LAKE ERIE NUTRIENT LOADING AND HARMFUL ALGAL BLOOMS: Research Findings and Management Implications

Final Report of the Lake Erie Millennium Network Synthesis Team

14 June 2011

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Background

In December 2008, USEPA's Great Lakes National Program Office (GLNPO) and the Lake Erie Protection Fund (LEPF) requested proposals to address nutrient loading, harmful algal blooms (HAB), and eutrophication problems in Lake Erie. Dr. Jeff Reutter (Ohio State University), representing Ohio Sea Grant and the Lake Erie Millennium Network (LEMN), and Jan Ciborowski (University of Windsor), representing LEMN, organized a series of open conference calls and meetings to facilitate development of coordinated and collaborative projects to address the calls for proposals. Up to 75 scientists from approximately 25 institutions and agencies participated in these calls. Ultimately, eight projects were developed, seven projects were supported (5 from GLNPO and 2 from LEPF), and they included 15 scientists from 11 institutions, agencies, and companies. Each of the principal investigators committed 5% of their funding to the outreach, summary, and synthesis effort led by Drs. Reutter and Ciborowski, and Dr. Joseph DePinto, LimnoTech. These funds were augmented with additional support from Ohio Sea Grant, LEMN, and the International Joint Commission, Council of Great Lakes Research Managers. From late 2008 to June 2011, these scientists have had conference calls and meetings to facilitate their collaboration on these projects. In addition to Drs. Reutter, Ciborowski, and DePinto, this summary is authored by Drs. Darren Bade (Kent State University), David Baker (Heidelberg University), Tom Bridgeman (University of Toledo), David Culver (Ohio State University), Elizabeth Dayton (Ohio State University), Douglas Kane (Defiance College), Robert Mullen (Ohio State University), and Christopher Pennuto (Buffalo State College). Steve Davis, retired NRCS, while not part of the original synthesis team, provided valuable input during our interdisciplinary analysis of the results from all of the projects, and contributed significantly to this report as one of the authors. Together this group of 12 scientists represents the LEMN Synthesis Team. It was prepared to aid Lake Erie managers and decision makers. We hope the expertise and diversity of this team has proved to be a great asset and we remain poised to be of service.

Data were collected for these projects between spring 2009 and late 2010. Preliminary results were presented to managers and decision makers on 10 February 2010 at the University of Toledo Lake Erie Center. This meeting also included a number of presentations by scientists working on related projects. In a second meeting on 28 March 2011 the authors of this report summarized their research findings and described some possible management implications from the seven projects supported by GLNPO and LEPF, supplemented with some additional pertinent information from related projects led by these investigators. Since that meeting the investigators have convened by conference call four times for a total of 9 hours with numerous emails in between. The interdisciplinary nature of this research team added great value to our discussions and to the final report. While extremely time consuming, these interactions were also very beneficial to each of the team members as we gained a much greater appreciation of the magnitude and scope of the nutrient loading and algae problem and the challenges we face in addressing it.

What are HABs and Why are We Concerned? Harmful algal blooms (HABS) are episodes during which large quantities of harmful forms of algae appear in parts of the lake. In freshwater ecosystems, they are caused by 6-7 species of algae of a group called cyanobacteria, commonly called blue-green algae. Although small numbers may be present at all times, these forms of algae normally require warmer temperatures (>60°F or 15^{o}C; maximum growth rates occur in the 25-30^{o}C range) and high levels of nutrients to germinate from propagules resting on the lake or river bottom and form blooms. Therefore, blooms of HABs are most likely to occur during the summer to early-fall time period. Some are capable of producing a number of toxins. The toxin we hear most about is "microcystin", and it has been implicated in human illnesses and deaths. The World Health Organization (WHO) recommends that the concentration of microcystin not exceed 1.0 parts per billion (ppb) for drinking water and 20.0 ppb at swimming beaches. The highest levels reported for Lake Erie are about 60 ppb. In July 2010, Grand Lake St. Marys was closed and people were advised to stay away from the water because the concentration had reached over 2000 ppb. Cyanobacteria are not particularly valuable as food for zooplankton and benthos, and as such may be viewed as weeds. For example, they can outcompete other algae that are good food for zooplankton even when waters are warm, dissolved carbon dioxide (needed for photosynthesis) is low, pH is high, and light is low. Some cyanobacteria can even transform nitrogen gas (N_2) into ammonia (called nitrogen fixers) when ammonia and nitrate required for growth are in short supply. All other algae must obtain ammonia or nitrate from the water. In addition to their toxin-producing capability, these blue-green algal species tend to create aesthetic problems when they form floating blooms and produce taste and odor problems in drinking water systems. They are not eaten by organisms that support fish production, but instead compete with those organisms for energy. Finally, when HABs drift to the Central Basin, die, sink to the bottom, and are decomposed by bacteria, the decomposition process uses oxygen and contributes to the dead zone. One of their weaknesses is that they are poor at obtaining phosphate from the water when it is at a low concentration, so reducing the phosphate concentration to below 5 µg/L as P will favor the growth of healthier forms of algae.

Are HABs Only a Lake Erie and Ohio Problem? No, HABs are a national and global problem. Allowing too many nutrients to enter our water systems is usually the cause. This problem is similar in Grand Lake St. Marys, and in a number of other lakes and reservoirs in Ohio and around the US and Canada. The variety currently causing problems in Lake Erie is *Microcystis sp*. The type causing problems in Grand Lake St. Marys in 2010 was *Aphanizomenon sp.* (a nitrogen fixer). *Aphanizomenon* is the same alga that dominated blooms in the 1960s and 70s in Lake Erie, when it was the poster child for pollution problems in this country.

Why Are We Targeting Phosphorus Control to Prevent HABs? In freshwater systems, phosphorus (P) is most frequently the limiting nutrient controlling algal growth—more phosphorus means more algae. P reduction efforts offer the most economical and ecologically sound means of preventing HABs. Reducing N might also be effective (although chemically removing phosphate is easier than removing ammonia or nitrate from water), but more research is needed. For example, nitrogen fixing cyanobacteria could offset the effects of any nitrogen load reductions, and greater needs to apply N to meet crop plant requirements may preclude recommending large decreases in fertilizer applications. It is interesting to note that in marine systems, N is most frequently the limiting nutrient, and in watersheds draining directly to the ocean, N load reductions are often recommended.

Understanding the Various Forms of Phosphorus. The phosphorus present in the waters of Lake Erie is derived from either external sources or internal sources. External phosphorus loading includes point sources and nonpoint sources located within the watersheds that drain into the lake, atmospheric deposition onto the lake, and inputs from the Upper Lakes carried by the Lake Huron waters that enter the St. Clair River. Internal loading is associated with various biological, chemical and physical processes that move phosphorus from lake sediments back into the water column. Of the above sources, point and nonpoint are by far the largest and are most amenable to management.

The analytical method most commonly used to describe the phosphorus coming from both point and nonpoint sources is a standardized procedure that yields what is termed "Total Phosphorus" (TP) concentration. Total phosphorus is comprised of two major portions, dissolved phosphorus and particulate phosphorus. The phosphorus in water that passes through a filter with a certain pore size (0.45 micron) is considered to be "dissolved" while phosphorus attached to particles that do not pass through the filter is labeled "particulate phosphorus." Both dissolved and particulate phosphorus can be chemically divided into various types, the most important of which is dissolved reactive phosphorus (DRP). This is dissolved phosphorus that directly reacts with a certain chemical (molybdate) to form a blue color. DRP and particulate phosphorus differ greatly in their ability to support algal growth, i.e., their bioavailability. DRP is essentially completely (100%) bioavailable to algae while only about 30% of the phosphorus making up particulate phosphorus is bioavailable. Since most particulate phosphorus settles out of the water column upon entering lakes, particulate phosphorus can also become "positionally" unavailable to algae. Indeed, most phosphorus that enters lakes and oceans eventually becomes buried in sediments. In general, point sources of phosphorus are dominated by highly bioavailable DRP, and nonpoint sources are dominated by particulate phosphorus having low bioavailability. Another important difference between point and nonpoint sources of phosphorus is that point sources enter surface waters at approximately equal daily rates throughout the year while nonpoint sources are delivered to surface waters in pulses associated with storm runoff events.

Are We Sure Phosphorus Reductions Will Solve the Problem? Yes. We had a similar problem in the 1970s, and solved it then by reducing P loading. While the characteristics of various phosphorus forms where well known in the 1970s, very few data on bioavailable phosphorus forms were available. Consequently, the target loads for Lake Erie were set in terms of annual loads of total phosphorus. In 1969 the estimated total P loading was approximately 29,000 metric tons. To eliminate nuisance algal blooms our models told us that we would have to reduce loading to 11,000 metric tons per year —approximately a 2/3 reduction. Approximately 2/3 of the total loading was coming from sewage treatment plants (point sources), so improving sewage treatment became the primary focus of reduction efforts. However, it should be noted that to achieve the target of 11,000 tons, phosphorus from non-point sources was also reduced by 50%. The 2/3 reduction in total P loading was accomplished, and, in general, the target loads have been met since 1981. The Lake responded quickly and dramatically. HABs were eliminated, the dead zone was reduced in size, and sport fish populations flourished. Lake Erie soon become known as the Walleye Capital of the World. Although large declines in DRP loading from agriculture occurred between 1975 and the mid-1990s (due to a combination of improved management practices and years with relatively few storms), subsequent increases in DRP loading from these sources indicate that the bioavailable phosphorus loading to Lake Erie from the Maumee and Sandusky rivers is now at the highest levels observed since monitoring began 35 years ago. While total P loading has not increased significantly in the last 15 years, the loading of dissolved P is back to the levels of the early 1970s, and it is possible that a 2/3 reduction in the current loading of dissolved P will again be required to control the problem. However, it is important to note that Lake Erie is a different lake today than it was in the late 60s and early 70s. For example, the presence of invasive species like zebra and quagga mussels and their ability to recycle P, could mean that reductions of more than 2/3 are required. We believe that the most improvement could be gained from investing our efforts in modifying agricultural practices.

Findings and Management Implications

The findings and implications presented below are a synthesis/summary of the results from all seven projects and a subproject linked to two of the seven. More results will be presented in the final reports from each of the projects.

- **Finding:** Sampling in the Maumee River and the Sandusky River began in April and high concentrations of *Microcystis* were already present in the rivers and in sediments within the river and lake. *Microcystis* was found as far upstream as first order streams that were only 0.3 m deep and it was always present in the rivers. It appears in the rivers before it appears in the Lake, and the river concentrations of *Microcystis* are higher than in the Lake in spring and early summer. Population densities increased from lower order streams, to higher order streams, to bays, to the Lake.
    - **Implication:** HAB species are likely present in most waters of the state and are simply waiting for the appropriate conditions to reproduce. In April, shallow, quiet, sun-baked areas of rivers and streams are likely warm enough to allow germination to occur. While reducing nutrient loading is the best way to prevent

HABs, it is possible that keeping stream habitats darker and cooler would also be beneficial (e.g., planting trees along stream banks for shade).

  - **Implication:** Sediment movement, from the river to the Lake during storms and dredging activities, may be one source of "seed" for algal blooms in the Lake.
  - **Implication:** Actions to reduce the magnitude of blooms in the rivers would not prevent blooms from occurring in the Lake, but those actions could potentially delay the formation of blooms in the Lake and reduce their magnitude, i.e., Lake blooms are not simply river blooms that have been flushed out into the Lake by storms.

- **Finding:** During storm runoff events in the Maumee River, dissolved nutrients from the watershed (predominantly cropland), such as dissolved reactive phosphorus and nitrate, are present at high concentrations and are carried with the storm runoff water well into the Western Basin where they likely support off-shore algal blooms and eventually mix with relatively nutrient poor waters derived from the Detroit River. Suspended solids and particulate phosphorus entering the Lake during these storm runoff events settle out of the water column shortly after entering the Maumee River navigation channel and do not immediately contribute to the elevated nutrient levels that support algal growth in the in the offshore areas of the Western Basin. The offshore mixing of storm event waters is frequently observed in satellite images, images that frequently show both residual suspended sediments in low concentrations and the development of algal blooms in the nutrient rich storm event waters entering the Lake from the Maumee River.
- **Finding:** During non-storm periods, dissolved nutrient levels in the lower Maumee River are relatively low, except where influenced by phosphorus from local point sources such as the Toledo Sewage Treatment Plant. These same low flow river waters have very high concentrations of conservative parameters (chloride and sulfate) that can be used to identify mixing zones with lake waters. Under low flows, mixing of riverine waters with waters of the Western Basin occurs at the mouth of the Maumee River, inside Maumee Bay, contrasting with the offshore mixing of storm event water.
- **Finding:** The net effect of the combination of (1) increasing loads of dissolved reactive phosphorus that is 100% bioavailable, (2) decreasing loads of particulate phosphorus that remain approximately 30% bioavailable, and (3) an increasing frequency, and intensity of storm events, is such that the overall loading of bioavailable phosphorus during the 2000s is at the highest level observed in the 35-year monitoring record for the Maumee and Sandusky rivers.
- **Finding:** While there is no question that storm events deliver the bulk of phosphorus from the watershed to the lake, most of those events occur during months when temperature does not favor *Microcystis* blooms in the lower Maumee River or Western Basin. However, during extended low flow periods following events, residual available phosphorus concentrations are high enough, hydraulic residence times are long enough, and typically temperatures are high enough for *Microcystis* blooms to occur. The magnitude and duration of these *Microcystis* blooms that appear as river plumes depend on the magnitude and timing of the causative environmental conditions.

- **Finding:** While high phosphorus loads from the Maumee River contribute to HABs during the summer, they also contribute to increased growth of other forms of plankton and aquatic vegetation throughout the year, e.g., diatoms during low temperatures, eel grass, etc. Certainly some of this material will drift in an easterly direction and settle to the bottom in the Central Basin where it will contribute to hypoxia and the "dead zone."
  - **Implication:** Dissolved reactive phosphorus loading to the Western Basin is particularly important, not only because of its high bioavailability, but also because it is delivered during storm runoff events that carry the nutrient rich waters well into the offshore areas of the Western Basin.
  - **Implication:** The frequency, timing and intensity of storm runoff events play an important role in overall loading among years. Water retention measures that can regulate the intensity of these pulses, especially during summer when other environmental conditions favor HABs should be investigated. This water could also serve as a source of irrigation water.
  - **Implication:** Management efforts to reduce phosphorus loading to Lake Erie should focus primarily on reducing dissolved phosphorus loading. It is much more important than particulate phosphorus and dissolved phosphorus loading has been increasing since the mid-1990s.
  - **Implication:** Particulate phosphorus not only is less bioavailable than dissolved phosphorus, it also settles out of the water column shortly after entering the lake environment. A portion of the particulate phosphorus that settles out can later be released if wave action resuspends the sediment or if the Lake becomes anoxic near the bottom and a reducing (rather than oxidizing) environment is created, allowing the phosphorus to be released in the dissolved reactive form.
  - **Implication:** In general, for Great Lakes research programs that seek to link landscape-level land use activities with adjacent nearshore and off-shore water quality, it is imperative to include studies during riverine storm events when the bulk of the pollutant loading is delivered from landscapes to lakes.
  - **Implication:** Additional research is needed to better understand relationships between dissolved nutrient loading into the Western Basin and the development of algal blooms, and to provide data that can confirm the predictions of new models that link hydrodynamics, the magnitude and timing of nutrient loading, and ecosystem processes in the Western Basin.
- **Finding:** In our Maumee Bay work we found that the microcystin concentration was related to amount of *Microcystis* that was present. Other work has shown that this is not always the case.
  - **Implication:** More work is needed to determine what causes toxin production.
- **Finding:** Dissolved phosphorus loading and the size and frequency of HABs appear to be increasing. HAB densities in 2008 and 2009 were the highest since recent monitoring began in 2002.
  - **Implication:** If nothing is done and nutrient loadings continue to increase, the problem will get worse in the future.
- **Finding:** In September (late-bloom) there was evidence that *Microcystis* became limited by the concentration of N in the Western Basin. When this happened a shift occurred

from *Microcystis* blooms to a bloom dominated by *Anabaena*, a nitrogen-fixing cyanobacteria. Later, as the bloom decreased with the onset of cooler weather, concentrations of dissolved reactive P increased, suggesting cell breakdown and release of P.

- **Finding:** While the area of the Western Basin covered by beds of the nuisance cyanobacteria *Lyngbya* is small, where *Lyngbya* occurs, on average approximately 20% of the phosphorus in a cylinder that includes the phosphorus in the *Lyngbya* biomass and in the water above the *Lyngbya* is contained in the *Lyngbya* biomass. In areas with dense *Lyngbya* mats, up to 75% of the phosphorus in the cylinder may be contained in the *Lyngbya*.
    - **Implication:** In the future, invasive species will likely continue to impact nutrient movement and how P is cycled in the ecosystem.
- **Finding:** Physiological indicators of P limitation were measured in nearshore to offshore stations in Lake Erie and also two tributaries, the Maumee River and the Sandusky River**.** P was rarely limiting in the river stations, possibly due to high P concentrations, low light levels, low algal biomass, or a combination of these. In the lake transects near Sandusky Bay, P was limiting in June, whereas in the Grand River and Cattaraugus Creek transects, P was limiting in September. In the lake transects there were no indications that P limitation differed from nearshore to offshore. Measurements of N fixation by cyanobacteria were also made in the Western Basin in the fall of 2010. N fixation was observed, and could contribute significantly to N loading.
    - **Implications:** These results suggest that P levels often exceed algal needs and that at times Lake Erie algal production is no longer constrained by P inputs. Therefore, further reductions of P loading are warranted in order to create conditions of P limitation, which should reduce algal production and discourage N fixation.
- **Finding:** At times, both P and N, together, are required to stimulate additional algal growth. During these periods reducing either P <u>or</u> N loading could reduce algal production.
    - **Implication:** Phosphorus should still be the primary target for nutrient loading reduction efforts as stated in the background of this summary. Reduction of both P and N loadings should be encouraged, when feasible.
- **Finding:** In laboratory studies, applying the same analytical methods for measuring phosphorus in water samples directly to dilute aqueous soil suspensions showed good correlations between soil test levels and dissolved reactive phosphorus in the aqueous suspensions. However, there is a very low correlation between particulate P concentrations in the aqueous suspensions and soil test levels.
    - **Implication:** Since particulate P is the major form of P exported from most cropland, the lack of correlation between P soil test levels and particulate P concentrations of soils needs to be considered in the development of an improved P index for this region.
    - **Implication:** Since in the laboratory dissolved reactive P in aqueous soil suspensions correlates well with soil test P, soil test P is likely a meaningful indicator of soil P solubility in the field.

- **Finding:** P and N are deposited and stored in lake sediments. Dreissenid mussels may be responsible for the deposition of more nutrients nearshore than are being transported offshore (supporting the nearshore shunt hypothesis). Similarly, sediment cores suggest less offshore P deposition than nearshore P deposition, but greater N deposition. Central Basin sediments have higher P concentrations than the Western or Eastern Basins.
    - **Implication:** Internal cycling from historical deposition of nutrients in lake sediments will slow recovery. Additional research and models will be required to determine the extent to which internal cycling will contribute to the problem. The expected in-Lake effects of reductions in external nutrient loading may initially be counteracted by contributions of internally cycled nutrients. It may ultimately require sustained reductions from many P sources (non-point source and point source) to meet water quality goals. We anticipate that the Western Basin will respond to nutrient abatement strategies very quickly, and certainly much faster than the Central Basin based on the differences in sediment nutrient concentrations, the constant inflow of a large volume of nutrient poor water via the Detroit River, and the fact that the retention time for water in the Western Basin is much shorter than the Central Basin (51 versus 635 days) thus providing less time for internal loading to occur.
- **Finding:** Invasive taxa (especially dreissenid mussels and round gobies) account for more than half the bottom organisms in the Lake. Round gobies serve as a possible link between an otherwise distinct nearshore food web and offshore food web.
- **Finding:** There are distinct nearshore to offshore declines in concentrations of water column particulate and dissolved nutrients in all 3 basins and during spring, summer and fall. All offshore sites were a minimum distance of 3 km offshore. The Western Basin did not always have the highest water column nutrient concentrations; its values were exceeded at times in the Central Basin. The Eastern Basin was always the most nutrient poor.
    - **Implication:** Will users be satisfied with further reductions in Eastern Basin productivity caused by nutrient loading reductions to the Western and Central Basins as we strive to control HABs and reduce areas of anoxia?
- **Finding:** Small plot, simulated rainfall runoff data from 5 experimental sites across Ohio showed that soil test Phosphorus (STP), alone, was a poor predictor of P runoff at low to moderate STP levels and across a wide range of soil types and tillage/management systems. However, STP was predictive of runoff P at 1 experimental site where large quantities of manure, applied 3 years prior, had driven STP to extremely high levels and where there was a common soil type and management system.
    - **Implication:** The large variability in runoff P at low to moderate STP levels illustrates that runoff P is affected, not just by STP but by soil conditions and management strategies as well.
    - **Implication:** Large additions of fertilizer or manure may change the soil mechanisms controlling P mobility by overwhelming a soil's ability to moderate P solubility resulting in a dominant P mineral phase, from the amendment (fertilizer/manure), controlling P solubility. This is an important finding because it

suggests that management of soils with a low to moderate STP may need to be considered differently than soils with high STP. It may be misleading to lump them together and attempt to predict runoff P at low to moderate STP levels using models developed where sites with very high STP are included, because the mechanisms controlling P solubility (transport risk) are different.

  - **Implication:** P runoff problems get worse when fertilizer application rates exceed Ohio State University recommendations for maximum crop yield. Following these recommendations should reduce P runoff risk and save money for the farmer, without reducing crop production. However, it is likely that soil conditions and nutrient management strategies such as timing and method of nutrient application, are more important than rate of application in determining nutrient runoff.

- **Finding:** Small plot, simulated rainfall runoff data was used to evaluate P transport risk at "first flush" where a large rainfall event occurred immediately following fertilizer/manure application. The mitigating effects of fertilizer/manure application method (surface applied or incorporated) was evaluated. Both dissolved P concentrations and loads in runoff water were significantly reduced where fertilizer/manure was incorporated into the soil rather than simply surface-applied prior to rainfall.
  - **Implication:** P surface runoff from agricultural fields could be significantly reduced by incorporating fertilizer/manure into the soil. The challenge is to balance this desired result while not increasing the potential for soil erosion that could occur. Even no-till systems allow for fertilizer/manure incorporation and this practice should be encouraged.

- **Finding:** At the same P application level, the commercial fertilizer (DAP) resulted in significantly more P runoff on both a concentration and load basis than the poultry litter, with or without incorporation.
  - **Implication:** While the use of manure is often vilified, the solubility of manure P is often lower than the solubility of P in commercial fertilizers, such as DAP. However, unlike manures, when commercial fertilizer dissolves in rainwater it is not dramatically visible as it is transported off the edge of the field
- **Finding:** Eleven major laboratories providing agricultural soil testing to Ohio were evaluated. In an inter-laboratory comparison, the Mehlich-III soil phosphorus analysis method gave more precise results than the Bray-Kurtz P-1 method. Of the 9 laboratories who conducted a Bray-Kurtz P-1 analysis, only 3 had >80% of the samples fall within 1 standard deviation of the sample mean. Of the 10 laboratories who conducted a Mehlich-III analysis, 8 of them had >80% of the samples fall within one standard deviation of the sample mean, and two laboratories had 100% of the samples fall within one standard deviation of the sample mean. This comparison is most clearly seen with three laboratories that used both Bray-Kurtz P-1 and Mehlich-III extractants. Two of the laboratories also used both extractants, but were among the labs who had >80% fall within one standard deviation for Bray-Kurtz P-1. However, even with these

laboratories the percentage was still slightly higher for the Mehlich-III extractant. OSU was the only lab that showed no difference between the two extractants**.**

  - **Implication:** With one exception, the laboratories evaluated performed fairly well.

- **Finding:** In general, the evaluated labs that provided recommendations, recommended higher P_2O_5 application rates than those recommended by OSU extension for similar test values. All of the laboratories, except one, recommended additions where OSU extension did not at the levels determined. Many of the labs do not provide recommendations.
  - **Implication:** Some soil test laboratories are recommending the application of more P than required. Correcting this could save money and improve water quality.
- **Finding:** Over a million soil samples from fifty Ohio counties collected over a decade were evaluated. Eleven counties showed decreasing STP levels over the last decade (Columbiana, Crawford, Darke, Defiance, Fulton, Henry, Medina, Miami, Paulding, Ross, and Van Wert). No county showed increasing soil test phosphorus levels.
- **Finding:** There is no agronomic benefit to applying P fertilizer when STP levels reach 60 mg/kg Mehlich 3 P. Considering this benchmark, the occurrence of soil samples exceeding 60 mg/kg Mehlich 3 P was < 20% for 19 counties, 20 to 40% for 28 counties, and > 40% in 4 counties. Across the fifty counties, STP levels that are >60 mg/kg occur 30% of the time.
  - **Implication:** While a significant number (30%) of soil samples evaluated in this study tested > 60mg/kg, there is no way to know from this data what percentage of cropland this represents. However, with over one million random samples analyzed it does not seem an unreasonable assumption that this is representative of the cropland acres from which the samples were pulled and the acres which are regularly soil sampled. One cannot conclude that this represents the total cropland situation, because of the gap in knowing what percent of the acres are routinely sampled.
  - **Implication:** The trend numbers in the counties with decreasing soil test values, and the percentage of tests for which soil tests at or below recommended levels is better than would have been predicted by some scientists and by the popular press. The good news in this is that high soil tests may not be as large a contributing factor as some have initially thought, but the bad news is this may mean that yet other unexplained and complicating factors are bigger contributors to the problem.
  - **Implication:** The enormous amount of cropland in the Western Basin Watershed means that even small losses from each field add up to large numbers at the mouths of the major tributaries. Full-scale implementation to solve the problem will require large numbers of varied and site specific BMP’s applied to a large number of fields in the watershed, in order to fully achieve the needed reductions.

Research Needs Related to:
Agriculture Management Practices, Nutrient Loading Reduction Strategies,
Land to Lake Limnology, and HAB Reduction Strategies

Preface/Rationale

Things We Know with respect to when nutrient loading occurs are that the vast majority of nutrient loading occurs during storm events.

Things We Do Not know include the impact of these slugs of nutrient rich water that enter the Lake during storm events on algal densities at various location and times throughout an annual cycle.

Things We Know that individually contribute to increased DRP runoff include many factors: surface fertilizer applications, broadcast applications, winter applications, frozen ground applications, excessive P soil tests, P stratification at the surface, excessive soil erosion, and increased connectivity of the drainage network to the lake.

Things We Do Not know include the collective interaction of the above factors in the watershed at the farm field scale, and the relative percentage importance of each individual factor as a part of the total problem. We know reducing the above factors will reduce the problem, but we do not know the most effective and efficient combinations to achieve the maximum benefits.

Things We Know with respect to Best Management Practices are that numerous BMP's can impact nutrient export. Obviously BMP's include Nutrient Management, Crop Rotations, Cover Crops, Conservation Tillage, Filter and Buffer Strips, Controlled Drainage, Wetland Restoration. Much is known about these practices from plot scale research, especially for total phosphorous and sediment.

Things We Do Not Know are in many cases the relative efficiencies of each of these for dissolved phosphorous on each of the above individual contribution factors, and the cumulative effects of different combinations applied at the farm field scale in the a practical way farmers can utilize these practices. Again we know from basic plot research, in most cased all of these things help, but which are the most effective combinations that fit the various different conditions within the watershed, and which combinations can be made to work by farmers in the real world production agriculture environment.

Much work has been done across the country, but the Western Basin problems originates in a large area of low land slopes, poorly drained soils, and intensive drainage, unlike anyplace else. These unique conditions will require some localized research to adapt what we already know to solve the problem.

A very large amount of the required research needs to be done beyond the plot scale to edge of field studies. These edge of field studies need to include edge of field instrumented sites, in which continuous year around runoff collection from small field areas is coupled with various production systems and BMP's applied to the contributing areas. The edge of field studies need to be integrated with designed crop production systems on the contributing areas, including a complete record keeping of cultural practices by participating farmers managing the drainage area. Research needs to be done over a variety of soil types and landscape slopes, and for a variety of different crops, tillage and crop rotations. Two examples of this concept are the instrumented small watersheds at the North Application Hydrologic Experimental Watershed at Coshocton, and the Wisconsin Discovery Farms project.

In Ohio, the risk of agricultural P transport into surface water is assessed by either the Ohio USDA-NRCS Phosphorus Risk Index (P Risk Index) Assessment Procedure, or the Soil Test Risk Assessment Procedure (STRAP), within the Nitrogen and Phosphorus Risk Assessment Procedures. A description of these assessment tools can be found at: http://efotg.nrcs.usda.gov/references/public/OH/Nitrogen_and_Phosphorous_Risk_Assessment_Procedures.pdf.

Despite all the good work we have done the past three years, and all that we know and have learned new, we are still seeking better answers to one of the questions we started with three years ago: ***At the farm field scale, what has changed since 1995 that has caused the very significant turnaround in the trend lines for DRP export to the lake?***

The following research, done as outlined above, will help answer that:

Specific Recommendations

Within the above framework, specific research recommendations are:

1. Research or data collection is needed on the extent and types of winter nutrient application practiced in the watershed. We know winter application occurs. There is no credible data to quantify when, where, how much, and under what conditions. All of this information is needed to both design effective

BMP implementation programs, and to populate watershed models to test various BMP scenarios.

2. Edge of field monitoring and edge of field runoff studies are needed to collect the information necessary to update and improve the Ohio Phosphorous Index.

3. Research is needed on the impacts to DRP runoff of fertilizer timing and placement under various crop production systems and under various application techniques.

4. Research is needed on the impacts of growing cover crops on DRP delivery over the entire water year and the entire multi-year cropping system. (Note: Cover crops are used and defined in the sense of green growing crops planted between the harvested crop and the planting of the next crop, not dead crop residue remaining from the last harvest.)

5. Research is needed on the synergistic effect of multiple BMP's combined into systems, as opposed the impact of individual BMPs applied alone. For example, compared to a traditional CSB rotation where P might be surface applied each year, what is the cumulative multi-year effect on DRP delivery of an example system that would include a five year C-SB-C-SB-W rotation, in which multi-year P would be fall applied by injecting in a strip till system before corn, and no P would be applied the other 3 years to the soybeans or wheat. What would happen to that same system if cover crops were added two of the five years? What happens when either controlled drainage or controlled traffic, or both, are added to that same system? What happens when precision nutrient management using GPS referenced soil sampling and GPS fertilizer application is added?

6. Research is needed on the impacts of tile and surface drainage on DRP runoff, and more importantly the Drainage Water Management techniques that are beneficial BMP practices to add to the conservation tool box to reduce DRP runoff.

7. Additional data collection is needed to properly interpret the research and transfer it to the many watershed prediction models that are being developed. Currently there are two substantial continuous monitoring and sampling stations in the Maumee – Waterville Main stem and the Blanchard Watershed. An additional 2, 3 or 4 tributary monitoring stations on various 8-digit HUC's would allow better interpretation of storm event transport, and well as identify areas or regions with greater or lesser loading rates. The additional data would allow better calibration of the prediction models and provide a more

precise and accurate record of export trends in the watershed(s) as implementation programs ramp up.

8. Social and economic research is needed into the fertilizer marketing, sales and delivery systems. Despite the best intentioned BMP's, or the best of intentions for producers or fertilizer dealers to adopt them, what structural and industry factors such as transportation, financing, storage, economics, and others, drive the decisions and practices of farmers? What industrial and institutional factors will need to be included as part of the solution.

9. The Ohio P Risk Index needs to validated and as necessary revised, using field-scale, edge-of-field runoff and drainage water monitoring data as related to in-field soil and management data, to ensure that P Risk Index scores accurately reflect the risk of P transport.

10. Many Best Management Practices (BMPs) affect P transport, however, only a few are included in the Ohio P Risk Index. Additional BMPs need to be quantitatively evaluated for inclusion into the P Risk Index. The ability to quantify reductions in P loss due to BMP addition will allow for prioritizing time and resources (bang for the buck) when choosing BMPs. Reduced P Risk Index scores due to BMP adoption will be a strong incentive for BMP adoption.

11. Once the Ohio P Risk Index has been validated/revised, it will only be effective if it is widely adopted and routinely utilized to reduce non-point source P transport. An extensive outreach/education program highlighting improved Ohio P management tools will be important to success.

12. In the flat watershed landscapes major event storm runoff can often bypass filter and buffer strips and enter the streams directly as concentrated flow. Filter effectiveness as a Dissolved Reactive Phosphorous BMP could be improved by identifying areas where concentrated flow enters streams, and grassing large blocks surrounding these points. This is time consuming and requires field surveys by technical staffs, and is difficulty to sell to producers. With the advent of digital soils and availability now of LIDAR Geospatial Contour data, the potential exists to automate this process and computer generate maps which could be used as sales tools with producers. Research is needed to develop a computer simulation buffer location tool which could be used by field technicians to identify filter areas for concentrated flow, and as a visual sales tool with producers.

13. How should management strategies change or adapt to accommodate projected climate change impacts on Lake Erie, most notably and increased frequency of severe storms and higher temperatures?

14. Improved quantification of the temporal and spatial linkages between the large volumes of nutrient-enriched storm runoff water from the Maumee Watershed and the Sandusky Watershed and the subsequent development of HABs in the Western Basin and the Sandusky Sub-basin of Lake Erie is needed for the calibration and confirmation of linked hydrodynamic/ecosystem models for this region.

15. Quantification of nutrient release during wind-driven re-suspension of bottom sediments in the Western Basin of Lake Erie is needed to assess its role as a nutrient source for HABs relative to the role of dissolved nutrients delivered during storm runoff events.

16. Quantification of nutrient releases from sediments from the hypolimnion of the Central Basin, determination of the spatial extent and during of areas of anoxia in the Western Basin, and quantification of P releases from these small Western Basin areas of anoxia and hypoxia.

17. In general, plot and field level research is needed to evaluate the effectiveness of various BMPs for reducing dissolved phosphorus runoff for the soil types and drainage systems of northwestern Ohio.

18. There is a need to monitor the environmental conditions through the course of blue-green algal blooms in the Maumee Bay – western basin region. This includes monitoring from Waterville out past the island area and into the Central Basin from approximately a month before the typical start of these late summer blooms to after the bloom die-off. We also need to document the dispersal of the blooms as they enter the Central Basin and determine the cause for their breakup. The monitoring should include all forms of phosphorus (SRP, TSP, particulate P) and nitrogen (NO3, NH4, TKN), total and volatile suspended solids, dissolved organic carbon, PAR light profiles, and periodic phytoplankton biomass and species identification and primary production measurement. This should be done for multiple years if possible. The purpose of this time and space monitoring is to gain a better quantitative understanding of the quantitative relationships between light, temperature, and nutrient conditions and the timing and magnitude of these blooms.

APPENDIX: Discussion Topics for Phosphorus Task Force

The Millennium Synthesis Team felt there was value in additional discussion on the following possible findings and implications. We hope that the Phosphorus Task Force will be able to do this.

- **Finding:** In laboratory studies, soils samples of known phosphorus soil test levels (5-150 ppm Mehlich 3P) were suspended in distilled water (0.5 grams soil per 500 ml of water) and shaken for 17 hours. These soil suspensions were then analyzed as though they were storm runoff samples from area rivers. There was approximately a 1:1 ratio between the dissolved reactive phosphorus content in the soil suspensions and Mehlich3 P soil test values (R^2 = 0.94). There was a very low correlation between the particulate phosphorus concentrations in the soil suspensions and the Mehlich 3 P soil test values (R^2 = 0.14).
    - **Implication:** This method represents yet another type of environmental soil test, similar to the standard Water Extractable Procedure (WEP). While multiple factors influence field scale runoff concentrations of dissolved reactive phosphorus, these results suggest that as soil test levels increase in the range of 5 to 150 ppm (Mehlich 3P), runoff concentrations of dissolved reactive phosphorus would be expected to increase, if other factors were held constant.
    - **Implication:** The lack of correlation between P soil test levels and particulate P concentrations of soils, as measured by standard water analysis methods (acid persulfate digestion) suggests that the use of soil test values in phosphorus indices for predicting particulate phosphorus export needs careful examination, especially since particulate P is the major form of P exported from most cropland. Soil test values are, however, useful for predicting dissolved phosphorus runoff, where these are estimated separately in phosphorus indices.
- **Finding:** Small plot, simulated rainfall runoff data from 5 experimental areas across Ohio failed to show a relationship between STP and runoff dissolved P, where STP values fell in the low to moderate range. This lack of correlation illustrates that runoff P is affected by multiple management factors, only some of which could be controlled or assessed in this type of research. STP concentration was not a "controlled variable" in these studies so that, for several areas, the data set contained a small number of samples with a very narrow and low range of soil test values. However, STP was predictive of runoff P at 1 experimental site where large quantities of manure, applied 3 years prior, had driven STP to extremely high levels, where there was a common soil type and management system, and where the data set contained a large number (34) of plots with a wide range of STP values.
    - **Implication:** The large variability in runoff P at low to moderate STP levels illustrates that runoff P is affected by soil conditions and other management factors, in addition of STP. Since the vast majority of runoff dissolved P in Ohio comes from fields with STP in the low to moderate category, appropriate research programs must be established to quantify the relationships between STP values in the low to moderate range and runoff dissolved P. Since the mechanisms controlling P solubility differ in low and moderate STP conditions from those in high STP conditions, such research needs to separately assess the relationships between STP values and runoff dissolved P in the high and low ranges of STP.
    - **Implication:** Following fertilizer application <u>rates</u>, as recommended by the Ohio State University according to the Tri-State Fertility guidelines, is but a first step in reducing cropland runoff of dissolved P. Such rates are designed to bring and/or

retain soil test levels within the maintenance range for crops grown in this region and hence, allow for maximum yields. In addition to fertilizer application rates, attention must be directed to fertilizer placement and timing of application, as well as other management practices that increase infiltration and reduce erosion.