Summary of Findings and Strategies to Move Toward a 40% Phosphorus Reduction

A White Paper[1]

By

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Introduction and Goal

A 40% Reduction in Phosphorus Loading. In March 2013, the Ohio Phosphorus Task Force recommended a 40% reduction in phosphorus (P) loading from the Maumee River and Western Basin tributaries to Lake Erie to address Harmful Algal Blooms (HABs) in the Western Basin. In October 2013, the International Joint Commission (IJC) endorsed the recommendations and expanded them with additional load reduction recommendations to address hypoxia in the Central Basin.

In May 2015, the Objectives and Targets Task Team (the Task Team) of Annex 4 of the Great Lakes Water Quality Agreement (GLWQA) issued their final report calling for a 40% reduction from 2008 loads in spring (1 March -31 July) total phosphorus (TP) and dissolved reactive phosphorus (DRP) loading to the Western Basin to address HABs and a 40% reduction in Western and Central Basin water year (Oct-Sep) loading to address hypoxia (GLWQA Annex 4, 2015). The TP spring loading goal from the Annex 4 Report for the Maumee River is 860 metric tons or less, and the DRP loading goal is 186 metric tons or less. Those amounts represent a 40% reduction from the 2008 loads. The Task Team selected 2008 as the base year because, among other things, it was a relatively wet year, and the spring discharge from the Maumee River in 2008 was only exceeded twice in the last 20 years. If we can achieve the target loads during wet years, TP and DRP loads will be less than the targets during drier years; i.e., the long-term average load will need to be less than the targets under current climatic conditions. These reductions are designed to reduce the severity of HABs, resulting in HABs like the small blooms observed in 2004 and 2012 or smaller, 9 years out of 10, or 90% of the time. The reductions are also designed to raise the average dissolved oxygen concentration in the hypolimnion (cold bottom layer) of the Central Basin to above 2.0 mg/l (the definition of hypoxic conditions). The US and Canadian Governments approved the recommendations in February 2016. In recommending the targets, the

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[1] This document will be updated periodically as new information and research results become available.

Task Team requested approval to use an Adaptive Management Approach, and the US and Canadian Governments approved that approach.

On 13 June 2015, the Governors of Ohio and Michigan and the Premier of Ontario signed a Collaborative Agreement to reach the 40% reduction target by 2025 and set an aspirational target of a 20% reduction by 2020. Ohio, Indiana, Michigan, Pennsylvania, New York, Ontario, the US, and Canada are all currently working on domestic action plans designed to achieve the 40% phosphorus loading reduction.

Reducing nutrient loading to Lake Erie is a very complex issue. We hope with this white paper to clearly and briefly summarize current scientific understanding. We are involved with, and aware of, a great deal of current and planned research, which will certainly influence our future thoughts and actions. Therefore, we intend to periodically update and revise this white paper as new information becomes available, new ideas and strategies are developed, and new incentives and policies are considered.

It is our hope that this white paper will aid elected officials, managers, and decision makers in the development of domestic action plans to move toward the 40% phosphorus reduction target, and in so doing, enhance agricultural productivity. It is also our desire that this document be useful to individual farmers, municipalities, businesses, and the general public as we all work together to achieve the 40% reduction.

Findings

Background and History

- Excessive nutrient loading resulting in large blooms of blue-green algae, or cyanobacteria, and dead zones (areas of hypoxia/anoxia or no dissolved oxygen) are not new to Lake Erie. These issues were common in the 1960s and 70s.
- The cyanobacteria we are observing in Lake Erie HABs are native to the lake. They prefer warm water (above 60°F) and high levels of nutrients, and Lake Erie is the southernmost, shallowest, warmest, and most nutrient enriched of the Great Lakes. Furthermore, the Western Basin of Lake Erie is the shallowest, warmest, and most nutrient enriched area of the lake, and therefore, the area where blooms of cyanobacteria are most likely to occur.
- The floating algae, or phytoplankton, in Lake Erie are the base of the food chain, and the phytoplankton community in the lake is normally very diverse. However, when a HAB occurs, diversity is greatly reduced, and the cyanobacteria are of very little value to the food chain as almost nothing will eat them.
- Following the burning of the Cuyahoga River in 1969, several federal agencies were created, laws were passed, and we celebrated the first “Earth Day.” Namely, the USEPA and NOAA were formed in 1970, the predecessor of Environment and Climate Change Canada was formed in 1971, the Great Lakes Water Quality Agreement (GLWQA) between the US and Canada was signed in

April 1972, and the Clean Water Act (CWA) passed in October 1972. The GLWQA allowed US and Canadian scientists to reach agreement that excessive phosphorus loading was driving the blooms and dead zones, and to set targets for phosphorus loads to the Lake—11,000 metric tons annually (approximately a 60% reduction). The GLWQA also allowed agreement on phosphorus concentration targets for sewage treatment plant discharges. The CWA provided the authority to regulate sewage treatment plants and require them to reach target discharge concentrations. In Ohio, sewage treatment plants outside of the Lake Erie watershed were not required to reach the target discharge concentrations.

- The 11,000-metric ton annual target was reached in the mid-1980s and the lake responded by becoming the Walleye Capital of the World, and coastal economic development and tourism grew rapidly. Today, tourism in the 8 Ohio counties that border Lake Erie supports almost 124,000 jobs and has an annual economic value in excess of $14 billion (Tourism Economics, 2016).
- The original phosphorus target (11,000 metric tons) from the GLWQA was for TP. TP is composed of both particulate phosphorus (PP), phosphorus attached to soil particles, and dissolved phosphorus, most of which is DRP, phosphorus dissolved in the water. PP is approximately 25% bioavailable (usable by plants and algae) and DRP is ~100% bioavailable.
- The annual load of TP to Lake Erie is still close to the 11,000-metric ton target, but the amount of DRP in that load has increased by 132% (Bullerjahn, 2016). This is the primary driver for the HABs we are seeing today (GLWQA Annex 4, 2015).
- Elevated numbers of cyanobacteria in the Western Basin began to reappear in the late 1990s and have grown rapidly since 2002 with the worst blooms occurring in 2011 and 2015.
- The US and Canada renegotiated the GLWQA in 2012 and established 10 Annexes focused on 10 important issues. Annex 4 focuses on nutrients and the three problems excessive phosphorus loading is causing in Lake Erie: HABs in the Western Basin, Central Basin hypoxia (dead zones), and an excessive growth of nuisance algae in the Eastern Basin of the lake. Other findings from the 2016 Annex 4 report include:
    - Because the retention time for water in the Western Basin is only 20-50 days, when P loading to the basin is reduced, the lake responds immediately, as evidenced by the huge reduction in bloom size between 2011 and 2012 and between 2015 and 2016, where 2011 and 2015 were very wet springs with large P loads, and 2012 and 2016 were very dry springs with very small P loads.
    - To reduce the intensity of HABs, strategies should focus on bioavailable P (DRP plus 25% of particulate P).
    - Reducing N loading is also important, as it sometimes limits HAB growth, and it is an important component in algal toxins (14% by weight).

Nutrient Sources Today

- The Maumee and Sandusky Rivers are the largest tributary loaders of P to Lake Erie and the Great Lakes, and 87% of this P is coming from nonpoint sources, of which agriculture is the dominant land use (>70% of the watershed; OEPA Mass Balance Study, 2016). Mean TP concentrations in these rivers (0.42 mg/l) are about 30 times greater than in the Detroit River (0.014 mg/l), and the Detroit River concentration is not high enough to cause a HAB. The Maumee River contributed over 3,800 tons of TP to Lake Erie in 2008 and is the major driver of HABs in the Western Basin, and the Sandusky River contributed over 1,100 tons of TP in 2008 and is a contributor to HABs in Sandusky Bay (GLWQA Annex 4, 2015). While the Detroit is not a major driver for Western Basin HABs, the Task Team identified it as one of their 14 priority tributaries, and its ~2,500-ton load is a contributor to Central Basin hypoxia.
- Between 2002 and 2013, 70-90% of the P and N loads discharged from the Maumee River occurred during the highest 20% of the flows from the river. This means most of the loading occurred during only ~10 storm events per year (Baker et al., 2014).
- Point sources of P from sewage treatment plants underwent major improvement in the 1970s and 1980s (over 75% reduction in P), and now contribute less than 9% of the P (OEPA Mass Balance Study, 2016).
- Combined sewer overflows (CSOs) have been greatly improved since the mid-1990s and more improvements are underway. Almost all CSO communities in the Lake Erie drainage basin have Long Term Control Plans to address CSOs. These plans require structural and treatment controls and must be implemented by permit requirements or court orders. By 2020, 40 of the 62 communities in the Lake Erie basin will have completed all the projects required by their Long-Term Control Plans (Ohio Lake Erie Phosphorus Task Force II Final Report, 2013). In 2013, CSOs in the Maumee River contributed less than 1% of the load (OEPA Mass Balance Study, 2016).
- In the Maumee River, home sewage treatment systems contribute 4% of the total P load annually (OEPA Mass Balance Study, 2016). Recent state regulations will continue to reduce this number.
- As of 2013, Scott’s Miracle-Gro removed P from its lawn care products, and the Ohio Phosphorus Task Force estimates that 95% of the lawn care fertilizer market followed Scott’s lead.
- Recent research indicates that internal loading of phosphorus from lake sediments is approximately 3-7% of the total load (Matisoff et al, in press).

Understanding Agricultural Nutrient Loss

- From the 1970s to the mid-1990s, phosphorus was applied at 10-40 pounds P_2O_5 above crop removal rates, resulting in an accumulation of phosphorus in the soils of the region (Mullen, 2013; Powers et al, 2016). Since the mid-1990s, reports of current application rates show rates applied near crop removal rates.

  - Mullen (2013) reports that phosphorus is being applied 5 pounds of P_2O_5 below crop removal rates.
  - NRCS (2016) found that average phosphorus application rates were 5.5 pounds of P_2O_5 above removal rates, and 58% of the fields had phosphorus applied at or below crop removal rates.
  - NRCS (2016) found that 42% of the acres accounted for 78% of the total phosphorus runoff and 80% of the sediment loss.
- When Soil Test Phosphorus (STP) does not exceed 50 ppm Bray P1, event median DRP concentrations in drain tiles generally meet Annex 4 guidelines (0.05 mg/l, the target flow-weighted mean concentration for DRP for the Maumee River). As STP levels increase above 50 ppm, DRP concentrations in tiles increase.
- Eighty percent of the soil test samples in the Maumee watershed have STP levels <50 ppm Bray P1, approximately 15% of the samples have STP levels between 50 and 100 ppm, and 5% of the samples have STP levels above 100 ppm (Herman, 2011; IPNI, 2017).
- Tri-state fertilizer guidelines used in Ohio recommend no additional phosphorus when STP levels are 50 ppm Bray P1 and above.
- Fields with STP levels above 100 ppm are typically the result of past manure application practices prior to concerns about P, such as utilizing nitrogen criteria to set P application rates. Current guidelines for manure applications do not recommend applications of any P source on fields with STP levels that exceed 150 ppm (NRCS, 590 Standard). Between 40 and 150 ppm, the 590 standards allow a P application rate equal to crop removal for 1 or more years with rates limited by the P index or 250 lbs of P_2O_5,whichever is less. Fields with STP levels above 100 ppm are often termed “Legacy P Fields”.
- Fields contribute P disproportionately with Legacy Fields generally contributing more. While STP measurements are a good initial screening tool to determine risk of P loss, reductions from Legacy Fields alone may not be enough to reach the 40% target.
- Vertical P stratification is a recognized occurrence even under a rotation no-tillage management system where soils are chiseled or disked following soybeans in part as a way to incorporate broadcast fertilizer. Highly stratified soils are found most commonly under conditions of no-tillage and surface placement (broadcast application) of organic and inorganic fertilizer. Soil cracks can connect drainage tiles to the surface, allowing preferential flow to tile systems from the elevated P in the surface zone and possibly increase DRP losses through tile (Baker et al, 2017).

Identifying Effective Best Management Practices (BMPs)

- Using appropriate BMPs is important for all farms, but it is critically important in Northwest Ohio due to the amount of intensive agriculture in each of the watersheds in that portion of the state. Northwest Ohio holds some of the most productive farmland in Ohio.

- Agricultural producers should be following the 4R's of Nutrient Stewardship (right time, place, rate, source) and two of the more important points would be to adopt subsurface placement of organic and inorganic fertilizer and use soil-test-informed application rates.
    - Soil test informed application rates: Soil testing should be done with sufficient frequency and density to accurately inform rates (e.g., once in the crop rotation, at a minimum following the 590 standards).
    - Subsurface placement: Placement of organic and inorganic fertilizer beneath the surface can reduce both DRP and TP (King et al. 2015; Williams et al. 2016). Watershed modeling analyses found that subsurface placement on all row crop acres across the Maumee watershed could result in reductions of DRP of 46% (annual) and 42% (spring), and reductions of TP of 29% (annual) and 27% (spring) (Gildow et al. 2016).
- Other BMPs that may be necessary in addition to precision in nutrient management include the following:
    - Blind inlets: Direct connections between the soil surface and tile drains, such as tile risers, increase P runoff. Eliminating these connections by converting tile risers to blind inlets can reduce P loss by 60% (Smith and Livingston, 2013).
    - Water management: Holding water on the landscape (through water control structures and maintaining/increasing organic matter in soils) can reduce DRP and TP loss.
        - Drainage water management can reduce DRP and TP from tiles by greater than 50% (Ross et al., 2016).
        - For every 1% increase in organic matter, the soil is capable of holding an additional 0.75 inches of water (Hudson, 1994).
    - Cover crops: Published research that includes DRP losses, has found that cover crops tend to reduce N and particulate P loss, but not DRP. Yet these studies were primarily in more northern climates with substantial spring thaws. In this region, recent edge of field studies have shown cover crops to be very effective at reducing N losses with no benefit to P in the short term, but more research is needed as there may be long term benefits through increased soil organic content and water holding capacity (Kevin King, unpublished).

Understanding Farmer Decisions

- To identify feasible policy solutions that will improve water quality *and* likely be adopted by the agricultural community, it is necessary to combine insights from the effectiveness of BMPs at field and watershed scales, with behavioral analyses of the likelihood of practices being adopted.
- For example, recent survey data in the Maumee River watershed indicates ~1/3 of farmers (equivalent to about 1/3 of the acres in the basin) are engaged in best practices or are willing to do so, ~1/3 are hesitant but considering best practices,

and ~1/3 are unlikely to change their practices in the short-term (specific numbers depend on the practice) (Wilson et al. 2014).
  - Those least willing to take additional action to reduce nutrient loss tend to:
    - be closer to retirement, and/or
    - farm more rented acreage.
- While watershed modeling indicates that cover crops and subsurface placement (along with filter strips) show great promise at achieving the 40% reduction at specified adoption levels (Scavia et al, 2017), not all are equally promising from a behavioral standpoint. The most promising practices *behaviorally* may be determining application rates based on STP, followed by subsurface placement, and then cover crops (Prokup et al. 2017).
  - As of 2015, 27% of farmers in the WLEB were reporting use of cover crops (including winter wheat). As of 2016, intended adoption decreased to 20%, while another 38% reported a willingness to do so in the future. This indicates that ~58% of the target farming population appears willing to use cover crops, but unlikely to do so without incentives to off-set the short-term cost/risk given the uncertainty around effectiveness.
  - As of 2015, 25% of farmers in the WLEB were reporting subsurface application (banding, in furrow), while 21% reported broadcast without incorporation, and 54% broadcast with incorporation. As of 2016, a total of 36% reported an intention to use subsurface placement, while another 29% reported a willingness to do so in the future. This indicates that ~65% of the target farming population appears willing to use subsurface placement, and may be persuaded with better information about the relative costs-benefits (increased application cost vs. decreased application rates).
  - As of 2016, 60% of farmers in the WLEB were reporting an intention to determine application rates based on soil test results. Another 30% indicated a willingness to do so in the future. This indicates that ~90% of the target farming population is willing to use soil tests at sufficient frequency to inform nutrient application and likely to do so with little additional persuasion.
- Overall, the majority of farmers in the WLEB are concerned and knowledgeable about nutrient loss and water quality concerns, but are not convinced the proposed BMPs are effective (either feasible to implement or likely to reduce nutrient loss and improve water quality) (Zhang et al. 2016; Wilson In Review).
  - Voluntary adoption of recommended practices will not occur unless outreach focuses specifically on building farmer’s confidence in their ability to implement a set of cost-effective solutions. Outreach efforts, such as the Blanchard River Demonstration Farms, will aid demonstrating efficacy of practices.

Possible Strategies to Move Toward a 40% P Reduction

This section focuses on potential strategies for the agricultural community. Current and past actions by point sources and others are discussed in the “Nutrient Sources Today” section of this white paper. Our goal in this section is to identify a set of strategies that current research shows will produce load reductions through changes in agricultural land management. These strategies are directionally correct, meaning that there is a likelihood of nutrient load reduction success. That said, any set of strategies should continue to be monitored and assessed for their water quality and agricultural production consequences since the relative effectiveness may vary by field and farm. Current research results provide information to guide management strategies, however we acknowledge that adaptive management and site-specific recommendations are critically important. We hope this document provides a foundation for managers and decision makers to consider what set of practices to pursue. It is also our hope that this document will help to focus efforts and discussions by providing a science-based foundation, and help us to speak with one voice as we work to reach the 40% reduction target.

- Advancing toward a 40% reduction will likely require a combination of changes in practice, appropriately placed in the landscape, addressing identified resource concerns, and promoted through multiple policy mechanisms. There are three common mechanisms that can be used to promote adoption of specific management practices. These include:
    - Outreach and education to encourage voluntary adoption of recommendations. This may be most appropriate for those practices perceived as potentially cost-effective by the agricultural community (e.g., subsurface placement).
    - Incentives to encourage voluntary adoption of recommendations that are costly in the short-term. This may be most appropriate for practices involving more farm production risk and uncertainty, or where the science on DRP reduction effectiveness is less certain (e.g., cover crops).
    - Regulations to mandate action. This may be more appropriate for common sense recommendations that clearly reduce P loss, are possible for farmers to implement (economically and logistically feasible), provide on-farm benefits (such as improving soil health and erosion control), and maintain/enhance production. This might include practices for which future intended use is high, such as soil-test-informed application rates, assuming the challenges farmers face with manure application can be managed (see research needs).
    - We expect that a combination of these mechanisms may be necessary. There is evidence that well-designed outreach and incentive programs could result in increased voluntary adoption of BMPs due to the high level of motivation to act among farmers in the WLEB (Prokup et al. 2017). An increase in voluntary actions means there will be less of a need for regulations. Additional modelling work underway will help us understand

    what we can achieve with voluntary adoption by focusing solely on those who are most motivated to change their practices.

- As highlighted earlier, there are many recommendations that may be appropriate depending on specific field characteristics and current management strategies. However, speakers at the SERA-17 Conference in Toledo in August 2017 agreed that the four most important sets of actions to reduce nutrient loading were:
    1. Soil-test-informed application rates (i.e., following tri-state guidelines and only applying the P that is needed),
    2. inserting fertilizer when applied (e.g., banding, in-furrow with seed),
    3. working to control erosion (e.g., filter strips, grass waterways, blind inlets), and
    4. working to manage and minimize the amount of water leaving a field (e.g., drainage water management).
- These sets of actions are consistent with the science reported earlier in this white paper, and represent a comprehensive strategy to continue the early successes at controlling particulate P loss, while improving the retention of DRP. Specifically:
    - Current adoption of soil-test-informed application rates may be as high as ~82% in the WLEB, and is generally low-cost, or no-cost, to farmers and provides concrete on-farm benefits. Generally, no application of fertilizer is needed when STP levels are above 40 ppm Bray P1 or 58 ppm Mehlich III-ICP due to a lack of economic return (corn-soybean rotation), and other BMPs related to fertilizer placement and managing erosion can help to retain P on fields regardless of STP and application rates.
    - As a means of retaining nutrients on the field, edge-of-field research and watershed models indicate that subsurface placement can reduce DRP loss significantly at the field level (King et al. 2015; Williams et al. 2016) and over 40% at the watershed level assuming 100% adoption (Gildow et al. 2016). Current adoption levels of subsurface placement are at 36% with another 29% reporting that they are likely to use the practice in the future. Adoption of subsurface placement is limited by the cost and accessibility of the equipment and the slower speed at which fertilizer is applied.
    - Direct connections between the soil surface and tile drains, such as tile risers, increase P runoff. Eliminating these connections by converting tile risers to blind inlets can reduce P loss by 60% at the field level (Smith and Livingston, 2013).
    - Implementing drainage water management or control structures (i.e. artificially raising the tile outlet elevation) can reduce the DRP and TP loads by greater than 50% at the field level (Ross et al., 2016). Behavioral data indicates that current adoption levels are at <20%, but another 15% of farmers are willing to consider the practice. Focusing adoption of water management on Legacy Fields may be the most effective use of this practice given the relatively low interest in this practice, and the expense.
    - Surface erosion can be reduced by maintaining 30% cover as crop residue/cover crop; adding filter strips, grassed waterways, water retention

    structures, wetlands and water diversion structures where appropriate; and installing two stage ditches and other stream bank stabilization practices to reduce loading. Behavioral data indicates that ~75% of the WLEB acres are in conservation tillage or no-till, and adoption of cover crops is at ~20%. However, another 38% of the WLEB farmers are considering cover crops as a management practice, but may require longer-term incentive-based programs to off-set the short-term cost given tight profit margins and uncertain future on-farm benefits that may take 5 to 10 years to realize.

- Conservation planning efforts should be prioritized to identify fields and management scenarios that result in a higher risk of elevated P losses where conservation practices can be applied in field situations i.e., focus on fields with the greatest P losses. Two indicators that should be prioritized include:
    - Measurements of STP at both the 0-8 inch and 0-2 inch soil depth as an initial screening tool to identify combinations of current management and soil characteristics that should be evaluated more closely. The P index to speed this evaluation needs further development.
    - Enhanced hydrologic connectivity that increases preferential flow to subsurface drainage tiles such as tile risers and soil cracks and crevices that result in surface water directed through tile systems.
- Legacy Fields, where no additional P is being added, but past management has led to high STP, are a minority in the watershed. However, they contain the highest STP and may best be served by edge of field practices aimed at capturing runoff and removing DRP. In addition to preventing development of new legacy fields by following tri-state guidelines, the recommendations for current legacy fields include:
    - No additional P application with continued crop removal via planting and harvesting. Consider using P-hungry crops such as wheat.
    - Adding iron slag or alum to tile drain bioreactors or ditches
    - Adding wetlands to catch water leaving the fields, with careful pre-measurements to ensure soils will not release DRP when inundated.
    - Building phosphorus filter beds to treat runoff
- As highlighted earlier, multiple watershed models can be used to evaluate the effectiveness of suites of management practices at reaching nutrient reduction targets, while behavioral models can assess the likely adoption levels as a result of different policy mechanisms. Results from ongoing watershed modeling efforts indicate that there are multiple pathways to reach the 40% P reduction target. Each of these pathways typically requires a total adoption level of 50 to 75% for any specific practice (indicating the need for a majority to act, but that the 40% target is possible without 100% adoption). However, each of these pathways will require accelerated adoption of conservation management practices to move toward the 40% reduction target by 2025 (Scavia et al, 2017), as current adoption rates of recommended practices range from 20 to 50% on average (Prokup et al. 2017). Survey data indicate that targeting those individuals who are currently willing to consider the practice or focusing on the larger farms may be sufficient to achieve necessary adoption levels.

  - For example, assuming 78% adoption of filter strips across the WLEB, Scavia et al. (2017) found that subsurface placement on 50% of the WLEB acres and cover crops on 58% can attain the targeted 40% reduction. Behavioral data indicate that these levels are possible by just targeting adoption among the farmers who are open to using these practices (i.e., the motivated and willing audience). The motivated individuals equal about half of the current non-adopters in the WLEB (Prokup et al. 2017). Specifically, in addition to the 36% already using subsurface placement, another 29% are considering the practice, for a total of 58% of WLEB farmers. For cover crops, 38% are considering the practice in addition to the 20% already using the practice, for a total of 58% of WLEB farmers.
  - As of spring of 2018, a panel study of farmers in the WLEB will allow us to directly assess the rate of adoption for these practices by comparing 2015 adoption levels to 2017 adoption levels among the same group of farmers. This analysis will inform the pace of progress towards meeting the 40% reduction target for individual recommendations (e.g., cover crops, subsurface placement, soil test informed application rates, etc).
  - Maximizing the rate of change may be possible by focusing on the larger farms, and accounting for the impact of rental acreage. Farms greater than 50 acres only represent 45% of the farms, but 97% of the total acres (93% of corn production acres and 95% of soybean acres in Ohio). While over half of the land that is planted is rented (NASS, 2012), raising the importance of conservation on rented not just owned land.

Information Gaps and Research Needs

This section is not meant to be a complete list of research and information needs. We are simply attempting to highlight some of the most obvious needs, and we have not attempted to list them in priority order. More and better information on each of the bulleted items will lead to better policies and better management decisions. More research is needed to give us a better understanding of:

- alternative strategies and policies to aid farmers who are dealing with manure application and distribution challenges;
- understand the combined influence of soil chemical and microbial activity on P dynamics;
- the impact of Drainage Water Management (DWM) on surface flow of water and P;
- identify practices that accomplish both N and P reductions;
- how soil health impacts water holding capacity, P loss, and water infiltration as well as how soil health is impacted by inversion tillage;
- how the combination of incentives and efficacy-building outreach impact BMP adoption rates by farmers;
- the magnitude of the effect of soil P stratification vs preferential flow on DRP loss through tile drainage;

- empirical measures of how effective subsurface application of P will be at reduced DRP loss, and how long this practice will take to be effective if applied in fields with existing P stratification;
- What combination of practices will effectively retain water at the watershed scale
- cost-benefit relationship for cover crops, water management, and other BMPs, e.g., cost-benefit analysis of fertilizer placement tool bar for farmers;
- all agricultural statistics on tools, practices, and actions on agricultural fields;
- the structural or practical barriers for farmers (e.g., the lack of enough subsurface application equipment to serve the potential need);
- how all the individual parts interact, i.e. where are specific recommended practices most effective and under what conditions;
- how the impact of various strategies, policies, and BMPs change as commodity prices vary, e.g., we need strategies that will work whether corn is priced at $2 or $7/bu.;
- the colloidal P and DRP fractions and whether colloidal P is part of the DRP fraction and if colloidal P loss is controlled better by erosional BMPs or nutrient management;
- develop data collection methods that track adoption rates of practices;
- N impacts on toxin production;
- time effective tools to evaluate nutrient loss and identify BMP landscape placement;
- the ability to develop projections of P losses or reductions based on practice adoption to inform an adaptive management approach towards meeting the 40% reduction goal.

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