Saginaw Bay Watershed Research Bibliography

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This document will be edited and updated as needed. Please submit literature citations to sbesi@svsu.edu with “Saginaw Bay Literature” in the subject line. Your submission will be reviewed and included if appropriate to the context of this bibliography.

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I. Plants

a. Total Phytoplankton


- Growth rates based on different types of phosphorus (dissolved and stored) were found using Monod and Droop Models for the Great Lakes and Saginaw Bay.


- A simulation model was developed for five groups of phytoplankton, included nutrients, and was designed specifically for the Saginaw Bay.


- Phytoplankton simulation model for the Saginaw Bay.


- Phytoplankton simulation model for the Saginaw Bay.


- A model was developed to include nutrients as well as plankton biomass and was calibrated with water quality data after statistical analysis.


- The measurement of chlorophyll a has been used to determine the biomass of phytoplankton. Statistical analysis was necessary, which showed the variability in the assumption.

- High bacterial activity and chlorophyll biomass were found along with low carbon uptake. These results indicated that the phytoplankton community is old and/or aging. Most phytoplankton undergoing decomposition would settle before being mixed into the outer bay.


- The invasion of zebra mussels has drastically changed the community of phytoplankton by altering the diversity, reducing biomass, and changing average size. The filtering activity of the invasive zebra mussels has changed the phytoplankton community, thus changing the dynamics of the food web.

**b. Algae**

Armenio, P. M., Mayer, C. M., Heckathorn, S. A., Bridgeman, T. B., & Panek, S. E. Resource contributions from dreissenid mussels to the benthic algae *Lyngbya wolle* (Cyanobacteria) and *Cladophora glomerata* (Chlorophyta). *Hydrobiologia, 1-17.*

- In this study, the algae *Cladophora* showed an increase in biomass and *L. wolle* showed an increase in nutrients due to coexistence with *Dreissena*.


- Chlorophyll a was shown to decrease at a larger percentage than the percentage of the phosphorus decrease. When including Secchi depth, it was suggested that the re-suspension of sediment was due to waves which accounted for the unexpected results seen between phosphorus, chlorophyll a, and inverse Secchi depth percentages.


- This study confronts the aspects of plant and algae modeling that are lacking, need verification, or further research.

- It was found that green algae and filamentous algae were in greater abundance than macroscopic primary producers. Red algae was the dominant taxa found of the filamentous algae.


- Extensive algal blooms were exacerbated due to excess nutrient loading, climate, and lack of flow in Lake Erie. Predictions of harmful algal blooms are expecting an increase in instances like these.


- *Microcystis* was found to be most concentrated at the mouth of the Saginaw River. The community of phytoplankton was comprised primarily of diatoms and cyanobacteria. Trends were not easily defined as there was a great deal of variability given by numerous environmental factors.


- In 2003 and 2004, levels of the microcystin toxin were found in Lake Erie at greater concentrations than the WHO water quality standard allows. Fragments of 16S rDNA were used for the quantification of *Microcystis* using PCR to elucidate abundance and distribution.


- Models used for prediction of blue-green algae in the most problematic season using a model that includes total phosphorus, algae biomass, and depth.


- The biomass of phytoplankton is dependent upon light, nitrogen, and phosphorus. It was proven that when nitrogen and phosphorus are at a fixed ratio the biomass
is dependent upon light (when it decreases biomass increases) and the light, if fixed, will have a nitrogen to phosphorus ratio that will decrease as biomass increases.


- *Microcystis aeruginosa* was proven to be rejected by zebra mussels, which contributes to the overfeeding of other algae while allowing harmful blooms.


- This article points out the apparent issues in dealing with toxicity from cyanobacteria. It mentions gaps in knowledge that should be filled to benefit ecological and socioeconomic issues that can be related with water fouling.

i. **Cladophora**


- This study focused on the factors that affect the rate of phosphorus uptake, the internal phosphorus pool size and the dissolved phosphorus. Simulation of *Cladophora* growth can be found using the mathematical models.


- Photosynthesis, respiration, and carbon content were measured to determine growth rate of cladophora based on the size of the internal phosphorus pool. Looking at this relationship for use in phosphorus management was suggested.
- The effects of amount of light, different temperatures, variation in respiration and growth were explored.

- Cladophora biomass model developed for spatial and temporal variations seen with variable amounts of phosphorus and trends in spatial variation were observed. Results were collected to aid in phosphorus management.

- Growth rate in relation to variables such as light, temperature, seasonality, depth and distance from eutrophication sources were used in the model.

- It was verified that the model developed worked well in determining Cladophora response to changes in phosphorus based on the study using phosphorus removal as a check.

- Kinetic data on phosphorus uptake rates and the variability of phosphorus in the water was used as information in modeling the biomass of Cladophora.

- Landsat technology was used to map benthic algae distribution along the near shore areas of the Great Lakes. Percent coverage data was collected.

- Echo sound technology was used for the determination of percent coverage and height of *Cladophora*.


- Different variables in the environment were investigated using a revised version of the *Cladophora* Growth Model to determine the temporal and spatial patterns of *Cladophora*.


- The collapse of algal blooms was attributed to the algae exceeding the critical threshold, resulting in self-shading. Self-shading killed algae cells, thus causing their removal from the algal bloom.


- This review points out the historical occurrences of *Cladophora* pre- and post-phosphorus management. It also explores *Cladophora* occurrences pre- and post-mussel invasion, with focus on the dreissenid facilitated changes to the ecosystem.


- Carbon, nitrogen, and phosphorus ratios were examined using *Cladophora* tissue samples to relate these to land uses in urban and non-urban areas along the Great Lakes.


- It was found that light intensities over 28 μEm⁻²s⁻¹ led to better growth of *Cladophora*. Additionally, a model was developed to predict the depth of *Cladophora* colonization based on water quality parameters and light intensity.

- This *Cladophora* growth model was verified for the use in determining internal phosphorus for different areas of the Great Lakes.


- There was a difference seen between the distances from the wastewater discharge (when considering diatoms). A positive relation to the distance and the low occurrence of epiphytic congregations was found and the cause for the low abundance was unknown.


- The temporal and epiphytic relationship between diatoms and *Cladophora* was observed. *Cladophora* had the greatest growth in June and July; for diatoms it was September.


- Development of the Great Lakes Cladophora Model (GLCM) to assess *Cladophora* growth, which has been having negative impacts on near shore sites due to the greater amount of phosphorus, may aid in management decisions.


- The plants close to the mouth of the Saginaw River had very high concentrations of heavy metals. *Cladophora* and *Typha* had the highest concentrations although different parts of each plant had different concentrations of the metals.


- Algae, *Cladophora*, was collected to determine the *Clostridium botulinum* type E toxin gene, which was found to be present most in areas of the Great Lakes. Saginaw Bay and Bay City had the highest concentration. This could be due to variable factors that affect water quality.

- 181 references regarding Laurentian Great Lakes *Cladophora*.

### c. Macrophytes


- This tool gives the ability to track invasive plant species using hyperspectral imagery.


- Multiple sensors have been employed to enhance mapping that is difficult for wetland areas.


- It was found that spatial distance from the water’s edge influenced the diversity and abundance of plankton, fish, and macroinvertebrates. Half of the species examined in the Saginaw Bay had horizontal spatial trends of abundance.


- To determine the depth at which different macrophyte colonization would take place, linear regression models were developed in relation to Secchi depth. Other water quality parameters could be incorporated to improve predictions.


- A comparison study on heavy metals in macrophytes showed that Charity Island had high concentrations of nine of the metals tested. It was suggested that the mechanism of heavy metal movement is dependent on the metal itself.

- Invasive plants were found in both the diked and the undiked wetlands. However, the diked wetlands had more invasive species, increased nutrients, and other factors that could contribute to more water quality issues.


- In order to determine the abundance and distribution of invasive and potentially invasive, non-native plants, several species and study areas were mapped. Management guidelines and a field guide are of the tools that were developed to help prevent spread of plants that could pose a large ecological threat.


- An attempt to determine wetland health by taking into account human stressors, water depth, biological conditions, and geography was made. They employed CART models were employed for analysis.


- This study focused on the vascular fresh water plants and their significance as toxin removers due to higher concentrations of heavy metals being found in plant tissues than in the surrounding water.


- It was determined that the decrease in turbidity, due to the filtering activity of zebra mussels, can lead to the distribution and abundance of macrophytes to increase.

• This study looked at the effect of long term human stressors on meadow plants. It was found that wet meadow vegetation, in particular, is hearty and can reestablish in disturbed areas. However, nuisance meadow vegetation, such as purple loosestrife, were more common in disturbed areas.


• The analysis of 15 heavy metals in 22 different macrophyte species showed that the highest concentration of heavy metals were in the macrophytes closest to the Saginaw River mouth.

i. **Phragmites**


• This study addresses the relationship dynamics of invasive species with microorganisms and how these affect the native species. This knowledge could lead to more specialized invasive species management.

Mazur, C. The GLRI Phragmites Decision Support Tool Mapper. USGS.

• Different components and tools work together to create a map that gives insight into resource management by providing necessary information on *Phragmites*.


• Species distribution modeling was used to determine current areas invaded by *Phragmites* and to locate areas that could be colonized in the future based on climate, soil types, topography, and land use.


• Through DNA research, it has been found that the invasion of non-native *Phragmites* has overreached by expanding into areas that did not historically carry this plant and has outgrown the native species. This is concerning as the invasion in New England wiped out the native species.

- Exposed soil and shallow water were the factors that attributed to the most invasive *Phragmites* growth. This is concerning because of decreasing water depths that may be exacerbated with climate change in the future.


- The determination of element uptake by different parts of *Phragmites* in natural and constructed wetlands as it related to the wastewater treatment in the Czech Republic.

**II. Invertebrates**

*a. Zooplankton*


- It was determined by weight based filtering rate comparisons that the reduction in phytoplankton was not due to the zooplankton grazing.


- The type of matter and particle size of the sediment had the greatest impact on diversity and distribution of zoo benthos, where macrophytes had less of an effect.

*b. Macroinvertebrates*

• Stratification model for prediction, taking into consideration water temperature, wind speed, and data in the water column. The effect stratification will have on mayfly nymphs for Lake Erie was discussed.


• This study looked for the correlation between physiochemical factors of oligochaetes and their relative distribution.


• The development of IBI’s was determined by comparison of biota from less polluted wetlands than those in the Saginaw Bay and 14 metrics were successful in determining the difference between impacted and not impacted sites.


• The effects of waves on plant and invertebrate community distribution were analyzed. It was found that there was no major difference seen in plant communities, but a conceptual model was proposed for the invertebrates.


• The goal of this study was to expand on the relationships and dynamics that are involved in the health, abundance, and diversity of macroinvertebrates in the Great Lakes Coastal wetlands.


• Community shifts correlated with changes in water depth greatly although other factors would have been influential as well.


• *G. tigrinus* is a non-native amphipod that is thriving in the Great Lakes.

- This study was proactive in sampling populations in the Saginaw Bay to be sure that the invasive mud snail had not been introduced to Lake Huron.


- Both the inner and the outer Saginaw Bay were observed for determining community trends. Distinct differences were found in each portion of the Bay and these differences were attributed to the changes that occurred post Dreissena.


- A strong correlation was found between traits of species and the physical habitat. Linear regression models showed some predictability of species. The reach-scale properties seemed to be more significant.


- This analysis showed the importance of substrate characteristics in macroinvertebrate communities although many habitat conditions were monitored.


- This study showed that the effects of land use and the geological features have near equivalent impacts on the health of streams.


- Based on historical records and data it was determined that mayflies were native in the Saginaw Bay and that the eutrophication of the bay caused a decline.
Additionally, it was found that there is a possibility for recovery of the mayflies if the proper conditions are met to support the growth of nymphs.


- After sampling both mayfly adults and nymphs at different sites in the Bay and finding the composition of sediments through modeling, it was found that the Hexagenia population is beginning to recover in the Saginaw Bay.


- This invertebrate IBI was developed with differing water levels and wave fluctuations in mind. Spatial and temporal variations in sites were tested using the index with what was reported as satisfactory results pointing to use and implementation of this index.

i. **Dreissena**


- Improvement of existing models, USCAE, and development of new models for ecosystem restoration.


- Post-zebra mussel invasion, Microcystis blooms inhabited the area. This study employed models to develop a baseline for pre-invasion conditions and attributed the Microcystis blooms to the selective avoidance of it by the zebra mussels and the increases in phosphorus cycling due to zebra mussel populations.

- AVHRR was used to capture images that allowed the reflectance to be seen and to determine differences in water quality pre and post *Dreissena* colonization. Regression models were used; SeaWiFs and MODIS are possibilities that can monitor future reflectance change that can occur in areas of high *Dreissena* density (turbidity changes also occur seasonally).


- Comparison of water nutrients, algae, and *Microcystis* in microcosms with and without zebra mussels. Shifts in nitrogen and phosphorus in the water, as well as possible selective feeding were attributed as causes of *Microcystis* blooms in zebra mussel inhabited waters.


- Two different species of mussel were addressed: the quick near shore colonizing zebra mussels and the slower offshore quagga mussels. Mass balance models show high percentages of phosphorus retention by mussels which could attribute to the reduction of other species such as *Diporeia*.


- Different effects were observed when monitoring zebra mussel bacterial selection between the inner and outer Saginaw Bay.


- In areas with a large number of zebra mussels (primarily the inner Bay), it was found that chlorophyll and total phosphorus decreased, while Secchi depth increased which showed a spatial change in water quality.

ETS was found to be higher in the outer Bay and was contributed to higher quality of food. Also, ETS and respiration varied with temperature. It was indicated that these units of measurement maybe better suited for long term study.


- Filtration rates were measured from the inner and outer Bay. A relationship between filtration rate and temperature was observed. In 1992, it was found that the inner bay filtration rates were lower than in the outer bay.


- The effects of zebra mussels are clearer waters (less turbidity), phosphorus cycling, and the rejection of *Microcystis* that leads to blooms.


- This study proved that zebra mussels alter the phytoplankton community by filtration, nutrient cycling, and by altering overall water quality, all of which change the depth to which light penetrates through the water.


- Algal growth was found to be phosphorus limited. Also, it was found that various changes occurred throughout the year and was attributed to water clarity as affected by mussel filtration.

• This study showed increases in SRP and decreases in algae and chlorophyll, as well as decreased turbidity that accompanies a greater abundance of zebra mussels. The research results proved that there are increases in the clarity of water, as well as changes in water quality parameters in areas with large numbers of mussels.


• This study set out to determine the nutrient cycling that occurs as the result of zebra mussel filtration. Total suspended solids and chlorophyll were shown to be removed at greater than 70% from the water. Increases in nutrient cycling were observed for nitrogen and phosphorus.


• Analysis of water contents between the years pre- and post-zebra mussels shows reduction in contents suspended in the water. Studies of water parameters pointed to zebra mussels being a sink for phosphorus.


• This study showed significant alterations in the composition of phytoplankton and protozoa as a result of high zebra mussel density.


• Zebra mussels filter water for their food sources, thereby lowering turbidity and allowing more light to reach benthic algae. This research concluded that filtering allows for increased rates in photosynthesis and the ability of larger algae such as filamentous algae to dominate the previously common phytoplankton community of diatoms.


• Water quality is dramatically altered by the filtering activity of zebra mussels. Filtration leads to the reduction of plankton and suspended solids, which allows
for decreases in turbidity, consequently allowing an increase in photosynthetic productivity of plants.


- This was a monitoring effort in the Saginaw Bay to determine physical and chemical variables in response to the zebra mussel invasion.

- After looking at densities of larvae, juveniles, and adults it was uncertain if the population could be at equilibrium or not. Relationships between these life stages and density were not observed with a definitive trend.

- Spatial and temporal variance in the chlorophyll to phosphorus ratios were seen throughout different areas of the Great Lakes.

- Controlled studies showed that a high abundance of rusty crayfish decreases the abundance of zebra mussels and macroalgae.

• Dissolved phosphorus was found to be decreased during the experiment. Through the nutrient manipulation experiment additions of phosphorus increased chlorophyll where nitrogen did not have a noticeable effect, but the increase in water clarity from the mussels seemed to have the greatest effect. This study suggests a new ecological equilibrium.


• This study found that rusty crayfish did not reduce the abundance of Dreissena but did reduce other invertebrates in Lake Erie.


• Focused study on the Hudson River ecosystem and the niche that clams and mussels fill.


• The selectivity of the different species of mussels showed some importance. Both quagga and zebra mussels filter feed similar sizes but have differing rates of filtration and reasons for differences are given.


• Different mechanisms of feeding behavior were studied at sites in the Saginaw Bay and Lake Erie for comparison.


• Microcystis aeruginosa was proven to be rejected by zebra mussels, which contributes to the overfeeding of other algae while allowing harmful blooms.

Regression models were developed to predict the biomass of zebra mussels with respect to phosphorus water levels.

**Diporeia**


- Solid phase bioassays of *Diporeia* were used as an indicator of water health based on sediment preferences and mortality. Sediments were taken from various locations in the Bay and river and mouth regions. The site for Tawas Bay was found to be the most toxic to *Diporeia*, it was the most preferred sediment, and had the highest mortality. The site near the Bay City Water Treatment plant was found to have the highest mortality in December of 1989. The results indicated contamination in the Saginaw River and Bay.


- The invasive *Dreissena* has replaced *Diporeia* and therefore has made the benthic community less able to supply the upper trophic levels with energy as it had in the past. Reasons for this were not well known.


- Despite the proposed theory that the decline of *Diporeia* is due to out competition of food supply by *Dreissena*, there was no evidence to support of starvation in the species. Additionally, at some sites, near zero densities of *Diporeia* were found where *Dreissena* were not present.


- Competition for food was not the causative factor for *Diporeia* decline post zebra mussel invasion. The adequate lipid content and no signs of starvation point to other causes for the decline of *Diporeia*. 
III. Vertebrates

a. Fish


- Threatened lake sturgeon were found to occupy sand, silt, and sand/gravel areas of rivers in their early stages of life. This study also gave locations of populations, as well as predictions of reproduction. This information can help rehabilitation efforts.


- The shifts in fish community abundance and relationships have continued to change and are projected to continue although the complete cause of the changes in predator prey dynamics are not fully understood.


- Trout-perch were found to have a similar diet as young walleye and yellow perch. It was found that trout-perch were not common prey for higher trophic levels of fish.


- The changes in water quality brought on by eutrophication can have temporally different effects on fish communities by initially increasing in size before having developmental and reproductive issues that hinder survival.


- The non-native goby was not found to correlate with the location of mussels and had a varied spatial distribution and their diet consisted mainly of zooplankton and two-winged insects.


- Data showed that the growth of yellow perch in Saginaw Bay was poor, potentially due to inability to build up energy reserves. Behavioral differences were given as a cause for the variability in age distributions between the inner and outer bay.


- The SWAT model was used to determine the effects of climate change on current ecological stressors and the success that conservation practices could provide in forecasting future needs.


- Different techniques were employed to determine PCB concentrations in order to give an overall view of the contamination in aquatic life, in the water, and in the sediments, as the concentrations that were found varied.


- Determination of sex ratios, length, and weight in yellow perch. This study also looked at growth rate, size, and age distributions.


- Spring temperature was determined to have a large impact on the success of reproduction. The changes in fish populations, such as walleye and alewives, also had an effect and growth rate increased with the fishery intensification.

- It was found that the spawning reefs in the Saginaw Bay were not widely used by walleye. The population consists of wild fish and mostly of hatchery fish.


- MDNR discusses research and current recovery goals. Recovery goals include self-sustainability, carrying capacities, predator-prey relations for the walleye population, and ecological balances.


- A fish community survey was conducted including yellow perch and walleye. Yellow perch were found to have improved growth and lower density and the walleye had years of low recruitment which coincided with absence of stocking. Zebra mussels were not pinpointed as a cause of distribution changes.


- Development of Ricker-stock recruitment models to account for factors that affect reproductive success of the walleye population. It was found that alewives were a major factor but not the only one.


- Reduction of adult alewives appears to be positively affecting the overall fish population with an increase in walleye documented.

- This study attempted to determine the bioavailability of halogenated hydrocarbons for fish.


- Significant concentrations were not found when looking at carp, walleye, and alewives.


- Collection of samples from different species throughout the Arctic and North America, and especially the Great Lakes, were obtained to determine the concentration of perfluorooctane sulfonate (PFOS). PFOS were found to bioaccumulate in higher trophic levels. The greatest concentrations were found in urbanized areas and the Great Lakes.


- It was found that the major food eaten by smelt consisted of crustaceans, insects, and fish eggs. The majority of insects eaten were mayflies.


- This survey of walleye gives information of the sex ratio, length, weight, and age of the population in the Saginaw Bay.


- This study was conducted to determine the overall trends in the populations of walleye and yellow perch and they were found to have different trends.

- This study was conducted to determine the PCB concentrations in walleye from 2007 and compare them with the data from 1990.


- Food web dynamics and insight into the fish community composition in rivers was determined through various analyses.


- The difference in PBDE concentration between the sexes was attributed to females spending less time in the Saginaw River than the males, which had higher PBDE concentrations.


- This study showed that lake trout eggs that remained buried in the substrate had a higher rate of hatching than those that were not adequately buried in the spawning substrate.


- An overview of fish species diversity and the interaction of these species and their environment with the goal to aide in presenting information to be used for conservation efforts. It reports that of the 129 species of the 1970s, 20 species have been destroyed or are extremely at risk.

The analysis of DNA sequences of yellow perch to determine the genetic divergence/diversity could help give insight into the success of the species in the future.


- A combination of hydrodynamics, particle transport, and bioenergetics models were used to assess successful hatching sites for walleye in the Saginaw Bay.


- The condition of the Saginaw Bay had lowered the abundance of the benthic community especially mayflies and this affected yellow perch composition which had a high natural death rate. Energetic models were employed and suggested that the food supply of yellow perch was limited.


- This study showed genetic barriers in the Great Lakes; the preservation of genetic integrity should be included in conservation of walleye.


- This study showed that yellow perch were primarily eating immature insects, such as larvae, pupae, and nymphs.


- Water quality parameters were tested to determine concentrations and correlations between the parameters and the sample sites. It was found that phosphorus was able to be mobilized in wetlands that had low DO and low pH. Higher levels of phosphorus were found in these hypoxic areas.


- The involvement of commercial fishers partnering with biologist to collect data, report on, and tag lake sturgeon is helping this threatened species.

### i. Fish Diseases


- Fish at the point of death were examined and found to carry *C. botulinum*. This has implication for live fish eating birds. Fish that were healthy and recently dead were also examined and had evidence of *C. botulinum*.


- Key components of disease such as botulism, bacterial kidney disease, and thiamine deficiency complex were addressed. A population-level research dynamic looks at ecological factors in relation in order to disease to attempt to have some predictability as to how disease affects fish and the ecosystem.


- Decreases in abundance were found in this bottom dwelling fish survey and were as high as 99% for common fish species of Lake Huron over the 1974-2006 timespan. Temporal separation was used for distinction of early and late sampling times.

- The males had a higher ratio of PCB concentration in comparison to females, which was attributed to differences in habitat use and prey consumption. However, in this study it was found that the dredging and removal of contaminated sediment drastically reduced the percentage of PCB concentration in both genders as observed in a ten year period.

**b. Herpetofauna**


- This was a compilation of data from various sources to determine the species richness in the wetlands of Lake Huron. They estimate that there are about 10 species of frogs and toads and about 7 types of salamanders. The reptiles (about 20 species with no lizards) were estimated at over 10 different species of turtles and snakes each. It was mentioned that data was lacking for the herpetofauna.


- Spatial scales of bird and amphibian IBI’s with disturbance gradients were developed to determine the overall condition of wetlands. Included were ways to improve the IBI’s.


- Updates to the list of herpetofauna of Northern Michigan were made through efforts at different collecting stations.


- Determination of the effects of PCB on amphibians was carried out by comparing those living in known contaminated habitats to those that were not. Differences in population density were not found although negative effects to amphibians were found when treated with PCB in the lab during early life stages.

A study to determine the effects of anthropogenic stress on lizards in Canada found that the removal of suitable habitats—large woody decaying materials such as logs—was the main cause of lowered skink abundance, not just high traffic of humans.


- This study observed 25 herpetofauna species and also found correlation with the invasive species Phragmites; the areas containing Phragmites did not have any notable amount of species and removal of this invasive could increase species abundance.


- Extensive research in topography, habitat, flora and fauna.


- IBI’s are used as measurements for the determination of wetland conditions. However, variability can play a role when it is difficult to find comparable sites and when water levels change. This can be especially true for herpetofauna IBI’s that may change drastically in comparison to avian IBI’s if water levels change.

c. **Avian**


- It was determined that although there was a correlation between the toxicity in red-winged black birds and concentrations in sediment, it was suggested that tree swallows would be a better indicator of bioaccumulation based on location.


- This study determined the structure of six previously unidentified brominated substances in the eggs of herring gulls from the Great Lakes.
- This study looked at chick growth, foraging time, and fish acceptance of common terns.

- Between 1974-1993, samples were taken to determine the persistence of PCB and similar toxins in herring gulls; it was found that the toxic substances were persistent throughout the study. In the 1990’s, Saginaw Bay had the highest PCB concentrations found in the gulls sampled.

- Based on the derived biota-sediment accumulation factor, the concentration of PCB toxins in the sediment of the Saginaw Bay should not be great enough to cause harmful effects to the swallows sampled.

- A management plan was proposed for the population of tundra swans and looked at population dynamics, habitat availability, and socioeconomic issues to determine the best management plan.

- The Michigan State document prepared for Consumers Energy for the maximization of effectiveness of wind energy while minimizing the negative impact it can have for bird populations resulted in the best locations for turbines being in the regions that were predominantly agricultural fields.

- The complications regarding the study of wildlife toxicology were discussed. Focus was given to chemicals, such as PCB’s and DDT, in the environment due
to human action and the effect that they have on bird deformities and reproductive issues.


- GLEMEDS is found in many different avian species in the Great Lakes. It was found that this is similar to chick-edema disease which involves cytochrome p-448. The common signs of these diseases can be caused by furans, DDT, TCDD, and PCB. Lake Ontario saw initial improvement of reproduction with the decline of TCDD and PCB.


- PCDD and PCDF levels were found to be the highest in the eggs from Saginaw Bay. There was evidence found for bioaccumulation across species such as trout, walleye, and gull eggs.


- Mapping carbon and nitrogen isotopes in gulls showed differences that correlate to terrestrial and aquatic food availability, in which the aquatic had higher nitrogen content than the terrestrial.


- The ratios of different polychlorinated compounds were compared for cormorants and gulls. Varying ratios suggest that some species may be able to metabolize certain congeners better than other avian species.

Due to the flooding, sediment carried PCB and TCDD in levels that severely impacted the Caspian tern. The smaller birds were found to be more susceptible to this than the larger of the species which was attributed to higher metabolic rate.


Assessments of media reports and public opinion were used to determine shifts in views about the human and cormorant relationship.


Model to predict concentrations of residues in the Saginaw River Watershed.


The use of tracking collars allowed for the determination of times spent in migration areas during certain seasons. The Great Lakes are an important part of the migration area of tundra swans. Tracking like this can provide important information on the area in most need of conservation when relating to migratory birds.


Concentrations of PCBs in tree swallows were measured and compared to the concentrations found in the Great Lakes. Concentrations in the Hudson River were found to be greater than those in the Saginaw River.


The great blue heron and the belted kingfisher were analyzed for polychlorinated toxins. High concentrations were found in nesting sites downstream of industrial hot spots relative to the upstream sites.

- This study suggests that arithmetic means may not correctly estimate food abundance for migrating ducks and suggest that central tendency might be a better option. A model may be needed in this area to fill the gap and more closely determine the distributions of food biomass along areas of waterfowl migration.


- This study determined the levels of 24 organochlorine compounds in rivers and the Saginaw Bay. The areas of Fighting Island through the Detroit River had reports of the worst contamination in herring gull eggs.


- Many deformities, similar to the ones observed in the avian species of the Saginaw Bay, were found and characterized. The toxicity was dependent upon dosage. Increases in toxicity resulted in death of embryos however the effects of toxicity and extent of deformities are different across avian species.


- This study determined the density and diversity of avian populations in the invasive loosestrife. It was found that six species of birds were common, such as the red-winged black bird, and that breeding was apparent. Although there was significant high numbers for density, the diversity of species was lower in comparison to other vegetation types.

- The use of agriculture and water habitats was greater than that of wetland habitat and should be the focus of conservation specifically in the spring and winter for these birds. The use of wetlands was prompted by changes in food availability and habitat.

### i. Avian Botulism


- Outbreaks of botulism from types C and E were evaluated and were found to be widespread and occurred throughout summer and fall.


- The deaths of 592 loons were attributed to the ingestion of dead fish that were infected with botulism.


- Longer incubation times seem to increase the occurrence of type E toxin in the *Cladophora* algal mats sampled. Other types of *Clostridium* were found.


- Of the areas from which *Cladophora* was collected the type E toxin gene was found in approximately 75% of the samples. Further research was suggested for the determination of specific aspects of the bacteria-algae relationship. Saginaw Bay was not an area that was sampled.

• Causes of death of over 200 loons were assessed from different states. The highest occurrence of death attributed to avian disease was for those found in Michigan due to botulism outbreaks in Lake Michigan.


• Determination of outbreaks in the Great Lakes was conducted to facilitate monitoring for the presence of *C. botulinum*.


• The type E toxin was found in large numbers of birds, less in fish, a smaller number in mammals, and was also found in the sediment. Degrees of relatedness were determined and it was found that various distinct strains were involved in the outbreak in Lake Erie.


• Correlation was found between low water levels, higher surface water temperature, and increase in *C. botulinum* outbreaks. Predictions of climate change in increasing these factors were mentioned.


• The problems associated with carcasses remaining throughout the winter was proposed as a major contributor to outbreaks, along with increases in algae during times of avian molting, which increased risk of infection.


• This study showed landfills as a source of different types of *C. botulinum* and concludes that gulls that scavenge these areas are likely to be a source of distribution for the bacteria.

- Low pH and DO were found with increases in C. botulinum in sediment samples. C. botulinum was also found in invertebrates.


- Overview of the C. botulinum bacteria in the context of waterfowl relating characteristics, pathogenesis, and signs of infection.


- Of the samples taken of algae at Bay City State Recreation Area, 83% were found to have the Type E C. botulinum and of the sites tested Bay City had the highest concentrations.


- Four fish species were included in the study to determine if they could be a viable transporter of C. botulinum to birds of the Great Lakes. This was found to be an avenue of transmittance and yellow perch were found to live the longest after infection of all dose concentrations.

ii. **Avian Influenza**


- The effects of avian disease are not only detrimental to wildlife populations but H5N1 has risk of infecting humans. It was mentioned that a major gap is in the detection of when diseases emerge, the disease abundance, and the effect it may have on the whole population.

This study proved that zebra mussels that get exposed to H5N1 in water are able to take up the virus and can carry it for at least 14 days in water that does not contain the virus.

d. Mammals


- PCBs were found to negatively affect the reproduction, health, and offspring of minks exposed to as low as 0.25ppm. The effects of PCBs were greater as the concentrations increased.


- TEQ and PCB containing diets were given to mink to determine the effects it would have on the liver of females. Lower red blood cell and higher white blood cell counts were found in those exposed to toxic carp, along with behavioral signs of distress. The liver, spleen, and lungs all seemed to be affected based on the greater weight found in comparison to controls.


- Mink and river otter livers were tested for concentrations of toxins. Mink livers were found to carry PFOS in every case.


- Various physiological parameters were considered when determining toxicity directly linked to the ingestion of carp from Saginaw Bay. Some tests showed that the highest percentage toxicity diet had overall effects and some showed it to be no different than the controls.

- Extensive negative effects of mink diets containing PCBs have been proven. Links to hepatic estrogen binding sites and downregulation may play a role; uterine estrogen was not affected as much.


- Duration and time of exposure in parents and offspring to PCB toxins were examined to determine the negative effects in minks.


- PCB exposure may be able to be determined by use of biomarkers using liver enzyme activity as related to cytochrome P-450 induction.


- PHH and TCDD showed additive effects on the minks as found by bioassay. Mink are extremely sensitive to reproductive toxicity from these compounds.
Ecological Stressors

IV. Environmental Degradation

a. Soil and Sediment

i. Soil Movement


- Model incorporating time and transport of sediments was used to determine the sedimentation and movement and the resulting river bed bathymetry that has changed as a result. This study also showed uses of the model in long term prediction of changes.


- Transportation models were developed to address hydrodynamics in Saginaw Bay. It was found that seasonality affects resuspension events, mostly attributed to surface waves.


- This study showed soil associations and models for irrigation in the Saginaw Bay.


- A simulation model was used in conjunction with GIS and other tools to attempt the estimation of erosion. AGNPS model was used and it was found that the Cass River Watershed contributed greatly to the sedimentation in the Saginaw Bay and River.


- The focus of this paper is to present the uses of soil quality parameters as a tool for the development of research and to influence land uses, particularly to promote sustainability in agriculture.

• LANDSAT – reflectance data was used in mathematical models to relate it to suspended solids in water.


• In the Sebewaing Watershed, the Channel Sustainability Tool was employed to help address agricultural drainage issues and explore BMPs.

**ii. Sediment Pollution**


• Concentration and patterns of polycyclic aromatic hydrocarbons were analyzed in sediments of different parts of the world including Saginaw Bay.


• Sediment analysis showed Lake Huron to be the Great Lake least contaminated with mercury and suggest that the source may be natural for this lake.


• Retrospective analysis on human disturbances and the changes that resulted in the Great Lakes were discussed.

and floodplain soils of the Saginaw River watershed, Michigan, USA. *Archives of Environmental Contamination and Toxicology*, 55(1), 1-10.

- Polybrominated biphenyls were analyzed in sediments from different areas around the Tittabawassee and Saginaw Rivers as well as the Saginaw Bay. The highest concentrations were found at the mouth of the Saginaw River.


- A spatial trend of concentration of chlorobenzenes was found.

### 1. Dioxins and Furans in Sediment


- The use of dioxins and furans has contributed to the sediment concentration of these toxins in sediments of the Saginaw Bay. The release of these toxins from burning was suggested as a major source of the contamination.


- Extensive research in sediment was conducted for the Dow Chemical Company. Higher concentrations of toxins were found in surface sediments rather than deeper in the sediment on average.


- Total organic carbon did not correlate with sediment toxin concentration, however downstream concentrations were higher.


- Past and present contamination concentrations were analyzed for the Saginaw River. Trends in degraded contaminants were observed.

dibenzofurans, and biphenyls in sediments and floodplain soils from the Saginaw and Shiawassee Rivers and Saginaw Bay, Michigan, USA. *Archives of Environmental Contamination and Toxicology, 54*(1), 9-19.

- Polychlorinated dioxins and furans were found in the highest concentration in the Saginaw River and Bay in comparison to other areas of the watershed. The data suggested a source of PCDF’s in the watershed rather than the river.


- The chemical treating of products in industry and atmospheric deposition were the main causes discussed for the sediment contamination found.


- It was determined that the data shows steady state fluxes and kinetic rates which were calculated and silica fluxes were extrapolated.


- General correlations were found for spatially distributed particles of sediment. Diameters and other characteristics were measured and related to waves and water movement.

### iii. Muck


- The microorganisms in the muck of the Saginaw Bay were tested for identification and for the determination of possible fecal contamination by identifying species such as *E. coli*. The results showed fecal contamination.

- Several bacterial species were identified in the muck of the Saginaw Bay. Both animal and human sources of fecal contamination were found.

### b. Water Contaminants


- Analysis of the flow and circulation of Lake Huron showed how the mixing affects the chemical and water temperature parameters in the Bay and the variability that this produces when measuring contaminants that come from the Saginaw River as they decrease to the outer bay.


- DLBRM Distributed Large Basin Runoff Model- NOAA GLERL.


- Watershed model for materials runoff in the Great Lakes and Saginaw Bay.


- Model used for concentrations of heavy metals in suspended solids and sediments in the Saginaw Bay.


- SWAT- Soil and Water Assessment Tool- USDA Agricultural Research Service (ARS) continuous time model, Total Maximum Daily Load (TMDL)


- Estimation of loading potential of non-point sources in the Great Lake Watersheds.


- AGNPS- Agricultural Non-Point Source Pollution Model; GRASS- Geographic Resource Analysis Support System; GRASS WATERWORKS tool box for hydrologic modeling; Incorporation of different models for land use, amounts of erosion, nitrogen, phosphorus, volume of runoff, and sediment yields.


- Ecopath (for biomass flows among groups using mass balance modeling) and Ecosim (considered migration and nutrient concentrations and loads with dynamic modeling) models for modeling invasive species and their effects for Saginaw Bay.


- BASINS- Better Assessment Science Integrating Point and Non-point Sources – EPA.


- The development of simulation models for pollution, such as nitrogen and phosphorus, were used to acquire water quality baseline measurements for Saginaw Bay.

The concentrations of four heavy metals were found to vary greatly due to river discharge and seasonal changes. The source of contaminants was found to be in the lower 8 km of the river.


SAGEM2- Saginaw Bay Aquatic Ecosystem Model- Limno Tech


- Models were used to explore variances of different parameters.


- The total and soluble PCB concentrations in the river were analyzed and helped to determine the concentration and loading at different sites on the river.


- WASP from the EPA- Water quality Analysis Simulation Program – Takes into account multiple types of pollution.

### i. Phosphorus


- This ban aids to reduce the amount of phosphorus that needs to be treated and removed therefore lowering the amounts of chemical reagents needing to be used and making treatment more effective by lessening the starting amount.

- The necessity of needing to predict phosphorus loads in times where sampling doesn’t occur prompted the use of different models for this prediction.


- Greater than 50% decreases in phosphorus loadings to the Saginaw Bay were observed in 1980 in comparison to 1974. Other water quality parameters including chlorophyll and Secchi depth were measured.


- Bayesian network for phosphorus and chlorophyll a in the Saginaw Bay.


- Estimation of phosphorus load using a Bayesian model that allows for the reduction of uncertainty that accompanies small sample sizes.


- Modification of models including flow and diffusion of phosphorus in the Saginaw Bay.


- Mathematical phosphorus models determined the amount of phosphorus reduction that could induce significant benefits in the reduction of eutrophication.

Experiments in both the field and in a greenhouse showed the correlation between zinc and phosphorus as negative, found through different variations of applied zinc/phosphorus to corn plants and soil.


A conceptual model developed for the changes that *Dreissenia* have made in the nutrient and energy flow to address the nearshore phosphorus shunt. Mentions the necessity of heavy phosphorus management in areas where *Dreissenia* have become established.


Anoxic water conditions correlated with an increase in phosphorus release into the water. This study called into question the temporal variability of zebra mussel deposits and their release of phosphorus due to there being no evidence of release found from them in this study period.


The shifts that have occurred after the invasive zebra mussel have caused a greater split in the environments of the nearshore and outer bay regions. The inner and outer bay saw changes in macroinvertebrates.


This study proposed that Si depletion can be attributed to the increase in its uptake by diatoms which are affected by levels of phosphorus in the Great Lakes. A model was proposed for biogeochemical depletion.

Phosphorus input into the Saginaw Bay is still too high when compared to the standards proposed for the reduction of eutrophication. This indicates a need for increased effort in reduction and water quality management.


Estimating phosphorous load for the Saginaw Bay was the focus.

ii. **Nitrogen**


- A comparison of the excretion concentration of nutrients from both zebra and quagga mussels were tested to determine if there were differences present that could account for the changes in community distribution and the increase in harmful algal blooms. Quagga mussels were found to have lower rates of excretion in comparison. The increases in nitrogen and phosphorus cycling from mussels contribute to the overgrowth of algae.


- A possible positive nitrogen regeneration effect was suggested based on the rates of ammonium regeneration which were increased with the presence of zebra mussels.


- At two sites on the Saginaw Bay, water-sediment ammonium fluxes were measured. The zebra mussels play a role in nitrogen generation due to excretion.

- Nitrogen cycling at the sediment-water interface was the basis for the study and it was determined that the excretion of ammonia by the zebra mussels heavily influence the microbial community by increasing nitrogen.


  - A trophic state model was used to determine changes in nutrient levels in some of the Great Lakes. The rates of eutrophication were applied to nitrate content.

### iii. Carbonate


- Conditions of carbon dioxide and calcite equilibrium can be used as indicators of biological integrity due to biochemical reactions. This method was used for 11 sites in Saginaw Bay. Conditions varied seasonally. Photosynthetic activity was of importance nearshore, where in the outer bay temperature played an important role.


- The microenvironment of the water plays an important role in the cycling of carbon and the deposition of calcium carbonate by photosynthetic action, resulting removal of CO$_2$ by algae on certain anti-algae paint on boats.


- The clay content of the sediment was proportional to the amount of carbon found with Lake Huron and Ontario, which had higher amounts than Lake Erie. Higher concentrations of both carbon and nitrogen were found in the surface of sediments. Carbon and nitrogen were found to be proportional.
iv. **E. coli**


- Virulence genes associated with the pathogenic strains of *E. coli* were not common in the beach sand, however attachment genes were common.


- The correlation of *E. coli* and *Cladophora* was examined. Although it was stated that *E. coli* concentration was greater in dense areas of algae when compared to the surrounding water, there were problems with statistical significance in determining spatial distribution of *E. coli* from the algae.


- In relation to the other fecal pathogens studied, *E. coli* was able to last 45 days with *Cladophora* much longer than either of the other pathogens studied.


- Correlation of *E. coli* concentrations between water and those of *Cladophora* was not found. Detached *Cladophora* was examined for *E. coli*. The highest concentrations were found for the Saginaw Bay and this was attributed to the higher phosphorus concentrations found there.


- The highest concentrations of *E. coli* were found in shallow waters, sediment, and algal mats. The species specific testing showed predominance of contamination by human fecal source. Areas of high concentration are sensitive to disturbances such as movement from various sources.
v. Flow


- An attempt to characterize flow regimes as well as look at the historical flow and what may have caused the changes. This study also included a GIS attachment for developing hydrographs along with other tools. Flow Assessment by U of M used ESRI ArcView 3.X GIS modified to construct hydrographs, retrieve information about dams, and access contact information for the Great Lakes Basin.


- The currents measured in the inner bay agreed with the model used in contrast with the outer bay, in which the models did not accurately represent data. The water exchange was dependent upon the direction of the wind in regards to the Bay.


- Groundwater flow and hydraulic loading simulation models were used to analyze groundwater exchange for the Saginaw Bay.


- This study showed the variance in water quality associated with seasonality and land use. This study stressed the importance of databases that show spatial distribution of water quality which can be applied to a region.


- SWAN developed for a wave model for the Saginaw Bay.


- The Hydrologic Modeling System (HEC-HMS) simulates the hydrologic processes by both event and continuous simulations. Additional tools such as
depth, flow, sedimentation, erosion and nutrient water quality are available to estimate such parameters for watershed systems.

**Anthropogenic Conditions**

**V. Anthropogenic Stress**

*a. Human Disturbances*


- Variance in vegetation is found in different areas. Different types of removal strategies can reduce the diversity of plant life, cause root degradation, and erosion.


- Contamination mobility was researched in areas of concern to obtain information for a Remedial Action Plan.


- Regression and Markov Models were used for the prediction of the changes in forest cover due to socioeconomic changes in land use.


- This study used a watershed model for land use and climate change in the Saginaw Bay.

Simulation model for irrigation purposes with concern for water quality degradation were developed.


Ship ballast water methods of contamination have contributed greatly to invasive species. The presence of interchanges such as canals are projected to continue to introduce more non-native species.


Many issues in regards to waste water were addressed such as occupational risks, pharmaceuticals and other toxins, viruses, diseases, and more.


Models were developed for the indication of wetland condition based on seven taxa and four taxa models of emergent plants in the Great Lakes.


An attempt to determine wetland health by taking into account human stressors, water depth, biological conditions, and geography was made. They employed CART models for analysis.


Determination of invasive species entry was focused on in the retrospective review on non-native species.


Human stressors and their relationships to water quality and geology were analyzed.

- Extensive research was done on 88 sites of Lake Huron to determine health conditions as well as to suggest sources of stress and human disturbances based on gradients and four different health indicators.


- Land transformation model for the Saginaw Bay Watershed.


- An online survey attempted to attach priority to certain environmental stressors. Less priority was given to pollution and more priority was given to climate change and invasive species threats.


- DDT and PCB were the main chemicals analyzed. The effects of land use, seasonality, and surface water components were incorporated into the study of Michigan Lakes.

b. Remediation/ Conservation Efforts


- Conservation program with a focus on agriculture. Monitoring programs are in place to determine the success of the program.

• The dynamics of tradable credits for reduction of nutrient loading were explored. Models gave insight into the estimation of nutrient reduction upon implementation.


• Discussed are the needs for prioritization of watersheds and areas in need of BMP’s for the best action for conservation efforts.


• A look at the history of the Great Lakes ecosystem breakdowns and the focus of how to manage this before the damage becomes irreversible due continuing stressors on the self-regulating systems of the Great Lakes.


• This study considers the compounding effects of multiple stressors and the importance of looking at all aspects that affect the health of the waters to focus restoration efforts.


• The study sought out the determination of bias in models with a focus on data from the Saginaw Bay.

Distinctions between human disturbances and stressors are made and suggestions are given for habitat improvement.


- ANFIS and SWAT were used along with macroinvertebrate measurements to determine the impact of best management practices on stream health.


- The ranking of best management processes with analysis of different scenarios were used to consider different dimensions of potential agricultural issues as related to economics and environmental concerns.


- This study presented a proposal of how to determine the health of estuarine ecosystems based on specific indicators.


- The focus on continually analyzing and improving remedial action plans attempts to give a greater impact though restoration efforts.

The setting of targets of ecosystem health can help to determine impairment status and allow for reaching an agreement on remedial action plans.


- The loss of the coastal wetlands, through human development, which served as protectors for the lake by collecting toxins, has had a great impact on the health of the Saginaw Bay and Lake Huron. The restoration of these wetlands is suggested as a way to improve overall water quality.


- A simulation and wetland distribution models were developed to determine the effects of wetland restoration in reducing nutrient loads to the Saginaw Bay.


- Sensitive design in constructing subdivisions was a goal of the Conservation Development projects of The Conservation Fund.


- The incorporation of different methods of outreach to include absentee landowners will be beneficial in continuing conservation work.


- A goal of including absentee landowners in the ideals of conservation practices was highlighted.


- Analysis of landowner dynamics and how they relate to and affect conservation efforts.


- This paper states that the translocation of species that are endangered in a particular area could cause unforeseen trouble when moved outside their natural habitat range. Though conservation has used risk assessment this paper argues the danger in adjusting species habitat.


- Spatial multifactor models were used to explore the differences associated with varying areas of human disturbances on streams as well as IBI models that demonstrated stream health.


- Importance was given to the management and ecosystem models that are region specific in contrast to wide range types to be more effective in restoration efforts.


- Past, present and future restoration efforts in the Saginaw Bay Watershed were examined.


- This paper evaluated different aspects of dioxin remediation along with different ways to implement the proposed cleanup. This paper also touches on the EPA phase approach of remediation.
- The Ecological Protection and Restoration Program of the GLNPO of the USEPA.

### Socioeconomic Conditions

#### VI. Socioeconomic Conditions

##### a. Economic Context

- This discusses the changes that need to be made for the most successful outcome. An integrated network of laws that has ecological aspects considered may be more cost effective and yield a faster result than individual laws that focus on one type of pollution.

- Trading of nutrients is proposed as a way to reduce pollution emissions while still having credits or profits possible for the industry.

- This paper gives an overview of water quality history, issues, and concerns throughout different areas of the world. The discussion of point source and non-point source pollutions shows the difficulty posed by the regulation of non-point source and the financial and technical problems associated with addressing point source pollution in less developed countries. Because of the different costs associated with different companies and their respective wastes, the idea of water trading allows for a cost effective way to obtain industrial benefits from water quality regulation.

- The employment of economic tools was used to attempt to quantify the monetary values of certain uses, resources, and purposes of the Saginaw Bay.

Nassauer, J. I., & VanWieren, R. Vacant property now and tomorrow. *thelandbank.org*

- The Genesee County Land Bank Authority is attempting to utilize the large amounts of vacant property to investigate other natural land uses and/or to engage the community to take care of their land and neighborhoods thus creating value for vacant land by contributing to a healthy and attractive place to live.


- Natural resources are valuable for different reasons to different people. Trends of natural resource use, tourism, recreation, and land use were determined.


- Scientific assessment of environmental risk analysis on water quality simulation models.


- The Saginaw Coastal Bay land and the economic value attached to this area is addressed.


- The employment of economic tools was used to attempt to quantify the monetary values of certain uses, resources, and purposes of the Saginaw Bay.

- Estimation of the economic benefits of Saginaw Bay will aid in attaining conservation funding.


- A focus on stakeholder opinion and involvement in important environmental projects is considered, including the CREP filter strip program. Suggestions for improving participation in the CREP program were given.

**b. Impact on Humans**


- The measurements of soil dioxins were compared to the spatial instances of breast cancer and they found a correlation between the soil dioxin concentration and the occurrence of breast cancer.


- Serum dioxin concentrations were assessed and the identifications of the factors that contribute to it were examined to determine spatial variability.


- Widely used and degradation resistant FOCs were analyzed to determine persistence and toxicity in blood plasma and liver tissue.

- Individuals living near the rivers were found to be at a higher risk for breast cancer and individuals that lived nearer to highways were more at risk for lung cancer.


- This study used random sampling to determine if there was statistical significance between a reference group and Saginaw and Midland populations that are exposed to PCDD/PCDFs due to localized chemical industry. Statistical significance was found although differences in concentrations were small and regression models were suggested as a continuation for analysis.