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Bone Lake Diagnostic Study

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water | ecology | community

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PROJECT BACKGROUND

Following the recent completion of the Moody Lake Sequential Diagnostics Study in December 2014, a similar study was proposed for the next downstream watershed: Bone Lake (Figure 1). The objective of this diagnostic study was to conduct additional flow and water quality monitoring along stream tributaries of Bone Lake to target watershed pollutant loading hotspots, and to develop a BMP watershed scenario model to determine the siting and effectiveness of BMPs throughout the Bone Lake watershed. Another objective of the proposed work was to aid District grant writing in August 2015 for the BWSR Targeted Watershed Demonstration Program or other eligible grants.

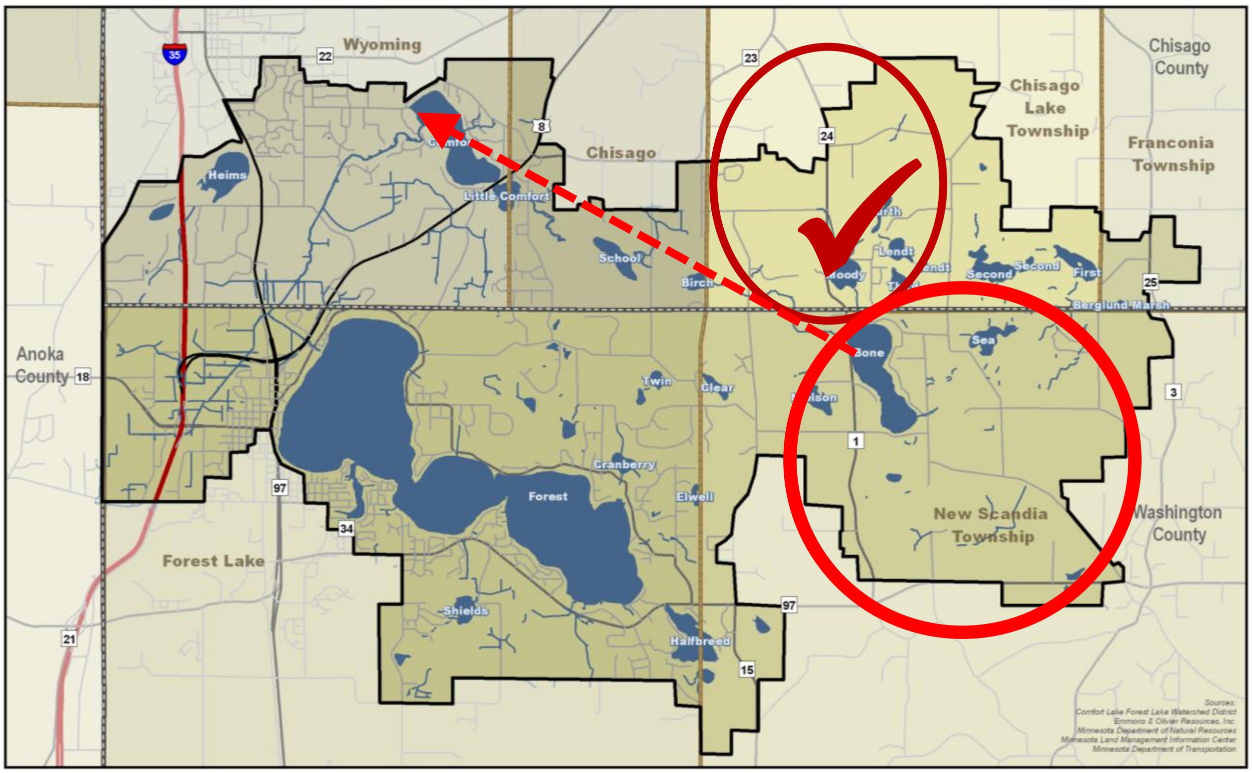

Figure 1. Comfort Lake Forest Lake Watershed District northern flow network

DIAGNOSTIC STUDY

Flow and water quality samples were collected along the main tributaries to Bone Lake to estimate the distribution and quality of phosphorus loads originating from the watershed. The results from the diagnostic study were used to calibrate an EPA SWMM model constructed for the Bone Lake watershed and to target agricultural and structural BMPs that reduce phosphorus loads to Bone Lake and improve lake water quality.

Tributary Monitoring

Potential monitoring locations were assessed along the main tributaries to Bone Lake to determine the suitability of the channels for flow gauging and monitoring. Eight suitable monitoring stations were selected on six tributaries: 238th East, Melanie Trail, Meadowbrook, Otte Farm, Oakhill Way, 228th East, and 228th West (Figure 2). A staff gauge and level logger was installed at each site to monitor water elevations and to develop a stage-discharge relationship (rating curve). Continuous flow is collected by the Washington Conservation District at the outflow from Moody Lake (238th West). Field observations from each monitoring site are summarized below:

- **228th West**: Logger was installed at the upstream end of the culvert to avoid possible backwater issues from the lake. Small bullhead were observed within the downstream end of the culvert this spring, but it is unknown if they successfully migrated through the culvert.
- **228th East:** Logger was installed in the small ditch located between the lake and 228th St.
- **Otte Farm:** Logger was installed at the upstream end of the culvert. This was not a good location for a precipitation logger due to repeated funnel clogging from bird droppings.
- **Oakhill Way:** Logger was installed at the downstream end of the culvert. The culvert is set low under the road and has standing water in the culvert during periods of no flow. Reported stage is stage above the plunge pool natural overflow (standing water in the culvert occurs when the stage drops below the natural overflow).
- **Meadowbrook:** Logger was installed in the ditch upstream of the culvert. The gravel substrate made it difficult to install a mount for the monitoring equipment. No fish were observed in the ditch or culvert this spring/summer.
- **Melanie Trail:** Logger was installed at the upstream end of the culvert. Very turbid water was observed during a high flow event due to agricultural runoff, exasperated by local topography and soils. Very flashy flows were observed through the culvert.
- **238th East:** Logger was installed at the upstream end of the culvert. While no problem exists, the culvert is relatively small for the drainage area and could potentially plug with woody debris from the ditch. The downstream end of the culvert is perched and rusted out at the invert.

Flow Data

Continuous flow was monitored from March 12 through July 13 in 2015. Continuous flow records collected by EOR (all sites except 238th W) and corresponding precipitation measured at Scandia, MN are provided in Appendix A. Instantaneous flow measurements were collected at all sites except 238th W using a Marsh McBirney flow meter several times during spring snowmelt (March 12 and April 2), and following large rainfall events (April 10; May 8, 25, and 29; July 6). Measurable flow was only present at all 8 monitoring sites during the July 6 rainfall event of 3.25 inches, sites with flow on other monitoring dates are summarized in Table 1. Rating curves were developed for all sites except 238th W using instantaneous flow measurements collected during grab sampling and level logger stage (see Appendix B).

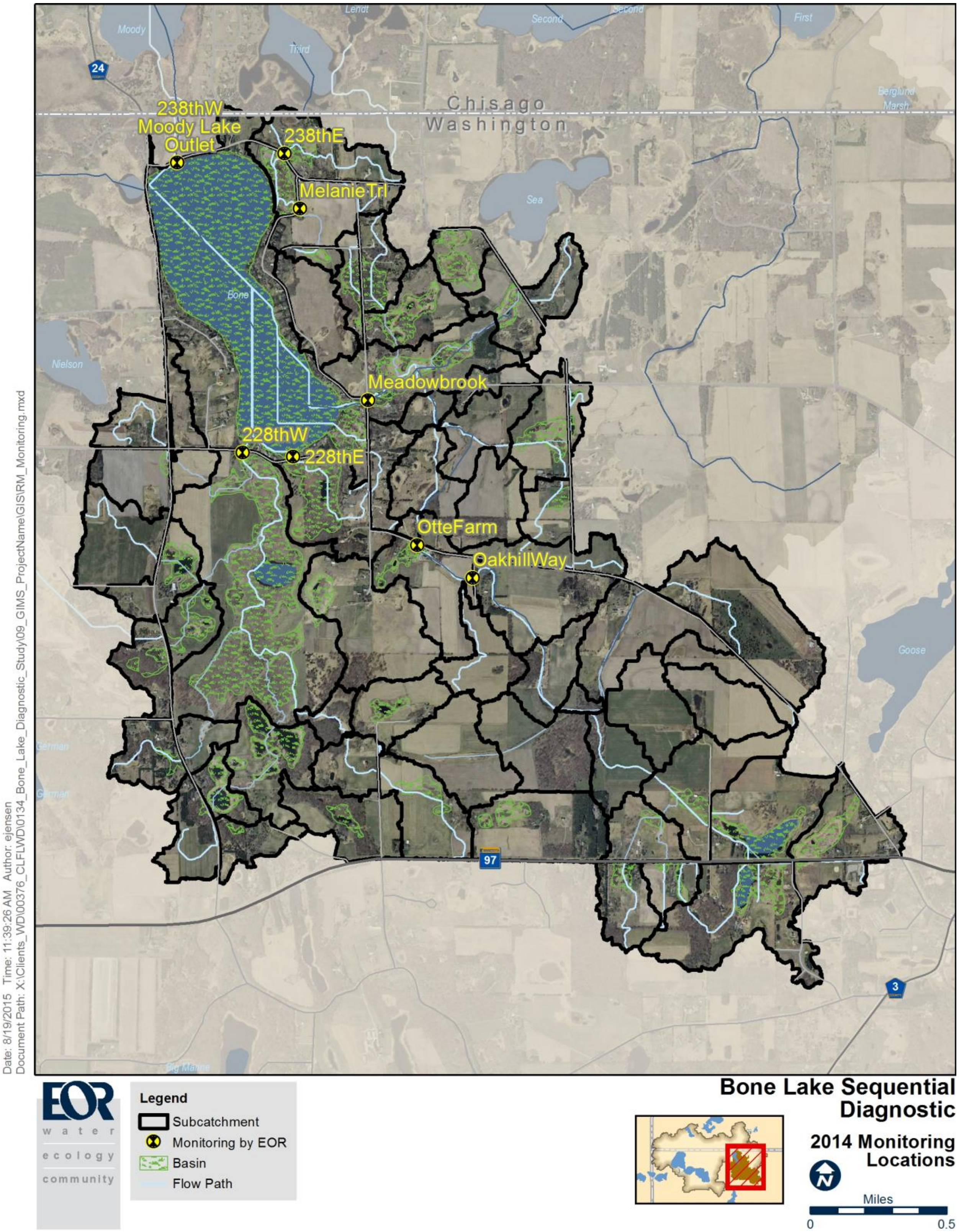

Figure 2. Bone Lake tributary monitoring locations

Flow was flashy at the monitoring sites with small drainage areas (238th E, Melanie Trail, Otte Farm, Oakhill Way). Peak flows ranged from 1.1 cfs at 228th E to almost 20 cfs at 238th W. The 228th E culvert appeared partially plugged and may attenuate peak storm flows through the ditch.

Table 1. Flow present at Bone Lake monitoring sites by date

Date:	March 12	April 2	April10	May 8	May 25	May 29	July 6
Rainfall Event:	Snowmelt	Snowmelt/ 0.15 in.	0.76 in./ 2 days	0.76 in./ 1.5 days	0.49 in./ 2 days	2.19 in./ 1 day	3.25 in./ 1 day
238th W	●	●		●	●	●	●
238th E		●		●	●	●	●
Melanie Trail					●	●	●
Meadowbrook	●		●	●	●	●	●
Otte Farm	●					●	●
Oakhill Way	●						●
228th E	●	●	●	●	●	●	●
228th W	●	●	●	●	●	●	●

Water Quality Data

Instantaneous water quality grab samples were collected at the time of instantaneous flow measurements (described above), and analyzed for total phosphorus (mg/L), ortho-phosphorus (mg/L), and total iron (µg/L). These data were used as inputs to the FLUX32 model to calculate phosphorus loads, and to characterize the reactivity and availability of those phosphorus loads for algal growth.

Total phosphorus concentrations (Table 2) were highest in the early snowmelt period (March 12) and following the two rainfall events of greater than 2 inches in one day (May 29 and July 6). Phosphorus concentrations tend to be highest in early snowmelt due to the first flushing of decomposed organic material that accumulated in fall and was stored under snow cover during the winter. The high phosphorus concentrations observed following the 2 inches per day rainfall events may indicate erosion of sediment bound phosphorus.

The percent of ortho-phosphorus of total phosphorus (Table 3) and iron to phosphorus concentration ratios (Table 4) were calculated for each monitoring site to characterize the reactivity and availability of phosphorus. A high percent of total phosphorus that is ortho-phosphorus indicates that the phosphorus is more reactive and a more effective fertilizer for algae growth. Most of the sites had moderate flow-weighted average (mean) fractions of ortho-phosphorus (42-60%), except a high fraction of ortho-phosphorus at the Otte Farm site (74%) and very low fraction of ortho-phosphorus at the Melanie Trail site (5%). A low iron to phosphorus ratio indicates that there is little natural retention of phosphorus in watershed soils. Most sites had moderate average iron to phosphorus ratios (3-8), except low average iron to phosphorus ratios at the Otte Farm and Oakhill Way sites (< 2).

Table 2. Total phosphorus (P) concentrations at Bone Lake monitoring sites by date

Total Phosphorus (P, mg/L)	March 12 Snowmelt	April 2 Snowmelt/ 0.15 in.	April10 0.76 in./ 2 days	May 8 0.76 in./ 1.5 days	May 25 0.49 in./ 2 days	May 29 2.19 in./ 1 day	July 6 3.25 in./ 1 day	FLUX FWM Conc.*
238th W	0.09	0.11		0.24	0.20	0.09	0.13	**0.12**
238th E		0.23		0.35	0.33	0.29	0.34	**0.31**
Melanie Trail					0.10	3.30	0.47	**3.1**
Meadowbrook	0.93		0.09	0.20	0.24	0.45	0.49	**0.50**
Otte Farm	0.80					3.50	0.60	**0.80**
Oakhill Way	0.76						0.47	**N/A**
228th E	0.28	0.08	0.08	0.07	0.04	0.11	0.17	**0.11**
228th W	0.27	0.08	0.06	0.10	0.08	0.12	0.41	**0.20**

* FLUX Flow-weighted mean (FWM) concentrations from Table 5

Table 3. Ortho-phosphorus (% total P) concentration at Bone Lake monitoring sites by date
High fractions are indicated by gray shading

Ortho-phosphorus (% total P)	March 12 Snowmelt	April 2 Snowmelt/ 0.15 in.	April10 0.76 in./ 2 days	May 8 0.76 in./ 1.5 days	May 25 0.49 in./ 2 days	May 29 2.19 in./ 1 day	July 6 3.25 in./ 1 day	FLUX FWM Ave.*
238th W	46%	36%		50%	38%	45%	35%	**42%**
238th E		40%		54%	48%	59%	59%	**58%**
Melanie Trail					72%	5%	60%	**5%**
Meadowbrook	89%		36%	50%	50%	40%	63%	**60%**
Otte Farm	90%					77%	73%	**74%**
Oakhill Way	79%						68%	**n/a**
228th E	82%	30%	36%	23%	35%	50%	54%	**45%**
228th W	70%	36%	42%	37%	32%	83%	49%	**55%**

* Calculated as the FLUX flow-weighted mean (FWM) average ortho-phosphorus concentration in Table 6 as a percent of the FLUX FWM average total phosphorus concentration in Table 5

Table 4. Iron to total phosphorus ratios at Bone Lake monitoring sites by date
Low ratios are indicated by gray shading

Iron to Total Phosphorus Ratios	March 12	April 2	April10	May 8	May 25	May 29	July 6	Ave.
	Snowmelt	Snowmelt/ 0.15 in.	0.76 in./ 2 days	0.76 in./ 1.5 days	0.49 in./ 2 days	2.19 in./ 1 day	3.25 in./ 1 day	
238th W	7.9	7.8		6.3	5.4	6.6	6.3	**6.7**
238th E		4.4		4.4	4.1	3.8	1.6	**3.7**
Melanie Trail					0.7	14.3	2.0	**5.7**
Meadowbrook	0.4		3.8	3.2	3.9	4.9	2.2	**3.1**
Otte Farm	0.1					0.3	1.0	**0.5**
Oakhill Way	0.3						1.9	**1.1**
228th E	0.4	3.0	14.4	6.5	8.6	4.7	3.4	**5.8**
228th W	1.4	13.9	9.4	8.4	8.1	5.0	5.1	**7.3**

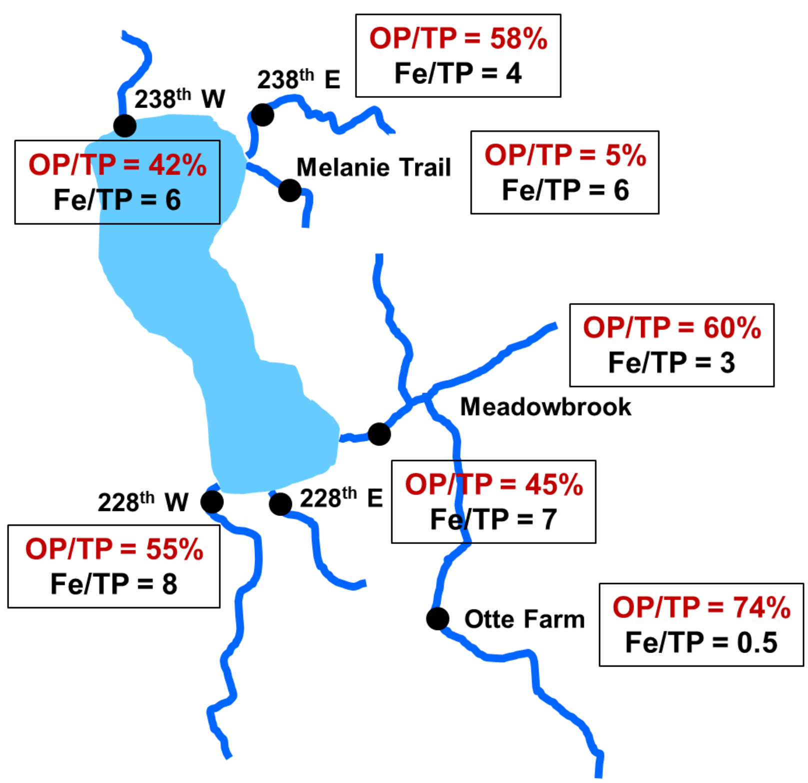

Figure 3. Bone Lake watershed reactivity (Fe/TP) and availability (OP/TP) of phosphorus loads

FLUX Load Estimate

The FLUX32 program was used to calculate total and ortho-phosphorus loads based on the total volume of runoff estimated from the 2015 continuous flow record and an annual flow weighted average phosphorus concentration based on paired grab samples of phosphorus and flow collected across a range of flows. The FLUX32 program also calculates the uncertainty of the load estimates with a Coefficient of Variation (CV).

The total volume of runoff, flow weighted average concentration, total load, and CV for each monitoring site is provided in Table 5 and Figure 4 for total phosphorus and in Table 6 for ortho-phosphorus. The CVs were low (less than 0.2) providing high certainty in the phosphorus loads calculated using FLUX, except for the Otte Farm, Melanie Trail, 228th E, and 228th W sites. Greater uncertainty may have existed at Otte Farm and Melanie Trail due to the flashiness of these sites, and at 228th W due to wetland dampening effects on flow and phosphorus concentration assumptions used by the model.

The total flow, total phosphorus load, and total ortho-phosphorus load estimated for the March 12-July 13, 2015 period was 2.36 cfs, 358 lb, and 175 lb, respectively. Note that the total watershed phosphorus load to Bone Lake estimated by Wenck (2007) was 669 lb/yr for the 2004 benchmark (average) water year. The 2015 total phosphorus load estimate does not represent a full water year and was 54% of the 2004 estimated annual load. Therefore, the loads presented in this report should only be used to compare loads and load reductions among monitoring sites, and not cumulatively as an estimate of the total load to Bone Lake in 2015.

Previous studies (Wenck 2007; 1976 National Biocentric, Inc.) have identified the Moody Lake outflow as the single largest source of total phosphorus to Bone Lake. However, for the 2015 snowmelt/early summer period, Moody Lake represented 42% of the total flow but 18% of the total phosphorus load. Another hotspot identified in previous studies was the 228th W tributary which has a cow farm in its drainage area. However, this site represented 28% of the flow and 21% of the total phosphorus load with the third lowest flow weighted mean phosphorus concentration compared to the other monitoring sites, suggesting that the phosphorus load is not excessive relative to its land use or contribution of flow to Bone Lake. The 2015 monitoring data identified two different hotpots: the Melanie Trail and Meadowbrook tributaries. The Melanie Trail tributary represented 1% of the total flow but 11% of the total phosphorus load monitored in 2015. The Meadowbrook tributary represented 19% of the total flow but 43% of the total phosphorus load. Both of these tributaries contributed a larger fraction of the phosphorus load relative to their fraction of total flow to Bone Lake. These tributary drainage areas should consequently be prioritized for BMP implementation.

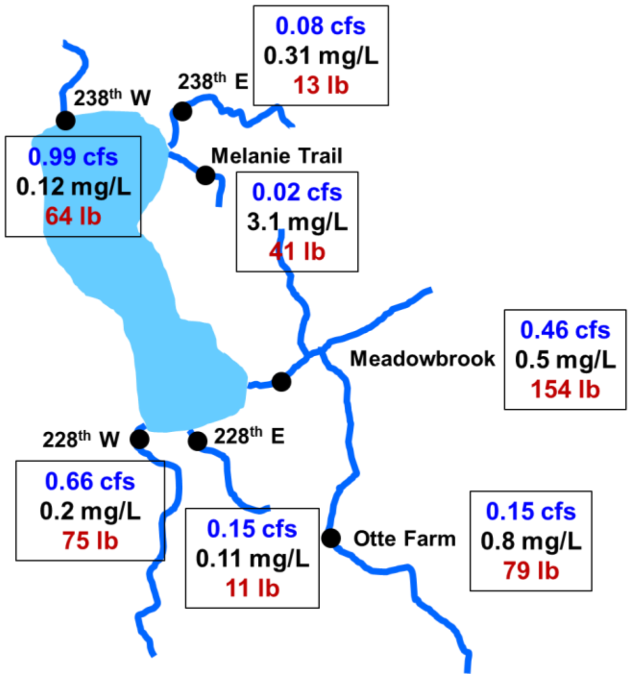

Figure 4. Bone Lake watershed flow, total phosphorus concentration, and total phosphorus loads

Table 5. FLUX total runoff volume, flow weighted average total phosphorus concentration, and total phosphorus load

Site	Runoff volume		Flow weighted average total phosphorus (mg/L)	Total phosphorus load		CV
	(cfs)	(% total)		(lb/yr)	(% total)	
238th W (Moody)	0.99	42%	0.12	64	18%	0.17
238th E	0.08	3%	0.31	13	4%	0.08
Melanie Trail	0.02	1%	3.1	41	11%	N/A
Meadowbrook	0.46	19%	0.49	154	43%	0.06
Otte Farm	0.15	6%	0.80	79	22%	2.03
228th E	0.15	6%	0.11	11	3%	0.21
228th W	0.66	28%	0.20	75	21%	0.53
2015 Monitored Total (excluding Otte Farm)	**2.36**			**358**		

Table 6. FLUX total runoff volume, flow weighted average ortho-phosphorus concentration, and ortho-phosphorus load

Site	Runoff volume		Flow weighted average ortho-phosphorus (mg/L)	Ortho-phosphorus load		CV
	(cfs)	(% total)		(lb/yr)	(% total)	
238th W (Moody)	0.99	42%	0.05	25	14%	0.12
238th E	0.08	3%	0.18	7.7	4%	0.09
Melanie Trail	0.02	1%	0.17	2.3	1%	<0.01
Meadowbrook	0.46	19%	0.30	92	53%	0.17
Otte Farm	0.15	6%	0.59	59	34%	2.1
228th E	0.15	6%	0.05	5.5	3%	0.3
228th W	0.66	28%	0.11	42	24%	0.36
2015 Monitored Total (excluding Otte Farm)	**2.36**			**175**		

BMP SCENARIO MODELING

An existing H & H model for the District – currently built in XPSWMM – was converted to PCSWMM and used as the base model for BMP scenario modeling of the Bone Lake watershed. To facilitate accurate calibration to the monitoring data, necessary improvements to the model were made, including:

- Updating hydrology using the latest GIS datasets
- Updating key hydraulic features such as major crossings (e.g., culverts and bridges)
- Updating storage curves for important water bodies using LiDAR-derived contours

Because PCSWMM facilitates streamlined model parameterization using GIS datasets, watershed-scale model updates are relatively simple. In addition, PCSWMM has been recently enhanced with agriculture-specific modeling tools that enable the generation of field-scale sediment yield estimates via MUSLE, as well as the simulation of both field-based (e.g., conservation tillage and cover cropping) and hydraulic (e.g., construction wetlands and denitrifying bioreactors) BMPs and their impacts on sediment, nitrogen, and phosphorus loading and delivery.

The Storm Water Management Model (SWMM) was developed by the United States Environmental Protection Agency (USEPA) and has undergone significant periodic upgrades since its original release in 1971 – most recently to SWMM5, which was released in 2005. SWMM is a dynamic hydrology-hydraulics-water quality simulation model, which can be used for both single event and long-term (continuous) simulations. A detailed history and description of SWMM5 can be found in James et al. (2010), available for distribution at no cost online at:
http://www.chiwater.com/Publications/Books/r242.asp.

A SWMM model was built and calibrated for the Bone Lake watershed using the OpenSWMM 5.1.909 engine (https://www.openswmm.org/Forum/About) due to its seasonal parameter variation capabilities, and additional functionalities available in the PCSWMM platform (namely the MUSLE soil erosion capabilities). PCSWMM is a decision support tool for EPASWMM, which essentially means it is EPASWMM with a robust GIS pre-processing and graphical post-processing interface. As part of model construction, a field-scale spatial database of cropping, tillage, and fertilization practices was constructed.

Model Construction and Calibration

Subcatchments and channels were derived using the NRCS GIS Engineering Tools ArcToolbox for ArcGIS (ftp://ftp.lmic.state.mn.us/pub/data/elevation/lidar/tools/NRCS_engineering/). Primary inputs to this toolset included the 1-meter LiDAR and culvert locations surveyed by EOR in June 2015. In addition, depressions in the landscape that provide storage were accounted for in the model using stage-storage relationships (storage curves) derived using elevation contours developed from the 1-meter LiDAR. The following meteorological, land use, soil, elevation, and field-scale agricultural practice data were also incorporated into the model:

- Precipitation data collected by EOR using rain gages installed at Wayne Moe's property and the Otte Farm property during the flow monitoring period
- Climate data from the NWS COOP Forest Lake weather station (for estimation of evaporation)
- MNDNR 2011 Minnesota Land Cover Classification System (MLCCS; Figure 28, Appendix D)
- USDA NRCS Soil Survey Geographic Database (SSURGO; Figure 29, Appendix D)

- 1-meter LiDAR (Figure 30, Appendix D)
- Existing inventory of field-scale agricultural practices within the watershed was derived from field verification (e.g., windshield surveys) and GIS methodologies (e.g., historical aerial photography), including:
  - 2015 crops (Figure 31, Appendix D)
  - 2014 crops (Figure 32, Appendix D)
  - Fields with cover crops (Figure 33, Appendix D)
  - Tillage practices (Figure 34, Appendix D)

The model was calibrated for the 2015 monitoring period (March 12-July 13, 2015) using continuous flow and total and ortho-phosphorus concentration data collected at seven EOR-operated locations and two WCD-operated locations (see *Tributary Monitoring* section).

Model Scenario Description

Flow, total phosphorus, and ortho-phosphorus reductions from a set of BMP scenarios were simulated in the model, including:

- Structural BMPs
- Conservation tillage
- Conservation cover
- Contour buffer strips

Structural BMPs

Structural BMPs simulated included three capital improvement projects:

1. *Wetland enhancement upstream of the 228th W monitoring location*: The simulation is based on the 2007 Wenck study design and assumes installation of a transverse sheet pile weir with a crest of 914’, which will create a ~18-acre impoundment at capacity. Load reductions predicted by the SWMM model are primarily due to settling of sediment in the impounded wetland.

2. *Infiltration basin located north of Oakhill Road across from the Otte Farm property*: The simulation is based on the 2007 Wenck study design with some additional assumptions and minor simplifications. Flow is diverted around the Otte Farm property from upstream of the Oakhill Way monitoring location across Oakhill Road (conveyance was simulated as 2 x 24” culverts) where it outlets at 950’ into a ¾-acre pretreatment basin. This basin overflows via a transverse weir with a crest at 948’ into two 1.5-acre infiltration basins connected with a flow equalization pipe (simulated as a single 3-acre basin). The basin bottom is at 944’ and has an overflow pipe at 948’, which outlets back into the channel just downstream of the Otte Farm monitoring location. Based on guidance from the Minnesota Stormwater Manual, the basin was simulated with a design infiltration rate of 0.8 in/hr, which is appropriate for the loamy sand soils present at the site. Load reductions predicted by the SWMM model are primarily due to adsorption of ortho- and total phosphorus by the infiltration basin soils.

3. *Wetland enhancement upstream of the Meadowbrook Avenue monitoring location*: The simulated design assumes installation of a transverse sheet pile weir with a crest of 915’ which will create a ~5-acre impoundment at capacity. Load reductions predicted by the SWMM model are primarily due to settling of sediment in the impounded wetland.

Conservation Tillage

Conservation tillage was applied to all row crop (i.e. corn, soybean, and small grain) fields in the watershed by modifying model input parameters for those fields, and then area weighting those changes to the subcatchment scale. The predicted sediment and phosphorus reductions are the result of increases in depressional storage and Manning's roughness, and a decrease in the MUSLE crop management (C) factor. No conservation tillage was observed in the Bone Lake watershed during the field survey in June 2015, so all fields were initially assumed to be under management by conventional tillage (Note: several no-tillage and conservation tillage soybean fields were spotted during the field survey, but these were all located in the Moody Lake watershed).

Conservation Cover

Conservation cover was applied only to those fields tributary to the Melanie Trail monitoring point (a known sediment and phosphorus hotspot) to provide an estimate of the upper limit to possible load reductions from this area. Additionally, this scenario allows comparison with the reduction estimates from the other field-based BMP scenarios. This practice essentially constitutes retiring the land from row crop production by changing those fields to established forage crops. The predicted sediment and phosphorus reductions are the result of increases in depressional storage and Manning's roughness, and a decrease in the MUSLE crop management (C) factor.

Contour Buffer Strips

Contour buffer strips were accounted for by locating fields with average slopes between 4% and 15% and reducing the MUSLE conservation practice (P) factor. Fields were vetted superficially for the presence of concentrated flow paths (which to some extent preclude the applicability of the practice), but a more rigorous analysis may need to be conducted on a field-by-field basis to determine the appropriateness of practice implementation. Additionally, because a rigorous terrain analysis was not conducted as part of this practice investigation, the P factor reduction is based on a conservative estimate assuming the buffer strips are applied on areas with 10% slope. Buffer strips implemented on slopes greater than 10% will likely see additional reductions beyond the estimates reported here.

Results

Modeled reductions for base scenario, structural BMPs, conservation tillage, conservation cover, contour buffer strips, and all practices at each monitoring site are summarized in Table 7 (flow volume), Table 8 (sediment-bound phosphorus), and Table 9 (ortho-phosphorus) below. Additionally, sediment-bound phosphorus reductions in lb/ac per row crop land were represented graphically at the field-scale to aid targeting of specific areas/landowners within a subwatershed for implementation of conservation tillage, conservation cover, and contour buffer strips in Appendix E.

Modeled sediment-bound and ortho-phosphorus reductions for all practices are summarized in Table 10 by monitoring site. The sum of sediment-bound and ortho-phosphorus reductions is roughly equivalent to the total phosphorus reduction. The total phosphorus reduction for all practices is 117 lb for the modeling time period (March 12-July 13, 2015), representing a 40% reduction in watershed runoff loads. Note that the loads and load reductions stated in this table only represent the 2015 4-month modeled period (March 12-July 13, 2015) and do not represent a full year. Full year loads and reductions will be significantly larger than the values in this table if the 2015 monitoring period extended for 12-months. Watershed runoff to Bone Lake needs to be reduced by 45%, in addition to other load reductions from Moody Lake and internal sources, to achieve an in-lake water quality phosphorus concentration of 40 µg/L (EOR 2010).

Table 7. Modeled implementation scenario flow volume reductions by monitoring site

Flow Volume Reduction (%)	Base Scenario	Structural BMPs	Conservation Tillage	Conservation Cover	Contour Buffer Strips	All Practices
238th E	0%	0%	0%	n/a	0%	**0%**
Melanie Trail	0%	0%	**6%**	**8%**	0%	***8%**
Meadowbrook	0%	**23%**	0%	n/a	0%	**23%**
Otte Farm	0%	**61%**	**2%**	n/a	0%	**61%**
Oakhill Way	0%	**78%**	0%	n/a	0%	**78%**
228th E	0%	0%	0%	n/a	0%	**0%**
228th W	0%	**34%**	0%	n/a	0%	**34%**

* Assumes reductions from the conservation cover scenario

Table 8. Modeled implementation scenario sediment-bound phosphorus load reductions by monitoring site

Total Phosphorus Load Reduction (%)	Base Scenario	Structural BMPs	Conservation Tillage	Conservation Cover	Contour Buffer Strips	All Practices
238th E	0%	0%	0%	n/a	0%	**0%**
Melanie Trail	0%	0%	**25%**	**87%**	**6%**	***87%**
Meadowbrook	0%	**15%**	**45%**	n/a	**5%**	**56%**
Otte Farm	0%	0%	0%	n/a	0%	**0%**
Oakhill Way	0%	0%	0%	n/a	0%	**0%**
228th E	0%	0%	0%	n/a	0%	**0%**
228th W	0%	**36%**	**43%**	n/a	**3%**	**69%**

* Assumes reductions from the conservation cover scenario

Table 9. Modeled implementation scenario ortho-phosphorus load reductions by monitoring site

Ortho Phosphorus Load Reduction (%)	Base Scenario	Structural BMPs	Conservation Tillage	Conservation Cover	Contour Buffer Strips	All Practices
238th E	0%	0%	0%	n/a	0%	**0%**
Melanie Trail	0%	0%	**8%**	**22%**	0%	***22%**
Meadowbrook	0%	**17%**	**1%**	n/a	0%	**18%**
Otte Farm	0%	**61%**	0%	n/a	0%	**61%**
Oakhill Way	0%	**78%**	0%	n/a	0%	**78%**
228th E	0%	0%	0%	n/a	0%	**0%**
228th W	0%	**21%**	0%	n/a	0%	**21%**

* Assumes reductions from the conservation cover scenario

Table 10. Summary of modeled sediment-bound and ortho-phosphorus reductions for all practices by watershed runoff monitoring sites discharging to Bone Lake

Watershed runoff monitoring sites discharging to Bone Lake	Sediment-bound Phosphorus			Ortho-Phosphorus			Total Phosphorus	
	Existing Load (lb)	Reduction (%)	Reduction (lb)	Existing Load (lb)	Reduction (%)	Reduction (lb)	Existing Load (lb)	Reduction (lb)
238th E	5.3	0%	**0.0**	7.7	0%	**0.0**	13	**0.0**
Melanie Trail	38.7	87%	**33.7**	2.3	22%	**0.5**	41	**34.2**
Meadowbrook	62	56%	**34.7**	92	18%	**16.6**	154	**51.3**
228th E	5.5	0%	**0.0**	5.5	0%	**0.0**	11	**0.0**
228th W	33	69%	**22.8**	42	21%	**8.8**	75	**31.6**
2015 Monitored Total (% Existing)	144.5		**91.2 (63%)**	149.5		**25.9 (17%)**	294	**117.0 (40%)**

Note: The loads and load reductions stated in this table only represent the 2015 4-month modeled period (March 12-July 13, 2015) and do not represent a full year. Full year loads and reductions will be significantly larger than the values in this table if the 2015 monitoring period extended for 12-months.

RECOMMENDATIONS AND COST-EFFECTIVENESS

Two hotspots were identified through the 2015 monitoring: the Melanie Trail and Meadowbrook tributaries. The Melanie Trail tributary represented 1% of the total flow but 11% of the total phosphorus load monitored in 2015. The Meadowbrook tributary represented 19% of the total flow but 43% of the total phosphorus load. Both of these tributaries contributed a larger fraction of the phosphorus load relative to their fraction of total flow to Bone Lake. These tributary drainage areas should consequently be prioritized for BMP implementation.

Additionally, the 228th W monitoring site contributed 21% of the total phosphorus load with a moderate flow-weighted mean phosphorus concentration (0.2 mg/L). The 228th W monitoring site is located downstream of a large wetland complex which provides phosphorus removal for agricultural practices located upstream of the wetland. Therefore, implementation in this drainage area should also be a priority for the District to preserve the phosphorus removal capacity of the wetland complex.

Recommended implementation scenarios based on the 2015 monitoring and SWMM simulations, including their cost-effectiveness, are described by the three priority tributary drainage areas below. The EQIP payment for installing conservation cover is generally $122/ac (Ag BMP Handbook, EOR 2012). The cost of contour buffer strips is dependent upon value of the land taken out of production, buffer installation, plant establishment, and maintenance. According to the Ag BMP Handbook, installation cost is approximately $52/ac and land opportunity cost is approximately $56/ac for a total estimated cost of $108/ac. Conservation tillage is approximately $26/ac. **The costs in this report are intended for planning purposes only; more detailed cost estimates will need to be developed through feasibility and design of the individual projects.**

Melanie Trail

High phosphorus loads at the Melanie Trail site are the result of agricultural practices on fields with soils of naturally high erosion potential. Gullies were observed on these farm fields on the crest of hills during the field survey of agricultural practices by EOR, the CLFLWD Administrator and Chisago SWCD technician. The most effective practices identified in this drainage area were:

- conservation tillage or conservation cover on 31.5 acres of cropland.

Conservation tillage was estimated to reduce sediment-bound phosphorus loads by 25% and ortho-phosphorus loads by 8%, for a total of phosphorus reduction of 10 lb/yr. The estimated cost for 31.5 acres of conservation tillage is $819/yr, for a total cost-effectiveness of $82/lb/yr. Alternatively, permanent conservation cover on these fields, via land acquisition or conservation easement, was estimated to reduce sediment-bound phosphorus loads by 87% and ortho-phosphorus loads by 22%, for a total of phosphorus reduction of 34 lb/yr. The estimated cost for 31.5 acres of conservation cover is $3,843/yr, for a total cost-effectiveness of $113/lb/yr.

Meadowbrook

The cause of high phosphorus loads at the Meadowbrook monitoring location is not clear given the high infiltration capacity of most of the upstream portion of the drainage area. There was a large, shallow groundwater component of the flow and phosphorus load budget for this drainage area. Peak stream flows were slightly attenuated and delayed by several hours following rainfall events, suggesting infiltration of rainfall into shallow, groundwater which then travels to the stream.

The most effective practices identified in this drainage area were a combination of:

- a 3-acre infiltration basin located north of Oakhill Road across from the Otte Farm property,
- a 5-acre wetland enhancement located just upstream of the Meadowbrook Avenue monitoring site,
- conservation tillage on 156 acres of cropland,
- and contour buffer strips on 5% of the 143 acres of suitable cropland.

Implementation of all of these practices was estimated to reduce sediment-bound phosphorus loads by 32% and ortho-phosphorus loads by 17%, for a total phosphorus reduction of 36 lb/yr. 20-year estimated costs for these practices are $490,000 for the 3-acre infiltration basin, $120,000 for the 5-acre wetland enhancement, $81,120 for conservation tillage, and $15,444 for contour buffer strips, for a total cost-effectiveness of $981/lb/yr.

228th West

The most effective practices identified in this drainage area were a combination of:

- an 18-acre wetland enhancement just upstream of the 228th W monitoring site,
- conservation tillage on 208 acres of cropland,
- and contour buffer stripping on 5% of the 200 acres of suitable cropland.

Conservation tillage and contour buffer stripping were modeled to have high sediment-bound phosphorus reductions in several subwatersheds (S60, S37, S22, S24, and S64) upstream of the 228th W monitoring site wetland. In addition, a large wetland complex just upstream of the 228th W monitoring site could be impounded to increase phosphorus removal. Implementation of all of these practices was estimated to reduce sediment-bound phosphorus loads by 56% and ortho-phosphorus loads by 21% for a total phosphorus reduction of 27 lb/yr. 20-year estimated costs for these practices are $480,000 for the 18-acre wetland enhancement, $108,160 for conservation tillage, and $21,600 for contour buffer strips, for a total cost-effectiveness of $1,129/lb/yr. Implementation of conservation tillage and contour buffer stripping only was estimated to reduce sediment-bound phosphorus loads by 43% for a total phosphorus reduction of 14 lb/yr. Based on 20-year costs for these practices listed above results in a total cost-effectiveness of $463/lb/yr.

Implementation Priorities

We recommend that practices identified in this report be implemented in the following order, according to increasing cost-effectiveness:

1. Conservation cover on 31.5 acres of cropland in the Melanie Trail site drainage area
(high cost-effectiveness)
2. Conservation tillage and contour buffer strips on cropland throughout the watershed, beginning with fields identified in red, then orange, then yellow, etc, according to Figure 35 and Figure 37 in Appendix E
(high cost-effectiveness)
3. Infiltration basin north of the Otte Farm in the Meadowbrook site drainage area
(moderate cost-effectiveness)
4. 5-acre wetland enhancement in the Meadowbrook site drainage area
(low cost-effectiveness)
5. 20-acre wetland enhancement in the 228th W site drainage area
(low cost-effectiveness)

REFERENCES

Emmons & Olivier Resources, Inc. 2010. Comfort Lake-Forest Lake Watershed District Six Lakes Total Maximum Daily Load Study. Prepared for the Comfort Lake-Forest Lake Watershed District and the Minnesota Pollution Control Agency.

National Biocentric, Inc. 1976. Bone Lake Nutrient Budget Study. Prepared for the Washington County Planning Comission. 49 pages.

Wenck Associates, Inc. 2007. Watershed and Lake Water Quality Modeling Investigation for the Development of a Watershed Capital Improvement Plan. Prepared for the Comfort Lake-Forest Lake Watershed District.

APPENDIX A. CONTINUOUS FLOW AND PRECIPITATION RECORDS

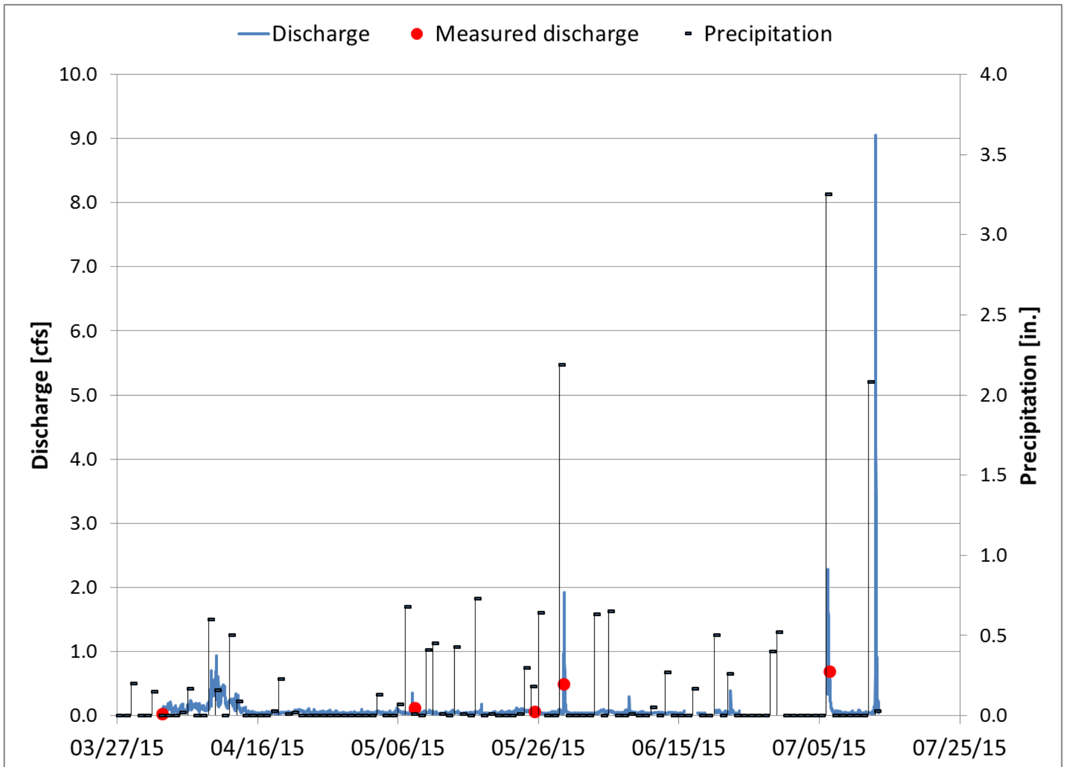

Figure 5. 238th E continuous flow and Scandia, MN precipitation (2015)

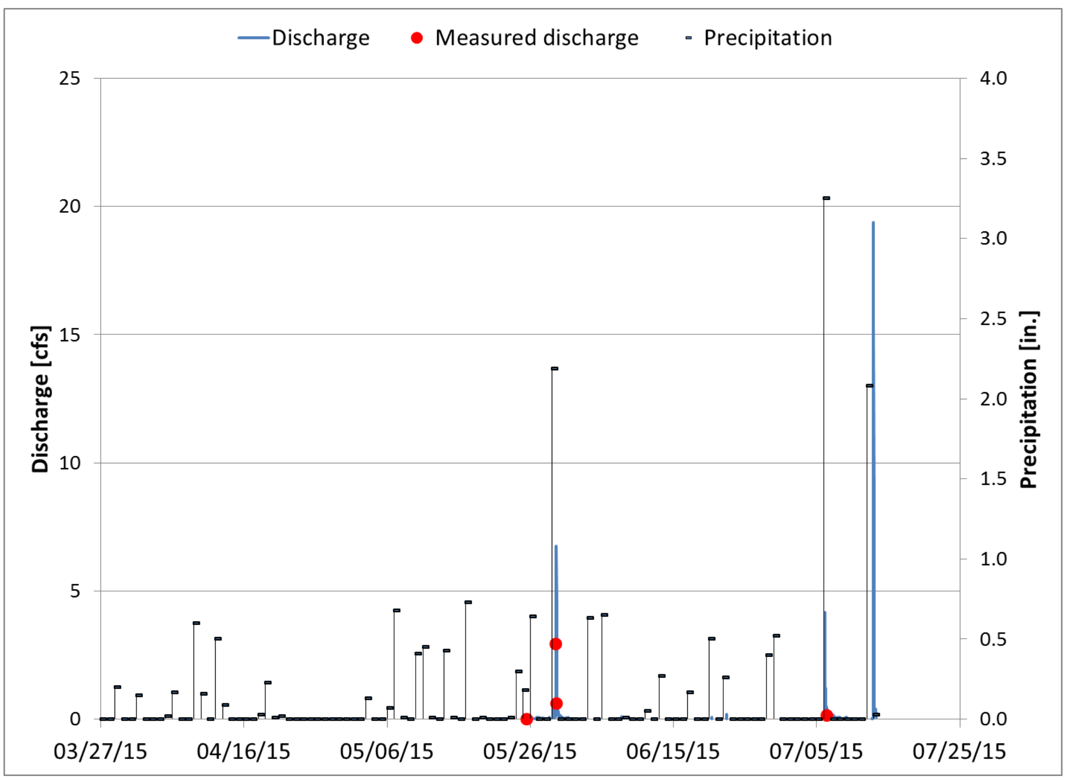

Figure 6. Melanie Trail continuous flow and Scandia, MN precipitation (2015)

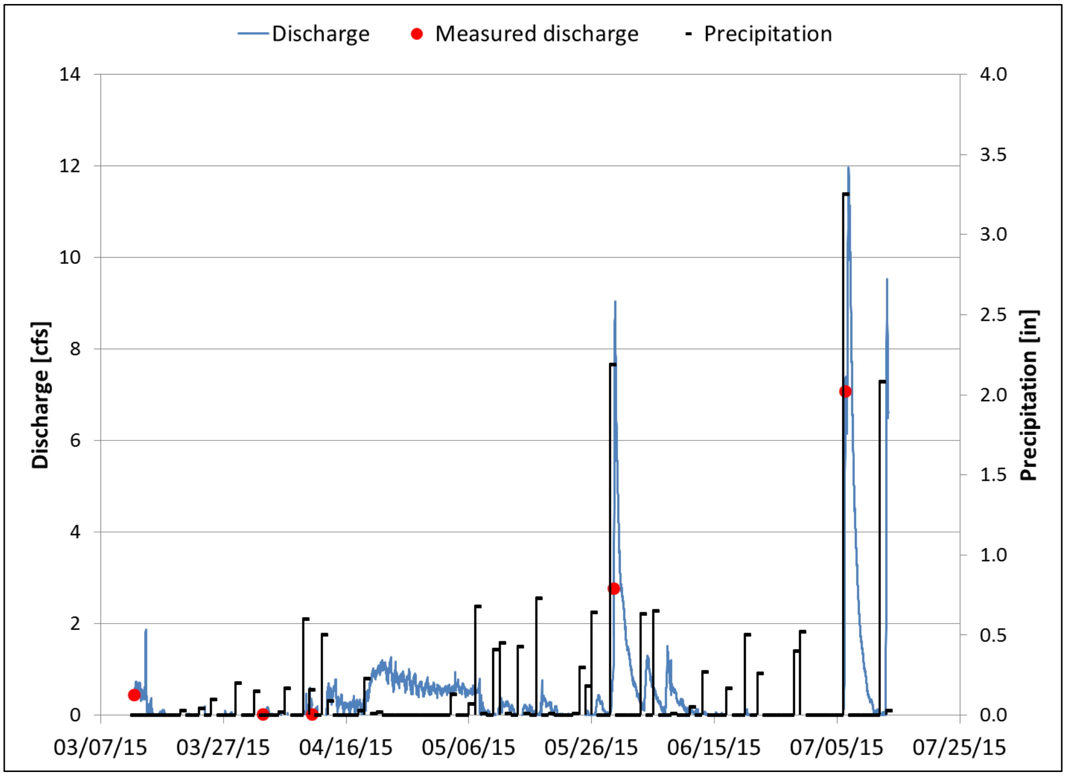

Figure 7. Meadowbrook continuous flow and Scandia, MN precipitation (2015)

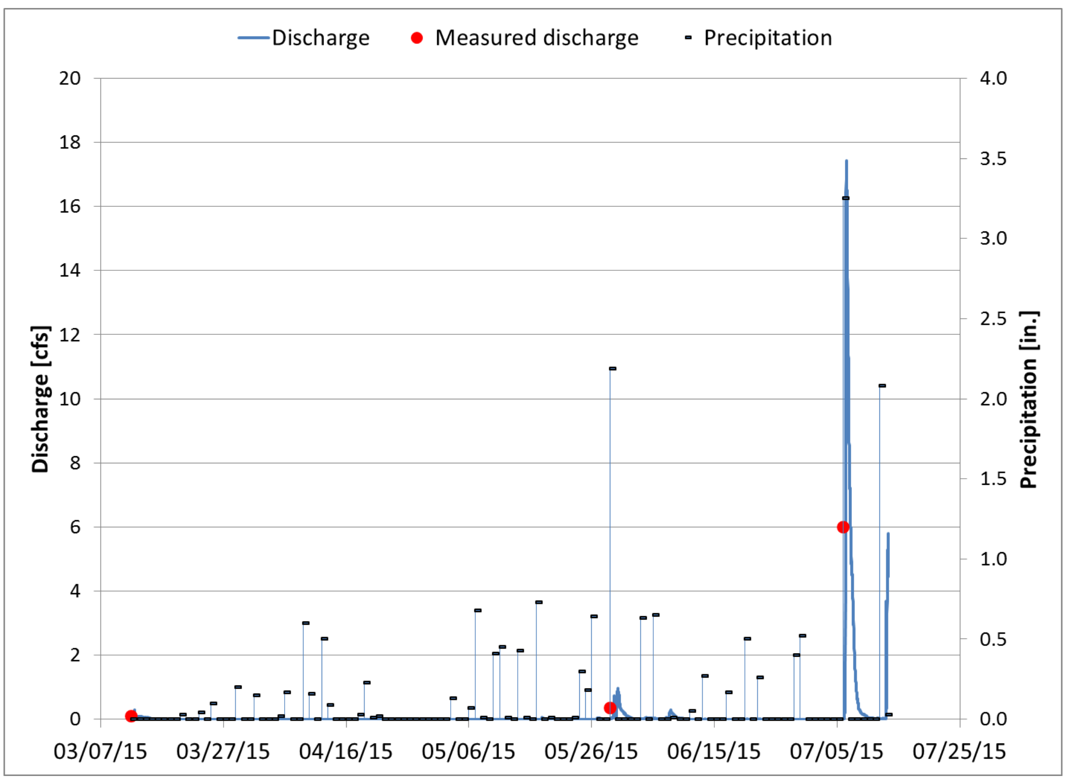

Figure 8. Otte Farm continuous flow and Scandia, MN precipitation (2015)

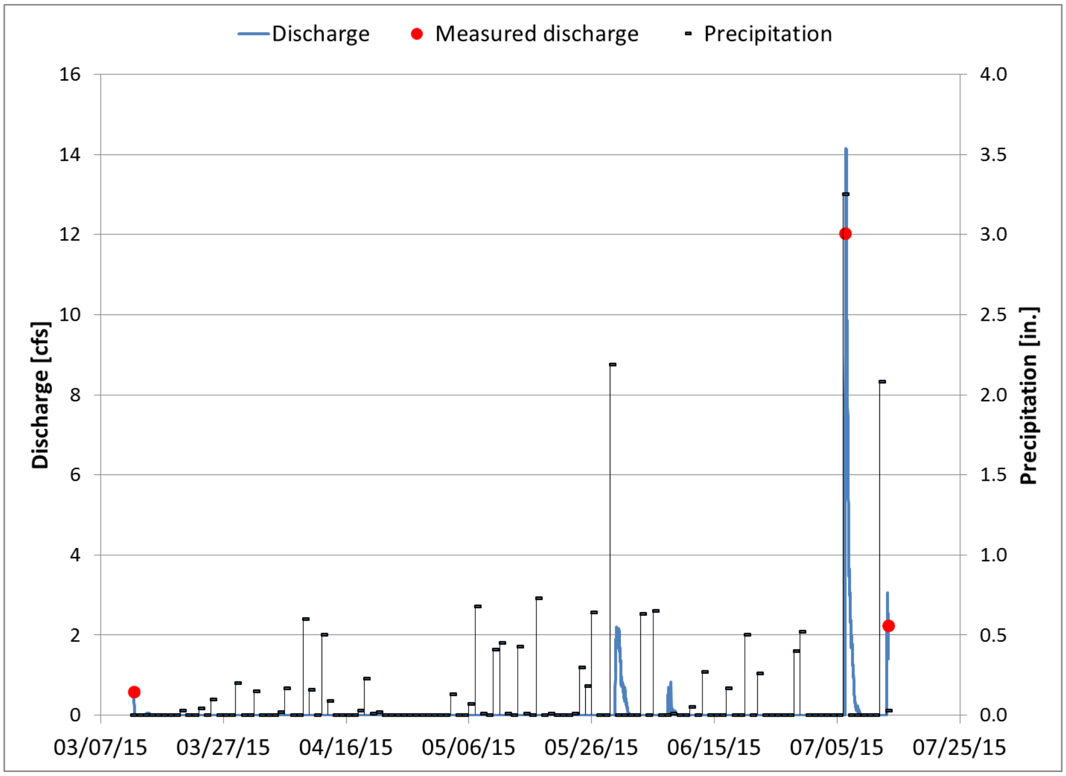

Figure 9. Oakhill Way continuous flow and Scandia, MN precipitation (2015)

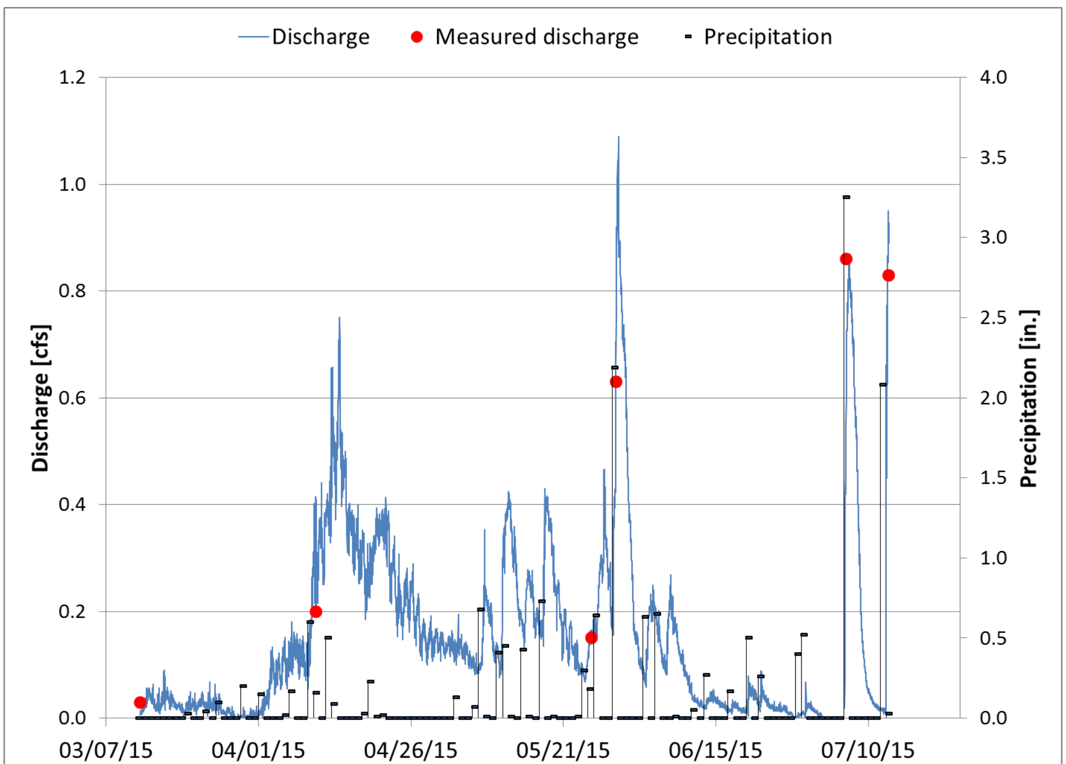

Figure 10. 228th E continuous flow and Scandia, MN precipitation (2015)

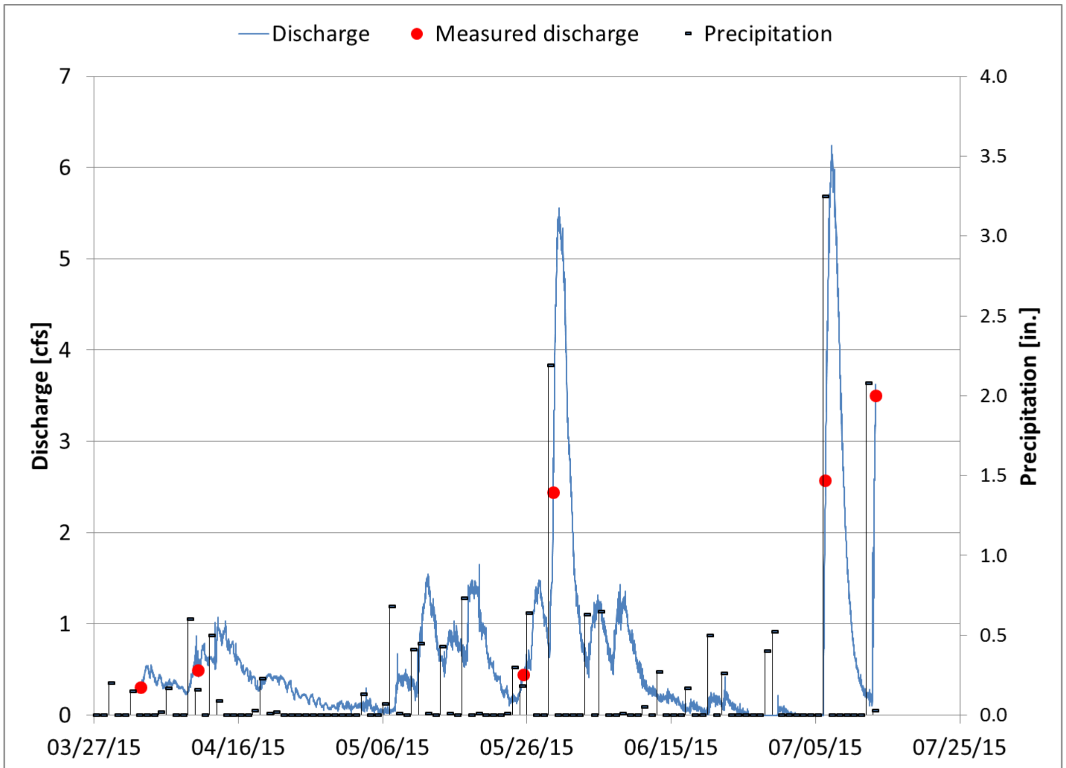

Figure 11. 228th W continuous flow and Scandia, MN precipitation (2015)

APPENDIX B. RATING CURVES

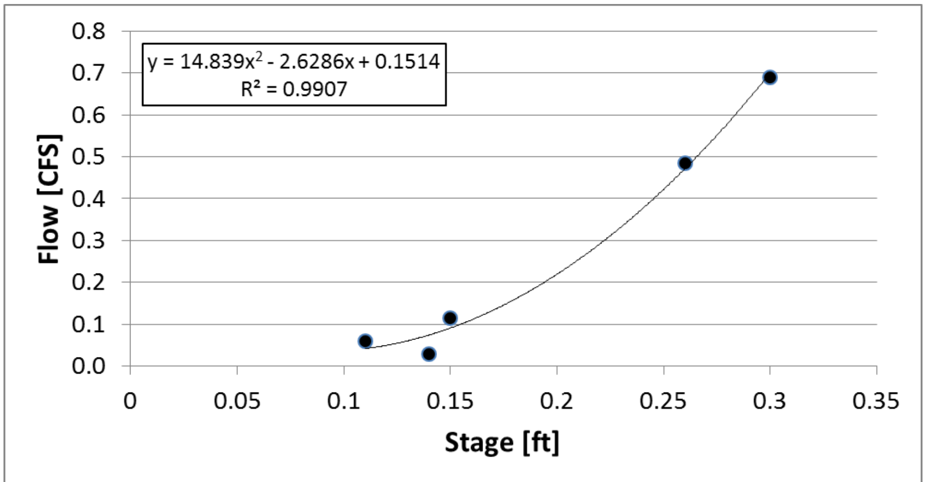

Figure 12. 238th E rating curve (2015)

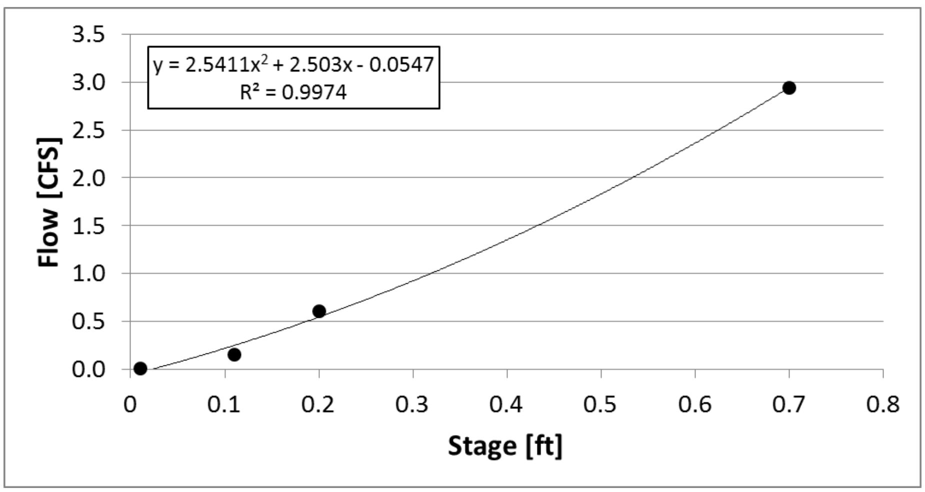

Figure 13. Melanie Trail rating curve (2015)

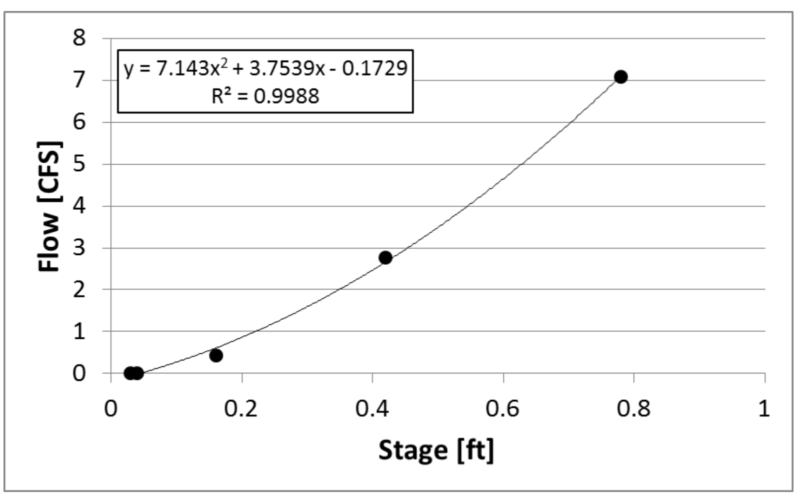

Figure 14. Meadowbrook rating curve (2015)

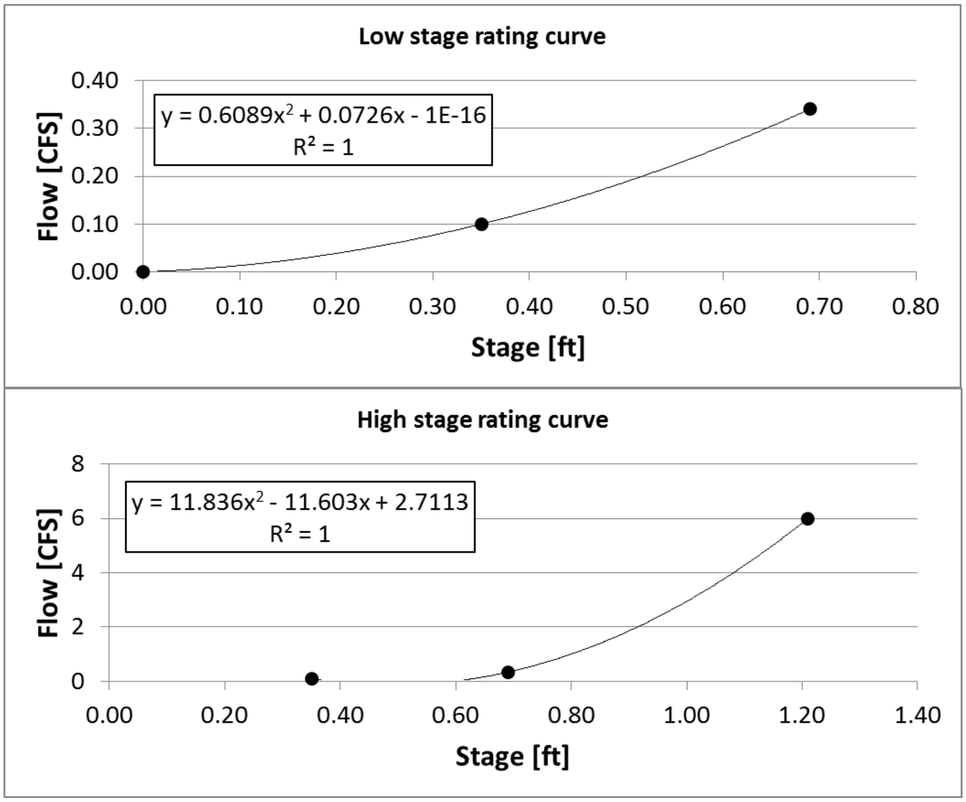

Figure 15. Otte Farm rating curve (2015)

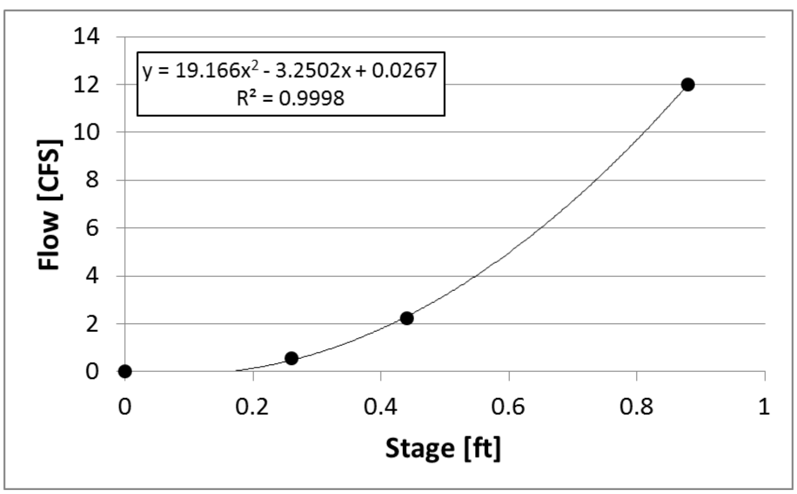

Figure 16. Oakhill Way rating curve (2015)

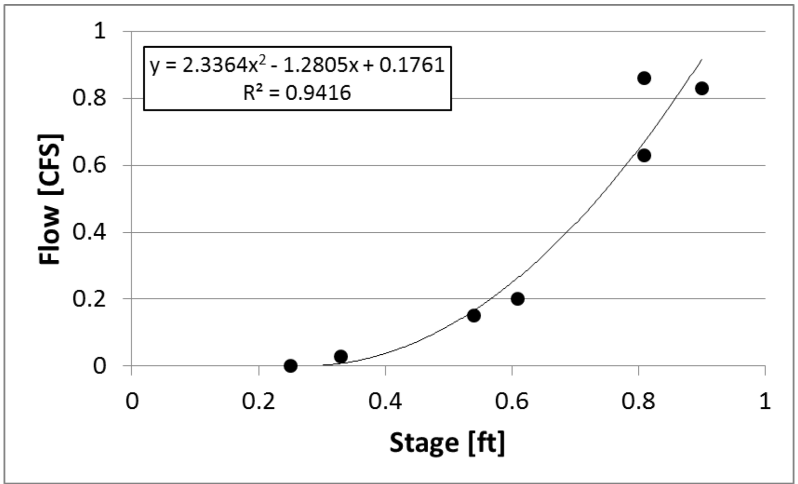

Figure 17. 228th E rating curve (2015)

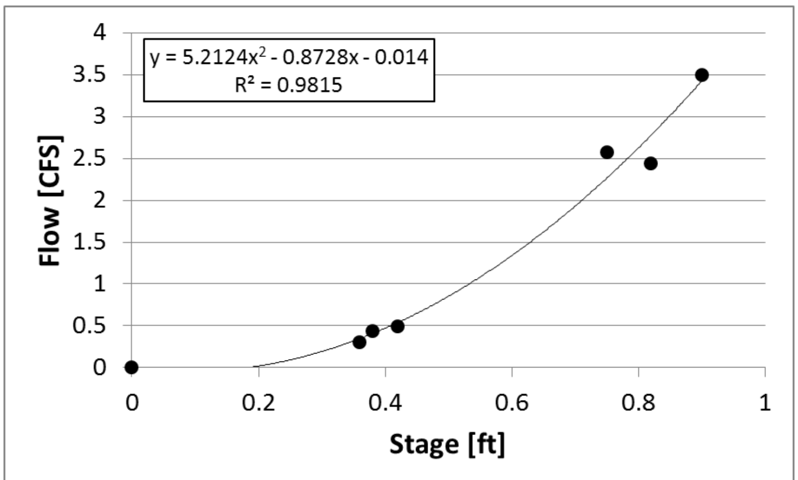

Figure 18. 228th W rating curve (2015)

APPENDIX C. CONTINUOUS FLOW AND TOTAL PHOSPHORUS

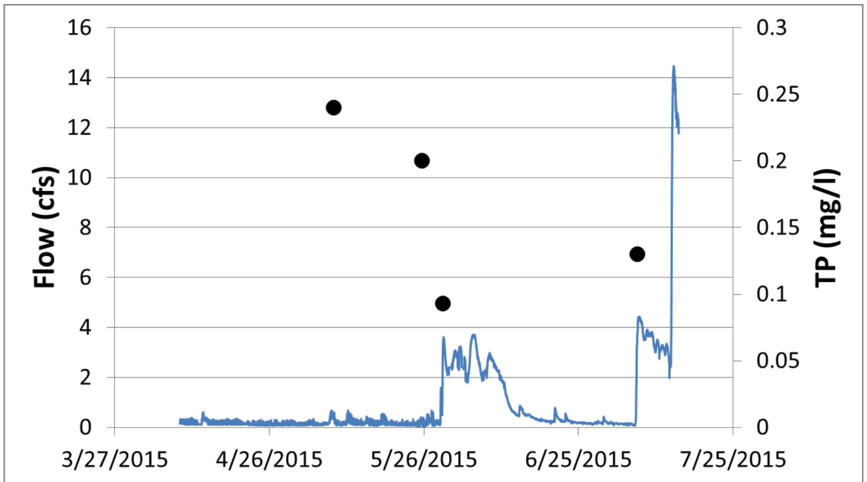

Figure 19. 238th W continuous flow and total phosphorus concentration (2015)

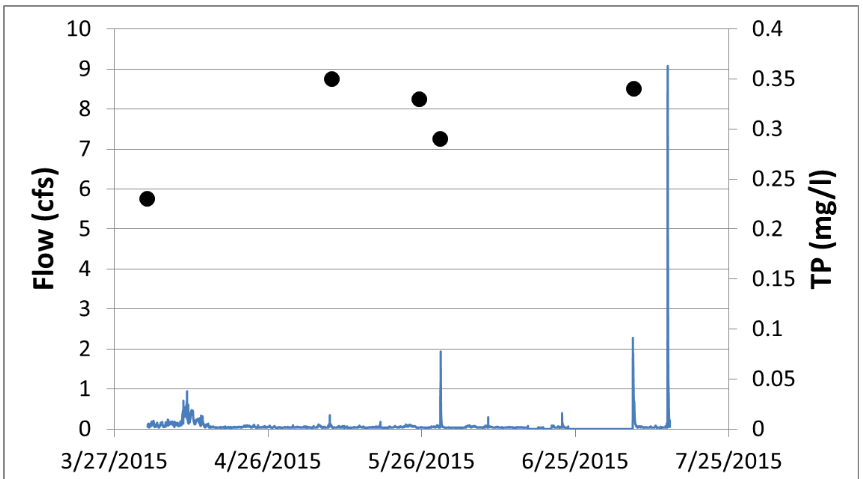

Figure 20. 238th E continuous flow and total phosphorus concentration (2015)

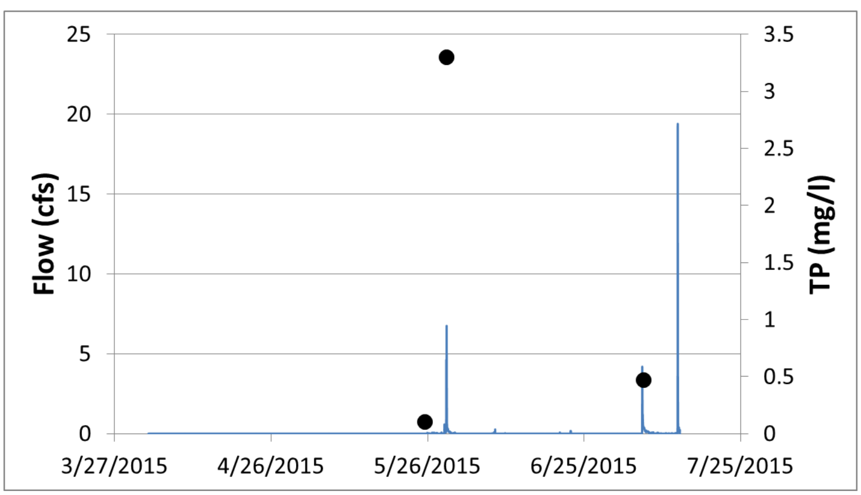

Figure 21. Melanie Trail continuous flow and total phosphorus concentration (2015)

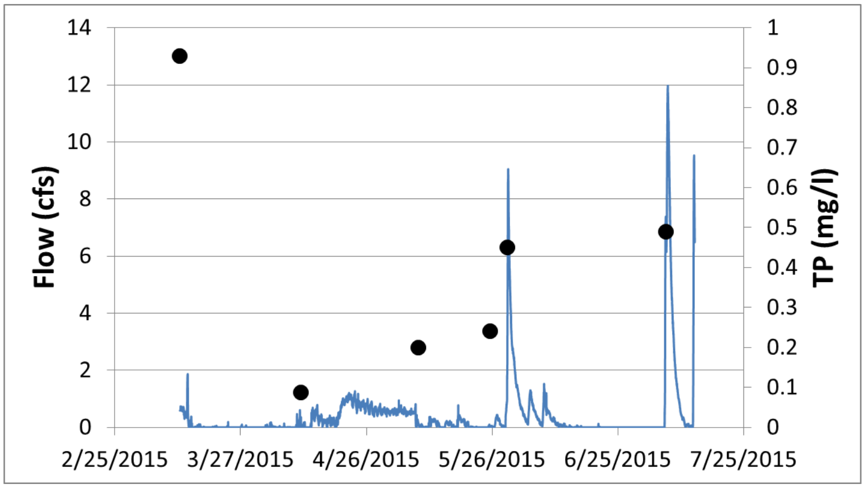

Figure 22. Meadowbrook continuous flow and total phosphorus concentration (2015)

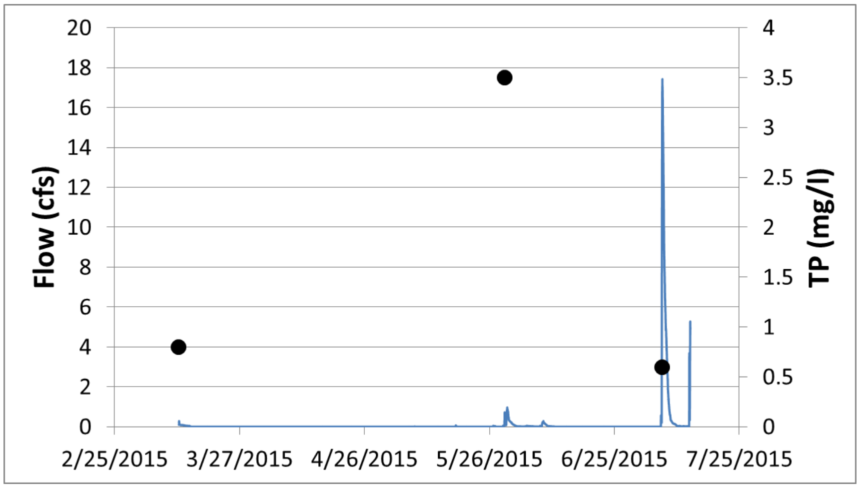

Figure 23. Otte Farm continuous flow and total phosphorus concentration (2015)

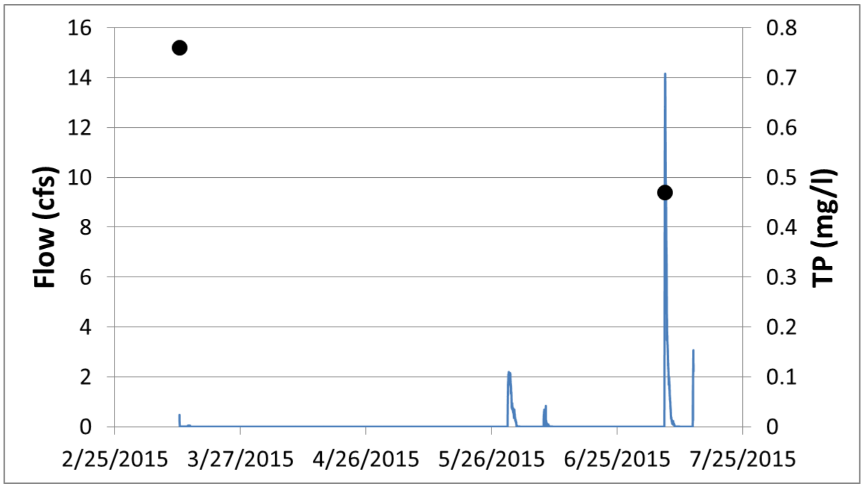

Figure 24. Oakhill Way continuous flow and total phosphorus concentration (2015)

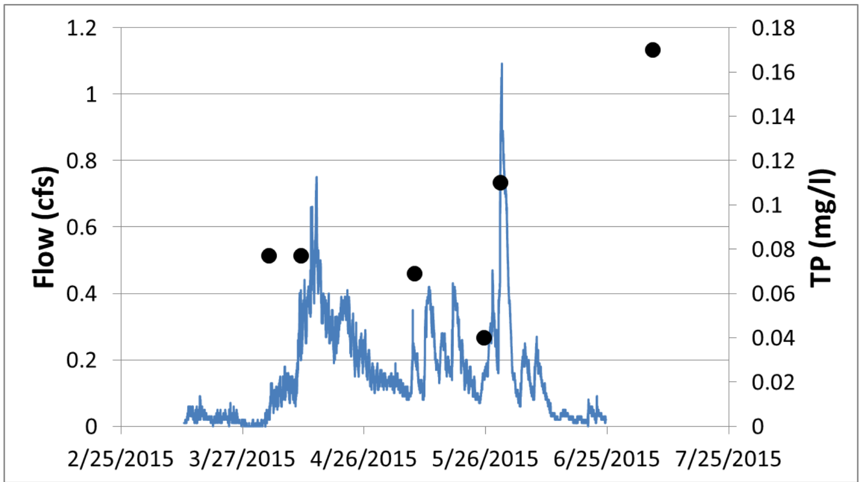

Figure 25. 228th E continuous flow and total phosphorus concentration (2015)

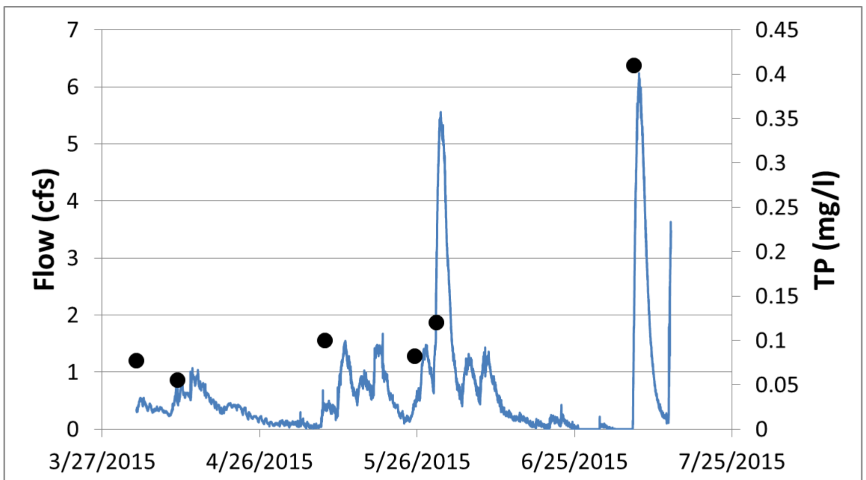

Figure 26. 228th W continuous flow and total phosphorus concentration (2015)

APPENDIX D. SWMM MODEL INPUTS

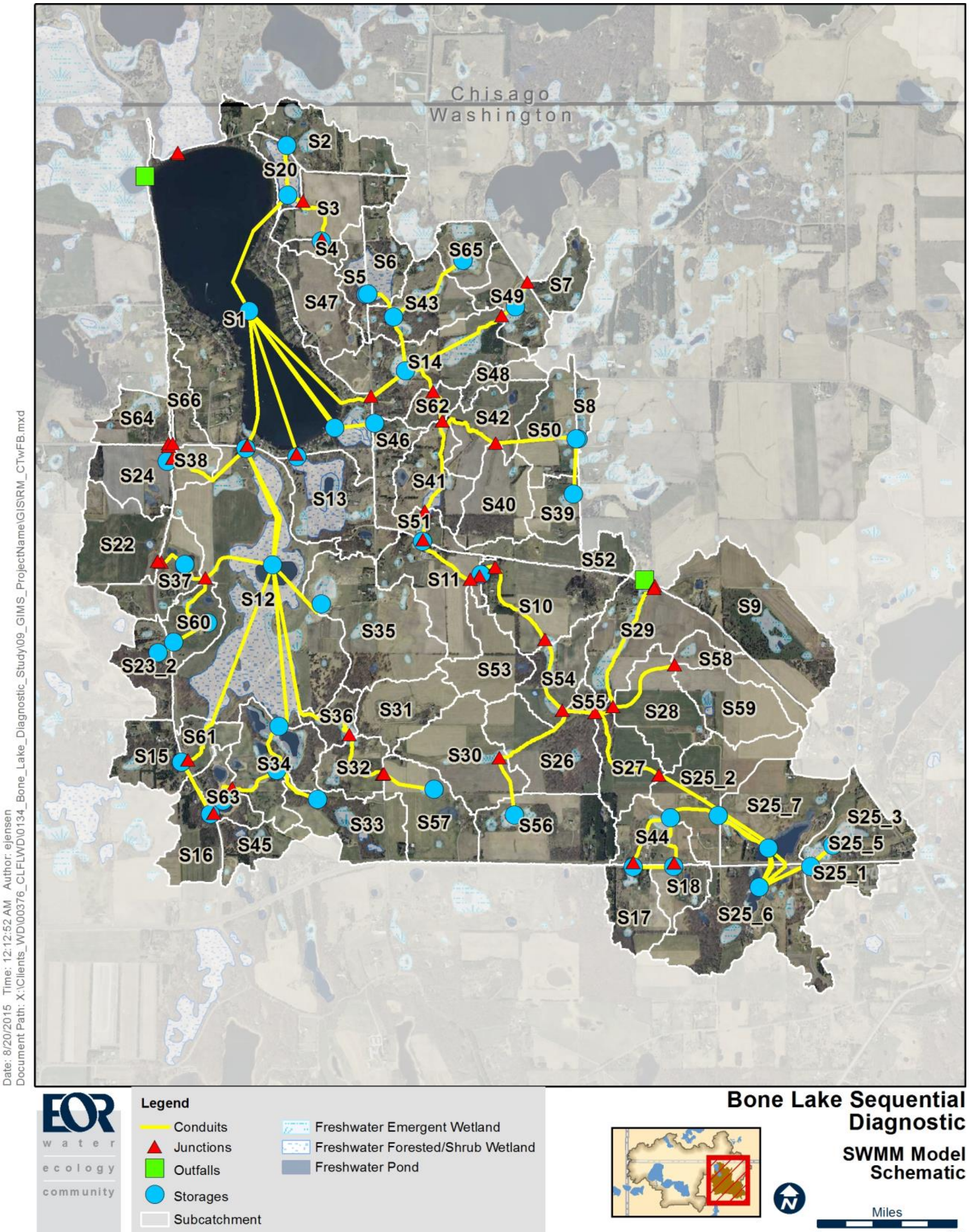

Figure 27. Bone Lake watershed SWMM model schematic

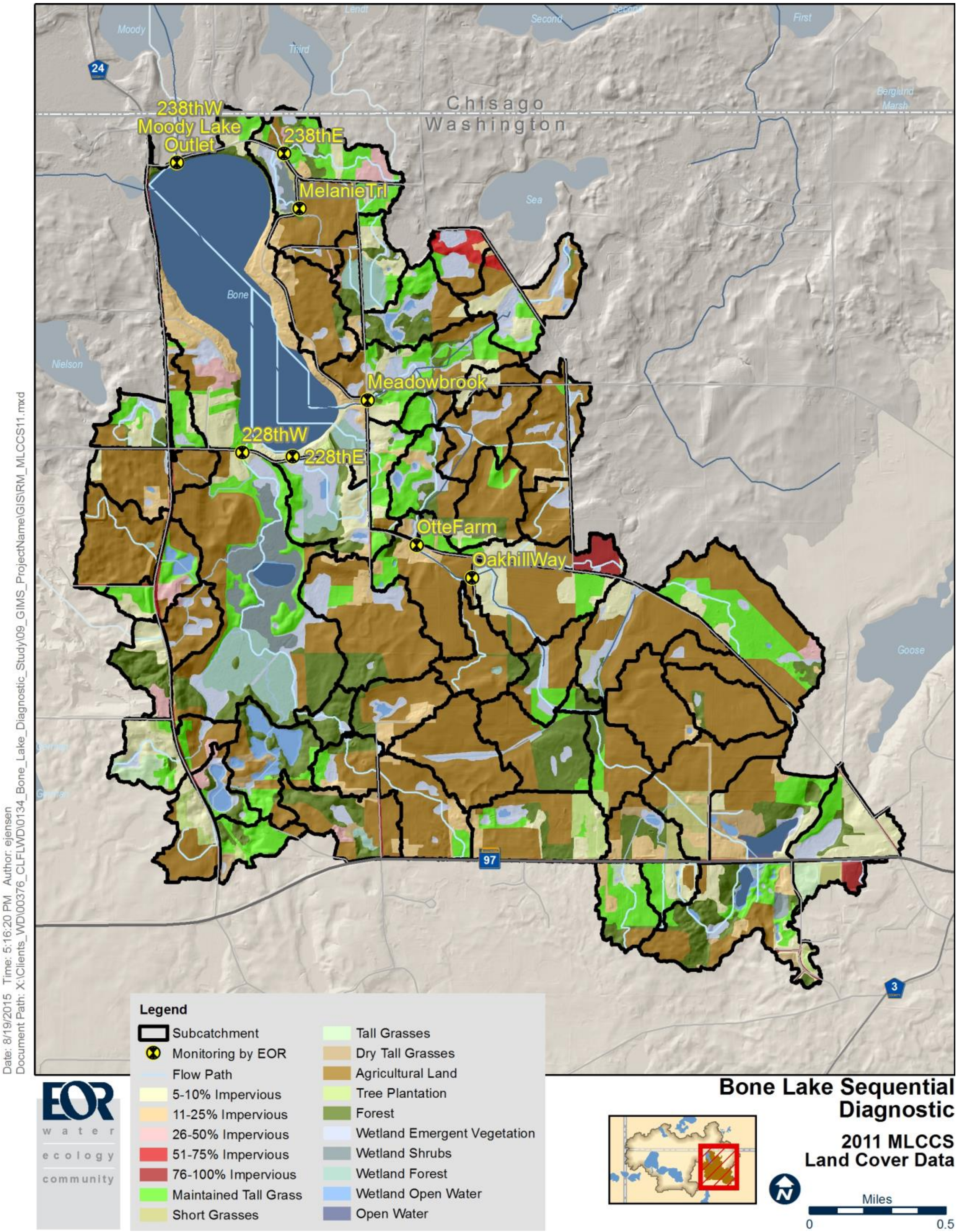

Figure 28. Bone Lake Watershed 2011 MLCCS Land Cover

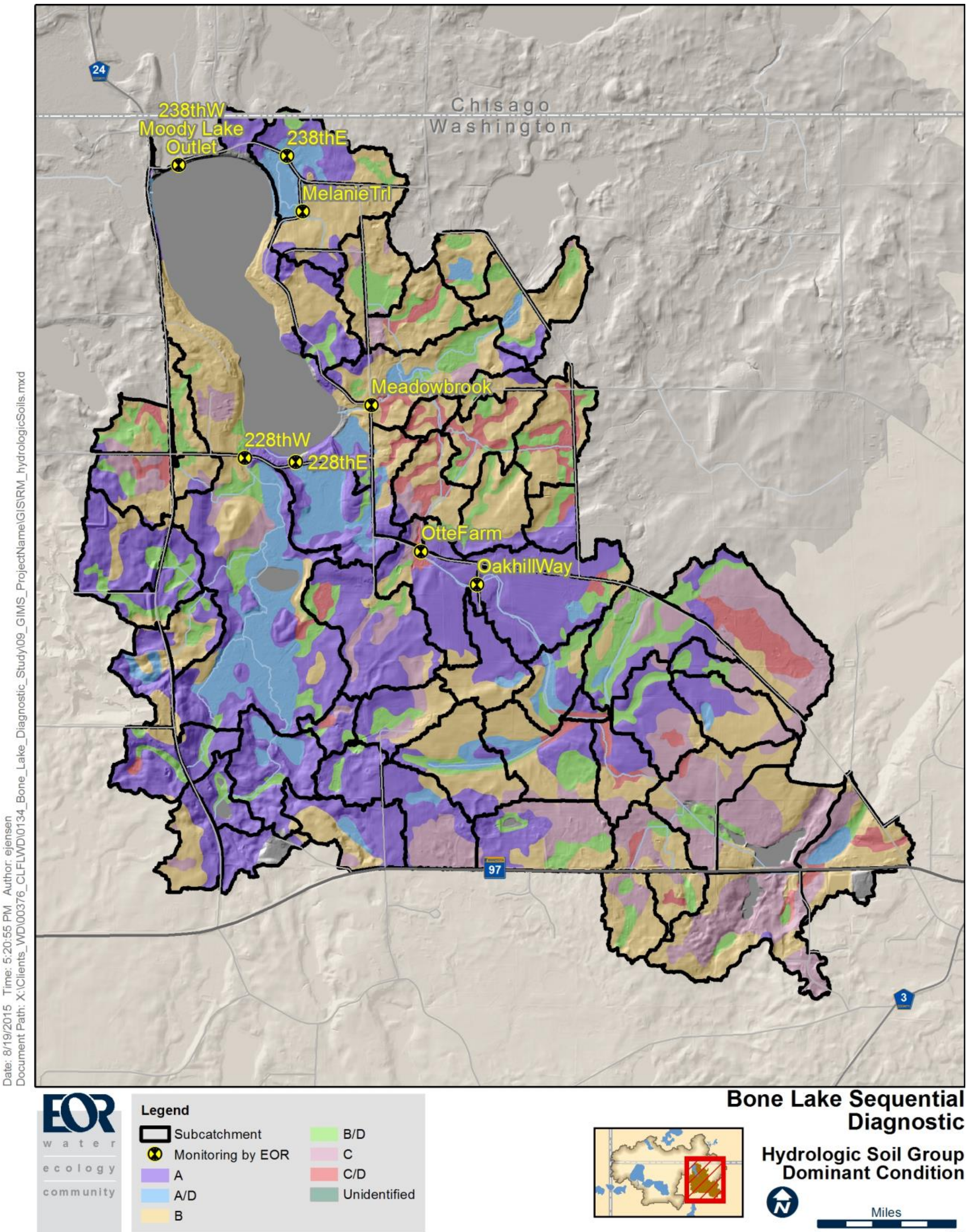

Figure 29. Bone Lake Watershed Hydrologic Soil Groups

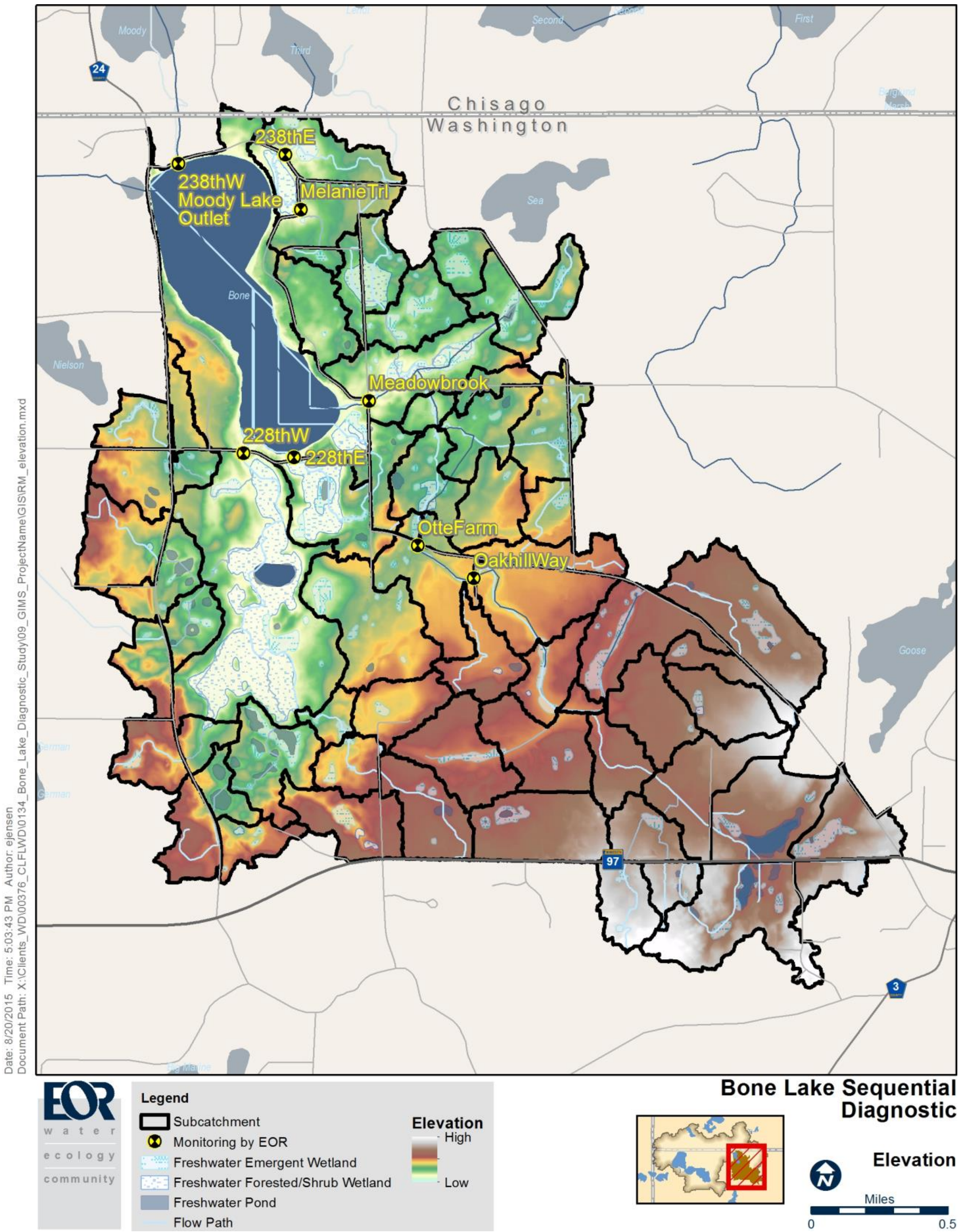

Figure 30. Bone Lake Watershed Elevation based on 1-m LiDAR

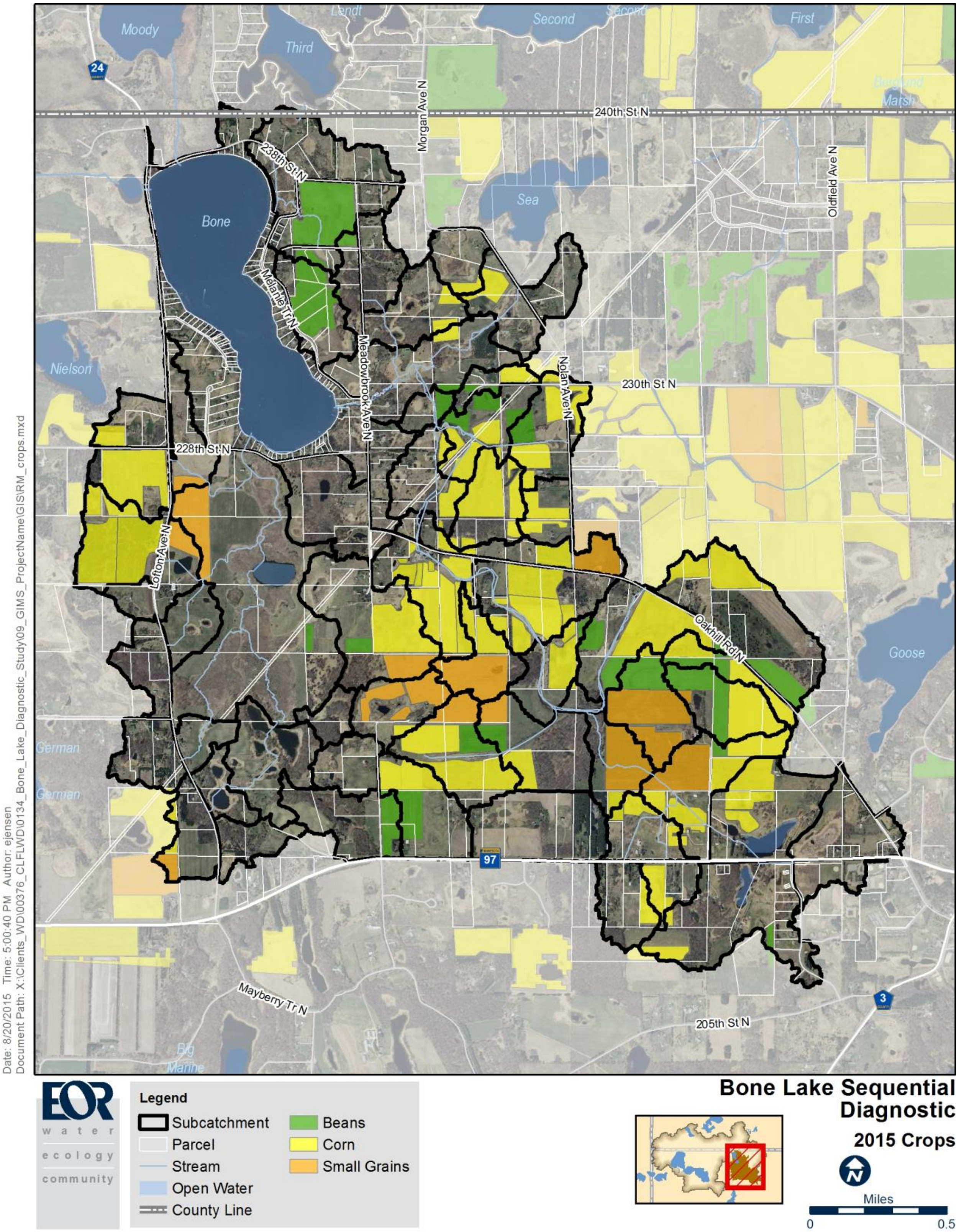

Figure 31. Bone Lake Watershed 2015 Crops

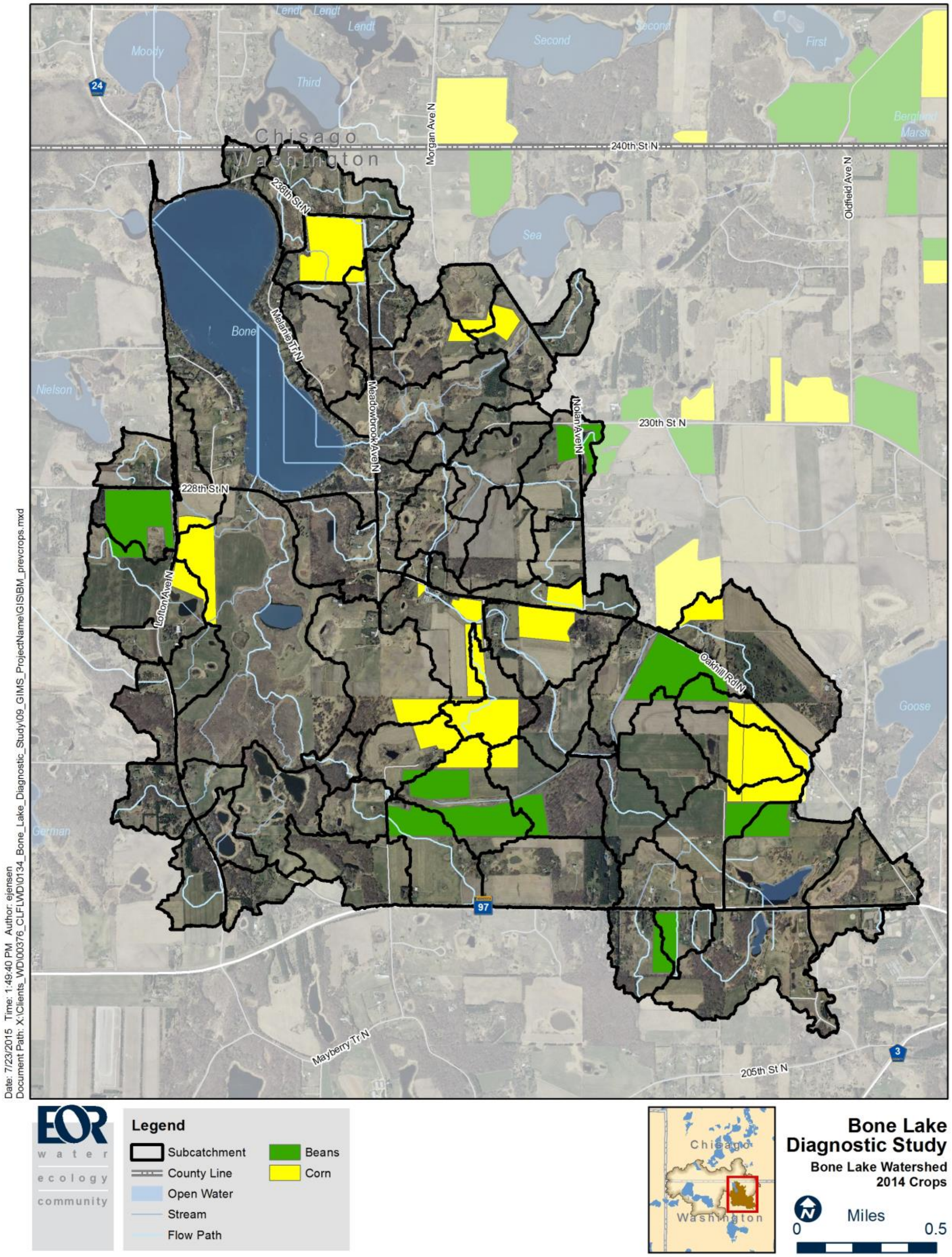

Figure 32. Bone Lake Watershed 2014 Crops

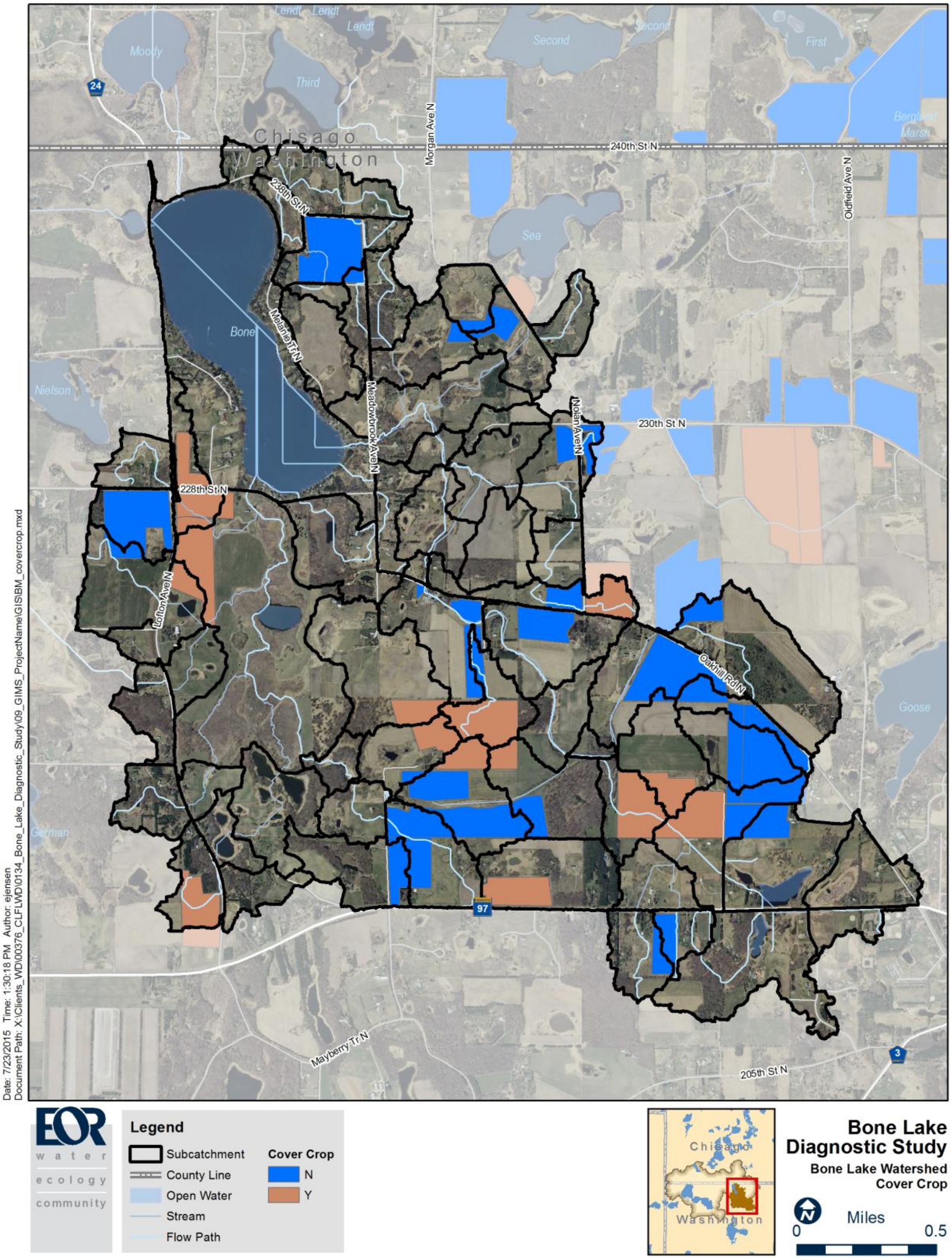

Figure 33. Bone Lake Watershed Fields with Cover Crop

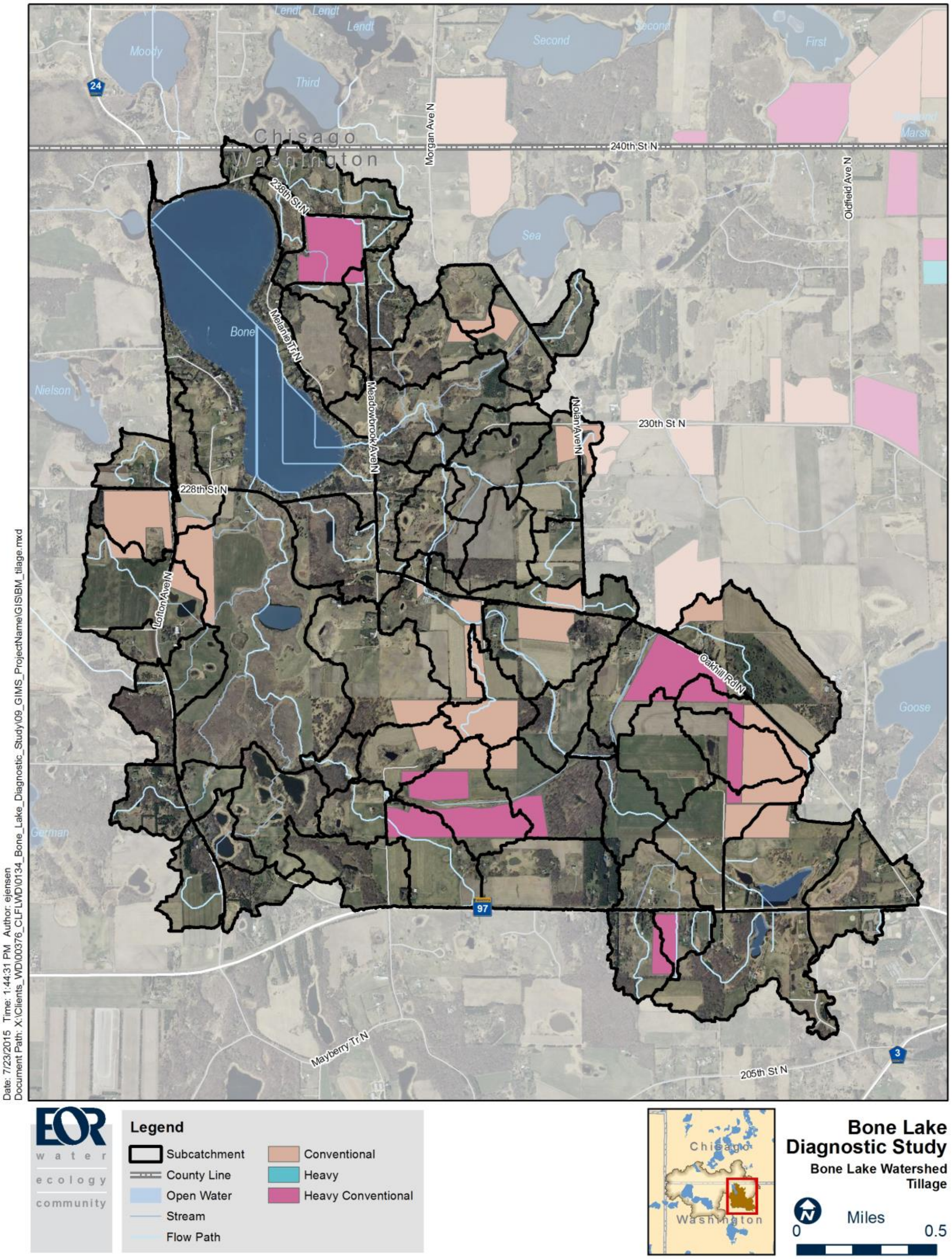

Figure 34. Bone Lake Watershed Tillage Practices

APPENDIX E. SWMM MODEL SCENARIO RESULTS

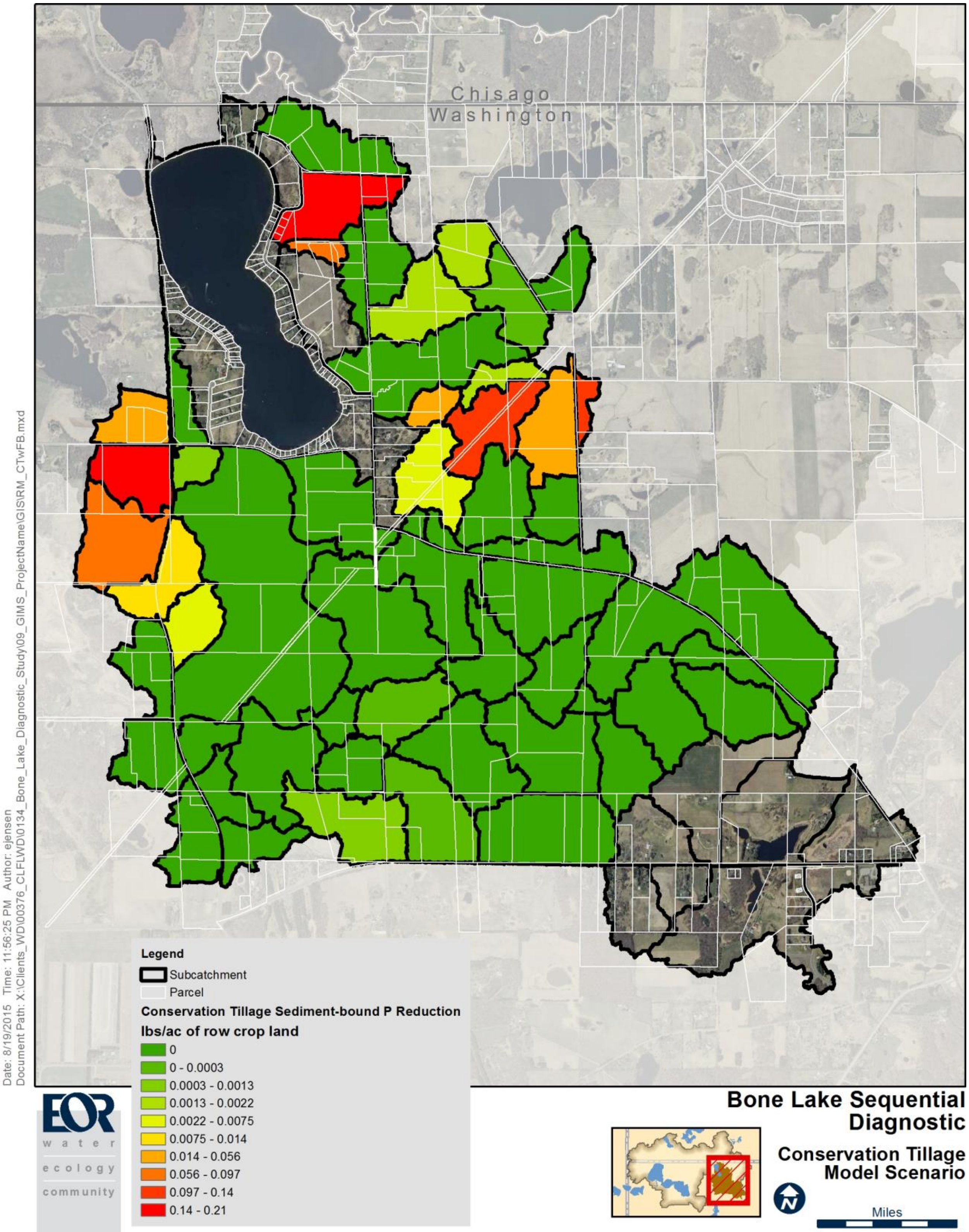

Figure 35. Conservation tillage model scenario sediment-bound P reductions per row crop land

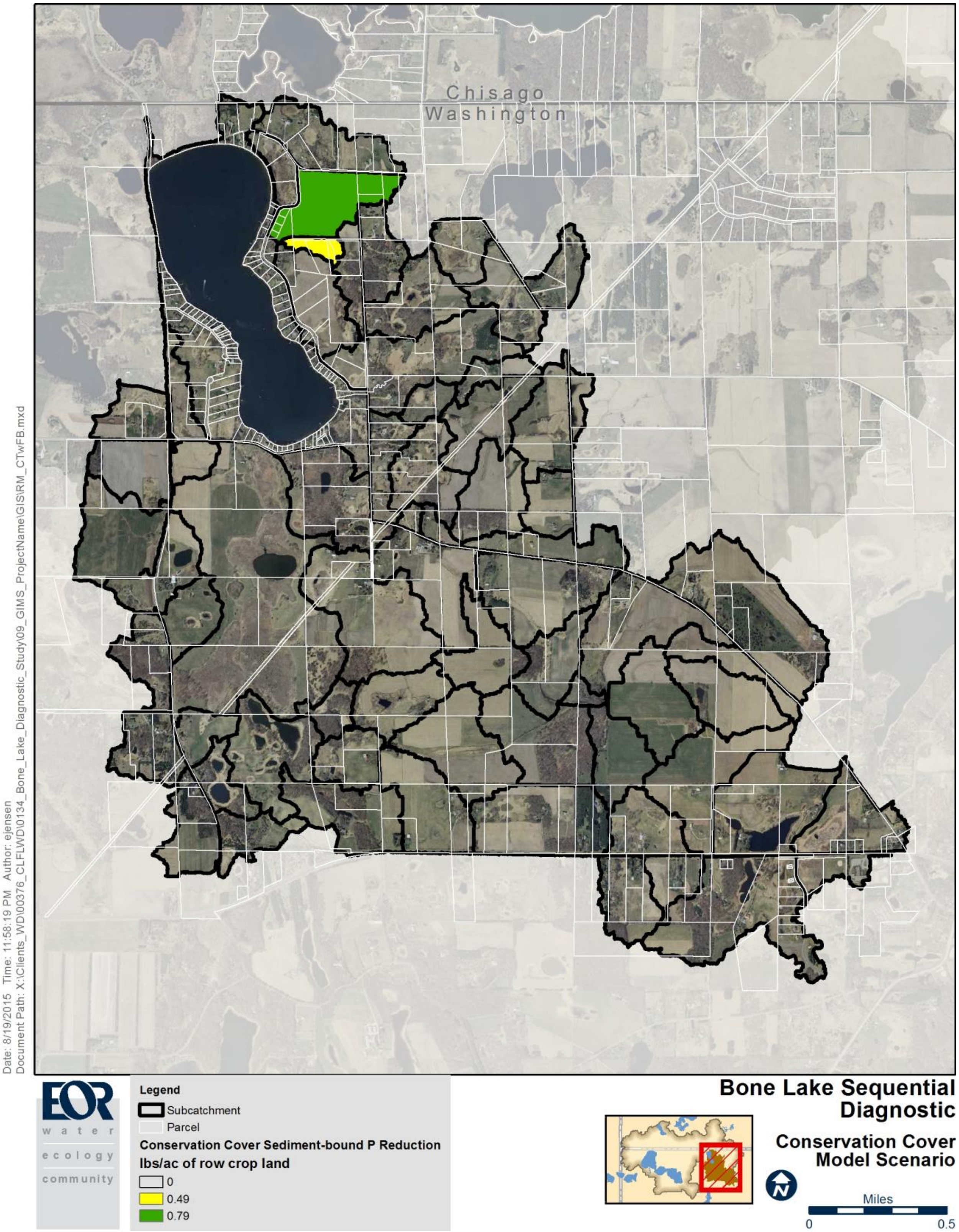

Figure 36. Conservation cover model scenario sediment-bound P reductions per row crop land

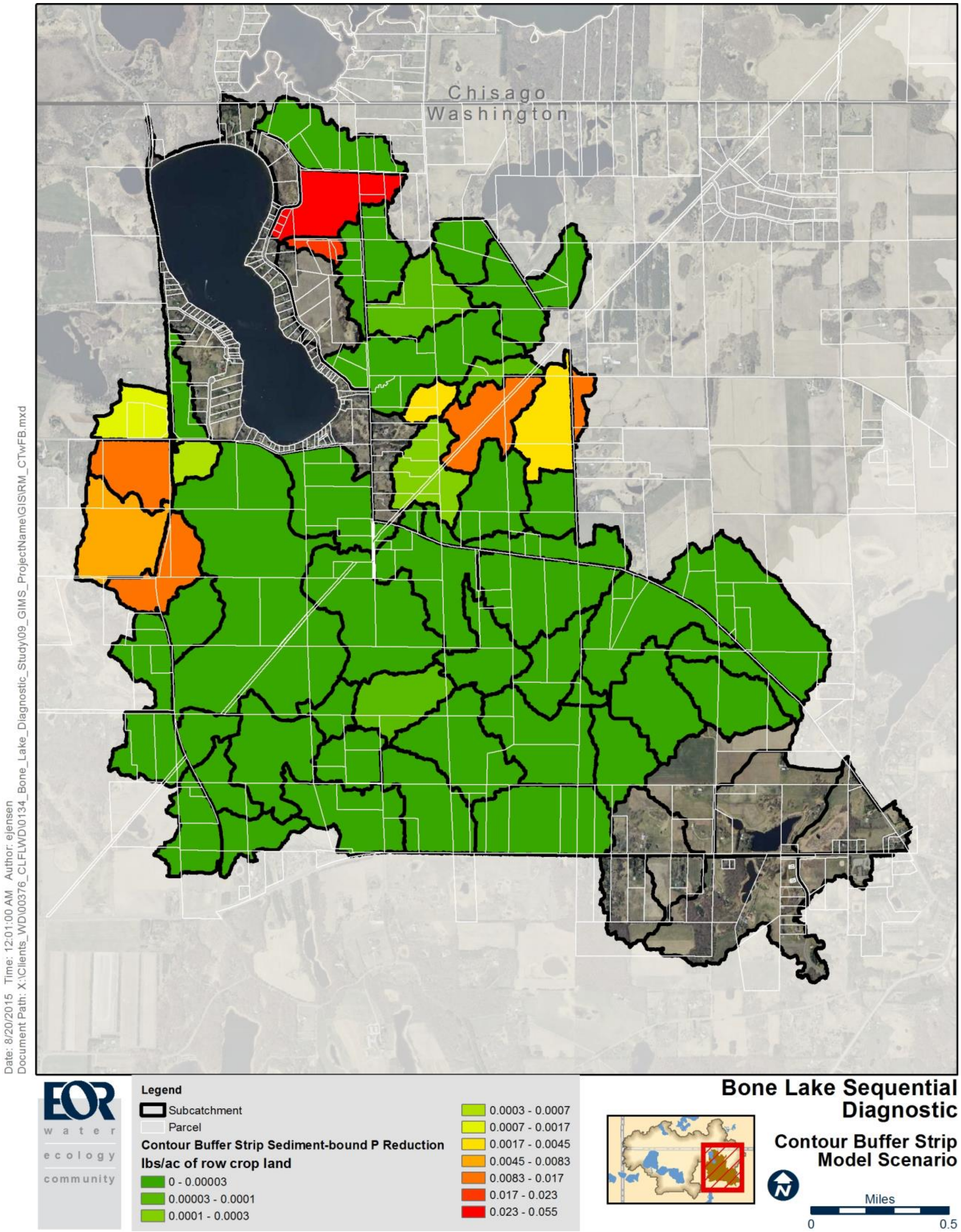

Figure 37. Contour buffer strip model scenario sediment-bound P reductions per row crop land