Stressors: Toxic Substances and Their Application within the Lake Champlain Basin
Stephanie DiBetitto, Joshua Fontaine, Rebecca Zeyzus

Executive Summary:
Toxic substances pose a threat to a myriad of living organisms, ecosystem functions, and aquatic habitats. These substances originate from several different sources and cause adverse effects unique to the habitat they are persisting in. An examination of the processes and impacts of these substances and the numerous effects they pose on habitats can be achieved by performing a comprehensive literature review. Habitats respond to toxic substances in different ways depending on the chemical and physical properties of the substances, along with intensity and the frequency of the exposure. Effects on living organisms may occur within a short or long period of time, causing either acute or chronic responses. The study considers these variables, though they are often a source of uncertainty. The goal of this assessment is to provide sufficient information and rationale to aid in understanding how toxins affect ecosystems. This knowledge can be utilized in future analyses and will be helpful in the completion of a relative risk assessment for the Lake Champlain Basin. The goal will be attained upon the completion of the following objectives: analyzing three subcategories of toxic substances; finding how they react in a range of habitats; and making a connection between the sources and the toxins persisting in the environment.
**Problem Statement:**

Toxic substances are derived from a number of sources and are abundant in many forms; they are transported throughout ecosystems where they cause negative effects to a variety of life forms.

**Background:**

Aquatic, human and plant life are affected by toxic substances in a variety of ways. Damages or illnesses caused by toxic substances can be acute and chronic for both organisms and ecosystem quality (Opportunities for Action (OFA), 2011). Certain habitats experience greater risk depending on their resilience to exposure. Characterizing risk is a detailed process which must incorporate many factors including intensity, frequency, response, sensitivity, and dosage. When dealing with toxic substances it is important to analyze the chemical characteristics, fate of the toxin pathways, sensitivity within habitats, and identify synergistic effects that may be occurring within the environment. This study will focus on five subcategories of toxic substances: heavy metals, organochlorines, polyaromatic hydrocarbons, phthalates and volatile organic compounds. Heavy metals include lead, mercury, arsenic, chromium, zinc, nickel and cadmium. Organochlorines include polychlorinated biphenols (PCBs), dioxins and furans, and dichlorodiphenyltrichloroethane (DDT). These substances were chosen for our study because The Lake Champlain Basin Program (LCBP) has categorized them under a high priority ranking as threats to the lake ecosystem. A framework provided by the LCBP’s Opportunities for Action (OFA) has outlined objectives aimed to help business managers understand the risks associated with toxic substances and means to reduce the amount of contaminants entering the ecosystem (OFA, 2011). Areas presenting the highest concern due to toxic substances within the LCB are identified in Figure 1 below. Findings regarding these substances can be applied to these efforts and will provide a greater understanding of the risks occurring within the basin.
Goal/ Purpose Statement:
The aim of this study aims to understand the potential risk posed by the three subcategories of toxic substances within ecosystems, and apply the findings in a relative risk model on the Lake Champlain Basin.

Objectives:
The objectives of this study include:
· Evaluate the negative impacts of the substances of concern
· Identify the toxic substance’s source and their modes of transport into the Lake Champlain Basin
· Examine the risk presented within the habitats and the link between the sources and toxins persisting within the environment

Approach:
Data and findings were obtained through a scientific literature review. The Lake Champlain Basin Program’s website provided the direction for our research on toxic substances within the basin. The University of Vermont’s database was used to access scientific and fact based articles. The primary search engines used to access scientific journals were EBSCO Host, ScienceDirect, and Google Scholar. Specific toxins were researched for background information. Keywords included organochlorines, mercury, phthalates, and polyaromatic hydrocarbons. After a
general chemical background was formed on the toxic substances, keywords were added to specific toxic substances to link these substances to a source e.g., wastewater treatment plants, agriculture, deposition, surface runoff and industry. Source keywords were ascertained from the background research on toxic substances. This process was repeated by linking toxic substances to habitats of concern e.g., water column, sediment, soil, rivers, wetlands, lakes and streams. Utilizing references from research papers revealed related key topics and ideas pertinent to this study.

Findings:

Heavy Metals

Heavy metals (Mercury, Arsenic, Cadmium, Chromium, Lead, Nickel, Zinc) pose a serious threat to our water systems due to their persistence in the environment, toxicity to humans and aquatic life, and contributions to water quality and sediment degradation (Pekey, et.al, 2004). Heavy metals can accumulate and transform into compounds that are more toxic than their original species. Subsequently, heavy metals biomagnify throughout the food chain, effectively harming organisms at all levels in the ecosystem, including humans (Wang et al., 2010). Heavy metals originate from multiple sources and through numerous pathways. These inputs can occur through surface runoff, wastewater discharge, or directly from the atmosphere via deposition (Pekey et al., 2004).

One of the heavy metals of highest concern listed by the Lake Champlain Basin Program (2011) is mercury (Hg) due to its persistence in fish tissue, which poses a risk when consumed by humans. Human exposure to mercury can affect the heart, kidney, lungs, immune system, and brain, regardless of age (U.S. EPA., 2010). The predominant source of mercury is from atmospheric deposition. This deposition is the result of sediments carried in from outside of the Basin by wind currents (Lake Champlain Basin Program, 2011). Mercury originates from industrial processes, such as discharge from mining, pulp and paper industries, emissions from coal-fired power plants, and waste incineration (Mercury Fact Sheet, University of Wisconsin).

As, Cd, Cr, Pb, Ni and Zn also enter water bodies through atmospheric deposition, urban runoff, and in the specific case of Burlington, historical contamination from industrial sites (Lake Champlain Basin Program, 2011). Lead is of highlighted concern within the Lake Champlain Basin due to its contribution to loon deaths through the use of lead sinkers. Since 1989, "19 of 38 (50%) of loon deaths died of lead poisoning from ingested lead sinkers" (Vermont Fish and Wildlife, 2011). A sediment quality study conducted in Lake Champlain determined that the highest concentrations of heavy metals (Cd, Pb, Ni, Ag, Zn) occur at sites located near Burlington’s sewage treatment plant (See Figure 1). This sewage treatment plant is permitted to discharge an average of 5.3 million gallons per day (Lacey et al., 2001). The Vermont Department of Environmental Conservation performed an analysis on sludge and effluent samples from the plant and found traces of zinc, cadmium, lead, and nickel (Lacey et al., 2001). In a study performed on Lake Balaton, located in Hungary, the highest levels of trace and major metals were found in site locations nearest to sewer outputs (Nguyen et al., 2005). The study also found abundant concentrations of heavy metals in harbor areas occupied by yachts and sailboats (Nguyen et al., 2005). Stormwater runoff is also a source of heavy metals. A study conducted in New Zealand examined heavy metal accumulation in stormwater runoff. Analysis of stormwater samples revealed that in addition to being a vector for the transport of runoff, roads also contribute street dust and tanker effluent solids that contribute heavy metals to the stormwater itself (Brown & Peake, 2005).
Heavy metals accumulate in sediments (Pekey et al., 2005). Due to this property, they are able to occupy streams, rivers, and lakes. Metals can attach to organic conglomerates, free sulfide ions, or individual/flocculated sediment grains, which can then be transported to the bottom and remain there unless otherwise disturbed (Mecray et al., 2001). A great deal of literature has been written on the subject of the correlation between grain size and heavy metal accumulation. By and large, finer grained sediment, i.e. clays, have a higher heavy metal content due to these particles’ negative charge and high surface to volume ratio (Lacey et al., 2001). As such, areas in the Lake Champlain Basin that are composed of finer-grained sediment are at risk of containing and accumulating higher levels of heavy metals.

Heavy metals occupy the water column on suspended solids. Samples taken from 20 cm below the surface water of Lake Balaton contained traces of heavy metals (Nguyen, 2005). Heavy metals adsorbed to sediment can also be released into the water column through sediment re-suspension (Pekey et al., 2004). In addition to the presence of heavy metals in the water column, a site in the Lake Balaton study found that the shallow depth of the site presented conditions conducive to sedimentation of suspended particulates (Nguyen et al., 2005).

Heavy metals can persist in sediment and throughout all depths of the water column. They are unrestricted to streams, rivers, and lakes. The effects of heavy metals on terrestrial areas and foliage are not examined in this report, but due to the unconstrained nature of depositional transport, all areas are subject to heavy metal exposure. The extensive reach of heavy metals within habitats incites the need to consider their impact on all of the water bodies of the Lake Champlain Basin.

Figure 2. Sediment Concentrations in Lake Champlain

Surface sediment trace metal concentrations (from partial digestion in g g−1) normalized by grain size (%less than 63 μm) and organic contaminant concentrations normalized by organic carbon (mg g−1). The key shows the relative sizes for the normalization for BH-11 (top dot) and BH-31 (lower dot). Note that in general there are higher contaminant concentrations in the southeastern portion of the inner harbor, near the STP outfall. (Lacey et al., 2001).
**Organochlorines**

Organochlorines (OCs) are commonly found in agricultural pesticides, waste water treatment effluent, combustion processes, and industrial waste products such as PCBs. “The cheap availability of chlorine gas, together with the development of industrial chlorinating procedures in the 20th century, led to the production of a wide range of organochlorine compounds many with a variety of commercial applications, including usage as insecticides, and defoliants and polychlorinated biphenyls (PCBs) used as coolants in electricity supply transformers” (Smith & Gangolli, 2002). These substances are regarded as highly toxic (Ruus et al., 2006), highly mobile throughout the environment, and are known to cause significant impacts on the environment and human health at low concentrations (Katsoyiannis et al., 2006). Chlorinated substances are persistent and hydrophobic, allowing them to remain in sediment and soil without breaking down for long periods of time. They are also lipophilic, which gives them the ability to accumulate in lipid or fat tissues of living organisms (Ruus et al., 2006). The order of magnitude of risk associated with the toxin is increased as concentrations bioaccumulate through the food web, posing increasingly higher threats to human life. These substances also act as endocrine disruptors and present major health concerns when incorporated into human diets (Smith & Gangolli, 2002).

OCs play a large role within atmospheric transport because they are generally semi-volatile with a low vapor pressure. These properties enable them to undergo diffusion, advection and convection, allowing them to travel for over 1000 km in distance and enter remote lakes, seas and mountainous areas that are not subject to a direct source of exposure (Teil et al., 2004). These substances are arguably the most detrimental to natural systems because of their ability to co-exist in both gas and particle phases and cycle through the atmosphere and earth’s surface (Teil et al., 2004). For example, PCBs are deposited by both wet and dry settling processes. Volatilization and deposition occurs simultaneously and are determined by wind speed, physical properties of the compound, vapor pressure, water solubility and temperature (Teil et al., 2004).

These processes allow for OCs to be absorbed from the gas phase by water, soil, plant surface and snow and become available within a range of ecosystems and habitats (Braune et al., 2005).

Significant amounts of persistent organochlorine pollutants (POPs) contained within forest soils due to deposition. Pollutants in the air are adsorbed to leaf and needle surfaces which fall as leaf litter, and transport contaminants to the soil. In a study done in Germany, pine trees were able to accumulate toxins by transfer from leaf litter to the O-horizon of soils, and into the pine. However, different soil horizons undergo alternate responses due to processes like degradation, dissolution, adsorption, and evaporation (Wenzel et al., 2001). A reservoir of POPs remains in the A-horizon due to the acidic properties of pine forests which lowers microbial activity and degradation. The greater persistence of toxins within the A-horizon should be recognized and may have greater adverse effects on soil organisms (i.e. isopods and earthworms), along with the ability to bring harm to the rhizosphere and groundwater (Wenzel et al., 2001).

OCs are transported from agricultural sites into the greater environment where they exist in common forms like endosulfan, aldrin, and DDT. Runoff from agricultural fields enables pesticides to wash into waterways. Rivers act as the largest receptacles for pesticide waste and agricultural runoff. (Kumari et al., 2001). Pesticides sprayed to prevent disease and vectors (mostly in developing countries) enter river systems through surface run-off from urban areas. Once this toxic substance is released into river systems it becomes bioavailable to the
organisms living in the river and bioaccumulates throughout the food chain. “Pollution by persistent chemicals is potentially harmful to the higher trophic levels of the food chain including fish which are able to accumulate contaminant pesticide residues in concentrations several folds higher than in the surrounding water” (Kumari et al., 2001). Harmful effects of the chemical when taken up by a fish species include complications in growth, development, reproduction, behavior and respiration (Kumari et al., 2001).

A study conducted to identify spatial and temporal trends in marine biota in the Canadian arctic used ringled seal as an indicator species to identify OC concentrations within the study area. It was found that marine invertebrates are the connection between phytoplankton and fish, seabirds and mammals in Arctic marine trophic levels. These species are responsible for transferring OCs from low to high order species on the food web (Braune et al., 2005). Sea birds (i.e glaucous gulls) and polar bears have the highest OC concentrations of all arctic mammals due to their dietary needs. Seabirds scavenge marine mammal carcasses and polar bears eat primarily seal blubber, both nutrition sources contain higher magnitudes of toxins due to bioaccumulation. Endocrine disruption was found to occur within polar bears due to their exposure to these toxins. Inuit populations are also at risk because their diets depend on arctic species higher up on the food chain (Braune et al., 2005).

POPs occur most often in densely populated regions, and become concentrated with estuarine and coastal marine ecosystems. Harmful effects on aquatic organisms caused by POPs are dependent on exposure severity and the physiochemical properties of the parent compound and the resulting transformation products (Pulster et al., 2009). Other factors to consider include the input duration, mass loading, predator- prey relationships, sensitivity of the species, and flushing time(Pulster et al., 2009). A study done on dolphins on the Atlantic Coast of Georgia in the United States concluded that effects of POPs including PCBs and organochlorine pesticides (OCPs) such as DDT, depend on the gender, age, diet, health condition, reproduction status, and the season determine the effect posed on the mammal (Pulster et al., 2009). Determining the effects and associated risk is a product of many factors.

POPs are present in wastewater treatment resulting from urban and agricultural runoff into the sewerage system, wet and dry deposition from the atmosphere, and from industrial waste discharges (Katsoyiannis et al., 2006). The hydrophobic property of organochlorines allows the toxic substances to absorb to sludge. Generally, the only way to extract these toxins from the waste water stream is through sludge extraction (Katsoyiannis et al., 2006). Within hydrologic systems, sediments act as a sink for persistent pollutants (Hong et al., 2006). Contaminated sediments are a threat to aquatic life because they can be ingested and bioaccumulate, along with being a direct source of toxicity. Lab analysis of organochlorines concentrations in sediment samples is an effective way to monitor remediation over time (Hong et al., 2006).

PCBs and dioxins are persistent in Lake Champlain’s sediment, and are among a group of substances presenting the highest concern throughout the basin. Low levels of PCBs exist throughout the lake, and as a result they have accumulated in fish tissue (Lake Champlain Basin Program, 2011). Concentration of the toxic substance exceeds the U.S. Food and Drug Administration for fish and the Environmental Protection Agency’s guidelines for humans. The largest single source of the contaminant is found in the Georgia Pacific sludge bed in Cumberland Bay (Watzin, 2005). Dioxin is brought into the basin through pesticide runoff from
agriculture, though both PCBs and dioxin are primarily transported from wind currents depositing substances from sources outside of the basin. Fish advisories are a result of the elevated concentrations and are issued to promote safe fish consumption and protect human health (*Lake Champlain Basin Program*, 2011).

**Polyaromatic Hydrocarbons**

Polyaromatic hydrocarbons (PAHs) are a group of compounds consisting of 10,000 different varieties of chemicals including benzopyrene, benzantracene, fluoranthene, and naphthalene. PAHs are released by the combustion and incomplete burning of these compounds. Major sources of these compounds include the burning of oil, wood, garbage or coal. Automobile exhaust, industrial emissions and smoke from burning wood, charcoal and tobacco contain high levels of PAHs (*Wisconsin Department of Health Services*, 2011). In general, more PAHs form when burning materials at low temperatures, like wood fires or cigarettes. High-temperature furnaces produce fewer PAHs. Some PAHs can dissolve in water and can enter groundwater from ash, tar, or creosote that is improperly disposed in landfills. When dissolved PAHs could be difficult to detect (*Wisconsin Department of Health Services*, 2011). Other PAHs may attach to dust or ash, which can cause lung irritation by inhalation. Skin contact with PAHs may cause redness, blistering, and peeling. Major health concerns associated with PAH poisoning include the development of cancer, reproductive problems such as still birth, and organ damage (*Wisconsin Department of Health Services*, 2011).

The Lake Champlain Basin Program classified PAHs as a high priority toxic substance. The LCBP considers PAHs to be a high priority because there are significant concentrations found in sediment, water, and biota at levels that exceed the regulation standards, which subject wildlife and the environment to potential health risks. A study done in the San Francisco Bay focused on monitoring PAHs in different geographic areas of the estuary discovered that PAHs can bioaccumulate in fish and shellfish (*Oros et al*, 2007). This bioaccumulation can lead to greater human health risks by consumption of contaminated fish. This information can be applied to the Lake Champlain Basin to better understand and account for the risk of polyaromatic hydrocarbons.

**Other Toxic Substances**

**Phthalates**

Phthalates are compounds known as esters, which are used in plastic synthesizing to increase the flexibility, transparency, durability, and longevity of the plastic. As plastics degrade, the phthalates are released; this is a problem because phthalates act as endocrine disruptors (*Barret*, 2005). Like organochlorines, these can cause harmful effects in growth, behavior, and hormone production of organisms exposed to phthalates. Endocrine disruptor's pose threats to wildlife populations due to the possibility of growth defects, which can result in mortality (*Hallmark et al*, 2007). A major issue concerning phthalates is the disposal of plastic materials. If these products are left to degrade in waterways or in watersheds, leaching can lead to water contamination. Water contamination exposes wildlife and humans to phthalates through skin absorption. (*Moody and Chu*, 1995).
The Lake Champlain Basin Program classifies phthalates as a potential concern toxic substance. Phthalates in the basin currently are not at a high enough concentration to pose a risk to human health or the environment based on the current standards. However, phthalates are known to have effects in other systems where concentrations are much greater (Lake Champlain Basin Program, 2011). The Lake Champlain Basin Program suggests that phthalates should be monitored more closely. In Japan, a study was conducted which examined high concentrations of phthalates in water and their relationship to prostate cancer in men. The study indicated that there is a direct link between high concentrations of phthalates in water and prostate cancer rates in men (Kim et al, 2002). Although there is a positive correlation shown from this study, the phthalates may not be the only substance responsible for the increased rate of prostate cancer. This study reinforces the Lake Champlain Basin Program’s statement demanding that the effects of phthalate be studied more extensively.

**Volatile Organic Compounds**

Volatile organic compounds (VOCs) include a variety of chemicals. Sources of VOCs include paints, lacquers, cleaning supplies, pesticides, building materials, office equipment, correction fluids, glues and adhesives, permanent markers, and photographic solutions. These compounds found in industrial and urban sources can have both short- and long-term adverse health effects (EPA, 2011). VOCs are used in many household products and when either left as an open air or disposed of improperly can result in the release of organic compounds into the air, water, and soil. Like phthalates, VOCs can be absorbed through the skin. Improper disposal of VOC containing products could subject wildlife and humans to the risk of headaches, loss of coordination, nausea and damage to the liver, kidneys, and central nervous system. Some of these compounds have been linked to cancer in some animals (EPA, 2011).

Like phthalates, the Lake Champlain basin classifies VOCs as a potential concern toxic substance, thus meaning that their levels in water, soil, and biota have not yet exceeded those of the standards for protection of wildlife and the environment. A study conducted in Atlanta focused on the effects of exposure to VOC mixtures on genetic variability, found that reactions to VOC mixtures vary greatly. This study looked at people who had been exposed to a relatively low concentration compared to the standard but still experienced neurotoxicity while someone else experiencing the same concentration had no reaction (Pohl et al, 2011). Although VOCs are not a high priority it is recommended they be monitored. In addition standards may need to be reevaluated if people experience vastly different symptoms to the same concentrations. Overall volatile organic compounds are a threat and need to be studied further to determine the risk that they pose to the Lake Champlain Basin.

**Rankings**

Four filters were used to quantify the risk of toxic substances within the Lake Champlain Basin. These filters are an impact filter, an impact importance filter, an effect filter, and an effect importance filter. The impact filter (Table 1) shows the link between the different sources and the stressor being evaluated. This table is designed as a binomial filter where if there is a link between a source and stressor it is be given a value of 1. If there is no link the source is
given a value of 0. Due to variability and difficulty identifying all toxic outputs of each stressor, a 0.5 value was given for sources that were thought to contribute to the stressor.

A sediment quality study conducted in Lake Champlain found that the largest concentration of heavy metals is at sites nearest to the sewage treatment plant (Lacey et al., 2001). Runoff from roads, industrial processes, external inputs, and marinas (boat traffic) were also found to be contributors of heavy metals. All of these sources have received a 1 for the impacts filter, indicating a link between the source and stressor.

Organochlorines can be attributed to many anthropogenic practices. There is a direct correlation between agriculture, urban, waste water treatment plants, roads, industry and external sources and the aforementioned stressor group, giving these sources an impact filter rating of 1 as shown in Table 1. Parks were given a ranking of 0.5 because though they are not direct links they cannot be eliminated because there is a possibility that pesticides or herbicides are applied to these areas (Table 1).

Polyaromatic hydrocarbons can occupy both sediment and water ways over a long period of time. This risk assessment has identified the main sources of polyaromatic hydrocarbons to be urban, roads, marinas, industrial, and external sources which are represented by a rating score of 1 in the impact filter. This is because there is a clear link between the source and stressor.

Partial sources such as agriculture and parks were identified with a 0.5 in the impact filter because there link to the stressor is not as clear.

The major sources of phthalates have been identified as places that use and dispose of plastic materials. The main sources were given a value of 1 which includes urban and industrial sources. Partial sources were denoted with a 0.5 which include roads and parks as sources.

Volatile organic compounds have been identified as materials that come from primarily household, industrial, and pesticide materials; therefore, their major sources are agriculture, urban, and industrial sources which are all valued as a 1 in the impact filter (Table 1).

### Table 1: Impact Link between Sources and Stressor

<table>
<thead>
<tr>
<th>Sources</th>
<th>Heavy Metals</th>
<th>Organochlorines</th>
<th>PAHs</th>
<th>Phthalates</th>
<th>VOCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>0</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Urban</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>WWTP</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Dams</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Roads</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>Fisheries</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Marinas</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Forested Area</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Industrial</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Parks</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>External</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The impact importance filter (Table 2) was designed to help quantify the strength of a source to its stressor. This was done because some sources produce less stress, and by assigning them the same value as a source that produces more stress, will result with a greater impact score and cause inaccuracies in the relative risk assessment. The filter values include 0, 1, 2, 4 with 0
being of no importance, 1 being of relative importance, 2 being a significant importance, and 4 being the cause of an apocalypse. No values of 4 were given to any of the sources.

Heavy metal sources include urban, waste water treatment plants, industrial processes and external, which have received a value of 2 due to evidence from the findings showing them to be significant suppliers of heavy metals. Roads, marinas, and parks have received a value of 1 because findings suggest their contribution of heavy metals to be less significant than other sources.

For organochlorines, the major impact importance sources are agricultural, urban, industrial, and external sources, which were given a ranking value of 2. Although waste water treatment plants, parks, and roads have an impact on habitats they are less import and receive a ranking value of 1.

Although all sources contribute to PAHs, some have a greater impact and contribution to PAH exposure. The greatest contributors of PAHs were identified with a ranking value of 2, which include urban, roads, marinas, and industrial sources. Agriculture, parks, and external sources were assigned a 0.5 because their production of PAHs is much less than the other sources listed above.

The greatest contributors of phthalates were identified as urban and industrial sources, which were given the high ranking value of 2. These sources focus primarily on places where plastics are being created, used, and disposed of. Roads and parks are sources which received a score of 1 because although they release phthalates, their contribution is minimal compared to urban and industrial sources.

Volatile organic compounds are primarily the product of urban and industrial sources; therefore, they were assigned ranking values of 2. Although VOCs are present in some pesticides, their contribution of VOCs in the environment is much less as compared to the improper disposal of urban and industrial materials, giving agriculture a ranking value of 1.

<table>
<thead>
<tr>
<th>Sources</th>
<th>Heavy Metals</th>
<th>Organochlorines</th>
<th>PAHs</th>
<th>Phthalates</th>
<th>VOCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Urban</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>WWTP</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Dams</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Roads</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Fisheries</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Marinas</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Forested Area</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Industrial</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Parks</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>External</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The effects filter displayed in Table 3 identifies specific habitats that may be affected by the toxic substances. If there is a link between the stressor affecting a habitat, then the habitat is given a ranking value of 1. If there is no effect of a stressor on a habitat, then the habitat is given
a ranking score of 0. If there is a possibility that the stressor may affect a habitat but it is not entirely clear, then a 0.5 ranking score is assigned.

The primary transport vector for heavy metals entering the Lake Champlain Basin is through atmospheric deposition. As such, heavy metal contamination is unrestricted to both land and water. Water includes rivers, lakes and streams. Heavy metals can attach to suspended solids in the water column and sediments on the lake bottom. The effect filter value of 1 has been assigned to lakes, rivers, streams, wetlands and open water environments due to these properties.

Organochlorines are transported through atmospheric deposition allowing them to reach pristine ecosystems as far 1000 km from a direct source (Teil et al., 2004). Due to these processes all habitats were given an effect filter score of 1, because deposition is an effect everywhere.

The two major transport vectors of PAHs are through runoff and atmospheric deposition. Through runoff of oil from roads and spills in marinas, waterways are often contaminated with different forms of PAHs. Lakes, ponds, rivers, streams, and open water of all depths are influenced by PAH exposure and were assigned a ranking value of 1. Runoff may also affect developed areas by washing PAHs into yards, parks, and other developed areas resulting in a ranking of 1. PAHs can be spread through atmospheric deposition as a result of the release of gases from the incomplete burning of coal and urban heating systems. PAHs transported via atmospheric deposition can contaminate forests, agriculture, and herbaceous habitats. Due to a lack of evidence and data they were assigned a partial ranking value of 0.5.

The major transport vector of phthalates is the leaching of plastics that have been improperly disposed. These plastics break down over time, releasing phthalates which are then released into waterways (Barret, 2005). This results in lakes, ponds, river, streams, wetlands, and all open waters receiving a ranking value of 1. Developed areas were also assigned a ranking value of 1 because of the presence and use of different plastics in the habitat.

VOCs are transported to habitats through the runoff of VOC containing materials into waterways including lakes, ponds, streams, rivers, wetlands, and open waters. These habitats were all assigned a ranking value of 1. Household products, industrial materials, and office supplies contain VOC and they are often disposed of them outside (EPA, 2011). This results in the contamination of developed areas and the assigned ranking value of 1.

Table 3: Effects Filter of Stressor on Specific Habitats

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Heavy Metal</th>
<th>Organochlorines</th>
<th>PAHs</th>
<th>Phthalates</th>
<th>VOCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake/ Ponds</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Rivers/ Streams</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Developed Areas</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Forested</td>
<td>0.5</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>0.5</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Agriculture</td>
<td>0.5</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wetlands</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Open water: Lake Champlain</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
The effect importance filter (Table 4) ranks the strength of the damage stressors have on habitats. Much like the impact importance filter, different stressors have greater effects on different habitats which are represented by this filter. The ranking system is the same as the importance filter with a range of values from 0, 1, 2, 4 ranking the effects importance on a given habitat. No values of 4 were assigned to any of the habitats.

Heavy metals can remain in sediment for as long as the sediment is undisturbed. Heavy metals adsorbed to suspended solids and in sediment provide a constant means of consumption by fish and other aquatic organisms. This negative impact of this characteristic is amplified due to the increased potency of heavy metals through the bioaccumulation of food web. Aquatic environments, aquatic organisms, and humans are at risk for heavy metal exposure due to this property. Lakes/ponds, rivers/streams, and the entirety of the open water environment have received a score of 2 for the effect importance filter.

Habitats that undergo the highest effect impacts caused by organochlorines include lakes/ponds, rivers/streams, and open water bodies both greater than or less than 6 feet in depth, were all given filter scores of 2 (Table 4). These habitats bioaccumulate toxins as they move through the food chain, and in the habitats that support moving water act as either receptacles or pathways for the toxin to be stored or transported farther. Developed areas, forests, herbaceous land, agricultural land, and wetlands are given ranking scores of 1 because they are effected by organochlorines, though not in as severe a way as the habitats listed above.

Since the primary vector transport was through runoff all of the water habitats were assigned a ranking value of 2. The monitoring of PAHs can be difficult due to their ability to dissolve in water (Wisconsin Department of Health Services, 2011). As mentioned before the effects of atmospheric deposition is a problem but due to the lack of data was not ranked high in attempts to avoid making it appear more harmful than it is; therefore forests, herbaceous, and agriculture were all assigned a ranking value of 1.

All of the habitats that were mentioned for both phthalates and VOCs received a ranking value of 1 because as the Lake Champlain Basin Program defined, these toxic substances are a potential concern toxic substance. Currently, there is no evidence of this substances being at a high enough concentration to cause adverse effects in both humans and the environment and thus the stressor is not contributing extreme damage.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Heavy Metal</th>
<th>Organochlorines</th>
<th>PAHs</th>
<th>Phthalates</th>
<th>VOCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake/ Ponds</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Rivers/ Streams</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Developed Areas</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Forested</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Agriculture</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Conclusions/ Recommendations:

The regulation of toxic substances in the Lake Champlain Basin is an especially difficult task due to the prevalence of outside industrial sources and atmospheric deposition. This mode of transport is a constant source with no boundaries, and does not allow for the quantification of the amount, frequency and intensity of inputs. There is also a lack of understanding regarding the synergistic effects between these substances and their effects on the environments in which they exist, causing unforeseen risk. The properties of these chemicals and their synergistic effects between other chemicals, the environment, and their effects as they are broken down into constituents and alternative compounds further enhance uncertainty. The amount of toxic substance that remains in sediment will act as a direct source of exposure within aquatic ecosystems and allows for concentrations to magnify throughout the food chain and cause adverse health effects. Additionally, new emerging toxins threaten the LCB and further investigation is needed in the years to come (LCBP, 2011).

In the case of heavy metals, the best defense is increased awareness of fish consumption advisories, as well as methods of safe disposal for household products, such as batteries. As for organochlorines, they will continue to persist and mobilize until they are broken down completely. The only way to prevent concentrations from increasing is to discontinue the use and manufacturing of chlorinated solvents, which may require a paradigm shift to become a reality. The best way to avoid polyaromatic hydrocarbons contamination is to halt the burning of fossil fuels altogether. A more realistic approach to deal with PAHs is to design a more effective way to respond and clean up oil spills. In addition, there needs to be the development of a scrubber that can clean the smoke stack exhaust from industries which will help trap and control the left over PAHs. Phthalates and volatile organic compounds have not yet exceed regulatory standards, and therefore pose no serious risks to wildlife and environment. Extensive monitoring of these two compounds needs to take place so that negative impacts can be avoided.

Education and awareness are the two most effective and achievable actions that can be taken in order to lessen the harmful impacts caused by these substances. Public awareness regarding disposal methods of household products is one such method that would aid in reducing the entry of toxic substances into the LCB. The greatest change that needs to be made, and also the most unlikely, is a paradigm shift in the way that energy is produced and in the products we manufacture and use. This is the only change that will truly ensure the health of our ecosystems and the life that it supports.

Acknowledgements:

We would like to thank Francis Churchill of the Risk Management department at the University of Vermont for acting as a consultant on this project. We would also like to thank our Environmental Science 202 instructors Breck Bowden, Pooja Kanwar, and Pam Johnston.

<table>
<thead>
<tr>
<th>Wetlands</th>
<th>2</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open water:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lake Champlain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;6ft</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>&gt;6ft</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
appreciate their patience and availability throughout the 2011 Spring semester.

**Literature Citations:**


http://www.lcbp.org/ATLAS/HTML/is_tconc.htm


Ruus, A., Berge, J.A., Hylland, K., Bjerkeng, B., Bakkes, T., and Naes, K. (2006). Polychlorinated Dibenzo-p-Dioxins (PCDDs) and Dibenzofuran (PCDFs) in the Greenland fjords (Norway)- Deposition, levels, and effects. Journal of Toxicology and


