Ecosystem Impacts of Electronic Waste in the Ohio Lake Erie Basin

December 23, 2012

Prepared by
Delta Institute
35 East Wacker Drive
Suite 1200
Chicago, Illinois 60601

The Delta Institute received financial support for this study from US EPA

Table of Contents

Overview

Innovation and rapid technological advancements with electronics have changed the way people interact and conduct business. These advancements involve the proliferation of electronic products including desktop and laptop computers, tablets, mobile phones, imaging equipment, and computer infrastructure, all of which make daily activities quicker and largely independent of physical location. However, these conveniences are associated with environmental impacts throughout the product life cycle including end-of-life (EOL) management, a term that generally describes either disposal or recycling of electronics or "e-waste".

This study, funded by the Great Lakes Restoration Initiative (GLRI), identifies the impact of electronic equipment EOL management on the Lake Erie basin. The Great Lakes Restoration Initiative is the largest federal investment in the Great Lakes in over two decades, with a task force of 11 federal agencies that developed an action plan to address urgent issues, including toxics reduction in the region[1].

This report explores the relationship between e-waste and toxic outputs to Lake Erie with an emphasis on northern Ohio's four identified areas of concern (AOCs), as identified by the Great Lakes Water Quality Agreement between the U.S. and Canada. Additionally, this report provides an overview of existing tools and practices that promote watershed health by protecting waters from polluted runoff or deposition.

Consumer Electronics

The demand for consumer electronics has grown steadily over time, driven in part by rapid technological development. By 2005, Americans owned nearly 3 billion electronic products[2]. Proliferation of handheld devices including smart phones, and more recently tablet computers, has been a strong driver of demand in recent years. *The U.S. Consumer Electronics Sales and Forecasts* predicts that industry sales will top $200 billion for the first time in 2012[3]. However, introduction of new or improved products to the marketplace often displaces products that have not reached the end of their useful lives. For example, in 2005, the Consumer Electronics Association estimated that 304 million televisions, VCRs, cell phones, and monitors were removed from U.S. households – most of them in working order[4].

When households or businesses replace and retire electronic equipment it is considered to be at the end of its useful life. However, it is common practice for businesses to retire computers at the end of a three year financial depreciation cycle even though the useful life of the product may be longer than three years. Despite the fact the electronics contain substances linked to potentially adverse health outcomes and contain recoverable materials of value, only a fraction of EOL electronics are actually recycled. In 2007, 18.4 percent of EOL electronics by weight were collected for recycling[5]. The majority of electronics are either disposed of in landfills or incinerated in the waste-to-energy process. Approximately 12 percent of all municipal solid waste (MSW) is feedstock for waste-to-energy[6]. While certain electronic products, such as CRT glass, is likely removed from the waste stream due to concern about lead ash, other electronics may not be removed because they contain plastic, which is combustible.

With the rising demand for electronic products, a growing number of retired devices are stored in attics, basements, warehouses, and other locations, awaiting EOL management. A variety of factors incline both residential and commercial consumers of electronics to store obsolete devices, including uncertainty about proper EOL management practices, and concern about the security of data stored on those devices.

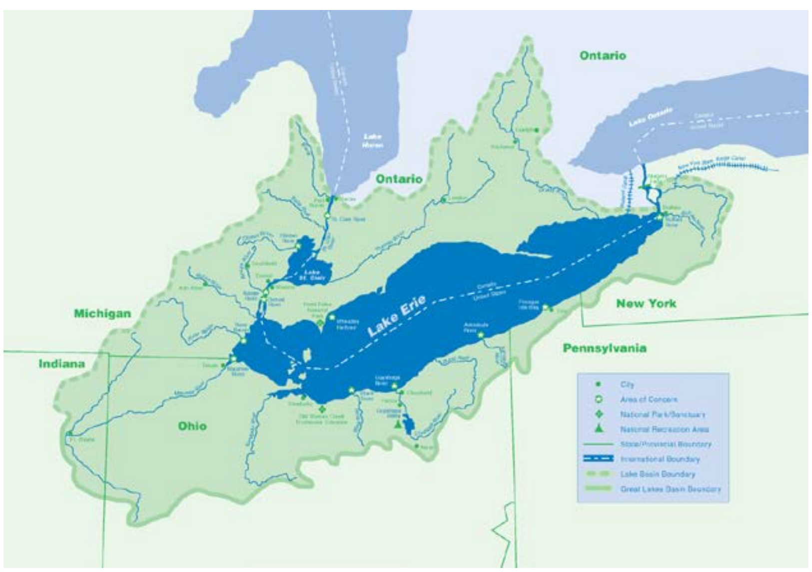
Lake Erie Basin

The Great Lakes basin is a particularly sensitive ecosystem of interconnected lakes threatened by a variety of pollutants, many of which result from decades of hazardous discharge that contaminated sediments and aquatic organisms, or legacy pollution. Some electronic components contain small quantities of these legacy pollutants as well as contaminants of emerging concern (CECs) - chemicals or materials characterized by a perceived, potential, or real threat to human health or the environment,[7] and have uncertain impacts to ecosystem health.

Lake Erie's drainage basin covers parts of Indiana, Michigan, Ohio, New York, Pennsylvania, and Ontario, Canada. Although it is the smallest of the Great Lakes by volume, its basin is home to over twelve million people, or about one-third of the total population of the Great Lakes Basin[8]. The population is comprised of approximately 10.4 million Americans and 1.9 million Canadians[9].

In Ohio, thirty-five counties, with a combined population of 5.2 million people, drain to Lake Erie[10]. We estimate that there are over 163.5 million pounds of electronics presently stored in the Ohio region of the Lake Erie basin. This figure is greater than the combined weight of fourteen thousand male elephants. The total amount of stored electronics includes 65.6 million pounds of home or commercial office equipment (e.g. computers, computer displays, hard copy devices, and mobile devices), and an additional 97.9 million pounds of televisions. We made these calculations using national data on quantity of products in use, storage, or EOL management in 2009, out of all electronic products sold between 1980 through 2009, from U.S. EPA's report on *Electronics Waste Management in the United States Through 2009.* The figures contained in that report were multiplied by .01679, or the percentage of U.S. residents that reside in the thirty-five Ohio counties that comprise Lake Erie's drainage basin. We also assume a constant rate of storage across geographic areas.

Figure 1: Lake Erie drainage basin[11]



Contaminants in Electronics

Electronic products contain a variety of materials that can potentially cause adverse impacts to the environment and human health. Many of the same materials have also been identified as substances of concern to the Great Lakes. Electronics that enter the waste stream may have potentially adverse impacts on terrestrial and aquatic ecosystems and human health because of their components, including heavy metals and flame retardants. Some toxins persist in ecosystems and organisms over long time horizons, and as a result are known as persistent toxic substances (PTS). A subset of these toxins, including lead and mercury, are considered the focus of EPA's restoration and remediation efforts because of their persistence and potential for bioaccumulation in organisms. These toxins are part of a broader category known as persistent bioaccumulative toxic (PBT) substances, where material concentrations increase up the food chain with the highest concentrations in fish, birds, mammals, and humans.

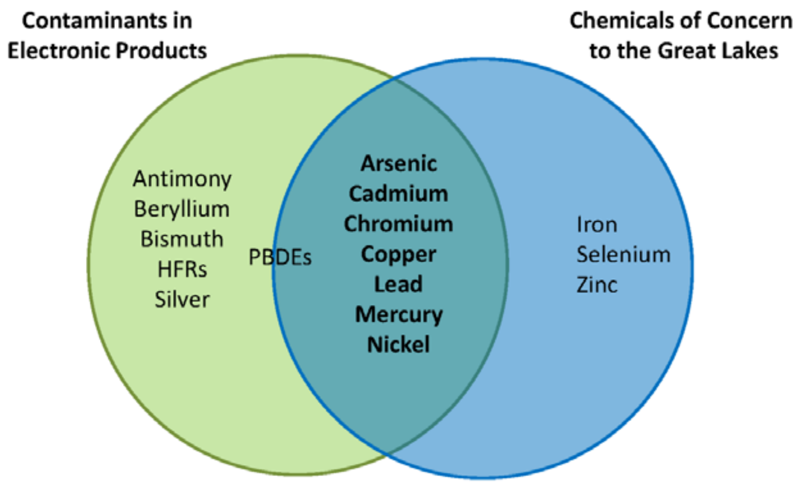
There has been significant progress in addressing concerns about these toxins over several decades, though new concerns are being raised. For example, uncertainty about CECs including brominated flame retardants (BFRs), pharmaceuticals, industrial chemicals, anti-bacterial substances in personal hygiene products, and plastic additives, among many other materials incorporated into a variety of everyday products[12]. There is an increasing effort on the part of researchers to understand CECs, and particularly the impacts of chronic exposure, how CECs interact with traditional pollutants, impacts of byproducts, and impacts to growth, reproduction, behavior, and metabolism[13]. The body of knowledge about these substances is growing and threats may emerge as new research becomes available. As a result, research and monitoring efforts are shifting toward CECs, including polybrominated diphenyl ethers (PBDEs), a type of BFR used as flame retardants in electronics and other products. The primary concern around CECs is uncertainty about adverse effects resulting from chronic exposure at low concentrations[14].

CECs are not generally subject to regulatory standards, although many are voluntarily phased out by manufacturers. For instance, "PBDE contamination increased rapidly [in the Great Lakes] from 1981 to 2000, primarily associated with the penta-BDE formulation[15]." However, total PBDE concentrations in top predator fish have been on the decline since 2000 resulting from voluntary efforts on behalf of the sole U.S. manufacturer of PBDEs to voluntarily phase-out production by 2004[16]. Voluntary efforts are driven primarily by concerns that CECs may cause potentially harmful effects through accumulation in sediments, fish, birds, other wildlife and ultimately humans.

Many contaminants of concern to the Great Lakes are legacy pollutants that cannot be directly attributed to disposal of electronic waste. However, given the proliferation of electronic devices in all facets of modern life, and the growing proportion of electronics in the waste stream, e-waste may have significant adverse impacts on ecosystems and human health. For example, although electronics account for only about two percent of municipal solid waste (MSW) by volume, they account for about seventy percent of heavy metals in U.S. landfills by volume[17]. Landfill leachate, or water that passes through landfills, contains components of landfilled materials including toxic chemicals, and may transport them throughout the environment. Landfills may also emit toxins to air, which will return contaminants to land and water. Thus, the increasing rate of electronic waste disposal to landfills potentially threatens to contaminate soil, air, and water with an increasing concentration of soluble or volatile heavy metals and flame retardants.

As shown in Figure 2, many of the contaminants in electronics are identified as concerns to the Great Lakes. However, it is also important to understand exposure pathways of CECs in order to take a precautionary approach and minimize impacts to ecosystems, organisms, and human health.

Figure 2: Contaminants found in electronic equipment and chemicals of concern to the Great Lakes



E-waste in Cuyahoga and Lucas Counties

Both Cuyahoga and Lucas Counties provide e-scrap collection services to residential and commercial residents. In Cuyahoga County, in 2009, the Cuyahoga County solid waste management district and municipalities collaborated to carry out computer collection events for residents. In Lucas County, the solid waste management district provides residents with year round drop-off sites for electronics. County solid waste managers have done a good job of creating opportunities to discard electronics according to best practices. However, there is a persisting gap between these opportunities and EOL practices at the consumer level.

Using data from the county solid waste management plans, Table 1 indicates that the amount of electronics recycled through district or municipal collection opportunities in Cuyahoga and Lucas Counties is equal to 0.06 and 0.01 percent of the total waste stream, respectively. These numbers may not represent the total amount of electronics recycled in the counties, such as electronics recycled through contracts with governmental or commercial entities, but illustrates some of the trends under discussion here. Compared to U.S. EPA's estimate that electronic waste comprises one to two percent of MSW streams[18], this data suggests that some proportion of e-waste is discarded as trash. In fact, county solid waste managers are aware of these issues and of the need to increase awareness of electronics recycling opportunities. In 2009, the annual Cuyahoga County Solid Waste Management District survey found that while fifty-five percent of respondents reported recycling electronics, nine percent of respondents reported that they did not know how, and discarded electronic waste as trash[19]. In addition to the nine percent that goes to landfill, there is uncertainty about the sixty-four percent of respondents whose EOL management practices were not identified through the survey results.

Table 1: E-Waste collections in Cuyahoga and Lucas Counties as percentage of total waste stream

County	Reference Year	Tons E-Waste Collected through Municipal Events	Tons of Residential and Commercial Waste Generated	E-Waste as Percent of Waste Generated
Cuyahoga	2009	990	1,731,395	.06
Lucas	2008	103.49	710,599	.01

There are several reasons for the gap between opportunities to recycle electronics and the rate of electronics recycling both in this area of study, and more broadly. Communication is a central barrier, and is essential for both education and awareness about the importance of electronics recycling. Different members of the community hold different sets of values, so values-based messaging may be an effective communication strategy. For example, while some people may be easily persuaded to follow best practices, others may be incented to act only if they understand linkages between recycling and issues they personally care about, such as clean water or enhanced fishing opportunities. Another barrier to electronics recycling is convenience. What the examples of Cuyahoga and Lucas counties show is that while leadership and initiative among solid waste management districts and municipalities are necessary to achieve widespread recycling, they are not sufficient. Collaboration among government, business, and residents is essential to ensure that waste managers can provide recycling opportunities to private and commercial citizens at convenient locations. For example, municipalities may consider providing a standing weekend collection opportunity at a local supermarket or other venue. This would provide an ongoing opportunity to safely discard electronics while managing personal business. Additionally, these types of campaigns are visible and build public awareness.

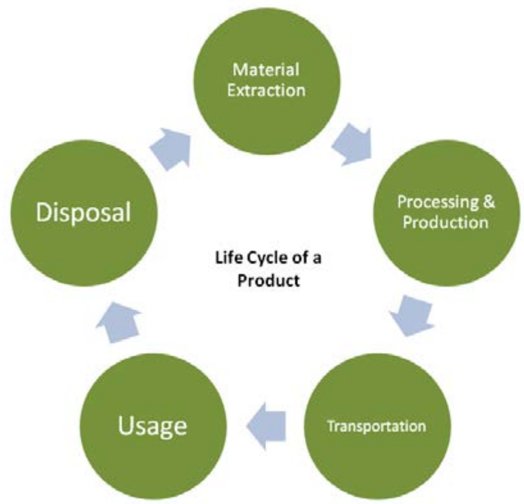
E-waste is a small percentage of total waste generated in these regions, although electronics are the fastest growing proportion of the waste stream nationally and around the world[20]. Local decision makers must be equipped with the right tools to understand environmental impacts and mitigate potential harm, and many different analytic frameworks to understand contaminants, pathways, and impacts on soil, air, and water.

Ecosystem Analysis

Ecological analysis involves monitoring the baseline and changing conditions of an ecosystem and the services it provides. This analysis enables decision-makers to tailor management strategies in order to achieve desired outcomes[21]. The Delta Institute created one form of ecosystem analysis, the ecosystem environmental management systems (ECO-EMS), to document emissions and discharges from facilities, such as port or marina operations near a lake. This tool maps contaminants and potential pathways and uses matrices to benchmark environmental impacts and improvements. The ECO-EMS tool is useful to show potential electronic contaminants and pathways within the Lake Erie basin and its AOCs. Similarly, life cycle assessment (LCA) is another technique to assess environmental impacts associated with a certain product, process, or service.

LCA is a “cradle to grave” approach to systems assessment concerned with the entirety of a product’s impacts, from raw component materials to disposal where those materials are returned to the earth. “LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle, often including impacts not considered in more traditional analyses (e.g., raw material extraction, material transportation, ultimate product disposal, etc.)[22].” As shown in Figure 3, the LCA approach engenders the notion that life cycle stages are interdependent, meaning that each leads to the next.[23]

Figure 3: Life Cycle Analysis



LCA also advances a notion of sustainability that goes beyond the natural environment. These assessments can promote higher efficiency and smarter resource use across industries. To date, several LCA methodologies have been applied to the electronics industry, but there is no standardized approach. However, the Economic Input-Output Life Cycle Assessment (EIO-LCA) stands out for its robust calculations and comprehensive toxics release data. EIO-LCA estimates the material and energy resource inputs, and emissions outputs from economic activity[24]. Results from the EIO-LCA online tool show relative impacts from different products, materials, services, or industries for resource use and emissions throughout the supply chain.

The EIO-LCA report shows emissions from electronics manufacturers (including air, water, underground and land) are 724 pounds per million dollars of economic activity. Including discharges to treatment plants, the total toxic release are 1,743 pounds per million dollars. The model also shows that the indirect impacts from suppliers across industries exceed the direct impacts[25].

While the LCA approach to electronic products is an invaluable tool for understanding global impacts, it has limited applicability to localized impacts of a particular stage of a product's life. Because this project is primarily concerned with how EOL management tools and practices can reduce toxic inputs to Lake Erie, it is also important to describe baseline ecological conditions around urban areas where business and residential consumers are concentrated.

AOCs indicate areas with significant environmental degradation, as designated by the Great Lakes Water Quality Agreement of 1972. Each AOC is associated with a particular set of beneficial use impairments (BUIs) that indicate a reference point for listing and delisting of AOCs as well as appropriate restoration criteria[26]. Overall, the state of Ohio comprises approximately three hundred twelve miles of Lake Erie's southern and eastern shoreline,[27] where several million residents depend on the lake and its ecosystems to provide water, food, commerce, and recreation[28]. Four AOCs have been identified in Ohio, including the lower Maumee River, lower Cuyahoga River, the Black River, and the Ashtabula River. See Table 2 for a list of BUIs in each AOC.

Table 2: Beneficial Use Impairments in Ohio Areas of Concern

Beneficial-Use Impairments	Ashtabula River	Black River	Cuyahoga River	Maumee River
Restrictions on Fish and Wildlife Consumption	X	X	X	X
Tainting of Fish and Wildlife Flavor				
Degraded Fish and Wildlife Populations	X	X	X	X
Fish Tumors or Other Deformities	X	X	X	X
Bird or Animal Deformities or Reproductive Problems				
Degradation of Benthos	X	X	X	X
Restrictions on Dredging Activities	X	X	X	X
Eutrophication or Undesirable Algae		X		X
Restrictions on Drinking Water Consumption or Taste and Odor Problems				X
Beach Closings		X	X	X
Degradation of Aesthetics		X	X	X
Added Costs to Agriculture or Industry				
Degradation of Phytoplankton and Zooplankton Populations				
Loss of Fish and Wildlife Habitat	X	X	X	X

For instance, the lower Maumee River including its tributaries and adjacent watersheds drain over eight thousand square miles of land to Maumee Bay, including the Toledo metropolitan area in Lucas County[29]. BUIs in Maumee bay result primarily from agricultural runoff, combined sewer overflows, and contaminated sediments[30]. Non point source (NPS) runoff from agriculture is a significant contributing factor to degradation of the river, though its designation owes largely to point sources including old dumps and contaminated industrial sites[31]. Following the designation, local stakeholders developed a Remedial Action Plan for the watershed which recognized that the watershed's designation resulted in part from sediments contaminated with heavy metals including lead, nickel, and chromium, among others, and recognized that dumps are a major reason the Maumee is an AOC; it listed fifty-eight refuse dumping sites and targeted thirty three for action [32]. More recently, the Lucas County Solid Waste Management 2010 Draft Update Plan identified seventy-three open dumps and waste tire dumps located in the solid waste district[33]. These sites contain a variety of waste types related to the heavy metals, toxins, and other contaminants associated with the Maumee BUIs.

The Cuyahoga River drains over eight hundred square miles of land including the industrial centers of Akron and Cleveland; The Cuyahoga AOC also includes approximately ten miles of the Lake Erie shoreline that spans both sides of Cleveland[34]. The AOC designation occurred in the late 1980s after several decades of intense pollution. "By the 1960s the lower Cuyahoga River in Cleveland was used for waste disposal, and was choked with debris, oils, sludge, industrial wastes and sewage. These pollutants were considered a major source of impact to Lake Erie, which was considered 'dead' at the time[35]." BUIs established for the Cuyahoga resulted from the presence of toxic substances including heavy metals originating from industrial and municipal discharges, atmospheric deposition, and urban runoff, among many others[36]. The Cuyahoga County Solid Waste Management Plan Update Draft 2013-2028 identified 104 open dumps and waste tire dumps located in the solid waste district[37].

Similarly, the Black River's drainage basin encompasses nearly five hundred square miles of land[38]. Although most of the land in the watershed is agricultural, it includes some drainage from Cuyahoga County to the east; Its AOC designation results from industrial discharges in the lower river that contaminated sediments with heavy metals[39].

The Ashtabula River, the remaining AOC in Ohio, is contaminated with both agricultural and industrial pollutants. Its watershed drains just over one hundred square miles of primarily rural and agricultural land to Lake Erie's central basin[40]. However, between the 1940s and 1970s unregulated discharge of hazardous waste significantly damaged riparian sediments and biological communities[41]. It is important to understand the baseline conditions described here in order to model potential impacts of stressors to AOCs and Lake Erie more broadly. The next step is identification of exposure pathways.

Exposure Pathways

The contaminants of interest and pathways for this ECO-EMS assessment include heavy metals, non-metals, and CECs including PBDEs with pathways of surface and ground water, air, and land. Various factors influence bioavailability and fate/transport of aquatic contaminants, including the availability of carbon, salinity, pH, temperature, flow, and trophic relationships, among others.

Landfills and open dumps are significant sources of contamination to soil, air, and water. Toxic materials may eventually leach to groundwater or surface water, or volatilize from landfill emissions. Atmospheric contamination may also occur as a result of incineration, although there are no local sources of concern[42]. The Lucas County Solid Waste Management 2010 Draft Update Plan indicated that there were no incinerators or resource recovery facilities in the county requiring air quality permits[43]. In Cuyahoga County, five residential or commercial facilities use incinerators to burn their waste. However, these operations are small and limited to using incineration for veterinary cremation of animal remains and so account for almost zero percent of the total waste generated[44].

Many contaminants in water settle to sediment at the bottom of water bodies. Contaminated sediment may expose benthic organisms that live on the sediment. These organisms are eventually consumed by larger aquatic organisms, which are consumed by birds, terrestrial wildlife, and humans. Contaminants that bioaccumulate through the food web are examples of the PBT type described above. Contamination that is not initially taken up by benthic organisms may adsorb to soil particles. For example, mercury is prone to bind to other minerals. However, bound particles may become available for uptake as a result of disturbances that re-suspend toxins and make them available for metabolic uptake. Also, many contaminants, such as PBDEs are not liquid soluble and will accumulate in the tissue of exposed organisms, and expose predators through the food web. Aquatic toxins that neither accumulate in tissue nor adsorb to soil may volatize to the atmosphere and return to aquatic and terrestrial ecosystems through the hydrologic cycle.

Exposure to contaminants in soil results from several pathways. Contaminated soil can travel through runoff or aquifers where it is carried to rivers, lakes and streams. Animals and humans may also be exposed through dermal uptake to contaminated sediments or ingestion of contaminated plants.

Atmospheric depositions return contaminants to terrestrial ecosystems through hydrologic cycling and may return contaminants to aquatic environments indirectly through non-point pathways, or may be directly deposited to rivers, lakes, and streams. This cycles water between soil and air, a natural process in which contaminants not adsorbed to sediments or consumed by other organisms may volatilize to the atmosphere, and be returned through precipitation events.

Understanding the pathways through which stressors will impact ecosystems is essential to building conceptual models and other tools that demonstrate impacts. These tools are critical for driving behavior change, both for public policy and at the scale of individual consumer.

Eco-EMS

The following tables depict the aspects and impacts of EOL management. In this sense, aspects are pathways resulting from EOL management practices and impacts are how water, air, and land are affected by these practices. Aspects that have a negative impact on ecosystems are indicated by an X, and aspects that have positive impacts are indicated by an O.

Table 3: Eco-EMS for Heavy Metals in Lake Erie Basin

Heavy Metals

	Water				**Air**			**Land Use**		
Impacts	Water Quality Standards	Sediment Contamination	Fish Consumption Advisories	Groundwater Contamination	Ambient Air Quality	Air Toxics Emissions	Indoor Air Quality	Land Use	Habitat	Chemicals
Aspects										
Landfill Leachate- leakage	X	X	X	X	X[45]			X	X	X
Landfill Leachate Sludge	X	X	X	X				X	X	X
Landfill Air Emissions	X	X	X	X	X	X	X		X	X
Incineration Air Emissions *	X	X	X	X	X	X	X			X
Incineration Landfilled Solids *	X	X	X	X	X	X		X	X	X
Open dumping	X	X	X	X	X	X		X	X	X
Electronics reuse	O	O	O	O	O	O	X	O	O	O
Electronics recycling	O	O	O	O	O	O	O	O	O	O

Table 4: Eco-EMS for Flame Retardants in Lake Erie Basin

Flame Retardants

	Water				Air			Land Use		
Impacts	Water Quality Standards	Sediment Contamination	Fish Consumption Advisories	Groundwater Contamination	Ambient Air Quality	Air Toxics Emissions	Indoor Air Quality	Land Use	Habitat	Chemicals
Aspects										
Landfill Leachate- leakage		X	X	X	X	X	X	X	X	X
Landfill Leachate Sludge		X	X	X	X	X	X	X	X	X
Landfill Air Emissions		X	X	X	X	X	X			X
Incineration Air Emissions *		X	X	X	X	X				X
Incineration Landfilled Solids *		X	X	X	X	X				X
Open dumping	X	X	X	X	X	X		X	X	X
Electronics reuse	O	O	O	O	O	O	X	O	O	O
Electronics recycling	O	O	O	O	O	O	O	O	O	O

As shown by Table 3 and Table 4, heavy metals and flame retardants threaten aquatic and terrestrial ecosystems in distinct and overlapping ways. However, because land drains to waterbodies, the most significant impacts across the two categories are to sediment contamination, fish consumption advisories, groundwater contamination, and chemical impacts to land use. The hydrologic cycle transports toxins between water, air, and land. These are significant pathways because of the tendency of flame retardants and certain heavy metals to bioaccumulate in organisms through the food chain. Contaminated groundwater, sediments, and assemblages are not easily remediated. For example, disturbing contaminated sediment often increases the amount of toxins available for uptake by aquatic organisms.

Best Practices

Electronic products are part of vastly complex value chains that involve extraction of raw materials, manufacturing, transportation, and EOL management. Regardless of purchasing decisions, market demand for electronic equipment has an environmental impact. Although electronics are not unique in this respect, there are a growing variety of tools and best practices designed to minimize the environmental impacts of electronics purchasing and EOL management. These tools are particularly impactful when applied by institutional purchasers because of the market share they command.

EPEAT

Although buying electronic products is the first step toward generating e-waste, purchasing products with low environmental impacts is also considered one of the best practices for of EOL management. The Electronic Products Environmental Assessment Tool, or EPEAT, is a global registry of reduced-impact products that links purchasing decisions to EOL impacts. For example, products are evaluated based on many criteria in the categories of: reduction/elimination of environmentally sensitive materials; material selection; design for EOL including ease of disassembly to promote recycling; product longevity; energy conservation; EOL management; corporate performance; and packaging. Products that meet required criteria are rated bronze, silver or gold based on the number of optimal criteria they meet. Also, all EPEAT registered products must have a program in place for takeback and recycling at the end of its useful life. The EPEAT registry is valuable tool for informing strategic purchasing decisions that can ultimately reduce toxic content of products, promote product efficiency in terms of raw material inputs and energy efficiency, and discourage product waste. The EPEAT registry presently includes ratings of desktop and laptop computers, workstations, thin clients, and displays. Imaging equipment and televisions will be added to the registry in 2013, followed by servers and mobile devices at a later date.

Certified Recycling

Best practices in EOL management can reduce the environmental impacts of e-scrap. For example, improperly recycled electronics can harm workers and the environment, or may be sent abroad where those impacts are unregulated. Additionally, concerns about data security can act as a barrier to recycling, resulting in land-filling or storage of electronic equipment. Certification systems address these concerns by designating leadership in the field and establishing best practices in recycling that conserve natural resources, preventing recyclable waste from being landfilled, and limiting exports to developing countries. While there are no precise figures on how much is exported, some estimates are as high as seventy percent. A 2008 report by the Government Accountability Office acknowledged that "a substantial quantity, however, ends up in countries where the items are handled and disposed of in a manner that threatens human health and the environment[46]. Localized recycling programs deliver additional economic benefits through job creation. In 2000, nearly one hundred thousand jobs in Ohio were dependent on recycling, which contributed $22.5 billion in sales to the economy and supported an annual payroll of $3.6 billion.[47]

There are several different certifications that indicate leadership in the recycling field. One of these certifications, R2, is a system designed to assure openness, transparency, and balanced governance of recycling practices and focuses on environmental and public health, worker safety, data and facility security, and takes a chain of custody approach to recycling that emphasizes the whole system. R2 relies on outreach to educate customers about the benefits of using certified recyclers. An alternative certification system, E-stewards, is a non-profit organization that is part of the Basal Basel Action Network, named of a UN treaty that restricts trade in hazardous materials to developing nations. E-stewards is similar to R2, but emphasizes a whole system approach to EOL management.

Electronics Environmental Benefits Calculator

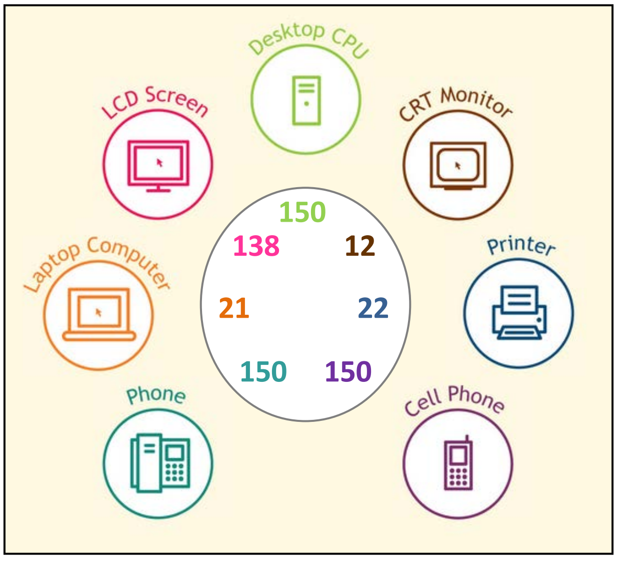
Another valuable tool to inform purchasing decisions is the Electronics Environmental Benefits Calculator (EEBC), the outcome of a collaborative effort between the public and private sector. For certain products the EEBC quantifies environmental criteria covered by EPEAT, including savings in: energy use; raw materials; CO2 and other greenhouse gases; water emissions; toxic materials; MSW generation; and cost. Presently, the EEBC calculates benefits for cathode ray tube (CRT) monitors; liquid crystal display (LCD) monitors; central processing units (CPUs); notebook computers; and mobile phones.

Similarly, Delta's Electronics Toxics Calculator (DETC) performs a similar function to emphasize how strategic purchasing or certified recycling can reduce the amount of hazardous chemicals released to the environment. Because the scope of Delta's tool is narrower than the EEBC, its calculations are not as robust. Where the tool adds greater value though, is in quantifying the amounts of specific hazardous materials whose release to the environment is avoided as a result of EPEAT purchasing or certified recycling, where the EEBC calculates the sum of toxic material saving. This tool is intended to assist companies with informing and monitoring the impact of EOL management decisions.

Users can select among different types of electronic products they wish to purchase or recycle, and enter either the quantity or total weight of products. The electronic products included in this tool are: desktop CPUs; CRT and LCD desktop displays; laptop computers; mobile phones; telephones; and printers. The calculator displays the avoided toxic outputs as a result of responsible EOL management. Outputs include: lead (Pb), mercury (Hg), cadmium (Cd), chromium (Cr), silver (Ag), arsenic (As), copper (Cu), nickel (Ni), and antimony (Sb).

To demonstrate the effectiveness of the tools, imagine a scenario in which a company that employs three hundred workers is refreshing half of its electronic equipment according to the breakdown in Table 5.

Table 5: Inputs to Delta's Electronics Toxics Calculator for Hypothetical Company



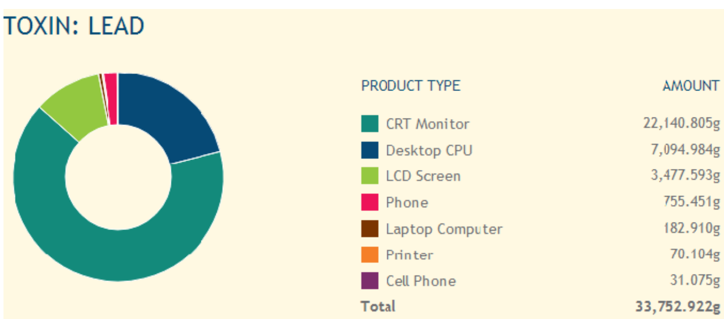
Product	Scenario Assumption
Desktop CPU	All employees are provided a CPU. CPUs are replaced for all employees receiving new equipment in this purchasing cycle.
CRT display	All employees are provided a monitor. Monitors are replaced for all employees receiving new equipment in this purchasing cycle. However, very few employees are still using CRTs.
LCD display	All employees are provided a monitor. Monitors are replaced for all employees receiving new equipment in this purchasing cycle.
Notebooks	Only managers are provided notebooks, and only half of managers are receiving new equipment in this cycle.
Mobile phones	All employees are provided a mobile phone. Mobile phones are replaced for all employees receiving new equipment in this purchasing cycle.
Telephones	All employees are provided a telephone. Telephones are replaced for all employees receiving new equipment in this purchasing cycle
Printers	Employees are generally assigned to shared printers; a handful of printers are being replaced in this purchasing cycle.

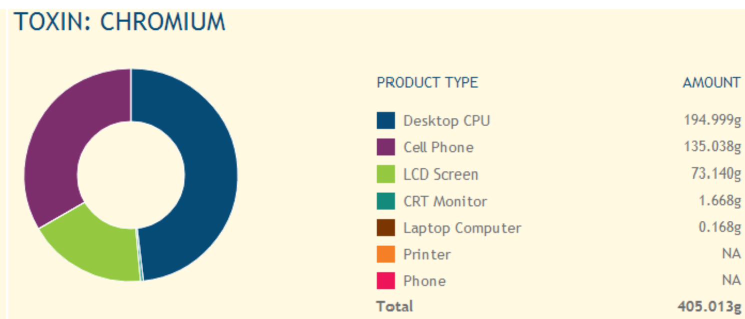
When the quantities in Table 5 are entered in the calculator, the total toxic output s to the Great Lakes ecosystem that are avoidable through EPEAT purchasing and/or certified recycling are shown in Table 6. In the scenario above, using best practices will keep 82872.66 grams, or approximately 182 pounds, of Combined toxins out of soil, air, and water.

Table 6: Delta's Electronics Toxic Calculator Output

	Pb	Hg	Cd	Cr VI	Ag	As	Cu	Ni	Sb	TOTAL (g)
CPU	7095.00	0.00	0.00	195.00	65.29	0.00	40827.17	1743.70	796.96	50723.12
CRT	368.40	0.00	0.71	1.67	0.00	0.00	0.00	0.00	0.00	370.77
LCD	3477.60	1.93	3.96	73.14	21.34	0.00	9039.33	99.81	40.61	12757.73
NTBK	182.91	0.13	0.02	0.17	4.01	0.30	2309.67	61.29	13.05	2571.53
MBL_PH	31.07	0.00	0.00	135.04	11.94	0.00	1974.37	98.88	15.65	2266.96
TELEPHONE	755.45	0.00	2.08	0.00	27.08	0.00	12940.95	428.07	51.38	14205.01
PRINTER	70.10	0.00	0.00	0.00	0.00	0.00	619.16	21.14	94.77	805.17
TOTAL (g)	11154.98	2.06	4.68	405.01	129.66	0.30	67710.65	2452.89	1012.42	**82872.66**

The calculated results can be viewed graphically on the Delta E-waste website located at http://www.delta-institute.org/ewaste. The results from lead and chromium are shown below.





Conclusion

As the electronics industry is quickly expanding in the marketplace and in the waste stream, the environmental impacts are still not comprehensively understood. In order to address this information gap, electronic industry officials and local decision makers—within areas like the Lake Erie basin—must be equipped with the right tools for ecological assessment and e-waste management. The electronic product life cycle is short, thus enabling the rapid growth of e-waste—while the environmental externalities can remain undetected for years to come. The toxics associated with EOL management of e-waste must be monitored and management properly in order to protect fragile ecosystems, such as the Great Lakes basin.

This report examines the relationship between e-waste and toxic outputs to Lake Erie with an emphasis on northern Ohio's four identified AOCs. The research utilizes the ecosystem-based environmental management systems (ECO-EMS) tool to map out potential pathways of toxics into the environment, while also examining life-cycle assessment and the EEBC for electronics. Finally, an overview of best practices gives insight into protecting watershed health from electronics.

Ultimately, the major contaminants within electronics and the pathways of exposure have been identified through ecosystem analysis. This information can be utilized on the local and national levels as a model for proper e-waste management. This model can be applied to other ecosystems beyond the Great lakes region to promote toxics reduction and best management practices in response to perpetual electronics growth in the environment.

References

[1] Great Lakes Restoration Initiative. *GLRI Home.* 2012. http://glri.us/

[2] U.S. EPA. *Electronics Waste Management in the United States, Preliminary Findings.* February 2007. <http://infohouse.p2ric.org/ref/50/49182.pdf>

[3] *CE industry yearly revenues to expected to surpass $200b for first time.* Consumer Electronics Association. 2012. <http://www.ce.org/News/News-Releases/Press-Releases/2012-Press-Releases/CE-Industry-Yearly-Revenues-Expected-to-Surpass-$2.aspx>

[4] U.S. EPA. *Electronics Waste Management in the United States, Preliminary Findings.* 2007. <http://infohouse.p2ric.org/ref/50/49182.pdf>

[5] U.S. EPA. *Electronics Waste Management in the United States, Approach 1.* EPA530-R-08-009. 2008. <http://www.epa.gov/osw/conserve/materials/ecycling/docs/app-1.pdf>

[6] U.S. EPA. *Wastes.* "Non-Hazardous Wastes." 2012. <http://www.epa.gov/epawaste/basic-solid.htm>

[7] Klaper, Rebecca. *Review of the Effects of Chemicals of Emerging Concern on the Environment.* 2011. Appendix E Priority Cycle Report on Chemicals of Emerging Concern. <http://meeting.ijc.org/workgroups/cec>

[8] U.S. EPA. *Great Lakes.* "Lake Erie." 2012. U.S. EPA. <http://www.epa.gov/lakeerie/>

[9] NOAA. *Great Lakes Environmental Research Lab.* "About Our Lakes, Lake by Lake Profies." 2012. <http://www.glerl.noaa.gov/pr/ourlakes/lakes.html>

[10] United States Census Bureau. *State and County Quick Facts.* "Ohio." 2012. <http://quickfacts.census.gov/qfd/states/39000.html>

[11] Sea Grant Michigan. *Lake Erie.* <http://www.miseagrant.umich.edu/explore/about-the-great-lakes/lake-erie/>

[12] Klaper, Rebecca. *Review of the Effects of Chemicals of Emerging Concern on the Environment.* 2011. Appendix E Priority Cycle Report on Chemicals of Emerging Concern. <http://meeting.ijc.org/workgroups/cec>

[13] Ibid.

[14] International Joint Commission. *2009-2011 Priority Cycle Report on Chemicals of Emerging Concern.* 2011. <http://meeting.ijc.org/workgroups/cec>

[15] Ibid.

[16] Ibid.

[17] Global Futures Foundation. "Computers, E-Waste, and Product Stewardship:Is California Ready for the Challenge?" *Report for the U.S. EPA Region IX*. 2001. <http://infohouse.p2ric.org/ref/41/40164.htm>

[18] U.S. EPA. *Wastes – Resource Conservation – Wastes & Materials – eCycling.* "Statistics on the Management of Used and End-of-Life Electronics." 2012. <http://www.epa.gov/osw/conserve/materials/ecycling/manage.htm>

[19] GT Environmental, Inc. *Cuyahoga County Solid Waste Management Plan Update Draft 2013-2028.* 2012. <http://www.cuyahogaswd.org/pdf_cuyahogaswd/en-US/SolidWastePlan/DraftPlanPortfolio2011.pdf>

[20] E-Stewards. *The E-waste crisis introduction.* 2012. <http://e-stewards.org/the-e-waste-crisis/>

[21] EIONET. *GEMET Thesaurus.* “Ecological Assessment.” 2012. <http://www.eionet.europa.eu/gemet/concept?cp=2440&langcode=en&ns=1>

[22] Scientific Applications International Corporation (SAIC). *Life Cycle Assessment: Principles and Assessment.* 2006. <http://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1000L86.PDF>

[23] Ibid.

[24] Carnegie Mellon. *eiolca.net.* “EIO-LCA: Free, Fast, Easy Life Cycle Assessment.” <http://www.eiolca.net/>

[25] Cobas, E., C. Hendrickson, L. Lave and F. McMichael, “Economic Input/Output Analysis to Aid Life Cycle Assessment of Electronic Products,” Proc. IEEE International Symposium on Electronics and the Environment, Orlando, Florida, pp. 273-278, May, 1995.

[26] International Joint Commission. *Anex 2.* “Restoring Beneficial Uses in Areas of Concern.” 2011. <http://www.ijc.org/rel/boards/annex2/buis.htm>

[27] NOAA. July 12, 2006. *Ocean and Coastal ResourceManagement.* “Ocean and Coastal Management in Ohio.” 2012. <http://coastalmanagement.noaa.gov/mystate/oh.html>

[28] Ohio Department of Natural Resources. *Welcome to the ODNR Office of Coastal Management.* 2012. <http://www.ohiodnr.com/Default.aspx?alias=www.ohiodnr.com/coastal>

[29] USEPA. *Great Lakes Areas of Concern.* “Maumee River.” 2012. <http://www.epa.gov/greatlakes/aoc/maumee.html>

[30] Toledo Metropolitan Area Council of Governments. *Maumee River Basin Area of Concern Remedial Action Plan: Recommendations for Implementing Executive Summary.* 1991. <http://www.epa.gov/glnpo/aoc/maumee/Maumee-River-RAP_Recomm-percent20ExecSum.pdf>

[31] USEPA. *Great Lakes Areas of Concern*. *“Maumee River.”* 2012. <http://www.epa.gov/greatlakes/aoc/maumee.html>

[32] Toledo Metropolitan Area Council of Governments. *Maumee River Basin Area of Concern Remedial Action Plan: Recommendations for Implementing Executive Summary.* 1991. <http://www.epa.gov/glnpo/aoc/maumee/Maumee-River-RAP_Recomm-percent20ExecSum.pdf>

[33] Gerken, Pete, Wozniak Tina, and Contrada, Carol. *Lucas County Solid Waste Management 2010 Draft Update Plan.* 2011. <http://www.co.lucas.oh.us/documents/Solidpercent20Wastepercent20Management/2005percent20Planpercent20Update/2011percent20Finalpercent20Draftpercent20Planpercent20>

[34] U.S. EPA. *Great Lakes Areas of Concern*. *“Cuyahoga River.”* 2012. <http://www.epa.gov/greatlakes/aoc/cuyahoga.html>

[35] Ibid.

[36] Ibid.

[37] GT Environmental, Inc. *Cuyahoga County Solid Waste Management Plan Update Draft 2013-2028.* 2012. <http://www.cuyahogaswd.org/pdf_cuyahogaswd/en-US/SolidWastePlan/DraftPlanPortfolio2011.pdf>

[38] U.S. EPA. *Great Lakes Areas of Concern*. "Black River." 2012. <http://www.epa.gov/greatlakes/aoc/blackriver.html>

[39] Ibid.

[40] U.S. EPA. *Great Lakes Areas of Concern*. "Ashtabula River." 2012 <http://www.epa.gov/glnpo/aoc/ashtabula.html>

[41] Ibid.

[42] GT Environmental, Inc. *Cuyahoga County Solid Waste Management Plan Update Draft 2013-2028.* 2012. <http://www.cuyahogaswd.org/pdf_cuyahogaswd/en-US/SolidWastePlan/DraftPlanPortfolio2011.pdf>

[43] Gerken, Pete, Wozniak Tina, and Contrada, Carol. *Lucas County Solid Waste Management 2010 Draft Update Plan.* 2011. <http://www.co.lucas.oh.us/documents/Solidpercent20Wastepercent20Management/2005percent20Planpercent20Update/2011percent20Finalpercent20Draftpercent20Planpercent20>

[44] Cuyahoga County Solid Waste Policy Committee. *A Summary of the Cuyahoga County Solid Waste Management Plan Update 2013-2028.* 2012. <http://cuyahogaswd.org/pdf_cuyahogaswd/en-US/SolidWastePlan/SWDPlanSummary2013-2028.pdf>

[45] Mercury may volatilize, is unique as heavy metal

[46] U.S. Government Accountability Office. *"Electronic waste: EPA needs to better control harmful exports through stronger enforcement and more comprehensive regulation."* 2008. <http://www.gao.gov/new.items/d081044.pdf>

[47] Ohio Department of Natural Resources. *Division of Recycling and Litter Prevention. "*Why Recycle?" <http://ohiodnr.com/Home/why/tabid/9402/Default.aspx>