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City of Mora Subwatershed Assessment Report

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City of Mora

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Responsive partner.
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List of Acronyms

BMP	Best Management Practice
CN	Curve Number
GIS	Geographic Information System
LiDAR	Light Detection and Ranging
MIDS	Minimal Impact Design Standards
MPCA	Minnesota Pollution Control Agency
NRCS	National Resource Conservation Service
NURP	Nationwide Urban Runoff Program
P8	Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds
SCS	Soil Conservation Service
SWCD	Soil and Water Conservation District
TP	Total Phosphorus
TSS	Total Suspended Solids

1.0 Summary

With a population of approximately 3,500, the City of Mora is the largest municipality in the Snake River watershed. In 2012, Kanabec Soil and Water Conservation district (SWCD) received a Clean Water Partnership (CWP) grant to monitor water quality in Mora Lake and five stormsewer outfall sites throughout the city. These monitoring results indicate high levels of total phosphorus (TP) and chlorophyll-a in Lake Mora, and high levels of TP and total suspended solids (TSS) at the stormsewer outfall sites.

Located in the center of the City of Mora, Mora Lake is a valued resource and improving water quality is important to the residents of the city and surrounding areas. Outflow from Mora Lake and the city stormsewer system drain to the Snake River and eventually to the St. Croix River, a National Scenic Riverway. Both the Snake and St. Croix Rivers support a diverse range of aquatic and provide a wide range of recreational opportunities such as boating, fishing and swimming. Cross Lake and Lake St. Croix are two nutrient impaired lakes located downstream of the City of Mora along the main-stems of the Snake and St. Croix Rivers. Both lakes have completed TMDLs that require significant load reductions from their watersheds. Thus, improving water quality in Mora Lake and throughout the City will help these lakes achieve their load reductions and help protect other resources in the Snake River and St. Croix River.

The purpose of this subwatershed assessment is to identify several stormwater best management practices (BMPs) for the City of Mora to improve water quality in Mora Lake and the Snake and St. Croix Rivers downstream of the City of Mora. A watershed model (P8) was developed to determine existing TP and TSS loading from the City of Mora and adjacent rural areas draining to Mora Lake. A BATHTUB lake response model was also developed to determine watershed load reductions needed for Mora Lake to reduce phosphorus levels to meet state water quality standards. Model output was used to identify several potential locations for stormwater BMPs throughout the city and surrounding areas. Each BMP was then evaluated to determine appropriate size along with estimated cost and phosphorus load reductions. Thus, this report provides the City and SWCD a cost benefit analysis which will help the City and SWCD prioritize future stormwater BMP implementation.

2.0 Background

2.1 PURPOSE

The purpose of this study is to help the City and SWCD reduce sediment, and phosphorus loading from the City of Mora to Mora Lake and the Snake River through implementation of stormwater Best Management Practices (BMPs). Recent monitoring for Mora Lake indicate average summer total phosphorus (TP) concentrations are 69 µg/L which is above the 60 µg/L state water quality standards for shallow lakes in this region of the state. Modeling completed as part of this study indicates watershed loading to Mora Lake will need to be reduced by approximately 181 pounds per year for Mora Lake to meet state water quality standards. Additionally, there are two lakes downstream of the City of Mora, Cross Lake and Lake St. Croix, that are currently impaired for excess nutrients by the Minnesota Pollution Control Agency (MPCA). Total Maximum Daily Load (TMDL) Studies completed for these lakes indicate phosphorus loads from the watershed need to be reduced by approximately 1,100 and 76,000 pounds per year for Cross lake and Lake St. Croix, respectively.

The City of Mora contains a mixture of land use with a moderately high impervious area that was developed under varying levels of stormwater management and BMPs. In this report, Wenck Associates will focus on areas with little or no stormwater treatment and identify opportunities for implementing BMPs to reduce sediment and phosphorus loads. Section 4 of this report provides general descriptions of several types of stormwater BMPs, and Section 5 provides specific BMP options throughout the City. The BMPs identified in this report could be implemented immediately or over time if/when funding becomes available or future capital improvement/redevelopment projects are incorporated throughout the City.

2.2 STUDY AREA

The City of Mora study area was broken into three areas for the purposes of this study: the Mora Lake drainage area, the Snake River drainage area, and the Fish Lake drainage area (Figure 2-1). The Mora Lake drainage area (approximately 4,578 acres, 67% of study area) includes areas within the City that drain directly to Mora Lake (1,132 acres) as well as the large rural area north/northeast of the City (3,446 acres) that drains to Spring Creek which flows to Mora Lake. The Snake River drainage area (2,197 acres, approximately 32% of study area) is made up of areas within City limits that drain directly to the Snake River. The Fish Lake drainage area (103 acres, approximately 1% of study area) is a small area in the southern most portion of the City that drains to Fish Lake just upstream of the lake's outlet to the Snake River.

Approximately 23% of the study area already incorporates some form of stormwater management. There are 18 constructed stormwater ponds (Figure 2-1) located throughout the study area that collectively drain approximately 1,549 acres of the watershed. There are also other smaller ponds and wetlands located throughout the study area that capture and store runoff from the City that at one time were likely small wetlands and low-lying areas that have been incorporated into the City drainage/stormwsewer network.

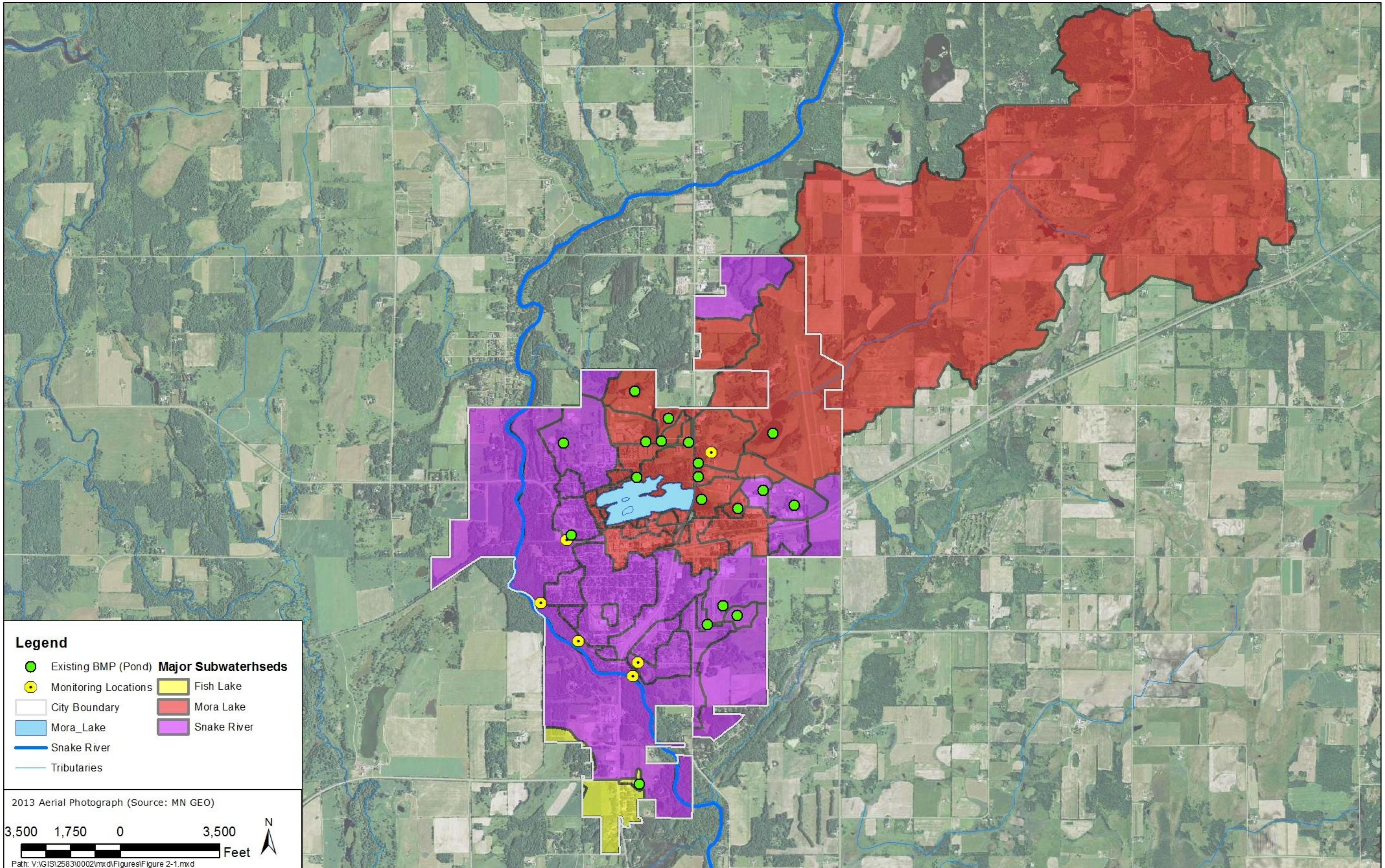


Figure 2-1. Study Area.

2.3 LAND USE

Within the City portion of the study area, land use is a mixture of agricultural/farmstead, park land, and low/medium/high density development based on the 2010 National Land Cover Database (NLCD). The rural area outside City limits draining to Mora Lake is predominantly agriculture and small farmstead (Table 2-1).

Table 2-1. Land Use within the City of Mora Study Area.

Land Use	*City Limits*		*Outside City Limits*	
	Acres	Percent	Acres	Percent
Agricultural	1,364	40%	2,201	64%
Farmstead	465	13%	850	25%
Park, Recreational, or Preserve	578	17%	193	6%
Open Water	190	6%	172	5%
Developed/Low Intensity	428	12%	23	<1%
Developed/Medium Intensity	264	8%	5	<1%
Developed/High Intensity	143	4%	2	<1%
Total	3,432	100%	3,446	100%

2.4 SOIL TYPE

The hydrologic soil group classifications based on Natural Resources Conservation Service (NRCS) Web Soil Survey data for the study area is predominantly groups B and C/D both within the City and the rural area draining to Mora Lake. (Table 2-2).

Table 2-2. Hydrologic soil groups within the City of Mora Study Area

Hydrologic Soil Type	*City Limits*		*Outside City Limits*	
	Acres	Percent	Acres	Percent
A	433	13%	0	0%
A/D	332	10%	449	13%
B	932	27%	795	23%
B/D	307	9%	599	17%
C	576	17%	235	7%
C/D	805	23%	1,341	39%
D	47	1%	27	1%
Total	3,432	100%	3,446	100%

3.0 Modeling

3.1 P8 MODELING METHODOLOGY

Wenck evaluated stormwater runoff volume and water quality in the study area by reviewing existing conditions using Geographic Information Systems (GIS) and data provided by City and SWCD staff. Wenck modeled the existing area hydrology and water quality using the computer program P8 (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds). P8 is a computer model originally developed for the United States Environmental Protection Agency (USEPA) for simulating the generation and transport of stormwater runoff pollutants in watersheds. P8 is a useful diagnostic tool for evaluating and designing watershed improvements and BMPs. The model requires user input on watershed characteristics, basin attributes, local precipitation and temperature, and other parameters relating to water quality and basin removal performances. Due to annual variability in historical precipitation records and subsequent model results, the P8 model was executed for a 10-year precipitation record to obtain average loading estimates that were used in the analysis.

The watershed characteristics used for the P8 model includes the Soil Conservation Services (SCS) hydrologic soil group, land use classification, and the impervious fraction of the land in the watershed. The land use classification was obtained from the 2010 NLCD as described in Section 2.3 and soil data was obtained from the NRCS Web Soil Survey as described in Section 2.4. The hydrologic soil group characterizes infiltration capacity of the soils and runoff characteristics. Arcview GIS software was used extensively in assessing watershed characteristics.

In P8, pervious and impervious areas are modeled separately. Runoff volumes from pervious areas are computed using the SCS Curve Number (CN) method. Runoff from impervious areas begins once the cumulative storm rainfall volume exceeds the specified depression storage, with the runoff rate equal to the rainfall intensity.

Because P8 calculates runoff separately from pervious and impervious areas, it was necessary to determine the impervious fraction of each watershed. For the P8 model, the impervious areas were assumed to be all directly connected. An impervious area is considered directly connected if runoff flows directly from it into the conveyance system via continuous paved areas. The directly-connected impervious fraction was calculated for each watershed based on the land use(s), with each land use having an assumed impervious percent. The assumed percent impervious associated with each land use is listed in Appendix A.

As discussed previously, watershed runoff volumes from pervious areas were computed for P8 by using the SCS CN method. Within each watershed a pervious CN was calculated based on the soil type and land use. The pervious CN was area weighted in each subwatershed using the values described in Appendix A.

The P8 model requires an hourly precipitation record (rain and snowfall) and daily temperature record. Precipitation and temperature data were obtained from the Mora Whether Station.

The treatment devices utilized in P8 provide collection, storage, and/or treatment of watershed discharges. A variety of treatment devices can be modeled in P8, including detention basins (wet or dry), infiltration basins, swales, buffers, aquifers, and pipes.

Detention basin (stormwater ponds) volume information was obtained from as-built plans (when available) with data gaps filled in using Light Detection and Ranging (LiDAR) data. For vegetated wetland areas, it was assumed that the permanent pool depth was 1 foot. For open water wetland areas, it was assumed that the permanent pool depth was 2 feet.

Basin outlet information was obtained from as-built plans (when available). If as-built plans were not available, the outlet was assumed to be the hydraulic equivalent of a 12-inch diameter culvert. LiDAR and aerial photography were used to approximate overland outlets where identified and as-built information was not available.

The NURP50 sediment particle distribution and concentration file was selected for the P8 models. The component concentrations in the NURP 50 file represent the 50th percentile (median) values compiled in the Environmental Protection Agency's (EPA's) Nationwide Urban Runoff Program (NURP).

Water quality monitoring data was available at four outfall locations throughout the City of Mora and at one location on Spring Creek upstream of Mora Lake (Figure 2-1). The water quality data was collected by SWCD staff in 2013, 2014, and 2015 and includes total phosphorus (TP) and total suspended solids (TSS). For model validation, the method that produced the best results was to compare the average modeled concentration for each parameter to the average monitored results across the entire monitoring period. Slight adjustments were made to the TSS and TP scaling factors in the P8 Water Quality Components inputs to better match modeled TP and TSS concentrations to the 2013-2015 monitored data (Appendix A).

3.2 EXISTING CONDITIONS P8 MODEL

Wenck created an existing conditions P8 model for the entire study area to mimic the watershed as it is today by routing runoff through the city stormsewer system, stormwater ponds, and surface channels/streams. The study area was broken into 85 individual subwatersheds as shown in Figure 2-1 and Appendix B.

Under existing conditions, the entire study area generates approximately 3,100 pounds of TP and 311,000 pounds of TSS annually. An average annual breakdown of the TP and TSS load from each of the major subwatershed groupings are summarized in Table 3-1. It is important to point out that these estimates include the expected removals due to the 18 existing stormwater ponds throughout the study area. Figure 2-1 shows the locations of the existing stormwater practices throughout the study area.

Table 3-1. P8 model results for the major subwatersheds in the study area

Major Watershed	Acres	Flow [acre-ft/yr]	TSS Load [lbs/yr]	TP Load [lbs/yr]
Mora Lake	4,578	4,342	87,625	1,426
Snake River	2,197	3,293	212,778	1,609
Fish Lake	103	161	10,926	80
total	6,878	7,796	311,329	3,115

3.3 MORA LAKE RESPONSE MODEL

A lake response model was setup for Mora Lake to estimate the phosphorus load reductions needed for Mora Lake to meet the 60 µg/L standard for shallow lakes in this region. The lake response model selected for this exercise was the Canfield-Bachman lake equation (Canfield and Bachman, 1981). This equation estimates the lake phosphorus sedimentation rate, which is needed to predict the relationship between in-lake phosphorus concentrations and phosphorus load inputs. The phosphorus sedimentation rate is an estimate of net phosphorus loss from the water column through sedimentation to the lake bottom, and is used in concert with user supplied lake-specific characteristics such as annual phosphorus loading, mean depth, and hydraulic flushing rate to predict in-lake phosphorus concentrations. Model predictions are then compared to measured data to evaluate how well the model describes the lake system. If necessary, the model parameters are adjusted appropriately to achieve an approximate match to monitored data. Once adjustments are made, the resulting relationship between phosphorus load and in-lake water quality is used to determine the assimilative capacity.

To setup the lake response model for Mora Lake, Wenck used the same methodology outlined in the Snake River Watershed TMDL Study (MPCA, 2013). The three major phosphorus sources defined in the model include atmospheric load, watershed load, and internal load. Atmospheric phosphorus loading to Mora Lake was estimated using literature rates for dry (<25 inches of rainfall), average (25-38 inches), and wet (>38 inches) precipitation years (Barr Engineering, 2004). Watershed loading was estimated using output for the Mora Lake portion of the P8 model described in the previous section.

Internal loading in lakes refers to chemical release of phosphorus from the lake sediment which typically occurs under anaerobic conditions. Internal load is typically measured by collecting sediment cores, incubating them in the lab under anaerobic conditions, and measuring the change in phosphorus concentration in the overlying water column. Sediment cores have not been collected or analyzed for Mora Lake, therefore model residual (i.e. remaining load after other sources were estimated) was used to estimate internal loading in Mora Lake.

Once the watershed and atmospheric phosphorus loads were defined, the internal load was adjusted until the modeled in-lake TP concentration met the average summer in-lake monitored concentration collected by SWCD staff in 2013-2014 (69 µg/L). Next, the phosphorus loads partitioned between the three sources were adjusted (lowered) until the model predicted that Mora Lake would achieve the 60 µg/L shallow lake standard.

Construction, calibration, and results of the Canfield-Bachman lake response models Mora Lake are presented in Appendix A.

Results of this modeling exercise suggest phosphorus loading to Mora Lake is dominated by watershed sources (Table 3-2). In order for Mora Lake to meet the 60 µg/L TP standard, watershed loading to the lake will need to be reduced by approximately 181 pounds and meet a watershed phosphorus concentration target of 95 µg/L. The subwatersheds located north of Mora Lake currently have a series of constructed ponds in place and the P8 model suggests these subwatersheds currently meet the 95 µg/L watershed TP target concentration. However, the direct subwatershed (193 µg/L) and the Spring Creek subwatershed draining the rural area northeast of the lake (103 µg/L) do not currently meet the 95 µg/L watershed TP target. Thus, watershed reduction efforts for Mora Lake should focus on the Spring Creek and Mora Lake direct subwatersheds. To meet the watershed target, TP loading from the Mora Lake direct subwatersheds and Spring Creek Subwatersheds will need to be reduced by approximately 115 pounds per year (50% reduction) and 66 pounds per year (7% reduction), respectively.

Table 3-2. Current and required TP load for Mora Lake to meet water quality standards.

Source	Current TP Load [lbs/yr]	TP Load to Meet Standard [lbs/yr]	Reduction [lbs/yr]
Atmosphere	18	18	0
Spring Creek Subwaterhseds	888	822	66
North Subwatersheds	50	50	0
Direct Subwatersheds	227	112	115
Internal	31	31	0
total	1,214	1,033	181

4.0 BMP Options

The purpose of this study is to identify a variety of BMP options to reduce stormwater pollutant loads within the study area. This section provides general descriptions of several types of BMPs that could be implemented within the study area to reduce runoff volume, peak discharge, phosphorus and sediment loads. Specific uses and locations for these BMPs will be discussed in Section 5.

4.1 INFILTRATION BASIN

Infiltration basins combine surface storage, infiltration, biological treatment, plant uptake, and evapotranspiration into a single BMP. Stormwater is collected into the treatment area which consists of a grass buffer strip, sand bed, ponding area, organic or mulch layer, planting soil, and plants. The infiltration system incorporates the more natural means of managing stormwater than any other treatment type.

Infiltration basin along a parking lot in St. Paul, MN.

The adjacent pictures show an infiltration basin along the perimeter of a parking lot in downtown St. Paul. Note the ribbon curb that defines the edge of the pavement but also allows runoff to flow over the curb, through the vegetated buffer and into the bioretention basin.

“Stepped” infiltration basin in Oakdale, MN.

Opportunities to include infiltration systems in the landscape include landscaping islands, cul-de-sacs, parking lot margins, commercial setbacks, open space, rooftop drainage and streetscapes (i.e., between the curb and sidewalk). Infiltration basins are extremely versatile because of their ability to be incorporated into landscaped areas. Maintenance activities typically include sediment removal and maintenance of the vegetation. Invasive species need to be managed, dead vegetation must be removed, and dead plants must be replaced.

4.2 INFILTRATION TRENCH/DITCH

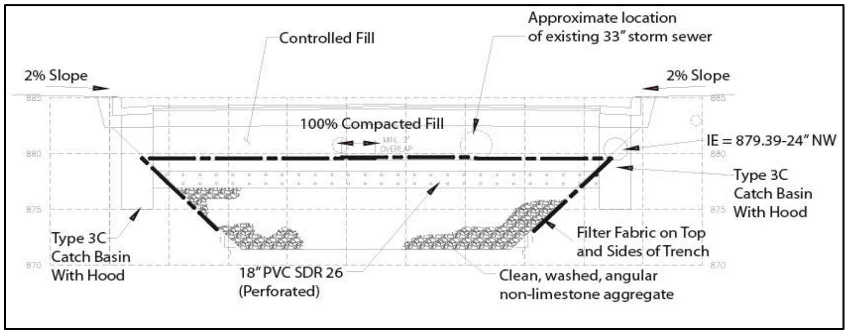
Photo credit: StormTech website

Infiltration trenches/ditches are stormwater practices that can be implemented within exiting roadside ditch systems that are currently collecting and conveying stormwater runoff. Infiltration trench design includes an engineered soil at the ditch bottom to infiltrate surface water from low flow events. To maximize treatment storage volume, the design also includes underground storage which is typically a combination of chambers and/or aggregate void space. High flows bypass the infiltration trench by either flow continuing through the ditch past the infiltration areas, or bypassing through a flow splitter structure to a receiving water body. This type of infiltration trench/ditch design was recently incorporated within a county road ditch system in Dakota County that drains a highly impervious industrial park. These systems have performed very well in infiltrating a significant portion of the stormwater runoff and removing TSS and TP.

4.3 UNDERGROUND INFILTRATION SYSTEMS

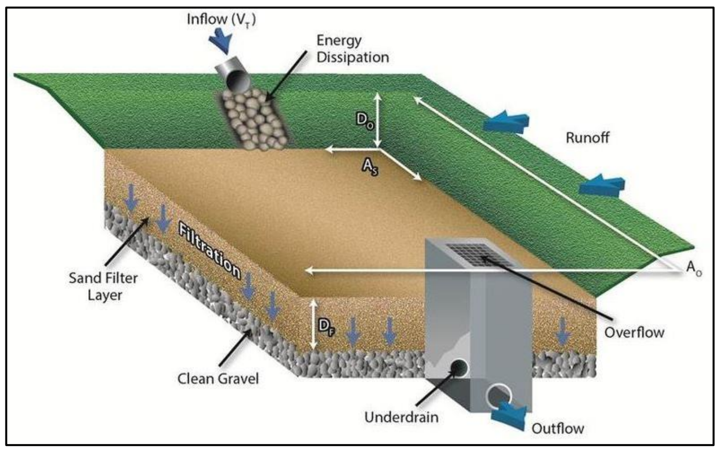
Underground infiltration systems are an adaptable stormwater BMP technique where space is limited, and is most suitable for highly urban areas where space is limited. Underground infiltration consists of perforated pipes, vaults, modular structures, or cisterns placed beneath a developed or open area. An example is shown to the right. Stormwater runoff is directed to this area via storm sewer for storage and infiltration. A manhole, filter, or hydrodynamic device provides pretreatment for runoff entering the storage area. In large storm events, the storage volume above the outlet reduces flow rates and discharge is directed into the storm sewer. Large angular rock (1-3 inches) surrounds the perforated pipes and provides additional storage capacity and structural stability for soils above. The design can be modified to include a filtration layer when infiltration is not practical.

Street replacement also provides an opportunity for this type of BMP. Underground infiltration systems can be placed beneath roads where no utilities are present. During road reconstruction the system can be added to the project to reduce downstream pollutant loads. Maintenance includes periodic removal of sediment accumulated in the pretreatment devices. To maintain system functionality, sediment deposition should not exceed 1 foot in depth.



4.4 SAND FILTERS

Filtration BMPs use a porous media, typically sand, to remove pollutants from stormwater before entering the downstream waterbody or BMP. Sand filters can be used in areas where infiltration is not feasible due to high water tables, limited infiltration capacity of the soil, or contaminated soil conditions. Both the surface basins and underground systems described previously can be designed as filtration BMPs rather than infiltration systems. Because filtration BMPs are not designed to infiltrate or store stormwater, these systems require use of an underdrain to convey treated stormwater out of the system. Surface filtration basins that incorporate vegetation into the practice will provide biological removal of nutrients via uptake by the vegetation. However, since filtration BMPs are not designed to infiltrate they do not provide stormwater volume reduction benefits and typically have lower pollutant removal capabilities compared to infiltration BMPs. Moreover, the underdrains and pipe work associated with filtration practices can make them more expensive than infiltration BMPs.

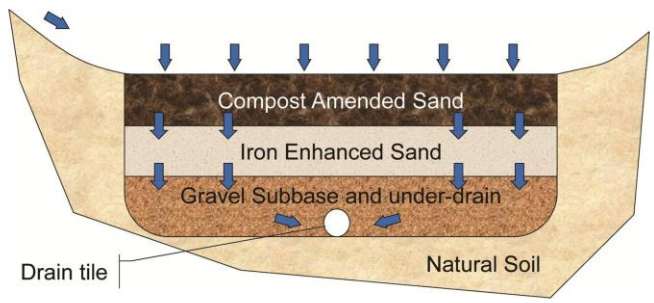


4.5 IRON-ENHANCED SAND FILTERS

Iron-enhanced sand filters are filtration BMPs that incorporate filtration media mixed with iron. The iron removes several dissolved constituents, including phosphate, from stormwater. Iron-enhanced sand filters could potentially include a wide range of filtration BMPs with the addition of iron; however, iron is not appropriate for all filtration practices due to the potential for iron loss or plugging in low oxygen or persistently inundated filtration practices.

Iron-enhanced sand filters may be applied in the same manner as other filtration practices and are more suited to urban land use with high imperviousness and moderate solids loads. Because the primary treatment mechanisms are filtration and chemical binding and not volume reduction, vegetating the filter is not needed and may impair the filter function.

Iron-enhanced sand filters require underdrains that serve to convey filtered and treated stormwater and to aerate the filter bed between storms. The exit drain from the iron-enhanced sand filter should be exposed to the atmosphere and above downstream high water levels in order to keep the filter bed aerated. Iron-enhanced sand filters may be used in a treatment sequence, as a stand-alone BMP, or as a retrofit. If an iron-enhanced sand filter basin is used as a stand-alone BMP, an overflow diversion is recommended to control the volume of water, or more specifically, the inundation period in the BMP. As with all filters, it is important to have inflow be relatively free of solids or to have a pre-treatment practice in sequence.



Maintenance of the iron-enhanced sand filters consists of removing accumulated sediment and debris, pulling out all vegetation throughout the growing season, and tilling the soil to prevent clumping and preferential flow paths.

4.6 STORMWATER REUSE

Stormwater reuse is the practice of collecting runoff from impermeable surfaces and storing it for future use. There are a number of systems used for the collection, storage and distribution of rain water including rain barrels, cisterns, evaporative control systems, and irrigation. Most commonly, these systems capture "free water" from a storage point and irrigate (after filtering) green space. For this study, the proposed stormwater reuse would use runoff collected in an underground chamber near a large green space area. Stormwater reuse systems typically includes an intake, pump/controls building, and irrigation network. One limitation of stormwater reuse is that it is not very effective during wet periods when much of the nutrient transport takes place.

4.7 STORMWATER PONDS

Stormwater ponds are the most commonly used practice for treating and reducing stormwater pollutant loads. Stormwater ponds rely on physical, biological, and chemical processes to remove pollutants from incoming stormwater runoff. The primary treatment mechanism is gravitational settling of particulates and their associated pollutants as stormwater runoff resides in the pond. In general, the longer the runoff remains in the pond, the more settling (and associated pollutant removal) and other treatment can occur, and after the particulates reach the bottom of the pond, the permanent pool protects them from resuspension when additional runoff enters the basin. Another mechanism for the removal of pollutants (particularly nutrients) is uptake by algae and aquatic vegetation.

Stormwater ponds are also one of the best and most cost-effective stormwater treatment practices for providing runoff detention storage for channel protection and overbank flood control. These goals are achieved with the use of extended detention storage, where runoff is stored above the permanent pool and released at a specified rate through a control structure.

4.8 RURAL BMPS

Residue and Tillage Management (No-till or Strip-till)

On annually planted cropland, examples of residue and tillage management, are no-till and strip-till. Both practices address the amount, orientation, and distribution of crop and other plant residue on the soil surface year-round. Crops are planted in narrow slots (no-till) or tilled strips (strip-till) established in the un-tilled seedbed of the previous crop. Benefits to the soil include increasing organic matter, improving soil tilth, and increasing productivity. The constant supply of organic material left on the soil surface is decomposed by a healthy population of earthworms and other organisms in the soil. Benefits to water quality include reduced runoff and increased infiltration. By leaving residue on the field, runoff and rain water are slowed by the plants/residue and given greater time to infiltrate into the soil.

Filter Strip

Filter strips are established where environmentally sensitive areas need to be protected from sediment, other suspended solids, and dissolved contaminants in runoff. Filter strips provide the environmental benefit of filtering contaminants from runoff water and infiltrating flood waters. Sensitive areas include streams, lakes, and wetlands, wells, drainage ditches, grassed waterways, sinkholes, springs, surface tile inlets and other surface inlets which deliver surface runoff to ground water or surface water. The benefits of installing filter strips include reduced suspended solids and dissolved contaminants in runoff.

5.0 Proposed BMPs

5.1 OVERVIEW OF PROPOSED BMPS

Wenck used the existing conditions P8 model described in Section 3.2 to identify high potential loading subwatersheds throughout the study area that may be good candidates for stormwater BMP practices. It is clear from the existing conditions model (see Figure B-1 in Appendix B) that the subwatersheds with the highest annual pollutant loads tend to be those that do not currently have BMPs in place and/or those with large amounts of impervious area. Thus, BMP siting mainly focused in these subwatersheds and several project opportunities were identified to improve water quality and reduce sediment and phosphorus loads to Mora Lake and the Snake River.

It is important to note that all the proposed projects have potential design challenges and cost considerations that need to be fully investigated prior to their implementation. During final design and monitoring, a proposed project may not meet estimated pollutant removal effectiveness and/or the cost estimates presented in this report due to design challenges that may be identified during the design process. BMP performance can also vary from year to year based on climatic conditions and other environmental factors. In addition, ongoing and consistent maintenance activities are required to maintain performance. This includes sediment removal, vegetation maintenance, filter maintenance and monitoring.

5.2 BMP SIZING, DESIGN, AND POLLUTANT REDUCTION CONSIDERATIONS

Wenck used methodology and research presented in MPCA's Minnesota Stormwater Manual (link) to evaluate sizing, design, and pollutant reductions for the BMPs sited in this study. In general, the infiltration practices sited in this report were sized to retain and infiltrate 1.1 inches of runoff (consistent with MPCA's Minimal Impact Design Standards) and to meet a drawdown time of 48 hours or less based on NRCS Soil Survey conditions. In some cases, footprint size and/or soil limitations would not allow for treatment of 1.1 inches of runoff and therefore the BMPs were adjusted accordingly. Filtration and stormwater ponds basins were sited in areas with poorly draining soils (C and D hydrologic soil groups) and/or areas where the groundwater table may be near the surface such as near lakes and rivers. Similar to infiltration practices, the filtration practices were sized to treat the 1.1 inch runoff event, where possible, and meet a drawdown time of 48 hours or less. Sediment and phosphorus reductions for all infiltration and filtration practices were calculated based on each BMP's estimated water quality treatment volume and the recommended pollutant removal efficiency for each general BMP type presented in the Minnesota Stormwater Manual. Stormwater detention ponds were sized so that the pond's dead pool storage will treat the 2.5 inch runoff event from the pond's drainage area, where possible, and achieve sediment and phosphorus reductions of approximately 85% and 50%, respectively.

5.3 PLANNING LEVEL COST ESTIMATES

Planning level cost estimates were developed and a cost benefit analysis was performed to aid in prioritization of proposed BMPs. The cost estimates are based on past experience with BMP retrofit projects and regional treatment projects. The cost estimates include:

- Construction costs for the proposed BMP, such as: mobilization, site preparation, outlet modification, minor storm sewer or structural work, and erosion control
- Level 2 sediment disposal costs (if any) according to the MPCA guidance
- Engineering costs (typically 15% of BMP cost)
- 30% contingency cost
- Annual maintenance estimate (included in the 30-year cost)
- Larger maintenance project estimate every 10 years (included in the 30-year cost)

These costs do not include wetland mitigation, major structural work, and/or land/easement acquisition. All costs were rounded to reflect planning level estimates. Therefore, it is recommended that a more detailed feasibility assessment and cost estimate be prepared for specific projects the City and SWCD wish to pursue.

5.4 PROPOSED BMP REDUCTIONS AND COST BENEFIT ANALYSIS

As discussed in Section 3.2, the current condition P8 model for the study area estimates average loading of approximately 311,000 pounds of TSS and 3,000 pounds of TP annually. The distributions of loads were used to identify potential BMP opportunities to reduce pollutant loading throughout the study area.

The following sections provide a general description of the proposed BMPs, along with pollutant load reductions and cost benefit analysis. The proposed BMPs were separated into three sections: Spring Creek Subwatersheds (outside City limits), Mora Lake Direct Subwatersheds (within City limits), and the Snake River Subwatersheds. No BMPs were proposed within the Fish Lake major subwatershed since this subwatershed exhibited relatively low TSS and TP loading rates and had limited BMP retrofit potential.

5.4.1 Spring Creek Subwatershed Proposed BMPs

Five Filter Strips and five Residue/Tillage Management were sited throughout the Spring Creek subwatershed (See Figure B-7 in Appendix B for locations). These BMPs are common management practices that can be integrated into field management operations that have a high reward for their relatively low cost. Table 5-1 show the cost and pollution reduction numbers on a per practice basis.

Table 5-1. Proposed BMP pollutant load reductions and cost analysis for the Spring Creek (rural) subwatershed draining to Mora Lake.

BMP ID	Priority	BMP Type	Planned Practices	TSS Reduction[1] [lbs/yr]	TP Reduction[1] [lbs/yr]	Construction Cost[1]	Life Cycle Cost[1] [30 yrs]	Life Cycle Cost per pound of TP Removed[1]
SC-2a, SC-2b, SC-2c, SC-2d, SC-2e	1	Filter Strip	5	28,100	18.9	$304	$65	$3.44
SC-1a, SC-1b, SC-1c, SC-1d, SC-1e	2	Residue Management	5	60,840	47.6	$553	$5,527	$116.19

1 Values in this table are presented as average reduction and cost estimates per practice

5.4.2 Proposed BMPs in the Mora Lake Direct Subwatersheds

Thirteen potential BMPs were sited throughout the Mora Lake direct subwatersheds (See Figures B-3 and B-4 in Appendix B). In siting and developing the list of proposed BMPs, Wenck focused primarily on public owned property such as easements, parks, schools and City/County/State right of way as they are usually easier to implement, maintain, and manage over the life of the practice. If all the proposed BMPs were implemented, Mora Lake would see reduced TP loads of approximately 103-134 pounds per year depending on which BMP option is selected. In addition, the proposed BMPs would reduce TSS loads by approximately 24,000-26,000 pounds per year and infiltrate 40-68 acre-feet of runoff per year. As discussed in Section 3.3, the target phosphorus reduction for the Mora Lake Direct subwatersheds is 115 pounds per year. Table 5-2 is a summary of the estimated TSS and TP reductions, construction cost estimates, 30-year life cycle costs, and cost benefit analysis for the 13 proposed BMPs. Below is a general description of each proposed BMP.

ML-E-C3

ML-E-C3 is a regional stormwater pond located at the end of Maple Lane southwest of Mora Lake (see Figure B-4 in Appendix B for location). This pond would capture and treat stormwater from subwatershed ML-E-C3 (47 acres) prior to discharging to Mora Lake's East Bay located east of Highway 65. The footprint of this pond would be relatively small and only capable of treating the 0.8 inch rain event due to limited space and slopes near the stormsewer outfall. However, this proposed BMP would result in a significant TP load reduction (25.2 lbs/yr) and has the best cost/benefit potential ($241) in the Mora Lake direct watershed in terms of cost per pound of TP removed.

ML-E-C2

ML-E-C2 is another regional stormwater pond located between North Walnut Street and Highway 65 (see Figure B-4 in Appendix B for location). This pond would capture and treat stormwater from subwatershed ML-E-C2 prior to discharging to Mora Lake's East Bay east of Highway 65. It appears that this site is not currently developed and sufficient space is available to accommodate a moderately sized pond capable of treating the 1.6 inch rain event from its 65 acre drainage area. This proposed BMP would result in a significant TP load reduction (25.9 lbs/yr) and is very cost effective in terms of cost per pound of TP removed ($447).

ML-W-C1

ML-W-C1 is a large underground infiltration/filtration system located in Library Park at the southwest corner of the lake (see Figure B-3 in Appendix B for location). This system would treat a portion of the runoff from the highly impervious ML-S-C1 (45 acres) and ML-W-C1 (2 acres) subwatersheds prior to discharging to Mora Lake. Additional feasibility analysis will need to be conducted at this site to determine if an infiltration or filtration system is the most appropriate BMP for this location. Information for the feasibility analysis should include determination of existing stormsewer elevations and collecting geotechnical boring information to determine soil types and groundwater elevations. Both infiltration and filtration BMP options are presented in Table 5-2. If infiltration is feasible at this site, this BMP would be sized to treat the 0.5 inch storm event and result in a TP load reductions of approximately 37.5 pounds per year. If infiltration is not feasible, a filtration system could be designed to remove approximately 18.8 pounds per year. While both options would remove a significant amount of TP, construction of these BMPs would be very costly and require significant excavation. That said, both options rank high in terms of cost-benefit analysis.

ML-D-C1a

ML-D-C1a is a small surface infiltration basin located downstream of the Union Street stormsewer outfall north of Mora Lake (see Figure B-3 in Appendix B for location). This basin would capture and treat stormwater from subwatershed ML-N-C2 (2 acres) and ML-D-C1a (7 acres). This proposed BMP would result in a relatively small TP load reduction (3.5 lbs/yr) but is a very cost effective option.

ML-E-C1b

ML-D-C1a is a small infiltration or filtration basin/ditch located at the southeast corner of the Maple Avenue and Highway 65 intersection (see Figure B-4 in Appendix B for location). This BMP would capture and treat runoff from the ML-E-C1b (4 acres) subwatershed. The NRCS Web Soil Survey indicates D soils in this area suggesting infiltration may be difficult. Thus, geotechnical soil borings should be collected to verify whether infiltration or filtration is the most appropriate BMP option at this site. If infiltration is feasible, this practice would remove approximately 4.1 pounds of TP per year and ranks high in terms of cost/benefit. If filtration is the only option, this practice would remove approximately 2.1 pounds of TP per year and would not be a very cost effective option. Both options are presented in Table 5-2.

ML-D-C1b

ML-D-C1b presents two options for treatment of runoff from subwatersheds ML-D-C1b (7 acres), ML-S-C4a (8 acres), and ML-S-C4b (1 acre) (see Figure B-4 in Appendix B for location). The first option is an underground infiltration/filtration system that would be located beneath the school track/play fields that would treat a portion of the runoff from the three highly impervious subwatersheds mentioned previously. This BMP option would be sized to treat the 1.1 inch storm event and result in a TP load reduction of approximately 10.9 pounds per year. While this option would remove a significant amount of TP, construction of the underground system would be costly and require significant excavation. This option ranks relatively high in terms of cost-benefit analysis.

The second option is a stormwater reuse system that would be located at the same location as option 1. This BMP would consist of an underground storage chamber that would capture and store stormwater runoff from the three contributing subwatersheds. This system would be sized to capture approximately 70% of the runoff from these subwatersheds which should meet the irrigation needs of the school track/play fields and surrounding greenspace from May through September. This BMP option would remove approximately 8.9 pounds of phosphorus per year, however construction costs are extremely high ($840,000) and it would not be very a cost-effective option. The construction cost estimate for this system includes the following considerations: an irrigation network, a pumphouse with controls, and an underground storage tank.

ML-S-C4a

ML-S-C4a is a series of underground infiltration/filtration chambers located underneath Maple Avenue across the street from the school (see Figure B-4 in Appendix B for location).

These chambers would capture and treat runoff from the ML-S-C4a (8 acres) subwatershed. Since this proposed practice is located underground and has relatively high potential construction costs, implementation would only make sense if it was done in conjunction with a major road resurfacing and/or reconstruction project at this site. The NRCS Web Soil Survey indicates D soils in this area suggesting infiltration may be difficult. Thus, geotechnical soil borings should be collected to verify whether infiltration or filtration is the most appropriate BMP option at this site. If infiltration is feasible, this practice would remove approximately 5.4 pounds of TP per year and has a moderate cost/benefit ranking. If filtration is the only option, this practice would remove approximately 2.7 pounds of TP per year and would not be a very cost effective option. Both options are presented in Table 5-2.

ML-S-C2

ML-S-C2 is another underground infiltration chamber that would be located underneath North Lake Street just south of Mora Lake (see Figure B-3 in Appendix B for location). This practice would capture and treat stormsewer flow from the ML-S-C2 (8 acres) subwatershed. Due to proximity to Mora Lake, additional feasibility analysis will need to be conducted at this site to determine groundwater elevations and existing stormsewer elevations. This project could potentially treat 7.7 pounds of TP per year and is moderately cost effective in terms of cost per pound of TP removed. Due to high construction costs, this type of practice would only make sense if it was done in conjunction with a major road resurfacing and/or reconstruction project at this site.

ML-S-C3

ML-S-C2 is a small surface infiltration basin located in the northwest corner of the school parking lot just south of Mora Lake (see Figure B-3 in Appendix B for location). This practice would capture runoff from part of the building rooftop and overland flow from the school parking lot of subwatershed ML-S-C2 (2.5 acres). This basin would potentially treat 1.6 pounds of TP per year and infiltrate 2.8 acre-feet of runoff. While the estimated construction cost of this practice is relatively low ($29,000), it is only moderately cost effective due to its small watershed and potential TP removal.

ML-W-C4

ML-W-C4 is an underground infiltration/filtration chamber that would be located underneath Wood Street on the west end of Mora Lake (see Figure B-3 in Appendix B for location). This practice would capture and treat stormsewer flow from the ML-W-C4 (5 acres) and ML-W-C2 (5 acres) subwatersheds. Since this proposed practice is located underground and has relatively high potential construction costs, implementation would only make sense if it was done in conjunction with a major road resurfacing and/or reconstruction project at this site. Due to proximity to Mora Lake, additional feasibility analysis will need to be conducted to determine groundwater elevations and existing stormsewer elevations. If it is determined infiltration is feasible at this site, this practice could potentially treat the 1.1 inch storm event and remove approximately 4.6 pounds of TP per year. If filtration is the only option, this practice would remove approximately 2.3 pounds of TP per year. The infiltration option has a better cost/benefit compared to the filtration option, however neither option is very cost effective compared to the other BMPs presented in Table 5-2.

ML-W-C3

ML-W-C3 is two small curb cut infiltration basins/rain gardens that would be located above the stormsewer catchments in subwatershed ML-W-C3 (2 acres) (see Figure B-3 in Appendix B for location). These basins would infiltrate approximately 1.3 acre-feet of runoff per year and remove approximately 0.7 pounds of TP. While the estimated construction cost of these basins is relatively low ($11,000), they do not rank very high in terms of cost per pound of TP removed due to the small drainage area and potential TP reduction.

ML-N-C1

ML-W-C3 is another curb cut infiltration basin/rain garden that would be located above the main stormsewer catchment in the ML-N-C1 (2 acres) subwatershed (see Figure B-3 in Appendix B for location). This practice would infiltrate approximately 1.0 acre-feet of runoff per year and remove 0.5 pounds of TP. Similar to ML-W-C3, this practice has a relatively low construction cost ($11,000) but does not rank well in terms of cost efficiency due to its small TP removal.

Table 5-2. Proposed BMP pollutant load reductions and cost analysis for the Mora Lake Direct Subwatersheds.

BMP ID	Priority	BMP Type	Volume Reduction [acre-ft/yr]	TSS Reduction [lbs/yr]	TP Reduction [lbs/yr]	Construction Cost	Life Cycle Cost [30 yrs]	Life Cycle Cost per pound of TP Removed
ML-E-C3	1	Stormwater Pond	NA	6,461	25.2	$130,000	$180,000	$241
ML-E-C2	2	Stormwater Pond	NA	6,703	25.9	$280,000	$345,000	$447
ML-W-C1	3	Option1: Infiltration	1.0	5,731	37.5	$620,000	$760,000	$677
	9	Option2: Filtration	NA	4,871	18.8	$745,000	$950,000	$1,690
ML-D-C1a	4	Infiltration	6.6	497	3.5	$61,000	$130,000	$1,252
ML-E-C1a	5	Option 1: Infiltration	2.8	942	6.2	$115,000	$235,000	$1,264
	14	Option 2: Filtration	NA	801	3.1	$175,000	$290,000	$3,159
ML-E-C1b	6	Option 1: Infiltration	6.9	633	4.1	$63,000	$170,000	$1,356
	15	Option 2: Filtration	NA	538	2.1	$98,000	$205,000	$3,267
ML-D-C1b	7	Option 1: Infiltration	18.9	1,624	10.9	$315,000	$440,000	$1,356
	17	Option 2: Water Reuse	15.4	1,324	8.9	$840,000	$980,000	$3,706
ML-S-C4a	8	Option 1: Infiltration	9.1	818	5.4	$150,00	$265,000	$1,636
	16	Option 2: Filtration	NA	695	2.7	$175,000	$290,000	$3,587
ML-S-C2	10	Infiltration	13.0	1,185	7.7	$285,000	$405,000	$1,755

BMP ID	Priority	BMP Type	Volume Reduction [acre-ft/yr]	TSS Reduction [lbs/yr]	TP Reduction [lbs/yr]	Construction Cost	Life Cycle Cost [30 yrs]	Life Cycle Cost per pound of TP Removed
ML-S-C3	11	Infiltration	2.8	239	1.6	$29,000	$88,000	$1,841
ML-W-C4	12	Option 1: Infiltration	4.2	666	4.6	$180,000	$295,000	$2,126
	19	Option 2: Filtration	NA	566	2.3	$205,000	$315,000	$4,604
ML-W-C3	13	Infiltration	1.3	93	0.7	$11,000	$61,000	$3,076
ML-N-C1	18	Infiltration	1.0	76	0.5	$11,000	$60,000	$3,740

5.4.3 Proposed BMPs in the Snake River Subwatersheds

Six potential BMPs were sited throughout the Snake River subwatersheds (See Figures B-5 and B-6 in Appendix B). In siting and developing the list of proposed BMPs, Wenck focused primarily on public owned property such as easements, parks, schools and City/County/State right of way as they are usually easier to implement, maintain, and manage over the life of the practice. If all the proposed BMPs were implemented, the Snake River would see reduced TP loads of approximately 168-247 pounds per year, and TSS load reductions 29,000-44,000 pounds per year depending on which BMP option is selected. In addition, the proposed BMPs would infiltrate 187-350 acre-feet of runoff per year. As discussed in Section 2.1, the target phosphorus reduction for Cross Lake and Lake St. Croix (located downstream of the City of Mora) is approximately 1,100 and 76,000 pounds per year, respectively. Table 5-3 is a summary of the estimated TSS and TP reductions, construction cost estimates, 30-year life cycle costs, and cost benefit analysis for the six proposed BMPs. Below is a general description of each proposed BMP.

R-S-C8

R-S-C8 is a large underground infiltration/filtration system located in the Kanabec County Fair Grounds (see Figure B-6 in Appendix B for location). This system would divert a portion of the flow from the main stormsewer line running underneath the fairgrounds. Additional feasibility analysis will need to be conducted at this site to determine if an infiltration or filtration system is the most appropriate BMP for this location. Information for the feasibility analysis should include determination of existing stormsewer elevations and collecting geotechnical boring information to determine soil types and groundwater elevations. Both infiltration and filtration BMP options are presented in Table 5-3. This BMP could be sized to treat a range of stormwater volumes depending on space limitations and the City/County's desired budget. For the purposes of this report, a 15,000 square foot infiltration/filtration underground chamber was selected. This footprint size would be capable of treating the 0.5 inch runoff event from the R-S-C8 subwatershed (160 acres). If infiltration is feasible at this site, this practice would infiltrate approximately 124 acre-feet of water and remove 70.8 pounds of TP per year. If infiltration is not feasible, a filtration system could be designed to remove approximately 35.4 pounds of TP per year. While both options would remove a significant amount of TP, construction of these BMPs would be very costly and require significant excavation. Both options rank very high in terms of cost per pound of TP removed.

R-S-C1a

R-S-C1a is a series of infiltration trenches/ditches located along the Highway 65 corridor that runs through the City of Mora (see Figure B-5 in Appendix B for location). These systems would capture and treat runoff from the highway as well as several of the commercial properties situated along the highway. These practices would be incorporated within the existing ditch network and the design would include underground storage with engineered soils and overflow bypass structures for high flow events (See section 4.2 for further description). A feasibility analysis of this site would need to be conducted to determine groundwater levels, current soil conditions, and the amount of engineered soils that may be required. Depending on infiltration capacity within the ditch system, these practices could have the potential to infiltrate the 1.1 inch runoff event from the R-S-C1a subwatershed and remove up to 90.0 pounds of TP per year. These BMPs rank very high in terms of cost efficiency, however construction costs would be high ($800,000).

R-S-C6

R-S-C6 presents two options for treatment within the R-S-C6 subwatershed (see Figure B-5 in Appendix B for location). The first option is a regional stormwater pond located north of Division Street between Aruthur Lane and Kristi Lane. This location is currently occupied by a mobile home park, however this property has been identified by the City as a potential redevelopment site. Runoff from subwatershed R-S-C6 (32 acres) and the roadside ditches in subwatershed R-S-C1a (105 acres) would be redirected to this pond in order to achieve maximize water quality treatment for this BMP. The footprint of this pond would be large (3 acres) and the pond would be able to treat the 2.5 inch rain event from the contributing subwatersheds and result in a large TP load reduction (66.2 lbs/yr). Despite high construction costs ($805,000), this pond is a cost effective option in terms of cost per pound of TP removed ($495). It is important to point out that the cost estimate for this practice does not include land acquisition, and therefore the City will need to evaluate these costs to better assess this BMP option.

The second option for R-S-C6 is a surface infiltration basin located in the large open space south of Division Street. Runoff from the R-S-C6 subwatersheds (32 acres) that currently flows through the main stormsewer line beneath Valley Lane would be directed to this infiltration basin prior to being discharged to the Snake River. This practice would be sized to treat the 1.1 inch storm event and would infiltrate approximately 38 acre-feet of water per year and reduce TP loads by 22.5 pounds per year. This BMP ranks high in terms of cost-benefit and has a modest construction cost ($190,000). Again, this BMP does not include land acquisition, and therefore these costs will need to be considered to fully assess this BMP option.

R-S-C10

R-S-C10 is a surface infiltration basin located at the dead end of Fair Avenue West on the far west end of town (see Figure B-6 in Appendix B for location). This basin would be constructed to intercept and treat flow from the catchments along Fair Avenue West as well as the stormsewer line draining Stewart Court to the north. This practice would be sized to treat the 1.1 inch storm event, infiltrate approximately 20 acre-feet of water per year, and reduce TP loads to the Snake River by 11.3 pounds per year. This BMP ranks high in terms of cost-benefit and has a modest construction cost ($103,000). The cost estimates for this BMP do not include land acquisition, and therefore these costs would need to be considered if any private land would need to be obtained.

R-S-C8a

R-S-C8a is a series of surface infiltration basins/raingardens located throughout a portion of the Kanabec County Fairgrounds property (8 acres) (see Figure B-6 in Appendix B for location). The basins would be installed next to stormsewer catchments throughout the fairgrounds to capture and treat as much of the runoff from this site as possible prior to discharging to the main City stormsewer line that runs beneath the fairground property. Assuming space is not a concern, it is estimated that enough basins could be installed to treat the 1.1 inch runoff event for this subwatershed. These BMPs would infiltrate approximately 10 acre-feet of stormwater per year and reduce TP loading to the Snake River by 6.1 pounds per year. While these practices do not rank as high as others in terms of cost-efficiency, they would be relatively cheap to install ($61,000) and their potential visibility throughout the fairgrounds property could make for a good public outreach/education opportunity.

R-S-C9

R-S-C9 is a series of curb-cut infiltration basins/rain gardens that would be located above selected stormsewer catchments along Riverside Street in subwatershed R-S-C9 (11 acres) (see Figure B-6 in Appendix B for location). Due to private property and space limitations near the catchments, these gardens would likely only be able to treat the 0.4 inch rain event from this subwatershed. These practices would infiltrate approximately 5 acre-feet of runoff per year and remove approximately 2.7 pounds of TP. While the estimated construction cost of these BMPs is relatively low ($29,000), they do not rank very high in terms of cost per pound of TP removed due to their small drainage area and potential TP reduction.

Table 5-3. Proposed BMP pollutant load reductions and cost analysis for the Snake River Subwatersheds.

BMP ID	Priority	BMP Type	Volume Reduction [acre-ft/yr]	TSS Reduction [lbs/yr]	TP Reduction [lbs/yr]	Construction Cost	Life Cycle Cost [30 yrs]	Life Cycle Cost per pound of TP Removed
R-S-C8	1	Option 1: Infiltration	124.1	10,506	70.8	$793,000	$932,000	$439
	6	Option 2: Filtration	NA	8,930	35.4	$907,000	$1,045,000	$985
R-S-C1a	2	Infiltration	152.6	13,608	90.0	$802,000	$1,315,000	$487
R-S-C6	3	Option 1: Stormwater Pond	NA	17,028	66.2	$805,000	$983,000	$495
	4	Option 2: Infiltration	37.9	3,420	22.5	$190,000	$362,000	$537
R-S-C10	5	Infiltration	19.7	1,674	11.3	$103,000	$215,000	$638
R-S-C8a	7	Infiltration	10.1	936	6.1	$61,000	$208,000	$1,136
R-S-C9	8	Infiltration	4.8	396	2.7	$29,000	$107,000	$1,318

6.0 Conclusions and Recommendations

The current condition P8 model for the City of Mora study area estimates average loading of approximately 311,000 pounds of TSS and 3,000 pounds of TP annually. If all the proposed BMPs presented in Section 5 were implemented, the study area would see reduced TP loads of approximately 271-381 pounds per year (9-13% reduction), and TSS load reductions of 53,000-70,000 pounds per year (17-23% reduction) depending on which BMP option is selected. As discussed in section 3.3, the TP load reduction goal for Mora Lake to meet state water quality standards is 181 pounds per year (15% reduction). Cross Lake and Lake St. Croix, two lakes located downstream of the City of Mora study area, have TP watershed load reduction goals of 1,100 and 76,000 pounds per year, respectively. Thus, the BMPs proposed in this report would go a long way in helping achieve the specific TP reduction goals for these waterbodies, as well as protecting overall water quality in the Snake and St. Croix Rivers.

It is recommended that the City and SWCD focus initial efforts on implementing the proposed BMPs they feel are most "shovel-ready" given estimated project cost and site conditions/feasibility. This assessment identified several larger BMPs that remove a significant amount of TP and TSS and rank very high in terms of cost-benefit, but have very high capital/construction costs. It is recommended that the City and SWCD investigate these BMPs further by performing a more detailed feasibility analysis for each BMP option. Once feasibility of the higher cost BMPs have been evaluated, the City and SWCD should explore grant and funding options that could help pay for these projects. Table 6-1 below is a summary of a few of the potential grant and funding options available for stormwater BMP projects. Several of the proposed BMPs are located within the right-of-way or underneath City/County/State roads and highways. For these projects, the City and SWCD should review the City's Capital Improvement Program (CIP) to determine if any of the proposed BMPs align with upcoming street resurfacing and/or reconstruction projects. If so, these BMPs could be incorporated into the City's CIP for these projects.

Table 6-1. Potential grant and funding opportunities to assist with proposed BMPs.

Source	Organization	Grant Name/ Funding Source	Local Match
Federal	MPCA	Federal clean Water Act Section 319 Grants	45%
Federal	FEMA	Hazard Mitigation Grant Program	25%
State	BWSR	Clean Water Fund Grants	25%
Municipal	City Program	Stormwater Drainage Utility	NA

7.0 References

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Appendix A:
Watershed Model and Lake Response Model Supporting Materials

Table A-1: Estimated impervious percent and pervious curve numbers for each land use type used in the City of Mora P8 model.

Land Use	Impervious Fraction (%)	Pervious Curve Number				
		A	B	B/D	C	C/D
Agricultural	5	49	69	76.5	79	81.5
Farmstead	10	49	69	76.5	79	81.5
Industrial and Utility	50	68	79	84.0	86	87.5
Institutional	32	39	61	70.5	74	77.0
Major Highway	50	49	69	76.5	79	81.5
Mixed Use Residential	60	39	61	70.5	74	77.0
Multifamily	60	39	61	70.5	74	77.0
Open Water	0	85	85	85.0	85	85.0
Park, Recreational, or Preserve	10	39	61	70.5	74	77
Retail and Other Commercial	67	49	69	76.5	79	81.5
Single Family Attached	30	39	61	70.5	74	77
Single Family Detached	20	39	61	70.5	74	77
Undeveloped	5	39	61	70.5	74	77

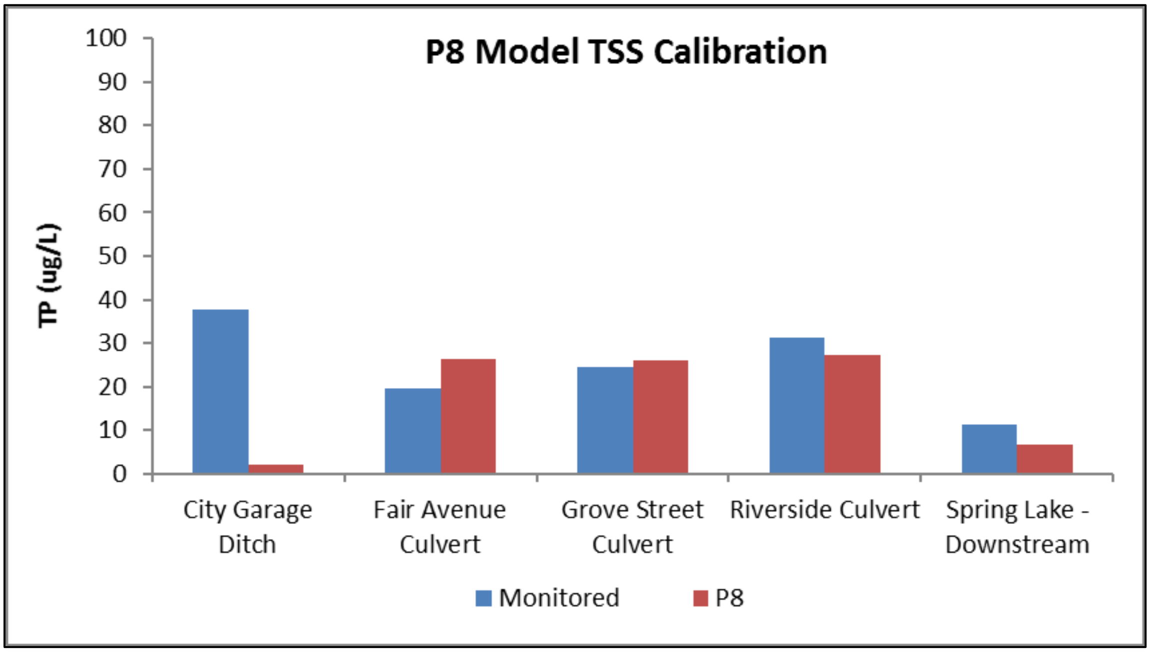


Figure A-1: TSS Calibration for the City of Mora P8 Model

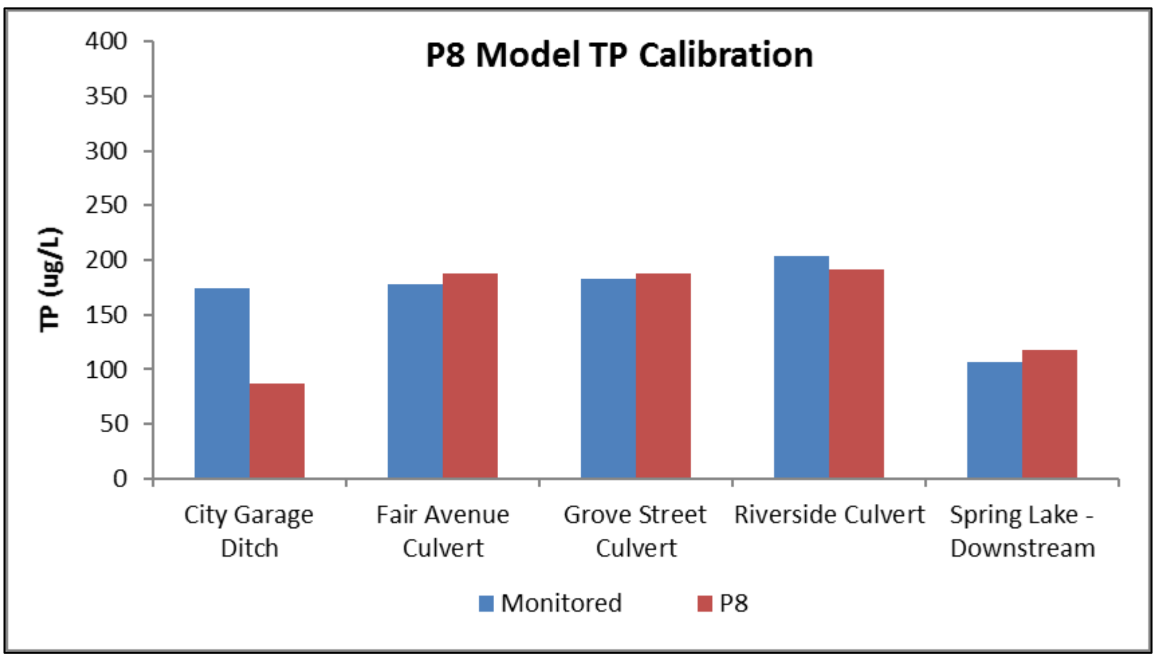


Figure A-2: TP Calibration for the City of Mora P8 Model

Current Condition Lake Response Model Summary for Mora Lake

Current Condition Loading Summary for Mora Lake

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Direct	305	17.1	433	193	1.0	227
2	Spring Creek	3,757	10.2	3,181	102.7	1.0	888
3	North	248	11.3	234	78.5	1.0	50
4							
5				0	0.0		0
	Summation	*4,310*	*39*	*3,848*			*1,166*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1				0	0		0
2				0	0.0		0
3				0	0.0		0
4				0	0.0		0
5				0	0.0		0
	Summation			*0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1							
2							
3							
4							
5							
	Summation	*0*	*0*	*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*
Atmosphere							
	Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
	[acre]	[in/yr]	[in/yr]	[ac-ft/yr]	[lb/ac-yr]	[--]	[lb/yr]
	73	35.7	35.7	0.00	0.24	1.0	17.5
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					
Groundwater							
Lake Area		Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
[acre]		[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
73		0.0		0.00	0	1.0	0
Internal							
Lake Area		Anoxic Factor			Release Rate	Calibration Factor	Load
[km^2]		[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.30			Oxic		1.0	
	0.30	47.3		Anoxic	1.0	1.0	31
	Summation						31
		Net Discharge [ac-ft/yr] =		**3,848**	**Net Load [lb/yr] =**		**1,214**

NOTES

1 Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

Current Condition Lake Response Modeling for Mora Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	2.84	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	551	[kg/yr]
		Q (lake outflow) =	4.7	[10^6 m^3/yr]
		V (modeled lake volume) =	0.2	[10^6 m^3]
		T = V/Q =	0.04	[yr]
		P_i = W/Q =	116	[μg/l]
Model Predicted In-Lake [TP]			**69**	**[ug/l]**
Observed In-Lake [TP]			**69**	**[ug/l]**

TMDL Condition Lake Response Model Summary for Mora Lake to Meet WQ Standards

TMDL Loading Summary for Mora Lake

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Direct	305	17.1	433	95	0.5	112
2	Spring Creek	3,757	10.2	3,181	95.0	0.9	822
3	North	248	11.3	234	78.5	1.0	50
4							
5				0	0.0		0
	Summation	*4,310*	*39*	*3,848*			*984*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1				0	0		0
2				0	0.0		0
3				0	0.0		0
4				0	0.0		0
5				0	0.0		0
	Summation			*0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1							
2							
3							
4							
5							
	Summation	*0*	*0*	*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*
Atmosphere							
	Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
	[acre]	[in/yr]	[in/yr]	[ac-ft/yr]	[lb/ac-yr]	[--]	[lb/yr]
	73	35.7	35.7	0.00	0.24	1.0	17.5
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					
Groundwater							
	Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	73	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.30			Oxic		1.0	
	0.30	47.3		Anoxic	1.0	1.0	31
	Summation						31
		Net Discharge [ac-ft/yr] =		**3,848**	**Net Load [lb/yr] =**		**1,032**

TMDL Lake Response Modeling for Mora Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	2.84	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	468	[kg/yr]
		Q (lake outflow) =	4.7	[10^6 m^3/yr]
		V (modeled lake volume) =	0.2	[10^6 m^3]
		T = V/Q =	0.04	[yr]
		P_i = W/Q =	99	[µg/l]
Model Predicted In-Lake [TP]			**60**	**[ug/l]**
Observed In-Lake [TP]			**60**	**[ug/l]**

Appendix B:
Proposed BMP Supporting Figures

Figure B-1: Existing TP Loading from Watershed

Figure B-2: Proposed BMPs and Subwatersheds

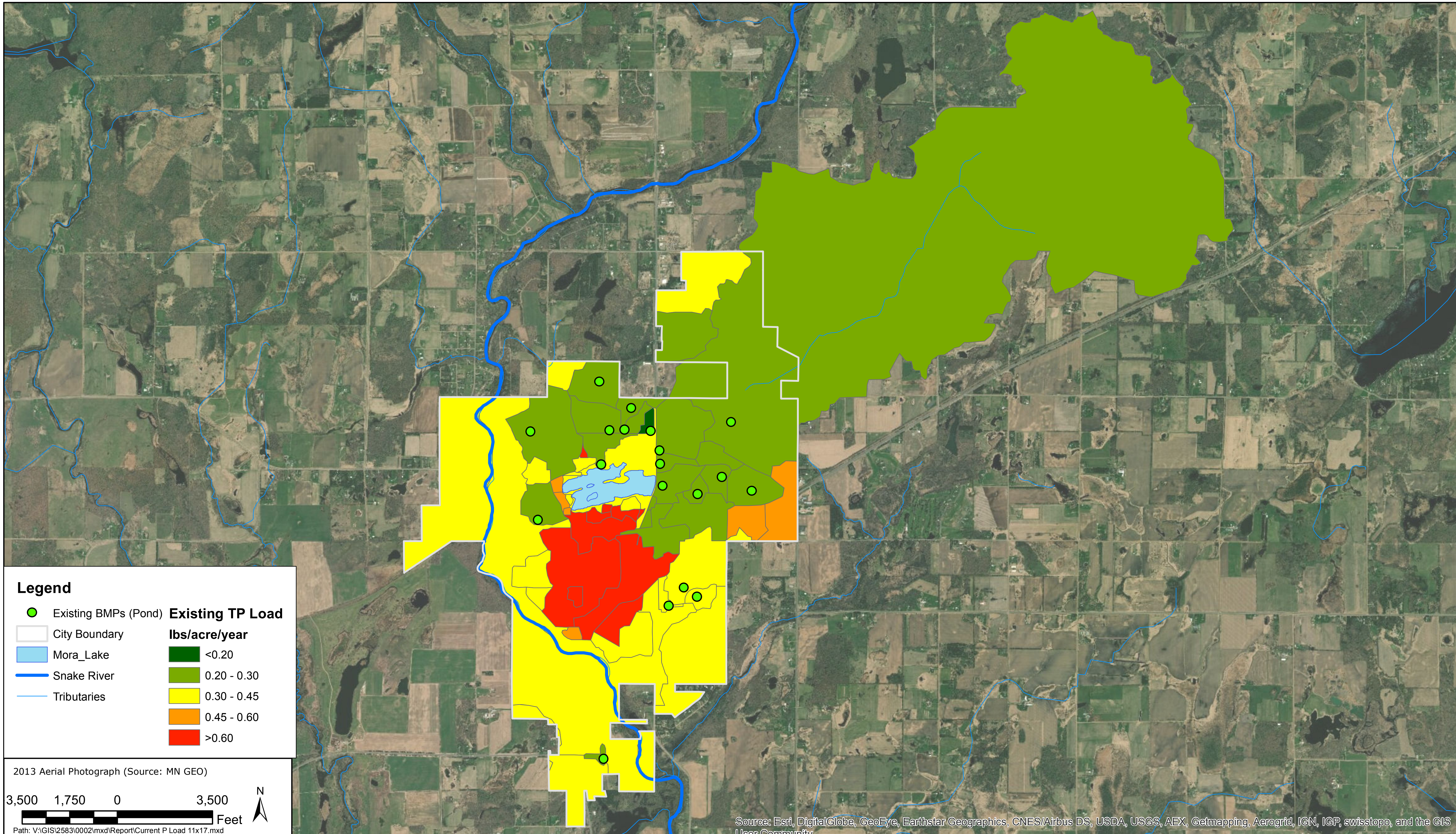
Figure B-3: Proposed BMPs near Mora Lake (North, West, and South)

Figure B-4: Proposed BMPs near Mora Lake (Southeast)

Figure B-5: Proposed BMPs Snake River (Southeast)

Figure B-6: Proposed BMPs Snake River (Southwest)

Figure B-7: Proposed BMPs in Spring Creek Subwatershed



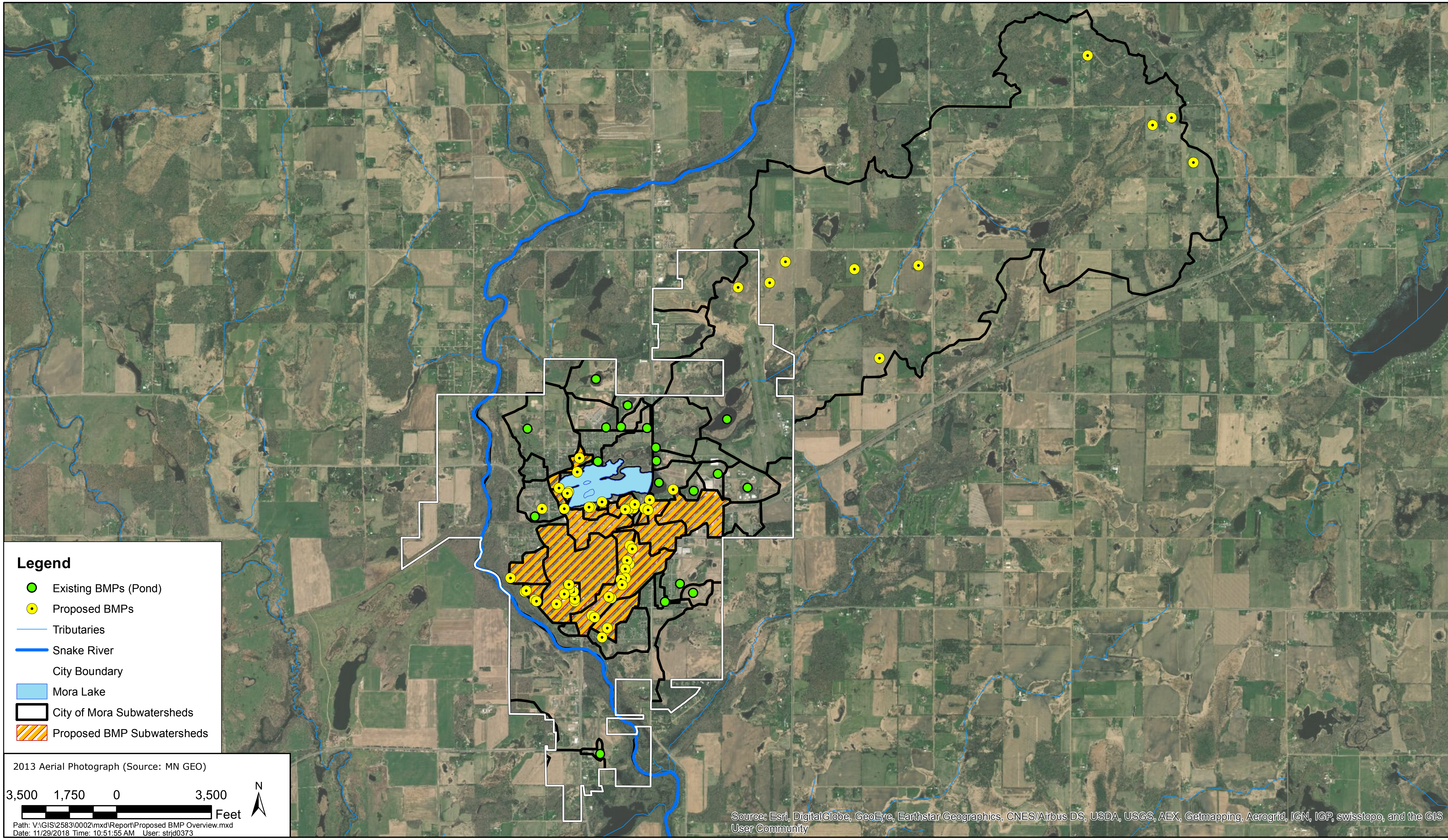
CITY OF MORA SUBWATERSHED ASSESSMENT

Existing TP Loading from Watershed

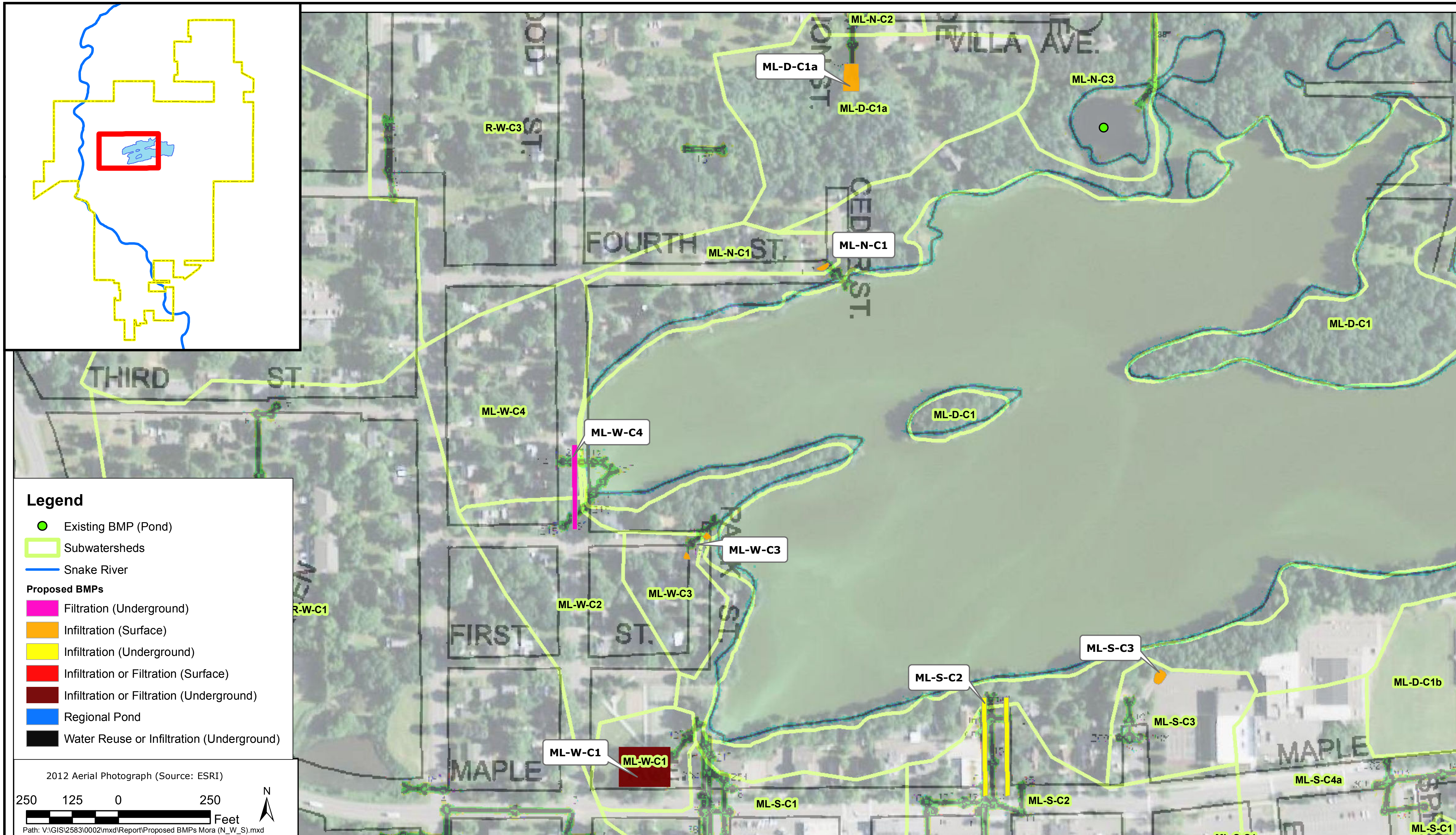
WENCK ASSOCIATES
Responsive partner. Exceptional outcomes.

NOVEMBER 2018

B-1



CITY OF MORA SUBWATERSHED ASSESSMENT	WENCK ASSOCIATES	NOVEMBER 2018
Proposed BMPs and Subwatersheds	Responsive partner. Exceptional outcomes.	B-2



CITY OF MORA SUBWATERSHED ASSESSMENT

Proposed BMPs near Mora Lake (North, West, and South)

WENCK ASSOCIATES

Responsive partner. Exceptional outcomes.

NOVEMBER 2018

B-3

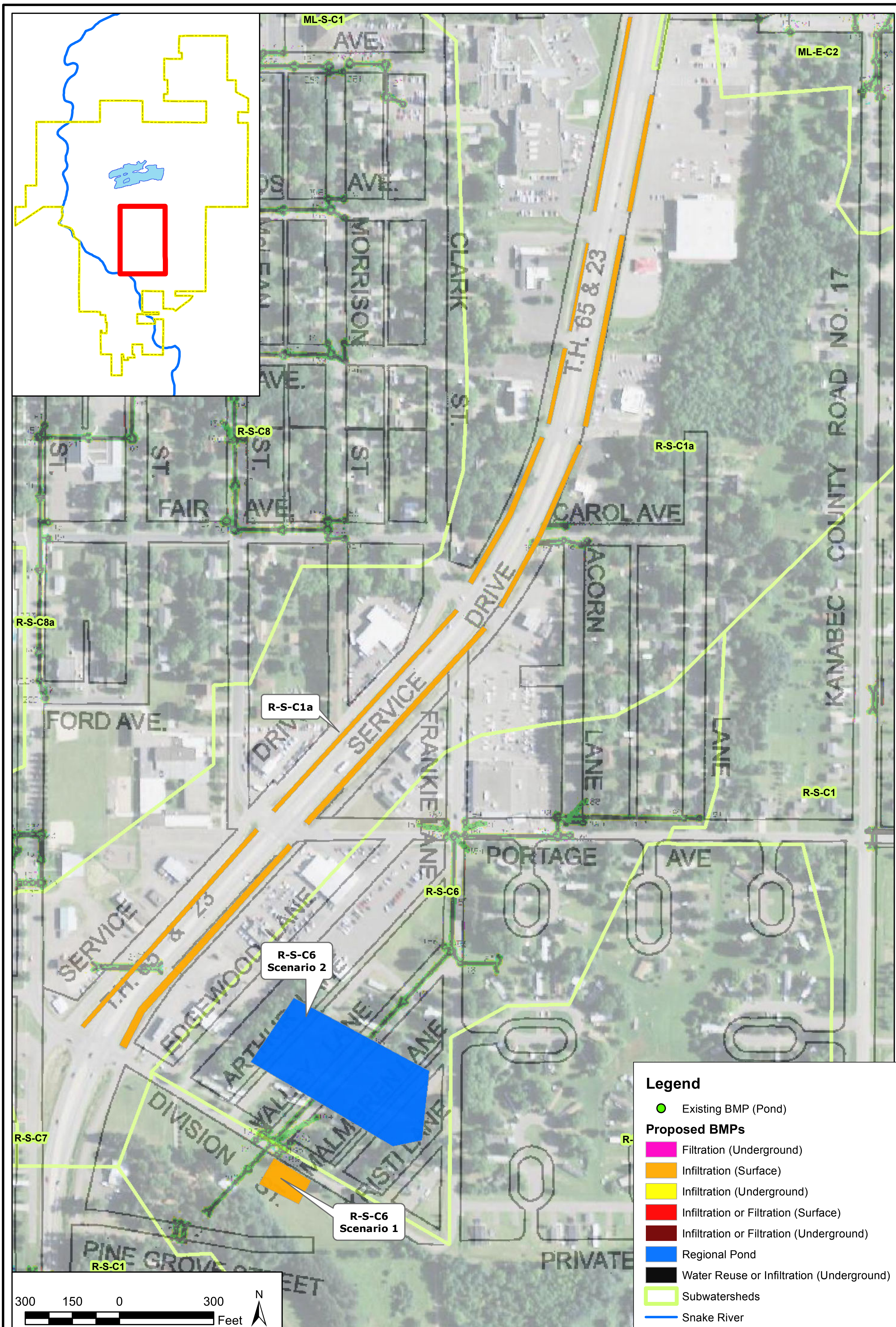
CITY OF MORA SUBWATERSHED ASSESSMENT

Proposed BMPs near Mora Lake (Southeast)

WENCK ASSOCIATES
Responsive partner. Exceptional outcomes.

NOVEMBER 2018

B-4



CITY OF MORA SUBWATERSHED ASSESSMENT

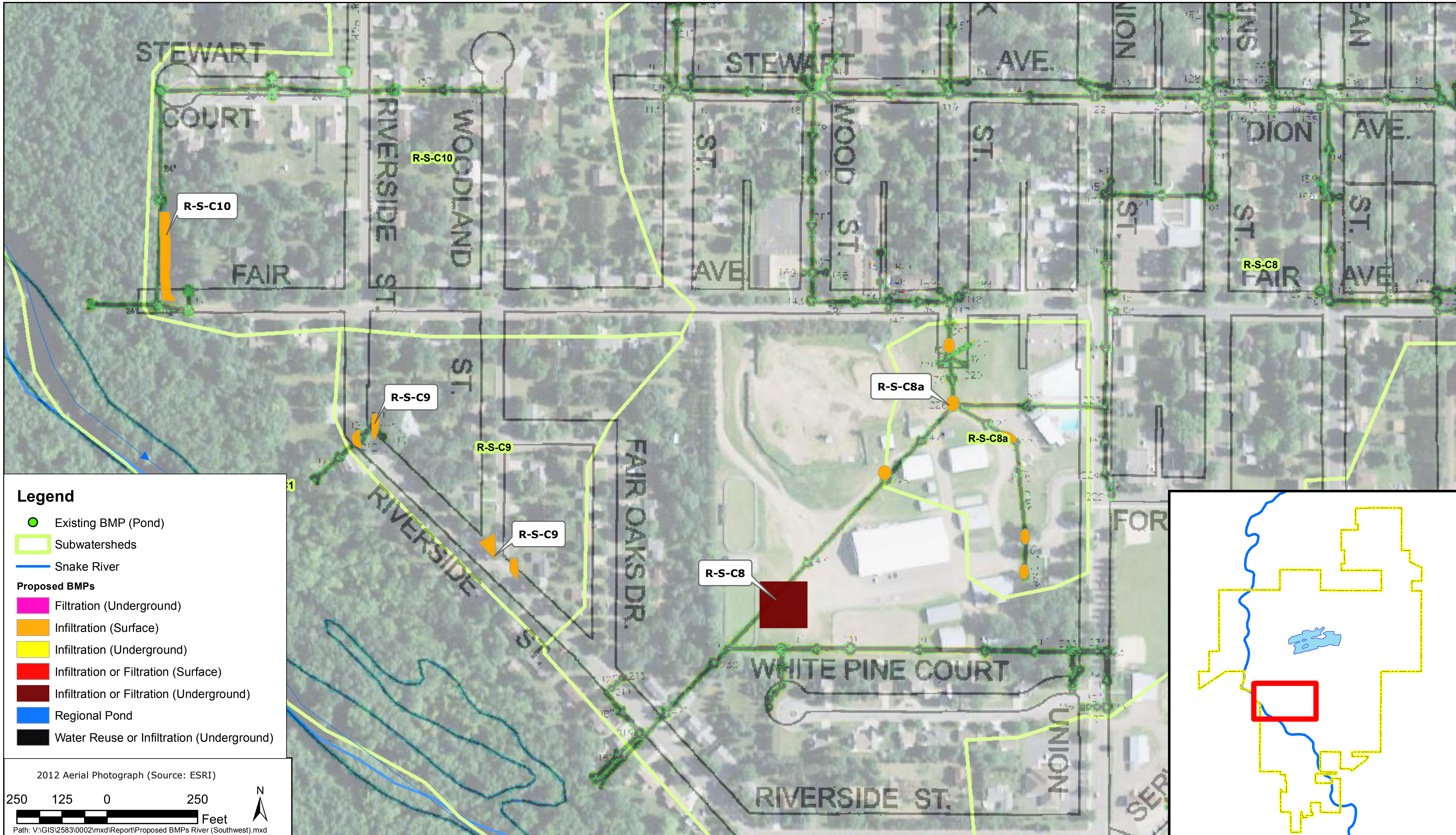
Proposed BMPs Snake River (Southeast)

WENCK ASSOCIATES

Responsive partner. Exceptional outcomes.

NOVEMBER 2018

B-5



CITY OF MORA SUBWATERSHED ASSESSMENT

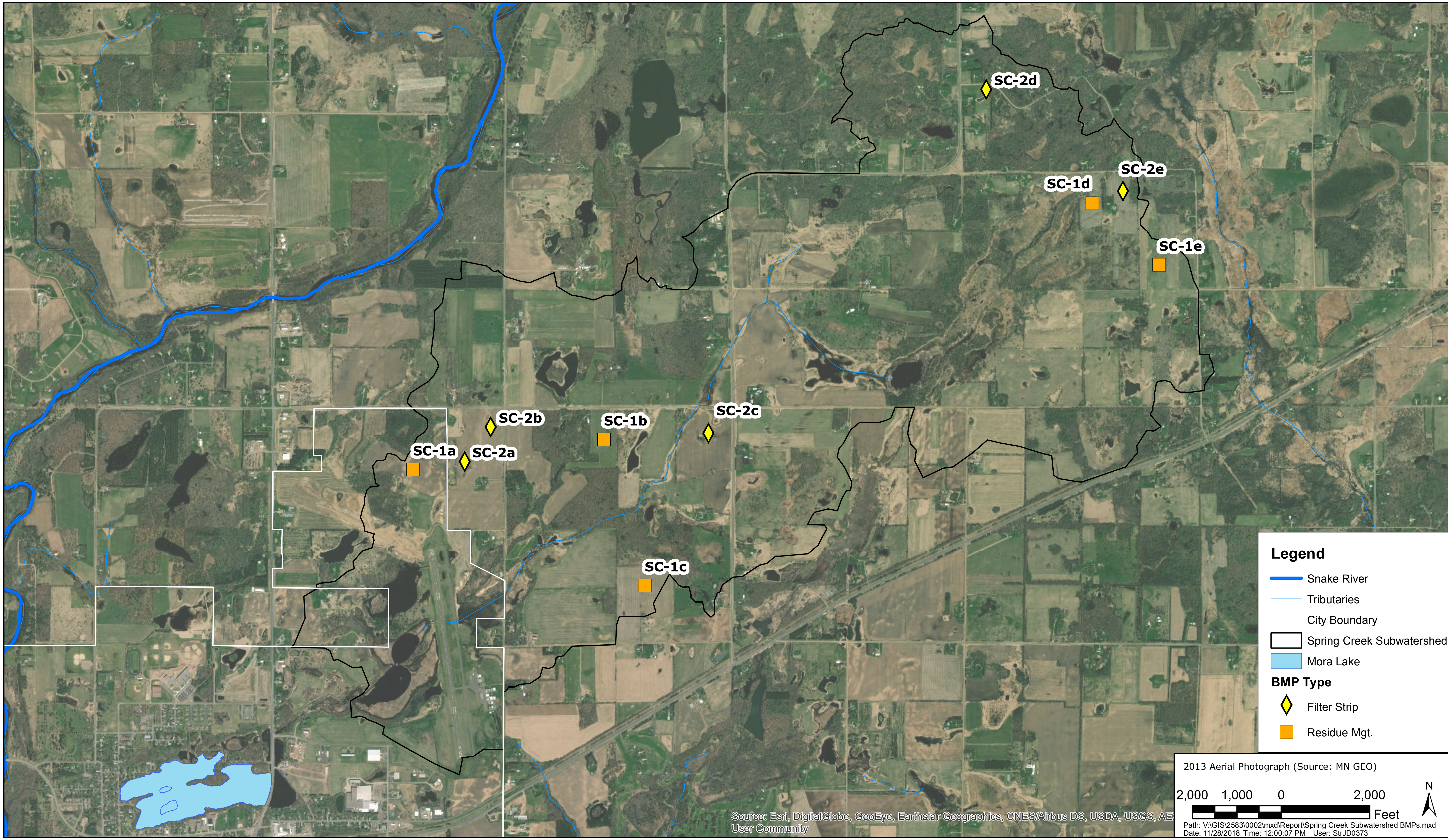
Proposed BMPs Snake River (Southwest)

WENCK ASSOCIATES

Responsive partner. Exceptional outcomes.

NOVEMBER 2018

B-6



CITY OF MORA SUBWATERSHED ASSESSMENT

Proposed BMPs in Spring Creek Subwatershed

WENCK ASSOCIATES

Responsive partner. Exceptional outcomes.

NOVEMBER 2018

B-7