# 1 INTRODUCTION

**Abstract**

*Agriculture is a growing end use for flue gas desulfurization (FGD) gypsum, a synthetic form of calcium sulfate. This project was developed to evaluate the use of gypsum in agriculture to improve soil and water quality, especially as related to phosphorus. The project has five specific objectives: (1) quantify at field-scale the degree to which FGD gypsum applied to agricultural fields can reduce phosphorus loading to surface waters; (2) assess at field-scale the role of FGD gypsum to enhance crop yields; (3) perform plot-scale studies to provide more detailed information concerning the effects of varying gypsum application rates on crop yields for different soil and crop types; (4) support development of best management practices for on-farm FGD gypsum use; and (5) perform education/outreach to support proper FGD gypsum.* ***This research is ongoing, and we present baseline information and in an overall summary of the project plans and first-year results.***

### FGD gypsum

FGD gypsum ($CaSO_4•2H_2O$) is produced by power utilities in limestone-forced oxidation wet scrubbers that remove sulfur dioxide from the flue gas stream after coal combustion. In general, limestone-forced oxidation exposes the flue gas to limestone slurry, initially forming calcium sulfite. Forcing additional air into the system oxidizes the calcium sulfite and converts it into gypsum (calcium sulfate). Fly ash is removed prior to the limestone-forced oxidation system, resulting in a relatively pure gypsum product. Processing of the gypsum may include centrifugation for initial dewatering and fines removal, followed by further dewatering, and sometimes washing to further remove soluble constituents. The gypsum that is recovered is high quality and suitable for manufacturing and agricultural uses. However, FGD gypsum production currently exceeds demand by a considerable margin. In 2010, 22 million tons of FGD gypsum was produced but only 10.7 million tons was used, mostly for wallboard products (ACAA, 2012). Agriculture is a growing end user of FGD gypsum.

### Prior studies of gypsum and phosphorus

FGD gypsum has been shown to boost yields for some crops while reducing fertilizer requirements. More recently, preliminary studies have shown gypsum can reduce soluble phosphorus, also called dissolved reactive phosphorus (or DRP), the form that moves into rivers and lakes.

The reduction in dissolved reactive phosphorus (DRP) is associated with the addition of calcium to the soil from the gypsum. For example, water-extractable phosphorus was reduced 48% when soil was equilibrated with gypsum (Stout et al., 1998) and phosphorus in runoff water was reduced 70% by gypsum (Franklin and Campbell, 2011). Laboratory data on soybean growth experiments under flooded conditions in pots by one of the principal investigators of this proposed project (Dick, paper in preparation), indicated a phosphorus reduction of 40%

accompanied by much less algae growth in a gypsum treated pot compared to an untreated pot. Work in Finland has also shown benefits of using gypsum to reduce phosphorus losses at the catchment basin scale (Ekholm et al., 2011). Use of FGD gypsum for phosphorus control has been evaluated in Georgia and Alabama over the last few years by a consortium that included several southeastern utilities and USDA-ARS (Torbert and Watts, 2014).

Poultry litter is often used as a fertilizer since it is cheap and plentiful in the southeastern U.S., along with having the nutrients and organic matter necessary for crop production. Gypsum was added to rice hull broiler litter and pine chip broiler litter to reduce soluble phosphorus concentrations (also called soluble reactive phosphorus, SRP) in runoff (Sheng et al., 2013). In the first runoff event, FGD gypsum reduced soluble phosphorus in pine chip bedding by 34% and in rice hull bedding by 40%.The amount of SRP was significantly reduced by surface application of wallboard gypsum to a field receiving poultry litter and where no-till agriculture was practiced (Norton, 2008). Gypsum was able to reduce the levels of SRP and total P although they were still higher than the levels from conventional fertilizer. A study by Endale et al. (2014) reported inconsistent findings on the reduction of phosphorus runoff from broiler litter with the addition of gypsum. Some years FGD gypsum lowered soluble phosphorus runoff while others there was no significant impact. This was potentially caused by the difficulty to isolate other factors between years, such as extreme weather, drought, and timing of application.

Gypsum was tested as a possible amendment to buffer strips to further reduce the runoff of soluble nutrients into waterways (Watts and Torbert, 2009). This study was conducted on land that applies poultry litter. The addition of a grass buffer strip was able to reduce the soluble phosphorus loss through runoff, but the addition of gypsum to the grass buffer strip significantly reduced soluble phosphorus runoff more than a buffer strip alone. The gypsum plus buffer treatment caused a 33% reduction in soluble phosphorus loss compared to the control (neither a buffer strip nor gypsum). After waiting four weeks, the study looked at the second rainfall event to see the long-term effects of gypsum. The effect of gypsum was reduced during this second event and further study is needed to determine the long-term impacts (Watts and Torbert, 2009). In a more recent study, FGD gypsum was also found to reduce SRP concentrations in runoff from soils treated with poultry litter (Torbert and Watts, 2014). However, as water runoff continued, the higher application rates of gypsum were more effective. Overall, a 61% reduction in SRP concentration was measured with the application of 8.9 Mg ha$^{-1}$ of FGD gypsum.

A drainage ditch filter comprised of gypsum is another technology that has been tested to reduce soluble phosphorus losses leaving a field (Bryant et al., 2012). One goal of this research was to keep costs and upkeep minimal since producers do not realize any economic benefit for constructing a filter. The filter was able to remove total dissolved reactive phosphorus from runoff waters at low water flows, but was not as efficient during large storm events. The water that flowed during these events was able to bypass the filter. Bryant et al. (2012) recommended setting up a “gypsum curtain” by trenching next to drainage ditches and filling the trench with gypsum. This will potentially increase the efficiency since it allows for the water to better flow through the gypsum. In another study, FGD gypsum trenches were reported to remove 50-95% of soluble phosphorus from groundwater flow (Baligar et al., 2011).

## Soil chemistry effects of gypsum

Gypsum application to soil leads to increased aggregation and then, in turn, increased water infiltration and reduced soil erosion. The result is a decrease in the level of chemical contamination that is carried on sediment and through the reduction of water leaving the field (Rhoton and McChesney, 2011). Gypsum stimulates phosphorus retention in the soil through increased surface adsorption and by increasing amount of Ca-P precipitation. Surface application of gypsum often seems to be more effective in reducing phosphorus leachate than when mixed into the soil but further study on this issue is needed. Long-term reductions in DRP seem to require repeated applications of gypsum (Brauer et al., 2005).

While gypsum can reduce phosphorus from going into the water, a concern has been raised about how its long-term application may affect overall nutrient balances in soil. For example, the large amount of Ca, added as gypsum, can replace essential nutrients such as Mg or displace $NH_4^+$ that is then lost from the soil (Favaretto et al., 2012).

A benefit of gypsum, in terms of nutrient use by crops, is that FGD gypsum reacts with toxic $Al^{3+}$ in more acidic soils, and this is especially important where there are acidic subsoils. This is because lime applications, applied at the soil surface or mixed into the tillage layer, cannot reach the $Al^{3+}$ at depth. However, gypsum is more soluble than lime and moves down into the acidic subsoil. It does not change the soil pH, but does either displace or complex with the toxic $Al^{3+}$ (Chen and Dick, 2011). This greatly increases root growth and root exploration of a larger soil volume. The result is increased water and nutrient use efficiency by the crop and less leakage to the environment.

## Project goal and objectives

The overall project goal is to evaluate the application of FGD gypsum to farm fields to reduce P loss from the fields. A secondary objective is to further evaluate the effect of FGD gypsum application on crop yield. Specific objectives of this project are:

(1) quantify at field-scale the use of FGD gypsum applied to agricultural fields to reduce phosphorus loading from agricultural fields;

(2) assess field-scale application of FGD gypsum to enhance crop yields;

(3) perform plot-scale studies to provide insights on application rates and yield increases as a function of soil and crop types;

(4) support development of best management practices for on-farm FGD gypsum use; and

(5) perform education/outreach to extend proper FGD gypsum use to agricultural communities.

# 2 FIELD-SCALE FARMER STUDIES

## Overview

The first priority of this project is to identify suitable testing sites. Sites are divided into two categories, Phase I and Phase II sites. Phase I sites are being tested for soluble reactive phosphorus concentrations in their tile water runoff, while Phase II sites are primarily tested for crop yield response to gypsum application. The goal of the project is to demonstrate at field-scale the practical application of gypsum to reduce phosphorus loading to surface loading in the Maumee River Watershed and Grand Lake St Marys Watershed. Another goal is to look at sites to see the crop yield response with the addition of FGD gypsum.

## Study Areas

The Maumee River Watershed is located in northwestern Ohio and is a major tributary to the Western Lake Erie Basin. The land area in the watershed is primarily used for agriculture with some urban areas. The Maumee River is the largest source of phosphorus to Lake Erie due to the large agricultural areas.

In the Maumee River Watershed eight Phase I and nine Phase II sites have been identified. As of November 2013, all research sites in the watershed have received at least one application of gypsum to the test portions of their fields, with some beginning as early as spring of 2012. Soil samples have been collected and analyzed for all sites in both watersheds.

The Grand Lake St. Marys Watershed is located in western Ohio and the land is predominantly used for crop and livestock production. Grand Lake St Marys is Ohio’s largest inland lake and supplies drinking water for the city of Celina. The lake contains large amounts of nutrients from agricultural runoff including large quantities of phosphorus. These excess nutrients contribute to algal blooms, which threaten the drinking water supply for the area.

In the Grand Lake St. Marys watershed, one Phase I site has been identified. Baseline description of these 18 sites is provided in Tables 1 and 2. As of November 2013, there has been at least one application of gypsum to test portions of the fields, with some receiving treatment as early as spring 2012. Soil samples have been collected and analyzed for all sites.

Table 1. Phase I sites selected.

| Site | Watershed | Total Size (Acres) | Treated Area (Acres) | App. Period | App. Rate (T/Acre) | Crops[1] | Soils[1] |
|---|---|---|---|---|---|---|---|
| M-1-P-1 | Maumee | 71.51 | 23.02 | Spring 2013 | 1 | Corn<br>Soybean<br>Wheat | Blount<br>Pewaumee<br>Haskins |
| M-2-P-1 | Maumee | 156.49 | 30.57 | Spring 2013 | 1 | Corn<br>Soybean | Hoytville<br>Nappanee<br>Mermill |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| M-3-P-1 | Maumee | 35.62 | 35.62* | Spring 2013 | 1 | Corn<br>Soybean | Hoytville<br>Haskins<br>Mermill |
| M-4-P-1 | Maumee | 117.97 | 6.02 | Spring 2012 | 1 | Corn<br>Soybean | Latty<br>Nappanee<br>Haskins |
| M-5-P-1 | Maumee | 231.77 | 6.266 | Spring 2013 | 1 | Corn<br>Soybean | Lenawee<br>Mermill<br>Haskins |
| M-6-P-1 | Maumee | 79.63 | 18.9 | Spring 2012<br>Spring 2013 | 1 | Corn<br>Soybean<br>Wheat | Hoytville<br>Latty |
| M-7-P-1 | Maumee | 68.757 | 26.42 | Spring 2012 | 1 | Corn<br>Soybean | Fulton<br>Latty<br>Toledo |
| M-8-P-1 | Maumee | 19.07 | 11.37 | Spring 2013 | 1 | Corn<br>Soybean | Latty<br>Nappanee |

Table 2. Phase II sites selected.

| Site | Watershed | Total Size (Acres) | Treated Area (Acres) | App. Period | App. Rate (T/Acre) | Crops[1] | Soils[1] |
|---|---|---|---|---|---|---|---|
| M-9-P-2 | | 58.21 | 25.15 | Fall 2013 | 1 | Corn<br>Soybean | Hoytville<br>Nappanee<br>Lenawee |
| M-10-P-2 | | 18.77 | 15.76 | Fall 2013 | | Corn<br>Soybean | Nappanee<br>Haskins<br>Shoals |
| M-11-P-2 | | 27.72 | 24.95 | Fall 2013 | | Corn<br>Soybean | Haskins<br>Kibbie<br>Millgrove |
| M-12-P-2 | | 69.42 | | Spring 2013 | | Corn<br>Soybean | Hoytville<br>Haskins<br>Nappanee |
| M-13-P-2 | | 41.13 | | Spring 2013 | | Corn<br>Soybean | Hoytville |
| M-14-P-2 | | 40.38 | | Spring 2013 | | Corn<br>Soybean | Hoytville<br>Toledo |
| M-15-P-2 | | 40.09 | | Spring 2013 | | Corn<br>Soybean | Hoytville<br>Mermill<br>Nappanee |
| M-16-P-2 | | 120.63 | 10.19 | Fall 2013 | 1 | Corn<br>Soybean | Haskins<br>Nappanee<br>Hoytville |
| M-17-P-2 | | 73.61 | 25.35 | Fall 2013 | 1 | Corn<br>Soybean | Latty<br>Fulton |
| G-1-P-1 | | 73.61 | 25.35 | Fall 2013 | | Corn<br>Soybean | |

## Methods

Two visits were made to northwest Ohio to plan for sampling of soil. These samples will be from the fields with paired areas treated alike except for gypsum addition (plus or minus). We have also obtained legacy soil sample data from Joe Nester to evaluate the impacts of gypsum additions on other nutrients. Between April of 2012 and June of 2013, 187 soil samples were collected from the Maumee River watershed test sites.

Tile water draining from both the control and test portions of the Phase I fields has been collected regularly after rainfall events and at other times when the tiles are flowing, beginning in May 2012. As of the writing of this report, approximately 120 tile water samples have been collected.

## Results

Even though this research is still underway, it is demonstrating extremely positive results. A single application of FGD gypsum on test sites in the Maumee River watershed reduced concentrations in tile drainage water of soluble reactive phosphorus (SRP), the most troublesome form in the area waterways, by a significant amount. The gypsum-treated plots showed an average 55% reduction of soluble reactive phosphorus in tile water runoff compared to the untreated plots. The ability of the gypsum to reduce soluble reactive phosphorus concentrations continues as long as 20 months after application.

Table 3. Soil water quality results in tile drainage.

(Include a summary table here. The detailed data can go into an appendix.)

# 3 FIELD-PLOT STUDIES

Besides the environmental benefits of gypsum, it seems another major benefit of gypsum will be increased nutrient use efficiency, especially nitrogen. Nitrogen fertilizer is a major economic input for crop producers as well as a major source of environmental pollution.

Plot-scale research will be conducted to evaluate gypsum rates and the frequency of application and the interaction with nitrogen rates on soil chemical properties as well as corn nutrition and yield.

### Methods

This study will take place in Wooster in northeast Ohio and Hoytville in northwest Ohio on soils with different characteristics and use the no-till system. The experiment will have three replications, and 63 total plots in each place (see next page for field plot design). The gypsum sub-plots will be 10 X 30 ft in size, with 10 ft border on each end of the study. The area required to do the study will be 100 X 250 ft (about 0.6 acres). The treatment variables to be studied are:

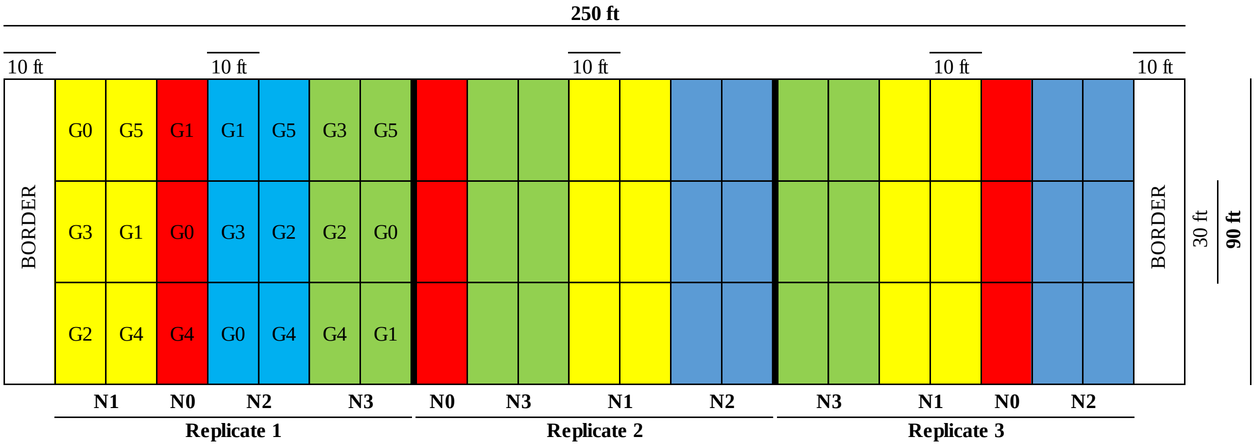
1. FGD gypsum rates/frequency of application – 6 treatments (no gypsum (control), 1,000 lb acre$^{-1}$ applied annually, 1,000 lb acre$^{-1}$ applied biennially, 2,000 lb acre$^{-1}$ applied annually, 2,000 lb acre$^{-1}$ applied biennially, 4000 lb acre$^{-1}$ applied triennially)
2. Nitrogen (N) rates (0, 75, 150 and 225 lbs of N acre$^{-1}$);

The experiment will use a split-plot design with nitrogen rates as main plots and gypsum treatments as subplots to provide greater sensitivity of statistical test for the gypsum treatments (see Figure 1 on next page). Corn crop will be sown every year and management practices such as lime inputs, weed, and pest control will be done consistently across all treatments and according to established agronomic practices. The plan is for these plots to be maintained long-term to allow evaluation of gypsum impacts beyond the normal 2-3 years of a research study. To date, the experimental sites have been identified, the plots have been laid out and gypsum has been applied. Planting was conducted in May once field conditions became appropriate.

Measurements to be made during this experiment include (1) soil chemical attributes (pH, EC, $Ca^{2+}$, $Mg^{2+}$, $K^+$, $Al^{3+}$, P, S-$SO_4^{2-}$) at 0.0-0.2 and 0.2-0.4 m depths, (2) corn nutrition (leaf nutrient levels), growth analysis and yield, and (3) soil physical attributes (water infiltration, bulk density, penetration resistance).

### Results

Results will be submitted to a variance analyses (ANOVA). When the interaction between FGD gypsum rates and frequency of application or nitrogen rates are significant ($p<0,05$), the regression analysis for FGD gypsum rates will be done for each nitrogen rates. If there are no interaction, the effect of the frequency of application will be compared by Tukey ($\alpha= 0,05$) and a



**Legend**

G0 = No gypsum (control)
G1 = 1,000 kg acre$^{-1}$ of FGD gypsum applied annually
G2 = 1,000 kg acre$^{-1}$ of FGD gypsum applied biennially
G3 = 2,000 kg acre$^{-1}$ of FGD gypsum applied annually
G4 = 2,000 kg acre$^{-1}$ of FGD gypsum applied biennially
G5 = 4,000 kg acre$^{-1}$ of FGD gypsum applied triennially

🟥 N1=0 lb of N acre$^{-1}$
🟨 N2=75 lbs of N acre$^{-1}$
🟦 N3=150 lbs of N acre$^{-1}$
🟩 N4=225 lbs of N acre$^{-1}$

Figure 1. Field plot design for the study of gypsum by nitrogen interaction on crop yield and soil quality.

Regression analysis will be performed with the average of each nitrogen amount on the same FGD gypsum rates, adopting the model with the best significance level.

Expected results are: (1) identification of technically and economically proper gypsum rates, (2) the best frequency of gypsum application, and (3) increased crop yields due to the interaction of gypsum and nitrogen fertilizer increasing absorption of water and nutrients.

Appendix Table 1. Tile water quality data as affected by gypsum application.

| Site | Sample Location | Sample Date | Treated | pH | TSS (mg/L) | Total P (mg/L) | Ortho P (mg/L) | NBR | NO3_N | Ca | Mg | SO4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-1-P-1 | Lloyd | 3-Jul-13 | No | 7.28 | 340 | <0.20 | 0.065 | 1530 | 13.7 | | | |
| M-1-P-1 | Lloyd | 3-Jul-13 | Yes | 7.38 | <1 | <0.20 | 0.012 | 1531 | 20.06 | | | |
| M-1-P-1 | Lloyd | 11-Jul-13 | No | 7.13 | <1 | <0.20 | 0.032 | 1631 | 16.57 | | | |
| M-1-P-1 | Lloyd | 11-Jul-13 | No | 7.19 | 4 | <0.20 | 0.029 | 1632 | 16.7 | | | |
| M-1-P-1 | Lloyd | 11-Jul-13 | Yes | 7.09 | <1 | <0.20 | <0.01 | 1633 | 19.55 | | | |
| M-1-P-1 | Lloyd | 11-Jul-13 | Yes | 7.06 | <1 | <0.20 | 0.017 | 1634 | 19.64 | | | |
| M-1-P-1 | Lloyd | 30-Dec-13 | No | 7.47 | <1 | <0.20 | 0.13 | 2909 | 4.65 | 58.5 | 11.68 | 17.93 |
| M-1-P-1 | Lloyd | 30-Dec-13 | No | 7.47 | <1 | <0.20 | 0.125 | 2910 | 4.64 | 60.51 | 12.02 | 17.77 |
| M-1-P-1 | Lloyd | 30-Dec-13 | Yes | 7.48 | <1 | <0.20 | 0.025 | 2911 | 6.49 | 91.65 | 19.27 | 114.84 |
| M-1-P-1 | Lloyd | 30-Dec-13 | Yes | 7.57 | <1 | <0.20 | 0.03 | 2912 | 6.47 | 90.38 | 19.05 | 113.22 |
| M-1-P-1 | Lloyd | 10-Apr-14 | No | | | | 0.039 | | | | | |
| M-1-P-1 | Lloyd | 10-Apr-14 | Yes | | | | 0.016 | | | | | |
| M-1-P-1 | Lloyd | 15-May-14 | No | 7.5 | <1 | <0.20 | 0.064 | 1176 | 7.22 | 65.32 | 13.31 | 21.9 |
| M-1-P-1 | Lloyd | 15-May-14 | Yes | 7.46 | <1 | <0.20 | 0.059 | 1177 | 4.61 | 93.69 | 21.76 | 77.85 |
| M-1-P-1 | Lloyd | 22-May-14 | No | 7.44 | 46 | 0.24 | 0.227 | 1184 | 9.34 | 52.07 | 11.14 | 19.03 |
| M-1-P-1 | Lloyd | 22-May-14 | Yes | 7.58 | <1 | <0.20 | 0.064 | 1185 | 4.64 | 94.36 | 22 | 78.6 |
| M-2-P-1 | Home | 9-Jul-13 | Yes | 6.8 | <1 | <0.20 | 0.037 | 0.037 | 5.63 | | | |
| M-2-P-1 | Home | 9-Jul-13 | Yes | 6.79 | <1 | <0.20 | 0.032 | 0.032 | 5.71 | | | |
| M-2-P-1 | Home | 9-Jul-13 | No | 6.66 | 11 | 0.26 | 0.054 | 0.054 | 5.42 | | | |
| M-2-P-1 | Home | 9-Jul-13 | No | 6.62 | 9 | 0.29 | 0.029 | 0.029 | 5.43 | | | |
| M-2-P-1 | Home | 10-Apr-14 | No | | | | 0.01 | 0.01 | | | | |
| M-2-P-1 | Home | 10-Apr-14 | Yes | | | | <0.01 | <0.01 | | | | |
| M-2-P-1 | Home | 22-May-14 | No | 7.35 | 2 | 0.27 | 0.277 | 0.277 | 22.51 | 102.7 | 102.7 | 144.66 |
| M-2-P-1 | Home | 22-May-14 | Yes | 7.47 | <1 | <0.20 | 0.037 | 0.037 | 22.63 | 120.3 | 120.3 | 192.63 |
| M-3-P-1 | Shop | 10-Apr-14 | No | | | | 0.015 | | | | | |
| M-3-P-1 | Shop | 10-Apr-14 | Yes | | | | 0.086 | | | | | |
| M-3-P-1 | Shop | 22-May-14 | No | 7.4 | 4 | 0.26 | 0.277 | 1188 | 22.58 | 103.7 | 15.5 | 146.01 |
| M-3-P-1 | Shop | 22-May-14 | Yes | 7.46 | 1 | <0.20 | 0.034 | 1189 | 22.7 | 119.4 | 16.54 | 189.84 |
| M-4-P-1 | KH Derck | 3-Jul-13 | No | 7.90 | <1 | <0.20 | <0.01 | 1523 | 14.13 | | | |
| M-4-P-1 | KH Derck | 3-Jul-13 | Yes | 8.05 | <1 | <0.20 | 0.02 | 1524 | 13.30 | | | |
| M-4-P-1 | KH Derck | 9-Jul-13 | No | 7.14 | <1 | <0.20 | 0.015 | 1606 | 17.14 | | | |
| M-4-P-1 | KH Derck | 9-Jul-13 | No | 7.1 | <1 | <0.20 | <0.01 | 1607 | 17.47 | | | |
| M-4-P-1 | KH Derck | 9-Jul-13 | Yes | 7.11 | <1 | <0.20 | <0.01 | 1608 | 17.99 | | | |
| M-4-P-1 | KH Derck | 9-Jul-13 | Yes | 7.12 | <1 | <0.20 | <0.01 | 1609 | 17.87 | | | |
| M-4-P-1 | KH Derck | 25-Mar-14 | No | 7.18 | <1 | 0.23 | <0.01 | 522 | 10.81 | 75.08 | 12.9 | 14.28 |
| M-4-P-1 | KH Derck | 25-Mar-14 | No | 7.36 | <1 | <0.20 | 0.029 | 523 | 10.6 | 65.1 | 11.78 | 12.51 |
| M-4-P-1 | KH Derck | 25-Mar-14 | Yes | 7.29 | 32 | <0.20 | 0.02 | 524 | 7.31 | 76.28 | 15.02 | 102.9 |
| M-4-P-1 | KH Derck | 25-Mar-14 | Yes | 7.27 | 35 | <0.20 | 0.026 | 525 | 7.34 | 76.69 | 15.03 | 102.75 |

| Site | Sample Location | Sample Date | Treated | pH | TSS (mg/L) | Total P (mg/L) | Ortho P (mg/L) | NBR | NO3_N | Ca | Mg | SO4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-4-P-1 | KH Derck | 8-Apr-14 | No | 7.44 | <1 | <0.20 | <0.01 | 664 | 12.06 | 70.25 | 13.54 | 14.35 |
| M-4-P-1 | KH Derck | 8-Apr-14 | Yes | 7.55 | <1 | <0.20 | <0.01 | 665 | 12.02 | 104.8 | 20.62 | 146.01 |
| M-4-P-1 | KH Derck | 10-Apr-14 | No | 7.78 |  |  | 0.012 | 681 | 13.65 | 61.2 | 11.81 |  |
| M-4-P-1 | KH Derck | 10-Apr-14 | Yes | 7.71 |  |  | 0.013 | 682 | 13.52 | 91.35 | 17.63 |  |
| M-4-P-1 | KH Derck | 15-Apr-14 | No | 7.77 | <1 | <0.20 | 0.031 | 743 | 13.16 | 65.66 | 12.45 | 15.66 |
| M-4-P-1 | KH Derck | 15-Apr-14 | Yes | 7.85 | <1 | <0.20 | 0.021 | 744 | 13.06 | 101 | 19.35 | 135.75 |
| M-4-P-1 | KH Derck | 15-May-14 | No | 7.57 | <1 | <0.20 | 0.015 | 1169 | 15.42 | 71.35 | 13.13 | 12.85 |
| M-4-P-1 | KH Derck | 15-May-14 | Yes | 7.49 | <1 | <0.20 | <0.01 | 1170 | 14.72 | 104.2 | 19.76 | 132.96 |
| M-4-P-1 | KH Derck | 22-May-14 | No | 7.59 | 45 | <0.20 | <0.01 | 1180 | 16.17 | 64.43 | 11.59 | 10.4 |
| M-4-P-1 | KH Derck | 22-May-14 | Yes | 7.53 | 68 | <0.20 | <0.01 | 1181 | 15.16 | 79.62 | 14.41 | 95.76 |
| M-5-P-1 | Home | 3-Jul-13 | Yes | 7.44 | <1 | <0.20 | 0.079 | 1534 | 10.06 |  |  |  |
| M-5-P-1 | Home | 3-Jul-13 | No | 7.22 | <1 | <0.20 | 0.116 | 1535 | 17.25 |  |  |  |
| M-5-P-1 | Home | 25-Jul-13 | No | 7.51 | 1 | <0.20 | 0.076 | 1745 | 4.62 |  |  |  |
| M-5-P-1 | Home | 25-Jul-13 | No | 7.27 | 1 | <0.20 | 0.081 | 1746 | 4.54 |  |  |  |
| M-5-P-1 | Home | 25-Jul-13 | Yes | 7.13 | 1 | <0.20 | 0.065 | 1747 | 7.07 |  |  |  |
| M-5-P-1 | Home | 25-Jul-13 | Yes | 7.1 | 1 | <0.20 | 0.067 | 1748 | 7.1 |  |  |  |
| M-6-P-1 | KH 3&4 | 3-Jul-13 | Yes | 7.33 | 4 | <0.20 | 0.015 | 1525 | 16.76 |  |  |  |
| M-6-P-1 | KH 3&4 | 3-Jul-13 | No | 7.27 | <1 | <0.20 | 0.015 | 1526 | 12.75 |  |  |  |
| M-6-P-1 | KH 3&4 | 3-Jul-13 | Yes | 7.28 | <1 | <0.20 | 0.018 | 1527 | 12.46 |  |  |  |
| M-6-P-1 | KH 3&4 | 30-Dec-13 | No | 7.51 | <1 | <0.20 | 0.018 | 2894 | 9.9 | 75.9 | 15.17 | 20.27 |
| M-6-P-1 | KH 3&4 | 30-Dec-13 | No | 7.72 | <1 | <0.20 | 0.025 | 2895 | 9.82 | 75.26 | 14.96 | 20.07 |
| M-6-P-1 | KH 3&4 | 30-Dec-13 | Yes | 7.8 | <1 | <0.20 | 0.018 | 2896 | 9.51 | 84.78 | 16.93 | 45.45 |
| M-6-P-1 | KH 3&4 | 30-Dec-13 | Yes | 7.84 | <1 | <0.20 | 0.023 | 2897 | 9.62 | 84.85 | 16.99 | 45.12 |
| M-6-P-1 | KH 3&4 | 10-Apr-14 | Yes |  |  |  | 0.016 |  |  |  |  |  |
| M-6-P-1 | KH 3&4 | 10-Apr-14 | Yes |  |  |  | <0.01 |  |  |  |  |  |
| M-6-P-1 | KH 3&4 | 10-Apr-14 | No |  |  |  | <0.01 |  |  |  |  |  |
| M-6-P-1 | KH 3&4 | 15-Apr-14 | No | 7.6 | <1 | <0.20 | <0.01 | 745 | 10.61 | 71.39 | 14.93 | 19.01 |
| M-6-P-1 | KH 3&4 | 15-Apr-14 | No | 7.54 | <1 | <0.20 | <0.01 | 747 | 11.07 | 72.97 | 14.84 | 16.7 |
| M-6-P-1 | KH 3&4 | 15-Apr-14 | Yes | 7.67 | <1 | <0.20 | 0.019 | 746 | 13.13 | 76.99 | 16.16 | 22.49 |
| M-6-P-1 | KH 3&4 | 15-Apr-14 | Yes | 7.57 | <1 | <0.20 | <0.01 | 748 | 10.97 | 85.85 | 17.73 | 65.58 |
| M-6-P-1 | KH 3&4 | 15-May-14 | Yes | 7.59 | <1 | <0.20 | 0.036 | 1171 | 20.53 | 79.54 | 16.15 | 19.16 |
| M-6-P-1 | KH 3&4 | 15-May-14 | No | 7.46 | <1 | <0.20 | 0.026 | 1172 | 19.24 | 81.91 | 16.47 | 30.66 |
| M-6-P-1 | KH 3&4 | 15-May-14 | Yes | 7.46 | <1 | <0.20 | 0.013 | 1173 | 17.59 | 92.28 | 18.97 | 64.02 |
| M-7-P-1 | Hale | 20-Dec-12 | No | 7.36 | 1400.5 | 0.16 | 0.16 |  | 7.62 |  |  |  |
| M-7-P-1 | Hale | 20-Dec-12 | Yes | 7.07 | 351.3 | 0.07 | 0.07 |  | 7.96 |  |  |  |
| M-7-P-1 | Hale | 11-Feb-12 | No | 7.22 | 339.5 | 0.10 | 0.09 |  | 9.88 |  |  |  |
| M-7-P-1 | Hale | 20-Dec-12 | No | 7.13 | 246.3 | 0.39 | 0.43 |  | 3.54 |  |  |  |
| M-7-P-1 | Hale | 21-Dec-12 | No | 7.22 | 813.7 | 0.12 | 0.12 |  | 9.33 |  |  |  |
| M-7-P-1 | Hale | 21-Dec-12 | Yes | 7.07 | 150.2 | 0.06 | 0.06 |  | 9.75 |  |  |  |
| M-7-P-1 | Hale | 11-Feb-12 | Yes | 7.3 | 142.7 | 0.06 | 0.06 |  | 7.87 |  |  |  |

| Site | Sample Location | Sample Date | Treated | pH | TSS (mg/L) | Total P (mg/L) | Ortho P (mg/L) | NBR | NO3_N | Ca | Mg | SO4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-7-P-1 | Hale | 11-Jun-13 | Yes | | | | 0.069 | | | | | |
| M-7-P-1 | Hale | 11-Jun-13 | No | | | | 0.154 | | | | | |
| M-7-P-1 | Hale | 3-Jul-13 | No | 7.81 | <1 | <0.20 | 0.158 | 1532 | 31.34 | | | |
| M-7-P-1 | Hale | 3-Jul-13 | Yes | 7.54 | <1 | <0.20 | 0.086 | 1533 | 22.69 | | | |
| M-7-P-1 | Hale | 11-Jul-13 | No | 7.39 | <1 | 0.24 | 0.207 | 1635 | 34.56 | | | |
| M-7-P-1 | Hale | 11-Jul-13 | No | 7.44 | <1 | 0.23 | 0.207 | 1636 | 33.71 | | | |
| M-7-P-1 | Hale | 11-Jul-13 | Yes | 7.13 | <1 | <0.20 | 0.062 | 1637 | 28.53 | | | |
| M-7-P-1 | Hale | 11-Jul-13 | Yes | 7.15 | 1 | <0.20 | 0.069 | 1638 | 28.8 | | | |
| M-7-P-1 | Hale | 30-Dec-13 | No | 7.73 | <1 | <0.20 | 0.118 | 2901 | 7.57 | 49.34 | 17.28 | 99.87 |
| M-7-P-1 | Hale | 30-Dec-13 | No | 7.78 | <1 | <0.20 | 0.099 | 2902 | 7.64 | 50.27 | 17.54 | 101.28 |
| M-7-P-1 | Hale | 30-Dec-13 | Yes | 7.65 | <1 | <0.20 | 0.061 | 2903 | 6.18 | 98.91 | 35.15 | 267.15 |
| M-7-P-1 | Hale | 30-Dec-13 | Yes | 7.66 | <1 | <0.20 | 0.061 | 2904 | 6.2 | 100.5 | 35.66 | 272.34 |
| M-7-P-1 | Hale | 30-Dec-13 | No | 7.7 | <1 | 0.26 | 0.136 | 2913 | 7.01 | 35.94 | 12.1 | 48.87 |
| M-7-P-1 | Hale | 30-Dec-13 | No | 7.65 | <1 | 0.2 | 0.134 | 2914 | 7.02 | 35.39 | 11.79 | 48.33 |
| M-7-P-1 | Hale | 30-Dec-13 | Yes | 7.43 | <1 | <0.20 | 0.093 | 2915 | 6.21 | 67.93 | 23.31 | 158.85 |
| M-7-P-1 | Hale | 30-Dec-13 | Yes | 7.11 | <1 | <0.20 | 0.052 | 2916 | 6.17 | 66.01 | 24.23 | 162.75 |
| M-7-P-1 | Hale | 25-Mar-14 | No | 7.03 | 30 | 0.31 | 0.236 | 534 | 1.06 | 18.66 | 5.53 | 7.75 |
| M-7-P-1 | Hale | 25-Mar-14 | No | 7.03 | 25 | 0.3 | 0.231 | 535 | 1.09 | 18.6 | 5.46 | 7.74 |
| M-7-P-1 | Hale | 25-Mar-14 | Yes | 6.87 | 15 | <0.20 | 0.111 | 536 | 3.04 | 42.04 | 14.09 | 73.98 |
| M-7-P-1 | Hale | 25-Mar-14 | Yes | 6.95 | 16 | <0.20 | 0.099 | 537 | 3.02 | 41.64 | 14.07 | 73.8 |
| M-7-P-1 | Hale | 8-Apr-14 | No | 7.27 | <1 | 0.2 | 0.145 | 668 | 2.41 | 30.54 | 8.52 | 30.66 |
| M-7-P-1 | Hale | 8-Apr-14 | Yes | 7.54 | <1 | <0.20 | <0.01 | 669 | 5.5 | 122.2 | 49.27 | 377.4 |
| M-7-P-1 | Hale | 10-Apr-14 | No | | | | 0.164 | | | | | |
| M-7-P-1 | Hale | 10-Apr-14 | Yes | | | | 0.066 | | | | | |
| M-7-P-1 | Hale | 15-Apr-14 | No | 7.71 | 14 | <0.20 | 0.104 | 751 | 4.98 | 89.45 | 27.1 | 170.43 |
| M-7-P-1 | Hale | 15-Apr-14 | Yes | 7.78 | 9 | <0.20 | 0.044 | 752 | 4.47 | 118.4 | 45.28 | 344.1 |
| M-7-P-1 | Hale | 15-May-14 | No | 7.55 | 22 | 0.31 | 0.317 | 1178 | 10.1 | 77.92 | 24.29 | 110.7 |
| M-7-P-1 | Hale | 15-May-14 | Yes | 7.45 | 19 | <0.20 | 0.111 | 1179 | 9.61 | 107.7 | 40.68 | 256.89 |
| M-8-P-1 | Keeesbury 3004 | 3-Jul-13 | No | 7.37 | <1 | <0.20 | 0.042 | 1528 | 26.86 | | | |
| M-8-P-1 | Keeesbury 3004 | 3-Jul-13 | Yes | 7.31 | <1 | <0.20 | 0.021 | 1529 | 32.26 | | | |
| M-8-P-1 | Keeesbury 3004 | 11-Jul-13 | No | 6.78 | <1 | <0.20 | 0.046 | 1627 | 31.74 | | | |
| M-8-P-1 | Keeesbury 3004 | 11-Jul-13 | No | 6.88 | <1 | <0.20 | 0.042 | 1628 | 30.66 | | | |
| M-8-P-1 | Keeesbury 3004 | 11-Jul-13 | Yes | 6.77 | <1 | <0.20 | 0.025 | 1629 | 24.23 | | | |
| M-8-P-1 | Keeesbury 3004 | 11-Jul-13 | Yes | 6.75 | <1 | <0.20 | 0.021 | 1630 | 24.26 | | | |
| M-8-P-1 | Keeesbury 3004 | 25-Jul-13 | No | 7.62 | 1 | <0.20 | 0.088 | 1741 | 3.21 | | | |
| M-8-P-1 | Keeesbury 3004 | 25-Jul-13 | No | 7.62 | 1 | <0.20 | 0.102 | 1742 | 3.15 | | | |
| M-8-P-1 | Keeesbury 3004 | 25-Jul-13 | Yes | 7.56 | 1 | <0.20 | 0.032 | 1743 | 2.04 | | | |

| Site | Sample Location | Sample Date | Treated | pH | TSS (mg/L) | Total P (mg/L) | Ortho P (mg/L) | NBR | NO3_N | Ca | Mg | SO4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-8-P-1 | Keeesbury 3004 | 25-Jul-13 | Yes | 7.54 | 1 | <0.20 | 0.036 | 1744 | 2.05 | | | |
| M-8-P-1 | Keeesbury 3004 | 30-Dec-13 | No | 7.84 | <1 | <0.20 | 0.067 | 2898 | 11.27 | 57.77 | 13.97 | 83.1 |
| M-8-P-1 | Keeesbury 3004 | 30-Dec-13 | Yes | 7.74 | <1 | <0.20 | 0.052 | 2899 | 10.99 | 95.39 | 27.13 | 234.33 |
| M-8-P-1 | Keeesbury 3004 | 30-Dec-13 | Yes | 7.74 | <1 | <0.20 | 0.046 | 2900 | 11.35 | 97.19 | 27.64 | 239.91 |
| M-8-P-1 | Keeesbury 3004 | 30-Dec-13 | No | 7.72 | <1 | <0.20 | 0.055 | 2905 | 10.28 | 51.19 | 12.03 | 66.57 |
| M-8-P-1 | Keeesbury 3004 | 30-Dec-13 | No | 7.66 | <1 | <0.20 | 0.061 | 2906 | 10.18 | 51.13 | 11.89 | 66.42 |
| M-8-P-1 | Keeesbury 3004 | 30-Dec-13 | Yes | 7.45 | <1 | <0.20 | 0.058 | 2907 | 10.23 | 84.5 | 23.02 | 200.37 |
| M-8-P-1 | Keeesbury 3004 | 30-Dec-13 | Yes | 7.36 | <1 | <0.20 | 0.058 | 2908 | 10.24 | 84.74 | 23.21 | 200.85 |
| M-8-P-1 | Keeesbury 3004 | 25-Mar-14 | Yes | 7.13 | 22 | <0.20 | 0.074 | 526 | 2.94 | 45.07 | 11.33 | 93.57 |
| M-8-P-1 | Keeesbury 3004 | 25-Mar-14 | Yes | 7.05 | 14 | <0.20 | 0.083 | 527 | 3.01 | 46.71 | 11.77 | 95.64 |
| M-8-P-1 | Keeesbury 3004 | 25-Mar-14 | No | 7.03 | 29 | <0.20 | 0.085 | 528 | 2.01 | 24.93 | 5.8 | 18.41 |
| M-8-P-1 | Keeesbury 3004 | 25-Mar-14 | No | 7.02 | 35 | <0.20 | 0.076 | 529 | 2.02 | 24.68 | 5.7 | 18.14 |
| M-8-P-1 | Keeesbury 3004 | 25-Mar-14 | Yes | 6.91 | 33 | <0.20 | 0.065 | 530 | 4.59 | 54.05 | 14.96 | 121.65 |
| M-8-P-1 | Keeesbury 3004 | 25-Mar-14 | Yes | 6.9 | 10 | <0.20 | 0.069 | 531 | 4.56 | 53.59 | 14.87 | 121.5 |
| M-8-P-1 | Keeesbury 3004 | 25-Mar-14 | No | 7.04 | 40 | 0.21 | 0.142 | 532 | 3.52 | 29.67 | 7.07 | 26.23 |
| M-8-P-1 | Keeesbury 3004 | 25-Mar-14 | No | 7 | 39 | 0.23 | 0.136 | 533 | 3.54 | 29.64 | 6.96 | 25.88 |
| M-8-P-1 | Keeesbury 3004 | 8-Apr-14 | No | 7.44 | <1 | <0.20 | 0.047 | 666 | 10.19 | 58.95 | 15.59 | 89.04 |
| M-8-P-1 | Keeesbury 3004 | 8-Apr-14 | Yes | 7.42 | <1 | <0.20 | 0.019 | 667 | 9.06 | 99.82 | 31.36 | 269.13 |
| M-8-P-1 | Keeesbury 3004 | 10-Apr-14 | No | | | | 0.098 | | | | | |
| M-8-P-1 | Keeesbury 3004 | 10-Apr-14 | Yes | | | | 0.033 | | | | | |
| M-8-P-1 | Keeesbury 3004 | 15-Apr-14 | No | 7.51 | <1 | <0.20 | 0.054 | 749 | 9.43 | 66.08 | 17.69 | 100.98 |
| M-8-P-1 | Keeesbury 3004 | 15-Apr-14 | Yes | 7.44 | <1 | <0.20 | 0.021 | 750 | 8.27 | 96.92 | 30.55 | 245.97 |
| M-8-P-1 | Keeesbury 3004 | 15-May-14 | No | 7.48 | 58 | <0.20 | <0.01 | 1174 | 13.68 | 57.86 | 15.06 | 77.85 |
| M-8-P-1 | Keeesbury 3004 | 15-May-14 | Yes | 7.43 | 10 | <0.20 | 0.042 | 1175 | 12.26 | 91.12 | 28.8 | 227.58 |
| M-8-P-1 | Keeesbury 3004 | 22-May-14 | No | 7.29 | 116 | 0.22 | 0.085 | 1182 | 11.12 | 30.13 | 6.7 | 20.59 |
| M-8-P-1 | Keeesbury 3004 | 22-May-14 | Yes | 7.17 | 98 | <0.20 | 0.043 | 1183 | 12.11 | 51.25 | 12.57 | 98.19 |
| M-8-P-1 | Keeesbury 3004 | 23-May-14 | No | 7.34 | <1 | <0.20 | 0.058 | 1218 | 10.7 | 92.95 | 25.2 | 186.12 |
| M-8-P-1 | Keeesbury 3004 | 23-May-14 | Yes | 7.35 | 13 | <0.20 | 0.034 | 1219 | 10.19 | 131.7 | 44.72 | 376.8 |