source of all information used for assessing K, C, and P for each site is documented in the site specific appendices. After annual soil loss was estimated for each site, PCB mass loading to surface water via overland flow was calculated as the product of soil loss, the erodible area of PCB contamination, and the 95% Upper Confidence Limit (UCL) of the mean PCB concentration in the erodible surface soil on the site (or, if the 95% UCL of the mean could not be calculated, the maximum total PCB concentration detected was used). The resulting estimate of PCB mass loading via overland flow is summarized in Table 1.

2.4.2 Groundwater Mass Loading

The estimate of the mass of contaminants entering (discharging to) a surface water body (mass loading) is the product of groundwater discharge (units of volume/time) and groundwater concentration (units of mass/volume). PCB mass loading to a surface water body via groundwater transport was estimated by multiplying the measured (or predicted) dissolved phase PCB concentration in the groundwater beneath the site by the volume of groundwater discharging from the site to surface water.

PCBs are not typically detected in groundwater due to their low aqueous solubility (1.45 mg/L for PCB-1232 to 14.4 µg/L for Aroclor 1260 (Montgomery, 2000)) and their tendency to bind to organic carbon and clay. These factors limit their mobility. Also, they may not be detected because the typically used analytical method (EPA Method 8082A) has a fairly high detection limit (the method detection limits (MDLs) for Aroclors, according to the method document, in the range of 0.054 to 0.90 µg/L in water).

2.4.2.1 Groundwater Concentrations

For sites where PCBs have not been detected in groundwater and are not present in subsurface soil which is in contact with groundwater, PCB groundwater discharge was assumed to be negligible (i.e., minimal migration of PCBs from the vadose zone), and therefore, no groundwater discharge calculation was performed. In situations where PCBs have not been detected in the groundwater, but are present in saturated subsurface soil, a calculated dissolved phase PCB concentration in the pore water was estimated using an equilibrium partitioning equation (Schwarzenbach, et.al., 2003). The equilibrium partitioning equation is:

[PCB]w = [PCB]s/(foc x Koc), where:

[PCB]w is the concentration of PCBs dissolved in the pore water;
[PCB]s is the PCB concentration in subsurface soil in contact with groundwater;
foc is the fraction of naturally occurring organic carbon in the subsurface soil; and
Koc is the soil/sediment partition or sorption coefficient.

The Koc is defined as the ratio of adsorbed chemical per unit weight of organic carbon to the aqueous solute concentration. It is an indication of the tendency of a chemical to partition between pore water and the organic carbon in the soil. Total organic carbon (TOC) data for the subsurface soil was not available for most of the sites investigated, therefore, foc was assumed to be between 0.01 and 0.05 kilograms of organic carbon per kilogram of dry sandy-loam soil (Gustafson, Tell, and Orem, 1997). Finally, Koc was estimated using the following linear free energy relationship (LFER) from Schwarzenbach (2003):

Log Koc = 0.74 Log Kow + 0.15, where:

Kow is the octanol-water partition coefficient. Kow values for PCBs are available in the literature for each homolog (Mackay et.al., 1992; ATSDR, 2000; Hawker and Connell, 1988; and Erickson, 1997). The Kow values presented below are a weighted average based on homolog content of the Aroclors and the Kow values of each of the homologs, as presented by Erickson. The majority of PCB Aroclors detected during this investigation were 1248, 1254, or 1260. The Log Koc for PCB-1254 (4.96) was used in the calculations to represent the typical value.

Aroclor	1242	1248	1254	1260
Log Kow	5.58	5.99	6.50	6.87
Log Koc	4.28	4.58	4.96	5.24

Once a measured (or estimated) PCB concentration in the groundwater was obtained, that concentration was multiplied by the groundwater discharge from the site to the surface water body (Section 2.4.2.3). Note that this calculation assumes that PCBs are only sorbed by organic carbon and that grain size is not a significant factor (i.e., no additional sorption to silt and clay). This method slightly underestimates the PCB concentration in fine grained sediment.

2.4.2.2 Groundwater Discharge

The groundwater discharge is a function of the hydraulic conductivity of the saturated soil, the horizontal groundwater gradient (hydraulic head), and the cross-sectional area of the aquifer.

Groundwater discharge was calculated using the general form of the Darcy equation:

$$Q = KiA$$

where:

Q = groundwater discharge (cubic feet/day)

K = hydraulic conductivity (ft/day)

i = groundwater gradient (ft/ft)

A = cross sectional area through which flow occurs (square feet)

<u>HYDRAULIC CONDUCTIVITY</u>

Hydraulic conductivity describes the ease with which groundwater can flow through pore spaces or fractures. The hydraulic conductivity is best estimated through aquifer testing. Aquifer testing is performed to assess the hydraulic properties of a water-bearing unit. There are two general types of aquifer tests, pumping tests and slug tests. In pumping tests, groundwater is pumped from a well and water levels are typically measured in one or more observation wells. In slug tests, the groundwater level in a well is abruptly raised or lowered and water levels are measured as the groundwater re-equilibrates. Pumping tests sample a much larger area and provide more representative estimates of large scale hydraulic properties in heterogeneous systems than slug tests, especially if the hydraulic conductivity is high or quite variable. Variable conductivity is frequently found in areas that have been filled with soil from multiple sources and/or contain debris. Slug testing results are locally very useful, but may be somewhat less representative of an entire site.

Aquifer testing was not performed at most of the sites; therefore hydraulic conductivity was estimated using effective grain size measurements, if available. The best grain size measurements are obtained by a sieve/hydrometer analysis. If sieve data was not available, the grain size was estimated from soil descriptions. These estimates are entirely dependent on the quality of the soil descriptions and can result in a wide variation in “typical” grain size. Even when using sieve analyses of well sorted soils, however, estimated conductivities can exceed an order of magnitude for each soil type.

HYDRAULIC GRADIENT

The groundwater gradient was calculated from groundwater elevations measured in monitoring wells. The accuracy of this measurement is dependent upon the accuracy of the vertical surveying, the density of monitoring wells, the complexity of the flow pattern, and whether the measurements made during limited testing are indicative of the typical flow pattern. Sites located near tidal rivers may have wide ranges of gradients and variable flow directions if the groundwater has a strong tidal influence. Also, sites with complex flow patterns need considerably more wells to fully assess groundwater flow.

At sites where no monitoring wells were installed or no groundwater elevations were measured, the gradient was estimated by assuming that it paralleled the ground surface. In this case, estimates of groundwater flow are dependent on quality of the topographic survey and on the contour interval. The projected gradient is difficult to assess if the ground surface is irregular.

CROSS-SECTIONAL AREA

The cross-sectional discharge area is based on a vertical measurement (the thickness of the saturated zone) and a horizontal measurement (the width of the PCB impacted area measured perpendicular to the groundwater flow direction). The thickness of the saturated zone was based on interpretation of borehole logs and on well construction. Saturated thicknesses were found to be variable across most sites and were difficult to accurately estimate if: 1) a lower confining unit was not encountered, 2) the borehole logs did not indicate the saturated interval, and/or 3) the water bearing thickness is based on potentiometric measurements in a confined aquifer. Estimates of saturated thickness using groundwater elevations are only applicable if the water bearing unit is unconfined. In heterogeneous material, such as fill, the groundwater is typically confined to some extent, and therefore, use of groundwater elevation measurements would overestimate the saturated thickness.

Assessment of the areal extent of PCB impacted soil or groundwater is dependent on the sample density. The extent of contamination can only be accurately assessed if there are enough samples to delineate the edge of the contamination and to delineate any “hot spots.” Also, to estimate the area where groundwater flows through PCB-impacted soil, the width of this zone must be measured perpendicular to the groundwater flow direction. Therefore, the cross-sectional area estimates are also dependent upon the quality of groundwater flow measurements and directions.

2.4.2.3 Mass Loading Calculations

After the volume of groundwater discharging to the surface water body and the PCB concentrations in groundwater have been estimated, the mass of material introduced to the water body in a given time (mass loading) is estimated.

Estimates of the potential PCB mass loading to a water body was calculated using:

Mass Loading = Q x GW concentration x 0.001 g/µg (assuming concentrations are measured in µg/L)

where: Mass Loading = estimate of daily PCB load to the water body (grams/year)

Q = Discharge (L/day)

GW Concentration = Measured or calculated groundwater PCB concentration (µg/L)

The resulting measurement assumes that there is no degradation or sorption of the PCBs between the source and the water body and that any groundwater dispersion conserves the mass balance (i.e., all PCBs estimated to be leaving the site end up in surface water). As such, the farther the site is located from the water body (flow distance), the higher the uncertainty of the PCB mass loading calculations. The estimate of PCB mass loading via groundwater transport is summarized in Table 1.

2.5 Uncertainty Evaluation

This section describes the procedures used to evaluate the level of uncertainty associated with the estimated quantity of PCBs currently being released to surface waters through overland flow and groundwater transport. A summary of the degree of uncertainty associated with each site is included in Table 1 and supporting information is included in each site specific appendix.

2.5.1 Overland Flow Mass Loading Uncertainty Approach

The input for each of the factors in the RUSLE equation was selected based on site specific information and each of the six factors has a degree of uncertainty. The parameters are presented below in a matrix that shows the various degrees of certainty associated with each parameter. Using the parameters, BrightFields has ranked the uncertainty associated with the overland flow calculations, based on the criteria outlined below. The criteria have been assigned values from the lowest uncertainty (1) to the highest uncertainty (5). Intermediate numbers were assigned if the factor fell between criteria. Each of these factors was also assigned a weight based on its impact on the output of the calculation. Using the weighting of each of these factors, an overall uncertainty value was assigned to each of the sites.

Criterion Used to Evaluate Uncertainty in the Overland Flow Mass Loading Estimates

Overland Flow Mass Loading Factor	**Uncertainty Criteria**			
	Low (1)	Moderate (3)	Moderate to High (4)	High (5)
Chemical Data Quality	Soil concentration based on congener analyses	Soil concentration based on laboratory Aroclor data	Soil concentration based on screening Aroclor data, GC/MS screening data, or Total PCBs	Soil concentration based on Immunoassay screening data
Soil Type (K)	National Resource Conservation Soil Survey Geographic Database SSURGO	Detailed logs from the area of concern	Based on poor quality site logs	Based on logs from off-site borings
Site Coverage	Based on a thorough site assessment	Based on a site assessment	Based on a limited site assessment and aerial photography	Based on aerial photography
Distance to Discharge Point*	0 to 100 feet to discharge point	400 to 700 feet to discharge point	700 to 1,000 feet to discharge point	> 1,000 feet to discharge point
Sample Density	Greater than 15 samples per acre	Five to ten samples per acre	One to five samples per acre	Less than one sample per acre
Map Quality**	Surveyed coordinates for sample locations	Scaled map or approximately scaled map with adequate match of parcel lines	Poorly scaled map (approximate or hand drawn scale); minor inconsistencies between features and layers	Unscaled map or hand drawn figure; features do not match up with layers

*Distance to Discharge Point assumes that PCBs will reach surface waters via overland flow. When the distance between the PCB-impacted erodible area(s) and the surface waters is higher, there is greater uncertainty that PCBs from the site will reach surface water bodies.

**Map Quality was based on how accurately the figures could be georeferenced into ArcGIS. To evaluate the accuracy, features from the figures, such as parcel lines, buildings, and/or roads, were compared to parcel line and aerial layers in ArcGIS to evaluate how closely the features from the georeferenced figures matched the parcel line and aerial layer files.

2.5.2 Groundwater Mass Loading Uncertainty Approach

As with the overland flow calculations, each of the factors in the discharge estimate also have a degree of uncertainty associated with them. Using the factors discussed below, BrightFields ranked the uncertainty associated with the groundwater discharge calculations. The matrix below shows the various degrees of uncertainty associated with each factor. The criteria were assigned values from the least uncertainty (1) to the highest uncertainty (5). Intermediate numbers were assigned if the factor fell between criteria. Each of these factors was also assigned a weight based on its impact on the output of the calculation. Using the weighting of each of these factors, an overall uncertainty value was assigned to each of the sites.

Criterion Used to Evaluate Uncertainty in the Groundwater Mass Loading Estimates

Groundwater Transport Mass Loading Factor	**Uncertainty Criteria**		
	Low (1)	Moderate (3)	High (5)
Groundwater PCB Concentration	Groundwater concentration based on groundwater congener analyses	Groundwater concentration based on Aroclor data in saturated soil	Groundwater concentration based on screening data in saturated soil
Sampling Density	Greater than two samples per acre; PCB distribution adequately defined	One to 1.5 samples per acre; Multiple samples but possible data gaps	Less than 0.5 samples per acre; Very few widely spaced
Hydraulic Conductivity	Conductivity based on Aquifer Testing	Conductivity based on good quality logs or geotechnical logs	Conductivity based on poor quality logs
Horizontal Gradient	Gradient based on multiple professionally surveyed wells	Gradient based on few professionally surveyed wells and/or tidal influenced wells	Gradient based on low quality topography
Saturated Thickness	High quality logs with consistent saturated thickness	Few logs, inconsistent saturated thickness	No or poor quality boring logs
Lateral discharge distance	High sample control/ quality, good groundwater flow data	Average sample control/ quality, acceptable groundwater flow data	Poor sample control/ quality, poor groundwater flow data
Distance to discharge point	Discharge point adjacent to site	Discharge point not adjacent, but < 200 feet	Discharge point >200 feet and/or not apparent

3.0 SUMMARY OF FINDINGS

In this study BrightFields evaluated existing information from 29 Delaware HSCA sites (pre-identified by DNREC) to estimate PCB mass loading from the sites to the surface waters of New Castle, Kent, and Sussex Counties. The sites ranged in size from 0.35 to 311 acres. Between 3 and 414 soil samples and between 0 and 32 groundwater samples had been collected per site and analyzed for PCBs. The quality of existing data varied from immunoassay screening (lowest quality) to GC/MS screening at the DNREC-SIRS laboratory to EPA Method 8082 to PCB Congener (EPA Method 1668a). Approximately one-quarter of the sites had very little PCB data. The most intensively investigated site had 381 soil samples and 32 groundwater samples.

3.1 Mass Loading Results

Table 1 summarizes the mass loading results for each site evaluated, including the PCB concentrations used in the mass loading calculations, the analytical method, estimated PCB mass loading from overland flow and groundwater discharge (grams/year), and associated uncertainty factor for each site. This table shows that the estimated PCB mass loading via overland flow from the 29 evaluated sites ranges from 0.002 to 2,800 grams per year and that the estimated PCB mass loading via groundwater transport from the evaluated sites ranges from 0.0 to 35 grams per year. The general level of uncertainty associated with both the overland flow calculations and the groundwater transport calculations is moderate. The mass loading results for each site are shown on Figure1a (New Castle County), 1b (Kent County) and 1c (Sussex County).

It is important to note when reviewing the results, that the mass loading calculations are based on the PCB concentrations of the sites at the time the sampling data was collected, BrightFields 2013 site inspections, and any information available in the DNREC site files regarding site remediation efforts. Some of these sites may have subsequently been remediated through excavation or capping and therefore their PCB contributions may currently be lower. Conversely, some of the sites may have experienced soil disturbance for non-environmental reasons, and therefore, their PCB contributions may currently be higher. Some of the sites could have generated additional soil or groundwater data that was not available at the time of the file review, which could make the contributions lower or higher.

Overland Flow:

Of the 29 sites, 23 sites were evaluated for PCB mass loading via overland flow. Of these:

- 1 site (CitiSteel Area A) has the potential to contribute more than an estimated 2,000 grams of total PCBs per year.
- 4 sites have the potential to contribute between 10 and 50 grams per year.
- 5 sites have the potential to contribute between 1 and 10 grams per year.
- 13 sites have the potential to contribute less than 1 gram per year.

Groundwater Transport:

Of the 29 sites, 10 sites were evaluated for PCB mass loading via groundwater transport. Of these:

- 1 site (Former Dagsboro Substation) has the potential to contribute up to 15 grams of total PCBs per year.
- 5 sites have the potential to contribute between 1 and 6 grams per year.
- 4 sites have the potential to contribute less than 1 gram per year.

This study indicates that overland flow of water/sediment generally transports significantly more PCB mass to waterways than does groundwater. This was expected and is consistent with the first phase of PCB Mass Loading (2009). In addition, as with the first phase, the sites with the highest PCB concentrations were not always the contributors of the maximum loads. The maximum load contributed by each site depends on a variety of site characteristics for both overland flow and groundwater discharge. Soil characteristics and preventive remedial measures may result in lower PCB loads being discharged even though the source concentration is higher.

3.2 Evaluation of Methods

The procedures outlined in Section 2.0 yield conservative, yet reasonable estimates of the total mass of PCBs entering waterways of New Castle, Kent, and Sussex Counties each year from the 29 sites. While there are sources of error in any evaluation, consistently evaluating sites using the same criteria allows the sites to be compared using a relative ranking system. This study provides a tool to prioritize the sites that contribute the highest PCB load to waterways.

One significant source of variability in mass loading via overland flow is the site cover assessments. The site cover factor was assessed by a site visit, observation of the site from the street, or interpretation of aerial photographs of the site. The site cover factor assigned to the site could make the mass loading higher or lower depending on differences between the assumed cover and the actual cover. For example, if the site was assumed to be bare ground based on aerial photographs or a site observation through a fence, and it actually had a gravel cover, the mass loading would actually be lower than estimated in this study. When prioritizing sites for further assessment and remediation, it would be beneficial to observe each site during or immediately following a rainfall event in order to observe the exact overland flow pathway.

One significant source of variability in mass loading via groundwater transport is that at sites where there are no PCBs detected in groundwater, the soil partitioning equation was used to estimate pore water concentration from subsurface saturated soil PCB concentrations. This concentration was then used in the transport calculations. The pore water concentrations estimated from the subsurface saturated soil are generally greater than measured groundwater concentrations. Therefore, this results in a higher estimate of mass loading via groundwater transport.

The loading estimates generated during this study may be in error by an order of magnitude or more, especially in cases where the uncertainty is higher; however, because the same methodologies were used in this study, the ranking of each site in relation to each other site is valuable. The sites listed above were the highest contributing sites in this study based on the data available and conditions at the time of the assessment. There are also likely to be more Hazardous Substance Clean-up Act (HSCA) sites as well as non-HSCA sites that are not part of this study that are also contributing to the PCB loading to the surface waters of New Castle, Kent, and Sussex Counties.

3.3 Recommendations

Based on the information that was available to be reviewed for these sites, we recommend that a combination of additional soil and groundwater sampling be performed to better define the extent and magnitude of PCB impact. In addition, PCB remediation or interim remedial actions should be performed to limit the migration of PCBs via overland flow and/or groundwater transport.

Additional sampling and/or other testing and/or surveying would help to better define some of the assumptions made in the calculations, thereby reducing the level of uncertainty. It would be important to use a consistent sampling approach to collect the new data. Samples from additional soil and groundwater locations would help to better define the extent of PCB impact as well as provide more sample values to be used in statistical evaluation.

Sediment results from waterways, where available, are posted on the surface soil maps; however, this study did not specifically evaluate sediment results or the relationship between surface soil PCB concentrations, predicted mass loading via overland flow, and sediment data. Evaluation of the sediment data and collection of sediment samples would help to document whether there is an actual impact, and if so, to quantify the actual impact, to the affected surface water body.

Additional groundwater samples, especially using Congener or Homolog analyses, would allow measurement of actual groundwater concentrations instead of calculating pore water concentrations from partitioning calculations on some sites.

In addition, because the groundwater seepage velocity is the most uncertain parameter, aquifer testing should be undertaken, if not already performed. This would remove much of the uncertainty regarding groundwater discharge volumes.

PCB remediation, to remove the PCBs or to restrict the erosion of PCB impacted surface soil (e.g., capping), would reduce the loading of PCBs to the surface waters of New Castle, Kent, and Sussex Counties. Impacts could also be reduced by restricting the partitioning of PCBs from saturated soils into the groundwater. In lieu of, or prior to site remediation, interim measures such as stabilization of the surface or the installation of sediment and erosion control devices (e.g., silt fence, inlet protection, etc.), could be taken to limit the migration of PCBs.

It would be prudent to further evaluate sites that appear to be the most significant contributors of PCBs to the surface waters of New Castle, Kent, and Sussex Counties and to give highest priority for further evaluation to the sites with the highest PCB loading via overland flow.

In order to maintain a current priority ranking, sites should be re-evaluated, using the same methodology described in this report, as new data is collected, or remediation or interim measures occur. New sites should be added to the study as they are identified by DNREC as potential PCB contributors.

4.0 REFERENCES

Note: General references and references specifically referred to in the text above are included below. All site specific references are included in the site specific appendices.

ATSDR, 2000, Toxicological Profile for Polychlorinated Biphenyls (Update), U.S. Department of Health & Human Services, Agency for Toxic Substances and Disease Registry, Atlanta, Georgia.

Breiby, Todd, 2006, Assessment of Soil Erosion Risk within a Subwatershed using GIS and RUSLE with a Comparative Analysis of the use of STATSGO and SSURGO Soil Databases, Volume 8, Papers in Resource Analysis, 22pp. Saint Mary's University of Minnesota Central Services Press, Winona, MN. Retrieved (1-11-2013) from http://www.gis.smumn.edu.

BrightFields, Inc., 2009, PCB Mass Loading from Hazardous Substance Release Sites to Surface Waters of the Christina River Basin, July 2009.

Delaware Department of Natural Resources and Environmental Control (DNREC), 1999, Remediation Standards Guidance Under the Delaware Hazardous Substance Cleanup Act., December 1999.

DNREC, 2012, Watershed Remediation: Site Fact Sheet, Retrieved (5-16-14) from http://www.nav.dnrec.delaware.gov/DEN3/Detail/SirbDetail.aspx?id=530284.

DNREC, 2014, Screening Level Table, January 2013, Updated January 2014.

EPA, 1985, Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water-Part I (Revised-1985), EPA/600/6-85/002a, U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

EPA, 1989, Risk Assessment Guidance for Superfund Vol. 1, Human Health Evaluation Manual, December 1989.

Erickson, M.D., 1997, Analytical Chemistry of PCBs, 2nd Edition, Lewis Publishing.

ESRI, 2014, GIS Dictionary, Retrieved (5-13-14) from http://support.esri.com/en/knowledgebase/ GISDictionary/term/raster.

Grigar, J., and S. Davis, 1995, Water Erosion Prediction and Control, Technical Guide, Section I-C, Michigan State Office, NRCS, USDA, 1995.

Hawker D.W. and D.W. Connell, 1988, Octanol-water partition coefficients of polychlorinated biphenyl congeners. *Environ. Sci. Technol.* 22: 382-387.

Mackay D, W.Y. Shiu, and I.B.C. Ma, 1992, Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals, Volume I Monoaromatic Hydrocarbons, Chlorobenzenes, and PCBs. Lewis Publishers, Chelsea, Michigan.

Montgomery, John H., 1991, Groundwater Chemicals Field Guide, Lewis Publishing.

Montgomery, John H., 2000, Groundwater Chemicals Desk Reference, Third Edition, Lewis Publishing.

Moore, I. and Burch, G., 1986, Physical basis of the length-slope factor in the Universal Soil Loss Equation. *Soil Society of America Journal*. 50: 1294-1298.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K McCool, and D.C. Yoder, 1997, Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE), Agricultural Handbook No. 703, U.S. Department of Agriculture, Washington, DC.

Schwarzenbach, RP, P.M. Gschwend, and D.M. Imboden, 2003, Environmental Organic Chemistry, Second Edition. John Wiley & Sons, Hoboken, New Jersey.

Stewart, BA, D.A. Woolhiser, W.H. Wischmeier, J.H. Caro, and M.H. Frere, 1975. Control of Water Pollution from Croplands, Vol. I. EPA-600/2-75-026a), U.S. Environmental Protection Agency, Washington, DC.

Gustafson, J. B., J.G. Tell, and D. Orem, 1997, Selection of Representative TPH Fractions Based on Fate and Transport Considerations, Volume 3, Total Petroleum Hydrocarbon Criteria Working Group Series, Amherst Scientific Publishers.

Toy, Terrence J. and George R. Foster, 1998, Guidelines for the Use of the Revised Universal Soil Loss Equation (RUSLE) Version 1.06 on Mined Lands, Construction Sites, and Reclaimed Lands

U.S. Department of Agriculture (USDA) Agricultural Research Service, 2003, User's Guide Revised Universal Soil Loss Equation (RUSLE) Version 2 RUSLE2, January 2003.

USDA Natural Resource Conservation Service (NRCS), 2004, RUSLE2-Instructions & User's Guide, May 2004.

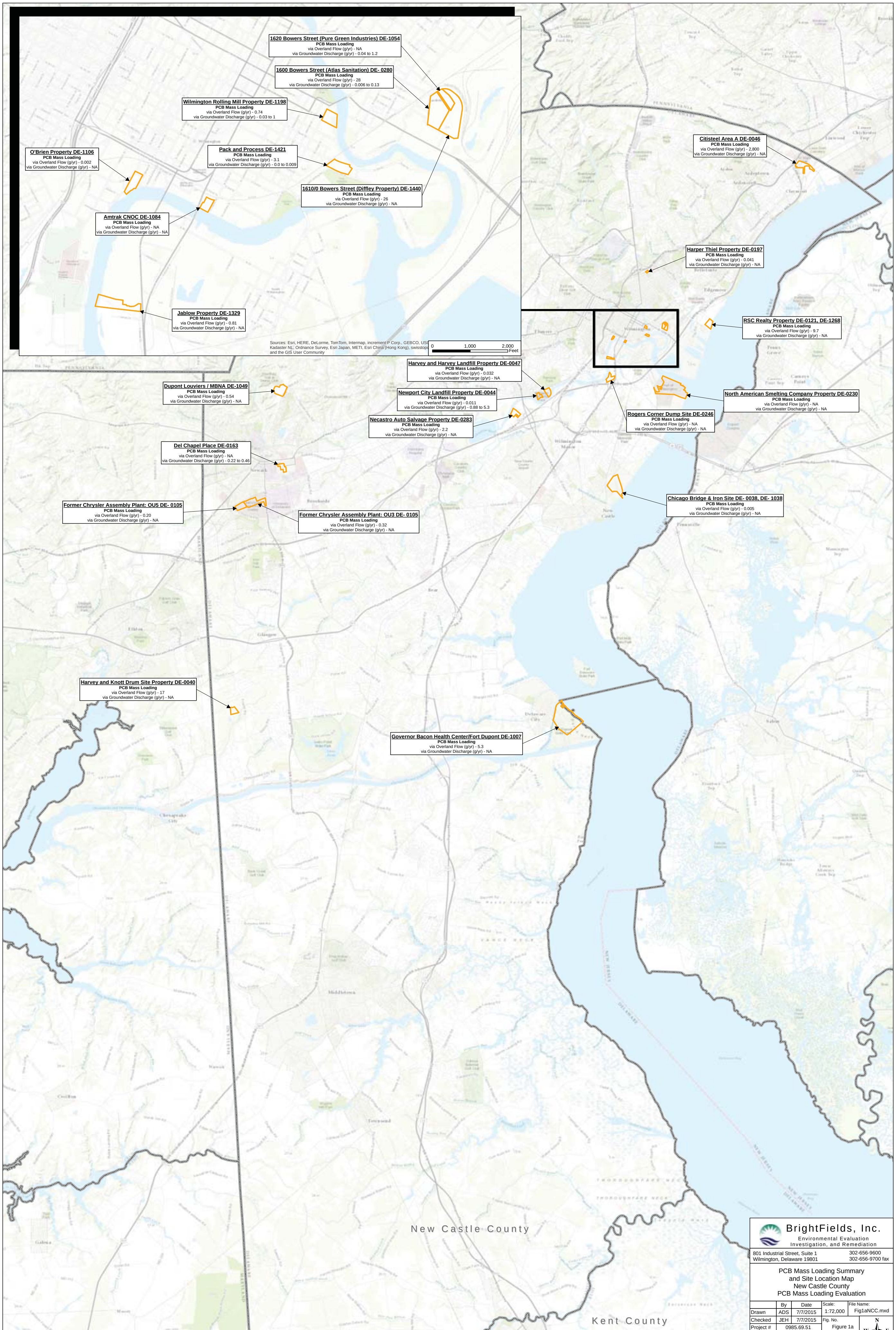
USDA NRCS, 2001, Field Office Technical Guide (FOTG), Erosion Prediction, The Revised Universal Soil Loss Equation RUSLE, December 20, 2001.

U.S. Environmental Protection Agency (USEPA), 2010, ProUCL Version 4.1.00 User Guide, EPA/600/R-07/038, May 2010.

USEPA, 2012, Stormwater Phase II Final Rule, Construction Rainfall Erosivity Waiver, Revised March 2012.

Wischmeier, W.H. and D.D. Smith. 1978. Predicted Rainfall Erosion Losses - A Guide to Conservation Planning. Agricultural Handbook No. 537. U.S. Department of Agriculture, Washington, DC.

Figures



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PCB Mass Loading Summary
and Site Location Map
New Castle County
PCB Mass Loading Evaluation

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