HoustonEngineering Inc.

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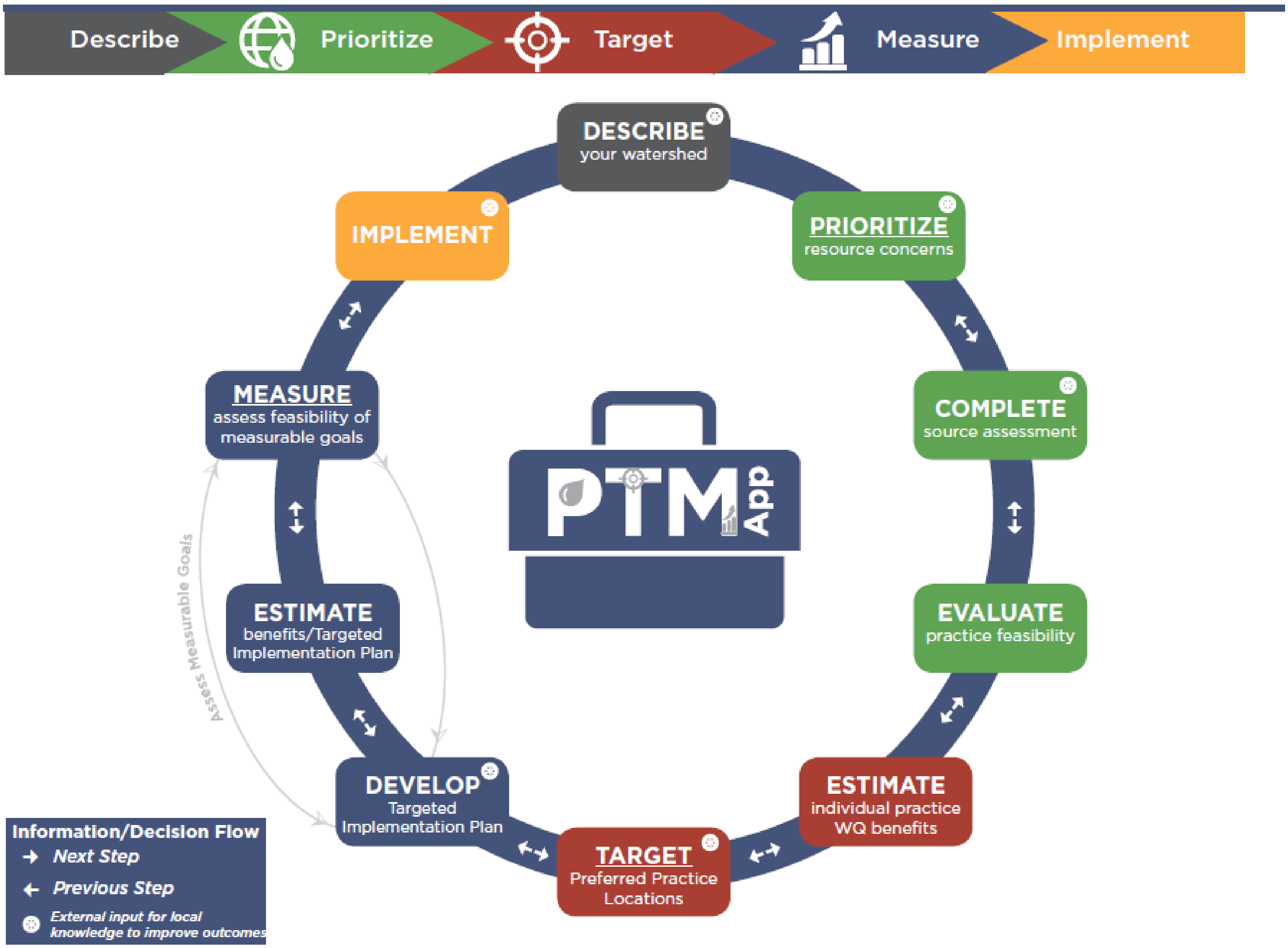


# (PTMAPP): THEORY AND DEVELOPMENT DOCUMENTATION

Minnesota Board of Water & Soil Resources

International Water Institute
Supporting Flood Research and Watershed Education

CLEAN WATER LAND & LEGACY AMENDMENT

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# 1 PROJECT COLLABORATORS

This project was conducted through a public, non-profit, private collaboration. The International Water Institute, on behalf of the Red River Water Management Board, led the effort to develop the Prioritize Target and Measure Application (PTMApp) using a Clean Water Fund Accelerated Implementation Grant from the Board of Water and Soil Resources (BWSR). Houston Engineering, Inc. was retained as a sub consultant on the project development team.

The entire project development team gratefully acknowledges the members of a blue ribbon panel that helped guide the development of PTMApp.

# 2 INTRODUCTION

The purpose of PTMApp is to leverage the geospatial data created by the IWI during the completion of their 2012 Accelerated Implementation Grant (AIG) by developing, testing, and deploying an operational application for informing the process of prioritizing watershed resources of concern and issues impacting resources of concern, targeting fields for the implementation of nonpoint source Best Management Practices (BMPs) and Conservation Practices (CPs), and estimating measurable water quality improvements that would result from BMP and CP targeted implementation plans.

The PTMApp is intended to be a statewide tool. It was specifically designed for use by local governmental units (LGU) in rural areas of the state, to facilitate the estimation of water quality benefits associated with the implementation of BMPs and CPs, as required under the Clean Water Accountability Act (CWAA) of 2013. This data and output products produced through PTMApp are intended to help inform the development of watershed plans (i.e., One Watershed, One Plan), further refine targeting completed as part of the Total Maximum Daily Load (TMDL)/Watershed Restoration and Protection Strategies (WRAPS) development, adapt and revise targeted implementation plans on annual or semiannual timesteps, and provide a means to reduce LGU's need for external technical support.

## 2.1 ASSUMPTIONS AND LIMITATIONS

PTMApp has several known limitations. The majority of calculations (described in details below) are based upon empirical information. Some specific know limitations include:

- PTMApp-Desktop processing times can be long, on the order of 1 month to process a HUC 8 watershed
- Outputs may be limited based upon the resolution of the land use/land cover data used
- Needs to be validated in a broader range of landscapes
- Does not account for existing conservation efforts
- Does not estimate species of total nitrogen or total phosphorus
- Does not estimate near channel sources of sediment and nutrients
- Does not perform hydrologic routing outside of the SCS curve number and unit hydrograph method

# 3 WORKSHOPS

As part of the project, a series of eight workshops were held. All eight of these workshops were used to inform the development of PTMApp. As such, the information garnered from these workshops were incorporated into the final PTMApp-Desktop and PTMApp-Web. A general description of the workshops is provided below. A summary of the information gleaned from the workshops is provided in **Appendix A: Workshops**.

Five workshops were designed to describe the PTMApp concept and obtain feedback from potential end users, primarily representatives from LGUs, from across the state. PTMApp intended users include local practitioners who desire data and tools which allow for the interactive prioritization, targeting and effectiveness measuring of specific BMPs and CPs, including those identified in a Total Maximum Daily Load (TMDL) studies or Watershed Restoration and Protection Strategies (WRAPS). The goal of the workshops was to insure that the PTMApp-Desktop and PTMApp-Web had statewide applicability, and resulted in user friendly tools that can easily be incorporated into efforts to implement conservation strategies to protection Minnesota's land and water resources. Briefly, the workshops covered the following topics:

1. Background and project understanding – overview of the project justification, data and expertise needed to run PTMApp, and draft data products
2. Fitting with LGU business workflows – overview of ways the PTMApp products could be used in LGU business workflows.
3. PTMApp usefulness and usability – workshop to get feedback as to whether or not the products from PTMApp will be useful and usable in LGU business workflows.
4. PTMApp-Desktop and PTMApp-Web – web based workshop to present how feedback from the 1st three workshops had been incorporated into the final PTMApp-Desktop and PTMApp-Web concept
5. Presentation of Final Products – presentation of the final products and how they can be used to develop a targeted implementation plan

# 4 PTMAPP-DESKTOP PTMAPP-WEB

This section describes the operation of PTMApp-Desktop and PTMApp-Web. It includes the technology requirements, overall structure of the application, and the workflow for both the Desktop and Web applications.

## 4.1 DEVELOPMENT/TECHNOLOGY REQUIREMENTS

**Table 1** shows the technologies that were used in the development of PTMApp-Desktop and PTMApp-Web including servers, databases, browsers, geographic information systems, and mobile device compatibility.

**Table 1.** PTMApp development and technology requirements.

| Question | Response |
|---|---|
| Where will the application be hosted? (include long-term plan) | HEI preference: Rent and configure a cloud server for the development/testing of PTMA. |
| Will the code be provided as a deliverable? | Yes. |
| Is written documentation required? | Yes. Database schema, architecture, end user. |
| What are the required platforms for this module? | Required: Desktop Web Browser;<br>Desired: Mobile tablet;<br>Not included: Mobile phone; |
| Does the application require a login or any type of user profile or specific authentication? | Yes. To store information to allow the user to save scenarios for evaluating Best Management Practices (BMPs) and Conservation Practices (CPs). |
| Does this application require https security? | No. |
| Who will completed testing? | Users selected by BWSR. |
| Is wire framing planned or completed? | Yes, some. Sufficient to illustrate primary pages. |
| What source control will be used? | SVN or GIT |
| How will application bugs get tracked? | Assembla Tickets |
| If desktop which operating systems to support? | Windows 7, Windows 8 |
| License agreement | Yes. Prior to distribution. |
| Does the application need to interact with a third party program such as document imaging system, financial system, etc.? | No. |
| How will maintenance and support be handled upon completion of the project? | Limited period of time, based on financial availability, subsequent to acceptance by BWSR. |
| **Server & Database** | |
| Is there a preferred server-side development language/framework? | HEI preference: Python with Django framework or PHP<br>HEI preference Web Server: Apache |
| Is a database required? | HEI preference: PostGreSQL |
| Do we need to design a database schema or is it provided? | Design. |
| Will it be a Windows or Linux server? | HEI preference: Windows |

| | |
|---|---|
| How large of a database (number of records) is anticipated (this can influence the decision on the database). | Not of concern. |
| Is ArcGIS Online or Arc Server required? | Yes. |
| Will the client want a backup copy of their database? | Yes. |

| **Client / Browser** | |
|---|---|
| What browsers does it need to support? | IE10+; Firefox; Chrome – versions as existing in 2014. |
| Is backward compatibility required with older browsers (IE 8,9)? | No. |
| Is there a preferred client-side programming language/framework? | HEI preference: JavaScript/HTML with jQuery Mobile, Jquery UI or Dojo Toolkit libraries (depends on mobile considerations) |
| Is there a preferred client-server communication standard? | WCF, REST |
| Are there any additional IT polices or standards? | |
| **Mobile** | |
| Does that application need to support use mobile devices? | Tablet if possible. Not in current scope of project. |
| Identify the mobile platforms. | Not applicable |
| Does it need to work in a disconnected environment? | Not applicable |
| **GIS** | |
| Does that application need GIS functionality? | Yes. |
| If so what? | Geoprocessing; map viewer; and digitizing. |
| Is there a preferred GIS platform? | HEI Preference: ESRI |
| Will the application require storing GIS data entry in the database? Example digitizing points, lines or polygons. | Yes. |
| What API's are desired? | ESRI JavaScript |
| If ESRI desktop, what map data formats to support | File GDB, SDE |
| Required extensions? | Spatial analyst |
| Is web map editing required | Yes. |

## 4.2 OVERALL STRUCTURE OF THE APPLICATION

PTMApp is made up of two components, PTMApp-Desktop and PTMApp-Web (**Figure 1**). PTMApp-Desktop is an ArcGIS Desktop toolbar. PTMApp-Desktop is the engine for conducting analysis to inform the prioritization of resources of concern, target conservation efforts, and measure the resulting water quality improvements from implementing BMPs. PTMApp-Desktop can serve as a standalone tool for developing watershed plans and targeted implementation plans. In addition, the functionality can be used for tailoring the results of targeted implementation plans through project design and build. However, PTMApp-Desktop requires access to ArcGIS and a moderate level of ArcGIS technical expertise (Table 2). PTMApp-Web was built to ingest the data created through PTMApp-Desktop and make PTMApp functionality available to a wider range of practitioners. Once initialize, PTMApp-Web can be used during watershed planning to inform the prioritization of resources of concern, target conservation efforts, and measure the resulting water quality improvements from implementing BMPs. In particular, PTMApp-Web is especially well suited to the collaborative design and tailoring of targeted implementation plans. Section *4.3 Workflow overview* describes the workflow overview for PTMApp-Desktop and PTMApp-Web.

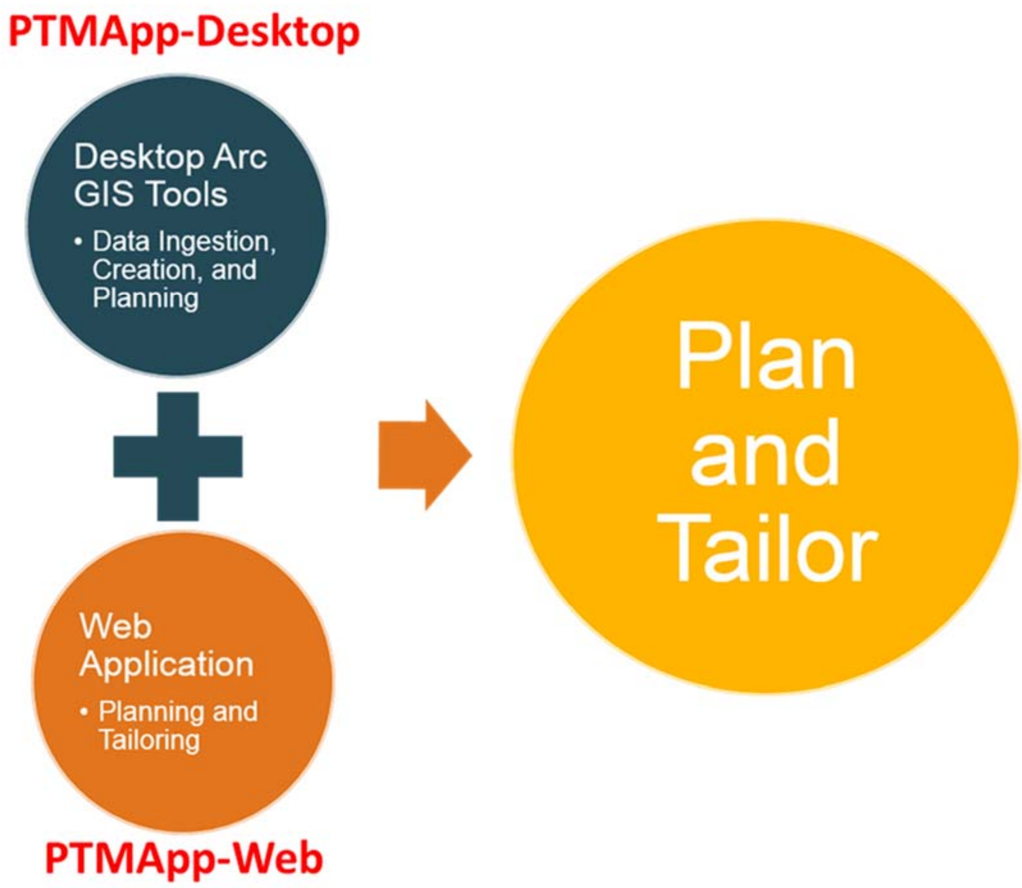



**Figure 1. Overall structure of PTMApp.**

Table 2. Capacity needed to utilize PTMApp-Desktop and PTMApp-Web.

| Need | Stage of Plan Development | Level of Expertise |
|---|---|---|
| Person capable of gathering the data needed to run the desktop application, and run the application to generate the products | Early | Moderate GIS skills |
| Load GIS products following generation of the desktop process to a GIS server and turn on web services | Toward end of plan development | Advanced GIS/ Technical skills |
| GIS base data creation capability for Time of Travel, Curve Number, etc. | Early | Moderate GIS skills |
| ESRI ArcGIS (9.X or >) with a spatial analyst license for processing the data for through the desktop toolbar | Early | NA |
| Person(s) capable of running the web application once it is set up | Post Plan (Tailoring) | Novice |

## 4.3 WORKFLOW OVERVIEW

**Figure 2** is a process workflow chart has been used to diagram the workflow process for PTMApp-Desktop and PTMApp-Web, including diagramming the relationship between the two PTMApp components. In Section *5.3.1:*

*PTMApp Desktop* and *5.3.2 PTMApp-Web*, the workflows within each of the two components of PTMApp are described.

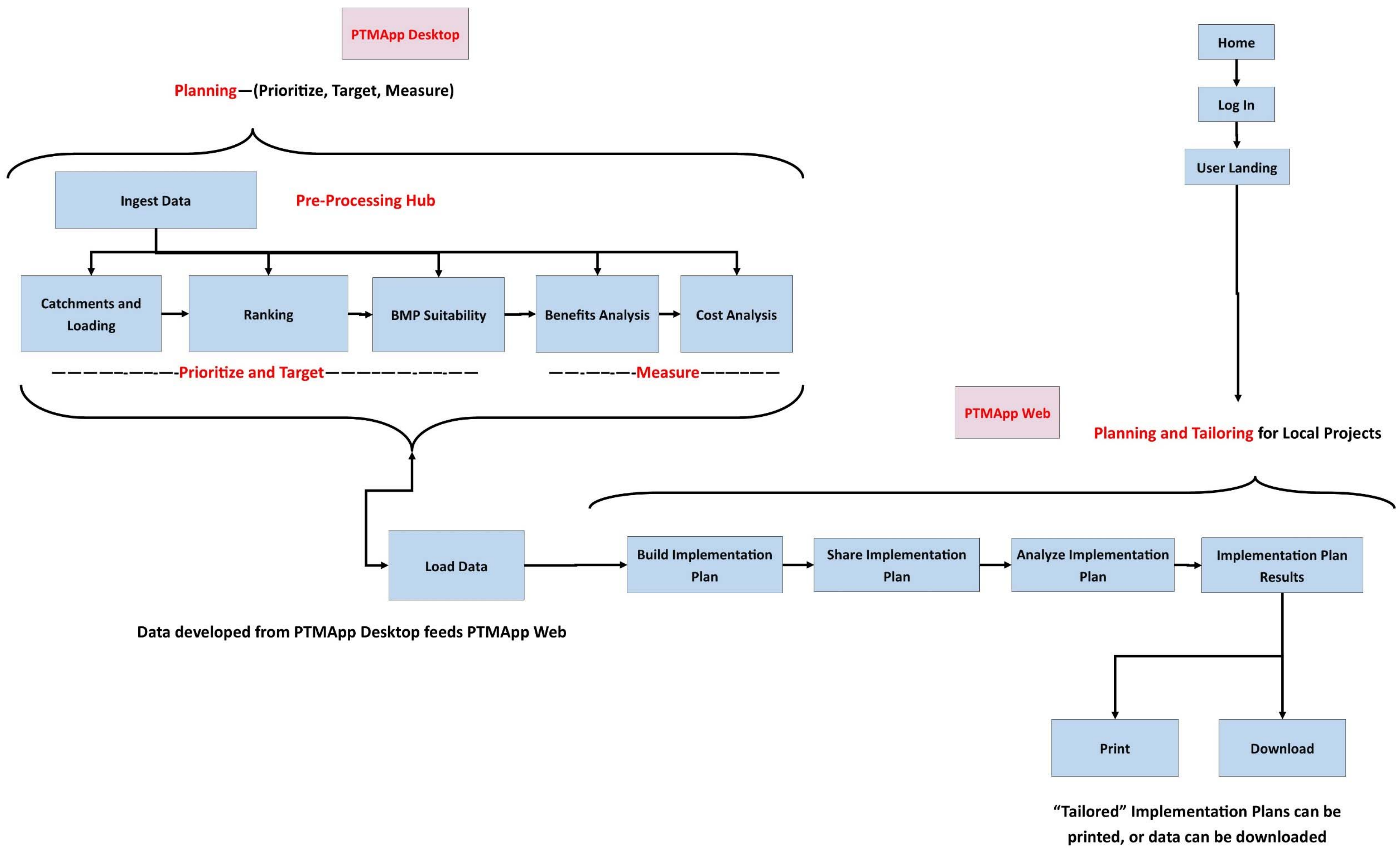



**Figure 2.** Workflow overview for PTMApp-Desktop and PTMApp-Web.

### 4.3.1 PTMAPP-DESKTOP

PTMApp-Desktop is comprised of several modules that perform different processing steps for the PTMApp-Desktop workflow (**Figure 2**). The desktop modules include Ingest Data, Catchments and Loading, Ranking, BMP Suitability, Benefits Analysis, and Cost Analysis. The process workflows for each module have been provided in this section describing the functionality provided by each of the modules.

#### 4.3.1.1 INGEST DATA

The Ingest Data module in PTMApp-Desktop sets the plan boundary extent, which in turn set the extent for all data used in the desktop analysis. This module establishes the working data that is utilized for the remainder of the PTMApp-Desktop calculations. Once set, all base data is clipped to the plan boundary extent. In addition, the optional planning data and the required processing data are input and clipped to the plan boundary in the Ingest Data Module.

#### 4.3.1.2 CATCHMENTS AND LOADING

The Catchments and Loading module allows the user to generate field scale (average size 40 acres) catchment for the entire plan boundary, process hydrologic travel times to catchment outlets and resources of concern, generate TP, TN, and sediment yield and loading, deliver TP, TN, and sediment yields and loads to catchment outlets and resources of concern, generate volumes and peak discharge for 2 year, 24 hour and 10 year, 24 hour events, and import scaling data (HSPF, SWAT, or 1 gage). The methods used in the Catchments and Loading Module are described in section *5.1 Catchments and loading*.

#### 4.3.1.3 RANKING

The Ranking module allows the user to calculate ranks (i.e. 0-100%) for the loading information generated in the Catchments and Loading Module. This includes ranking the delivery of TP, TN, and sediment leaving the landscape, to catchment outlets, and resources of concern. In addition, the Ranking Module allows the user to re-rank data based upon user provided zones (e.g. planning regions), adjust ranks developed by PTMApp by a user supplied weighting factor (e.g. zonation outputs, landowner willingness), and calculate a Water Quality Index (WQI). The methods used in the Ranking Module are described in section *5.2 Ranking*.

#### 4.3.1.4 BMP SUITABILITY

The BMP Suitability module allows the user to identify locations on the landscape that hold the potential for storage, filtration, biofiltration, infiltration, protection, source reduction, and user defined BMPs and CPs. The methods used to identify locations suitable locations for conservation efforts in the BMP Suitability Module are described in section 5.3 BMP suitability.

#### 4.3.1.5 BENEFITS ANALYSIS

The Benefits Analysis Module allows the user to measure the load reductions in TP, TN, and sediment that would occur from implementing BMPs and CPs on the landscape. This includes estimating load reductions based upon single practice treatments and treatment trains. The methods used to estimate load reductions in the Benefits Analysis Module are described in section *5.4 Benefits analysis*.

#### 4.3.1.6 COST ANALYSIS

The Cost Analysis Module allows the user to calculate the cost and treatment cost ($/mass of load reduced) of implementing BMPs and CPs. It includes an option for identifying the optimum treatment costs for single practice implementation scenarios. The methods used for the Cost Analysis module are described in section 5.5 Cost analysis.

### 4.3.2 PTMAPP-WEB

The PTMApp-Web allows users to collaboratively build, share, and analyze targeted implementation plans. After analysis is conducted on the targeted implementation plans, the results can be viewed, printed, or downloaded. The analysis of targeted implementation plans in PTMApp-Web is driven by the treatment train analysis functionality built into PTMApp-Desktop, and is described in section *5.7 Modeling Treatment Trains*. Similarly, the collaboratively built targeted implementation plans can also be viewed, printed, or downloaded by users. The functionality of PTMApp-Web is developed primarily with the goal of allowing local units of government to collaboratively build, share, and analyze BMP targeted implementation strategies that are prioritized, targeted, and result in measurable water quality improvements. The conceptual wireframes that were built during PTMApp development document the workflow process and have been provided in **Appendix C: PTMApp-Web Wireframes**.

# 5 THEORY AND METHODS

The theory and methods utilized by PTMApp-Desktop and PTMApp-Web are described in this section. The major modules within PTMApp include:

- Catchments and Loading
- Ranking
- BMP Suitability
- Benefits Analysis
- Cost Analysis

The theory and methods used in performing calculations within each of these major modules is described in the following sections.

## 5.1 CATCHMENTS AND LOADING

This section described the methods used to generate catchments, stream power index (SPI), sediment yields and delivery, and TN and TP yields and delivery.

### 5.1.1 CATCHMENTS

Catchments are generated with PTMApp-Desktop to represent field scale units (average size 40 acres) that are delineated based upon hydrology. Catchments serve as the finest scaled of data aggregation with PTMApp-Desktop and PTMApp-Web. As part of PTMApp-Desktop processing, the topological relationships among catchments are established for use in routing TP, TN, and sediment to resources of concern and adjoint catchment outlets. Adjoint catchments are defined within PTMApp as catchments that have catchments upstream of their location which contribute flow, TP, TN and sediment to their pour point.

### 5.1.2 STREAM POWER INDEX

SPI accounts for physical characteristics of a landscape to estimate the potential of overland and concentrated surface water flow to cause erosion. SPI values are computed by multiplying the slope of a point on the landscape by its contributing drainage area (i.e. flow accumulation).

$$SPI \ = \ln[(flow\ accumulation)\ x\ (slope)]$$

Higher SPI values indicate greater energy in moving surface water and thus a greater likelihood of sediment erosion. SPI is a simple analysis, not accounting for land cover, land use, soil type or other factors that impact surface water erosion. For this reason, it is best to compare SPI values across areas with similar land management practices, land covers, and soils.

In PTMApp, SPI values are computed using derivatives of a conditioned digital elevation model (DEM). Landscape slope is determined from the raw “bare earth” DEM. Contributing areas are determined using the flow accumulation raster created from the conditioned DEM. Typically, the primary focus of the SPI analysis is to locate areas with high potential for erosion and subsequently gully formation.

### 5.1.3 SEDIMENT YIELD

Sediment yields are estimated based on the implementation of the Revised Universal Soil Loss Equation (RUSLE). RUSLE accounts for land cover, soil type, topography, and management practices to determine an average annual sediment yield estimate as a result of rill and interrill flow. RUSLE requires several input parameters to be developed and multiplied an equation to form the estimated annual sediment yield. The development of input variables to RUSLE are described below. The RUSLE is calculated as:

$$A = R\ x\ K\ x\ LS\ x\ C\ x\ P$$

where, R is the Rainfall and Runoff Factor, K is the Soil Erodibility Factor, LS is the Length-Slope Factor, C is the Cover and Management Factor, and P is the Support Practice Factor. The R, K, C, and P factors are require inputs for PTMApp-Desktop (see PTMApp-Desktop user guide, available online: http://ptmapp.rrbdin.org/files/PTMApp_User_Guide.pdf ). A description of each of these factors is given below.

Rainfall and Runoff Factor (R-factor) – The R-factor accounts for the impact of meteorological characteristics of the watershed on erosion rates. Information on R-factors across the State of Minnesota is available from the NRCS Field Guide, on a county-by-county basis (NRCS, 1996)

Soil Erodibility Factor (K-factor) – Soil erodibility factors used in PTMApp should be taken directly from the NRCS’s SSURGO Database. The K factor accounts for the effects of soil characteristics on erosion rates.

Length-Slope Factor (LS-factor) – The LS-factor accounts for physical characteristics of the landscape on erosion rates. The US Department of Agriculture’s (USDA) Predicting Soil Erosion by Water: A Guide to Conservation Planning with RUSLE, Agricultural Handbook No. 703 summarizes the methodology used to derive the LS-factors within PTMApp. Length data is derived from the conditioned DEM and slope data was derived from the raw “bare earth” DEM.

Cover and Management Factor (C-factor) – The C-factor accounts for land cover effects on erosion rates. C-values in the NRCS’s MN Field Office Technical Guide should be used as the basis for developing the values used in this analysis. These C-Factors can be transcribed based upon land use, land cover. The most recent National Agricultural Statistics Service (NASS) Crop Land Datalayer (CDL) is the recommended land use, land cover data source. **Table 3** C-Factor values that can be transcribed based upon the 2013 NASS CDL. PTMApp currently uses generalized C-Factors as data on future crop rotations and an assessment of their transcription to C-Factors were unavailable at the time this project was developed. It is suggested that future work considers developing better estimates of C-Factors based upon rotational changes in land use, land cover.

**Table 3.** Cover and Management Factor suggestion for PTMApp based upon 2013 NASS CDL.

| C- Factor | NASS CDL Classification |
|---|---|
| **0.200** | Corn, Soybeans, Sunflower, Barley, Spring Wheat, Durum Wheat, Winter Wheat, Rye, Oats, Canola, Flaxseed, Peas, Herbs, Dry Beans, Potatoes, Other Crops, Fallow/Idle Cropland |
| **0.100** | Alfalfa, Other Hay/Non Alfalfa, Sod/Grass Seed, Herbs |
| **0.005** | Clover/Wildflowers |
| **0.003** | Developed/Open Space, Developed/Low Intensity, Developed/Medium Intensity, Developed/High Intensity, Barren |
| **0.002** | Deciduous Forest, Evergreen Forest, Shrubland, Mixed Forest |
| **0.001** | Grassland Herbaceous, Woody Wetlands, Herbaceous Wetlands |
| **0.000** | Open Water |

Support Practice Factor (P-factor) – The P-factor accounts for the impact of support practices on erosion rates. Examples of support practices include contour farming, cross-slope farming, and buffer strips. For the purposes of PTMApp, variations in P-factors across the study area were not accounted for in Sediment yield and load calculations, since there is not sufficient information to derive P-factors at the scale required for this analysis. Support practice P-factors are typically less than one and result in lower estimates of sediment yield than if the support practices were not accounted for. As such, the results of the RUSLE analysis in this work are conservative estimates of soil erosion, not accounting for support practices that may be in-place. Practices such as contour farming and buffer strips can be accounted for in the Benefits Analysis module within PTMApp.

### 5.1.4 SEDIMENT DELIVERY

Once the sediment yield is estimated within PTMApp, the sediment reaching a channel at the catchment outlet is estimated using a sediment delivery ratio (SDR). The estimated SDR for the catchment is a function of area (Maidment, 1993).

$$Overland\ SDR = 0.41 * catchment\ drainage\ area\ (sq.km)^{-0.3}$$

The SDR for each cell within an overland catchment is estimated as a function of the catchment SDR adjusted by the distance from a cell to the nearest area of channelized flow.

$$Overland\ SDR\ Adjustment\ Factor = 1 - \frac{\frac{Flow\ Length}{Maximum\ Flow\ Length\ in\ Catchment}}{0.75 + \frac{Flow\ Length}{Maximum\ Flow\ Length\ in\ Catchment}}$$

Therefore, the SDR for each cell is computed as Overland SDR (for the catchment) multiplied by Overland SDR Adjustment Factor (for the cell).

The sediment transported downstream to a priority resource is further reduced using a first-order transport function. In-channel downstream transport and loss follows an exponential decay function (i.e., first order loss) using travel time and median diameter of sediment:

$$SY = Ye^{-\beta T\sqrt{d_{50}}}$$

Where Y is sediment yield, β is transport coefficient, T is travel time, $d_{50}$ is mean sediment diameter. Values of 0.2 and 0.1 are used as defaults for β and the $d_{50}$, respectively. These values can be adjusted based upon local knowledge.

### 5.1.5 TN AND TP YIELD

Nutrient annual yields leaving the landscape are estimated using a method similar to sediment (i.e., they are computed for each cell in the raster). Yields for TP and TN follow an empirical approach using land use export coefficients from literature values. TP and TN annual yields are estimated using the values in **Table 4** and **Table** 5 applied to land use classes in the 2011 National Land Cover Dataset (NLCD), respectively.

**Table 4.** Total Phosphorus yield for NLCD 2011 land use classifications.

| NLCD Classification | Description | TP Loading [kg/ha/yr] | Source |
|---|---|---|---|
| **11** | Open Water | 0 | MPCA 2004 |
| **21** | Developed, Open Space | 1 | Lin 2004 |
| **22** | Developed, Low Intensity | 0.91 | LimnoTech 2007 |
| **23** | Developed, Medium Intensity | 1.15 | LimnoTech 2007 |
| **24** | Developed, High Intensity | 1.5 | LimnoTech 2007 |
| **31** | Barren Land | 1 | MPCA 2004 |
| **41** | Deciduous Forest | 0.075 | LimnoTech 2007 |
| **42** | Evergreen Forest | 0.075 | LimnoTech 2007 |
| **43** | Mixed Forest | 0.075 | LimnoTech 2007 |
| **52** | Shrub/Scrub | 0.075 | LimnoTech 2007 |
| **71** | Grassland/Herbaceous | 0.17 | LimnoTech 2007 |

| NLCD Classification | Description | TP Loading [kg/ha/yr] | Source |
|---|---|---|---|
| **81** | Pasture/Hay | 0.17 | LimnoTech 2007 |
| **82** | Cultivated Crops | 0.38 | LimnoTech 2007 |
| **90** | Woody Wetlands | 0 | LimnoTech 2007 |
| **95** | Emergent Herbaceous Wetlands | 0 | LimnoTech 2007 |

**Table 5.** Total Nitrogen yield for NLCD 2011 land use classifications.

| NLCD Classification | Description | TN Loading [kg/ha/yr] | Source |
|---|---|---|---|
| **11** | Open Water | 3.5 | MPCA 2013 |
| **21** | Developed, Open Space | 3.5 | MPCA 2013 |
| **22** | Developed, Low Intensity | 5.4 | US EPA 1983 |
| **23** | Developed, Medium Intensity | 9.6 | US EPA 1983 |
| **24** | Developed, High Intensity | 18.0 | US EPA 1983 |
| **31** | Barren Land | 3.5 | MPCA 2013 |
| **41** | Deciduous Forest | 2 | US EPA 1999 |
| **42** | Evergreen Forest | 2 | US EPA 1999 |
| **43** | Mixed Forest | 2 | US EPA 1999 |
| **52** | Shrub/Scrub | 2 | US EPA 1999 |
| **71** | Grassland/Herbaceous | 1.3 | USDA MANAGE[1] database |
| **81** | Pasture/Hay | 2.4 | USDA MANAGE[1] database |
| **82** | Cultivated Crops | 7.8 | USDA MANAGE[1] database |
| **90** | Woody Wetlands | 3.5 | MPCA 2013 |
| **95** | Emergent Herbaceous Wetlands | 3.5 | MPCA 2013 |

[1] U.S. Department of Agriculture – Agricultural Research Station. Nutrient Loss Database for Agricultural Fields in the US. (http://www.ars.usda.gov/Research/docs.htm?docid=11079)

### 5.1.6 TN AND TP DELIVERY

The mass leaving each cell comprising the raster is “routed” downstream to: 1) the overland catchment outlet 2) each priority resource, using a first order decay computed as a function of overland and in-channel flow travel times. The decay or loss of mass after leaving the landscape is used to represent the reduction in mass from physical, chemical and biological processes. A travel time raster is used in estimating the first order loss coefficient. The calculation methods for downstream routing can be subdivided into two parts 2) transport to the channel, and 3) an in-channel routing routine.

The nutrient mass loss as it is transported downstream was represented using a first order loss equation for both, as a function of travel time:

$$W = \exp(-kT)$$

where W is the portion of the yield leaving the landscape and delivered to the downstream, k is the decay rate and T is travel time from one location to the next The default values used for k was 0.1 for travel to the overland catchment outlet and 0.4 for in-channel transport. The delivery raster was created using the travel time raster to determine the portion of the mass reaching the overland catchment and priority resources.

### 5.1.7 RUNOFF VOLUME AND PEAK DISCHARGE

The runoff volume (i.e. excess depth multiplied by watershed area) is calculated in PTMApp-Desktop using the NRCS runoff curve number (CN) method. The table used for generating CN values has been provided in

**Appendix D: Curve Number Table.** Peak discharge is then calculated based upon methods describe in NRCS TR-55 (NRCS, 1986). These calculations are performed at the raster scale, giving a spatially distributed estimate of volumes.

### 5.1.8 ADJUSTING LOADS AND YIELDS

Two options for adjusting loads are available: adjusting to modeling data (e.g. Hydrologic Simulation Program-Fortran) and adjusting to point information (i.e. monitoring data). Spatial information includes land segment information from watershed models (e.g. SWAT or HSPF) or other known sources (e.g. event mean concentrations (EMCs)) which have a spatial extent (e.g. PERLNDs from HSPF, HRUs from SWAT, NLCD for EMCs, etc). Point information is observed loads at a gauging point the User would like to adjust the yields too.

## 5.2 RANKING

### 5.2.1 PERCENTILE RANKS

For Sediment, TP, and TN data, percentile ranks are calculated based upon the relative magnitude of contribution towards leaving the landscape, reaching a catchment outlet, and reaching a priority resource. Percentile ranks are calculated assuming a log-normal distribution, or linear distribution. PTMApp users will be able to choose which distribution is a better fit for their data.

### 5.2.2 WATER QUALITY INDEX

PTMApp, calculates a Water Quality Index (WQI) value that combines the sediment, TP and TN ranked rasters into one composite ranking computed as follows.

$$Water\ Quality\ Index\ (WQI) = 0.5\ x\ Sediment\ Rank + (0.25\ x\ TN\ Rank + 0.25\ x\ TP\ Rank)$$

By default, this formula gives equal weighting to both sediments and nutrients to identify areas contributing relatively high proportions of both sediment and nutrients downstream. Within PTMApp, these weightings can be adjusted based upon user preference.

## 5.3 BMP SUITABILITY

Within PTMApp, potential locations for BMPs and CPs are identified based upon treatment groups (**Table 6**). These groups are based upon the primary form of treatment and the primary treatment process. **Table 7** shows an example of how these treatment groups correspond to specific types of BMPs.

**Appendix E: Mapping BMPs to Treatment** Groups contains the list of specific BMP types and how they correspond to PTMApp treatment groups. PTMApp-Desktop application will identify suitability for representative BMPs based upon treatment groups. The suitability analysis is not expected to include all BMPs in **Table 6**.

**Table 6.** BMP and CP treatment groups and primary treatment process.

| | Storage | Filtration | Bio-Filtration | Infiltration | Protection | Source Reduction | User Defined |
|---|---|---|---|---|---|---|---|
| **Primary Treatment Process** | Sedimentation | Sedimentation | Sedimentation & biological | Volume abstraction | Physical protection of the landscape | Reduction of Mass Potential | User selects method (from those to left) or enters percentage |
| **Primary Form of Treatment** | Particulate | Particulate | Particulate | Dissolved | Total (Dissolved & Particulate) | Total (Dissolved & Particulate) | Total (Dissolved & Particulate) |

**Table 7.** Example of specific BMPs that have been categorized into Treatment Groups.

| Treatment Group‡ | BMP Type | NRCS Practice Code | BWSR Practice Code | MDA BMP Handbook Category |
|---|---|---|---|---|
| **Infiltration** | Alternative Tile Intakes | 606 | 170M – 173M | Controlling |
| **Filtration** | Grassed Waterways | 412 | 412 | Controlling |
| **Filtration** | Filter Strip | 393 | 393 | Trapping |
| **Protection** | Grade Stabilization Structure | 410 | 410 | Trapping |
| **Source Reduction** | Nutrient Management | 590 | 590 | Avoiding |
| **Storage** | Water and Sediment Control Basin (WASCOB) | 638 | 638 | Trapping |
| **Protection** | Critical Area Planting | 342 | 342 | Avoiding |
| **Storage** | Pond for Water Use | 378 | 378 | Trapping |

| Treatment Group‡ | BMP Type | NRCS Practice Code | BWSR Practice Code | MDA BMP Handbook Category |
|---|---|---|---|---|
| **Protection** | Streambank and Shoreline Protection | 580 | 580 | Controlling |
| **Storage** | Wetland Restoration | 657 | 657 | Trapping |
| **Filtration** | Conservation Cover Easement | 327 | 327 | Avoiding |
| **Bio-Filtration** | Vegetated Subsurface Drain Outlet (Saturated Buffers) | 739 | 739 | Trapping |
| **Storage** | Drainage Water Management | 554 | 554 | Controlling |
| **Bio-Filtration** | Denitrifying Bioreactor | 747 | 747 | Trapping |
| **User Defined** | User Defined† | User Input | User Input | User Input |

PTMApp identifies areas that are suitable for BMP Treatment Groups based upon the criteria in **Table 8.** These criteria are primarily based upon NRCS design standards. User defined can be any point on the landscape, however, the user would then have to match their location to one of the PMTApp treatment groups.

**Table 8.** Suitability criteria for BMP treatment groups.

| Treatment Group | Specific BMP | Criteria |
|---|---|---|
| **Storage** | WASCOB/Sediment Basin | • Accumulated sediment delivered to flow line; percentile rank > 90;<br>•Contributing drainage area < 40 acres |
| | Controlled Drainage | •National Land Cover Dataset (NLCD) 2011 cultivated lands;<br>•Slope < 1%;<br>•Not a hydric soil |
| | Ponds for Water Use | |
| | Wetland Restoration | |
| | Depression Storage | •Depressions(fill all on raw DEM – raw DEM);<br>•Minimum depth of 0.5 feet;<br>•Minimum surface area of 2 ;acres<br>•National Land Cover Dataset (NLCD) 2011 cultivated lands |
| | Drainage Water Management | |
| **Filtration** | Grassed Waterways | •Contributing drainage area < 7 acres; |

| Treatment Group | Specific BMP | Criteria |
|---|---|---|
| | | •Slope > 3% and < 12%;<br>•National Land Cover Dataset (NLCD) 2011 cultivated lands ;<br>•Upstream flow length less than 750 feet |
| | Filter Strips | •Land Within 100 ft. of channelized flowline;<br>•NLCD 2011 cultivated lands;<br>•< 8.1 tons/year of sediment;<br>•Contributing Area < 124 acres |
| | Saturated Buffer | •Land Within 100 ft. of channelized flowline;<br>•NLCD 2011 cultivated lands;<br>•Depth to groundwater < 2 feet |
| | Conservation Cover Easements | |
| **Bio-filtration** | Denitrifying Bio-reactors | •Slope ≤ 1%;<br>•NLCD 2011 cultivated lands;<br>•Not a hydric soil |
| **Infiltration** | 2-stage Ditch | •NLCD 2011 cultivated lands;<br>•Drainage ditch based on MN DNR 24K streams;<br>•Bank heights ≤ 10 ft. |
| **Protection** | Grade Stabilization | •SPI Ranks > 50;<br>•NLCD 2011 cultivated lands |
| | Shoreline Protection | |
| **Source Reduction** | Nutrient Management | |
| | Cover Crops | •NLCD 2011 cultivated lands; |
| | Perrenial Crops | •Crop Productivity Index ≤ 61;<br>•NLCD 2011 cultivated lands |
| **User Defined** | | |

## 5.4 BENEFITS ANALYSIS

One of the most challenging parts of "measuring" water quality improvements is estimating the reduction in total nitrogen (TN), total phosphorus (TP), and sediment resulting from implementing agricultural BMPs and CPs on the landscape. Some of the reasons that estimating the pollutant reduction benefits of agricultural BMPs and CPs is challenging include:

- The dependence upon specific design factors related to the BMP or CP;
- Effectiveness is a function of the location of the BMP or CP on the landscape, relative to the particular waterbody it is intended to protect or restore;
- Highly variable in-field monitoring results, caused in part because of the changing environmental conditions (e.g., amount of runoff); and
- Challenges associated with the ability to extrapolate monitoring data from one setting to another.

Because of these challenges, the pollutant reduction benefits of agricultural nonpoint source BMPs and CPs is often assumed as a fixed percentage of the load received and estimated at the BMP or CP location. These methods are inadequate for measuring progress toward achieving water quality goals at the actual waterbody for which a protection or restoration strategy is being developed. PTMApp utilizes treatment groups (see **Table 6**) to estimate load reductions at the BMP and at the downstream resource. This section documents the theoretical basis for methods for estimating BMP and CP load reductions and measuring water quality improvement for a proposed implementation strategy as part of PTMApp development.

### 5.4.1 REDUCTION RATIOS

A key step in "measuring" the impacts of BMPs for PTMApp is estimating the volume of runoff that can be treated by a BMP (treatment potential) resulting from different precipitation events (delivery potential). By default, 2-year, 24-hour and 10-year, 24-hour precipitation events are used as the standard precipitation events[2] in PTMApp based upon Atlas 14, as most BMPs are designed for treatment within this range. The assumption is that the mass reductions estimated using the 2-year, 24-hour precipitation event will approximate annual average values (since it is a 50% chance precipitation event). Users of the PTMApp will able to adjust storm events to their desired depths. The remainder of this section describes how reduction ratios will be calculated for each treatment group within PTMApp.

The "current" methods used to estimate BMP and CP effectiveness is to assign an assumed value. This approach fails to acknowledge that the effectiveness of BMPs and CPs in reducing load is typically based on either the volume of water they receive (e.g., storage), or how rapidly water moves across the surface (e.g., filter strips). Conceptually, the approach provides a continuous mathematical function between lower and upper percent reduction values (obtained from the literature), to estimate the reduction in load received by the BMP, based upon either the volume of water which can be treated or the rate by which water moves through the BMP.

[2] Water quality BMPs and CPs are generally designed for more frequent storm events, rather than less frequent events like the 100-year return period storm as is typical for flood control projects.

Within PTMApp, the percent reduction of a water quality constituent is based upon a reduction ratio and the empirical statistical distribution of BMP effectiveness within the treatment category (**Table 9**). For instance, the reduction ratio for Storage BMPS (e.g. wetlands, sediment control basins) is calculated as the ratio of the volume of water delivered (Delivery potential) to the BMP under 2-year, 24-hour and 10-year, 24-hour precipitation events to the volume of water held by the storage BMP (Treatment potential). The reduction ratios for each treatment group are shown in **Table 9**. BMPs and CPs will be placed in treatment groups based on the process by which water is treated (see **Table 6**). This is necessary because of the large number of equations which would need to be developed for each type of BMP and CP if they were not placed into treatment groups and the general lack of data relative to effectiveness.

**Table 9.** Methods for estimating the reduction ratio for BMP and CP treatment groups.

| | Storage | Filtration | Bio-Filtration | Infiltration | Protection | Source Reduction | User Defined |
|---|---|---|---|---|---|---|---|
| **Reduction Ratio (*r*)** | Treatment Volume / Runoff Volume Delivered | Velocity Design Standard / Velocity During Peak Discharge | Velocity Design Standard / Velocity During Peak Discharge | BMP Abstraction Volume / Volume Delivered | Modified RUSLE Parameters | Actual reduction in mass | User selects method (from those to left) or enters percentage |

#### 5.4.1.1 STORAGE

Storage BMPs generally provide treatment through sedimentation processes. The effectiveness of sedimentation processes are therefore related to the volume of dead storage (i.e., water stored within a permanent pool) and the volume of water delivered to the BMP. The storage reduction ratio is calculated based upon the treatment volume of the practice (treatment potential) derived from topographical data and the total volume of water delivered to the practice (delivery potential) under 2-year, 24-hour and 10-year, 24-hour precipitation events. The volume of water delivered to a storage BMP is calculated using the Curve Number (CN) method.

#### 5.4.1.2 FILTRATION

Filtration practices generally provide treatment by allowing water to infiltrate and by slowing the velocity of water to allow for sedimentation processes to occur. The effectiveness of filtration BMPs are therefore a function of the velocity design standard and the velocity of runoff delivered across the surface of the BMP. Filtration practices are typically designed to treat a maximum velocity of 0.06 ft. sec-1. PTMApp uses 0.05 ft. $sec^{-1}$ as the treatment potential of filtration BMPs and CPs. This treatment potential velocity was calculated using stoke's law, assuming a 50 foot wide filtration practice that results in the silt and sand fractions of sediment being retained within the BMP. The velocity resulting from the peak rate of runoff (delivery potential) is then calculated using the CN method and unit hydrograph theory to determine peak discharge for the 2-year, 24-hour and 10-year, 24-hour precipitation events. The reduction ratio is reduced if the velocity exceeds 0.05 ft. sec-1.

#### 5.4.1.3 BIO-FILTRATION

Bio-filtration practices generally provide treatment by slowing the velocity of water to allow for sedimentation processes and biological processes to occur. The reduction ratio for bio-filtration BMPs is calculated using the same method as Filtration practices. PTMApp uses 0.05 ft. sec-1 as the treatment potential of bio-filtration BMPs. The velocity during peak discharge (delivery potential) is then calculated using the CN method and unit hydrograph theory to determine peak discharge under 2-year, 24-hour and 10-year, 24-hour precipitation events. The effectiveness of bio-filtration practices is differentiated from filtration practices based upon the empirical statistical distribution of observed treatment.

#### 5.4.1.4 INFILTRATION

Infiltration practices generally provide treatment by allowing water to infiltration through the soil or other media. PTMApp calculates the reduction ratio for infiltration BMPs based upon the volume abstracted (i.e. infiltrated) from runoff (treatment potential) and the volume of water delivered (delivery potential) to the BMP under 2-year, 24-hour and 10-year, 24-hour precipitation events. Both the abstraction volume and volume delivered to the BMP are calculated using the CN method.

#### 5.4.1.5 PROTECTION

Protection practices generally provide treatment by physically armoring the landscape in areas with high potential for erosion. This could include natural materials (e.g. tree, shrub, grass plantings) and/or manmade materials (e.g. rock filled gabion baskets). PTMApp estimates the reduction potential of protection BMPs and CPs based upon the amount of water quality constituents (TP, TN, Sediment) no longer being eroded from areas where protection BMPs can be placed on the landscape. The percent reduction in water quality constituents is based upon the empirical statistical distribution of protection BMPs. For protection practices, reduction ratios will be set to 1 and their effectiveness will vary based upon empirical data.

#### 5.4.1.6 SOURCE REDUCTION

Source reduction practices generally provide treatment by reducing the amount of water quality constituents (typically TP and TN) applied to the landscape. For example, nutrient management plans usually reduce the amount of fertilizer applied to agricultural areas. PTMApp measures the reduction potential of source reduction BMPs and CPs based upon their empirical statistical distribution for reducing TP and TN. This empirical distribution is a function of published effectiveness values (e.g. AG BMP database, National BMP database) for the BMPs that are categorized into the source reduction treatment group.

#### 5.4.1.7 USER DEFINED

With the state, national, and international focus on reducing non-point source pollution through the use of BMPs and CPs, accounting for every potential type of BMP and CP proves challenging. In order to allow greater flexibility in the BMPs captured within the PTMApp, users are allowed to define and input the effectiveness of User Defined practices. This will allow end user's to measure the effectiveness of current BMPs not captured within PTMApp and allow future BMPs to be incorporated into the application. The user have the option of using assigning their custom defined BMPs to any of the treatment groups, or inputting their own effectiveness value.

### 5.4.2 ESTIMATING CONSTITUENT REMOVAL

An empirical treatment decay function is used to transform the reduction ratio (*r*) into a percent reduction of a water quality constituent from the implementation of a BMP. The percent reduction (*R*) will be calculated as:

$$R = ar^k$$

where *a* is a percent reduction in a water quality constituent taken from the empirical statistical distribution of the BMP treatment group, and *k* is a decay coefficient based upon the interquartile range of the empirical statistical distribution of the BMP treatment group. To account for potential uncertainty in the calculations, the *a* term is modeled as the median (*Q2*), upper (*Q3)* and lower limit (*Q1)* of the inter quartile range of the empirical statistical distribution of the BMP treatment group. The decay coefficient, *k*, is calculated as:

$$k = \frac{Q3 - Q2}{Q2 - Q1}$$

where Q3 is third quartile (i.e. upper limit) of the empirical statistical distribution of the BMP and CP treatment group, Q2 is the second quartile (i.e. median) of the empirical statistical distribution of the BMP treatment group, and Q1 is the first quartile (i.e. lower limit) of the empirical statistical distribution of the BMP treatment group. The empirical statistical distribution was established based upon the availability of research on a particular treatment group with priority going to studies conducted in Minnesota, then the Upper Midwest, and then the United States. **Figure 3** is a graphical illustration of possible treatment decay function ranges assuming different values of k. The decay coefficient values (k) for each treatment group based were fit based upon best available data.

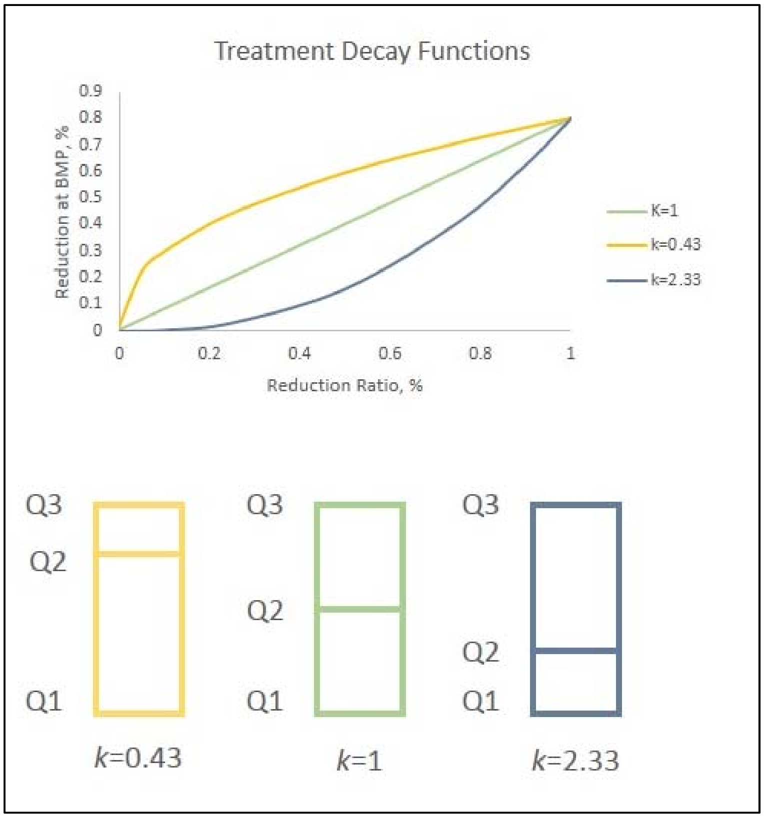



**Figure 3.** Illustration of different treatment decay functions based on different decay coefficients (k).

## 5.5 COST ANALYSIS

The cost of implementing BMPs and CPs is estimated on a per unit area, volume or length basis. The average per unit area, length, volume basis for different treatment groups was based upon NRCS EQIP payment schedules. These values are the default in PTMApp, but can be adjusted based upon local knowledge (**Table 10**). These payments do not necessarily reflect the true total cost of installing and maintaining BMPs and CPs. If better costs become available, it is suggested they be updated. This cost information is used to estimate the treatment cost of implementing BMPs on areas that are suitable for different treatment groups. The calculated costs is paired with the estimates of constituent removal for each BMP treatment group. This information is used to establish a treatment cost and total potential constituent removal for each BMP treatment group. An efficiency frontiers is then developed for each treatment group to identify the maximum reduction in a water quality constituent per dollar invested in a treatment group. The efficiency frontier will assume single practice implementation (i.e. won't account for BMP treatment trains). These efficiency frontiers will serve as a "measuring stick" for the treatment cost of implementing individual best management practices.

**Table 10.** Treatment group per unit area, length, or volume costs based upon EQIP rates.

| Treatment Group | Reporting Unit | Price, $ | Practices included in cost estimate |
|---|---|---|---|
| **Storage** | CuYd | $0.10 | Pond, Sediment Basin, Wetland Restoration |
| **Filtration** | acre | $474.07 | Conservation Cover, Conservation Crop Rotation, Contour Buffer Strips, Contour Farming, Cover Crop, Field Boarder, Filter Strip |
| **Bio-Filtration** | CuYd | $43.87 | Denitrifying Bioreactor |
| **Infiltration** | ft | $3.95 | Terraces |
| **Protection** | acre | $2,133.35 | Critical Area Planting, Tree & Shrub Establishment |
| **Source Reduction** | acre | $30.87 | Irrigation Water Mangement, Nutrient Management, Conservation Tillage |

## 5.6 EXAMPLE BENEFIT COST ANALYSIS

To clarify the methods described in *5.4 Benefits analysis* and *5.5 Cost analysis,* an example of the output data products that can be generated by PTMApp has been performed for filtration practices for a subwatershed in the Sand Hill River Watershed District (SHRWD). The SHRWD is used as the example because of past work completed in the District.

### 5.6.1 CALCULATING REDUCITON RATIOS

The delivery potential and treatment potential for filtration practices were calculated for a subwatershed identified as a high priority for sediment reduction in the SHRWD (based on HSPF model results) using the runoff resulting from a 10-year 24-hour precipitation event (**Figure 4**). Peak discharge was calculated using the CN method and unit hydrograph theory. Peak Discharge was converted to a peak velocity and used as the delivery potential. A design standard of 0.06 ft. sec.$^{-1}$ was used for the treatment potential of filter strips. The treatment potential was divided by the delivery potential to estimate the reduction ratio. This example illustrates how reduction ratios will be calculated in the PTMApp. Once calculated, the reduction ratio can be transformed with a treatment decay function to “measure” reductions in TN, TP, and sediment. The approach essentially assumes the reduction ratio is a function of how rapidly water moves across the surface of the filtration BMP.

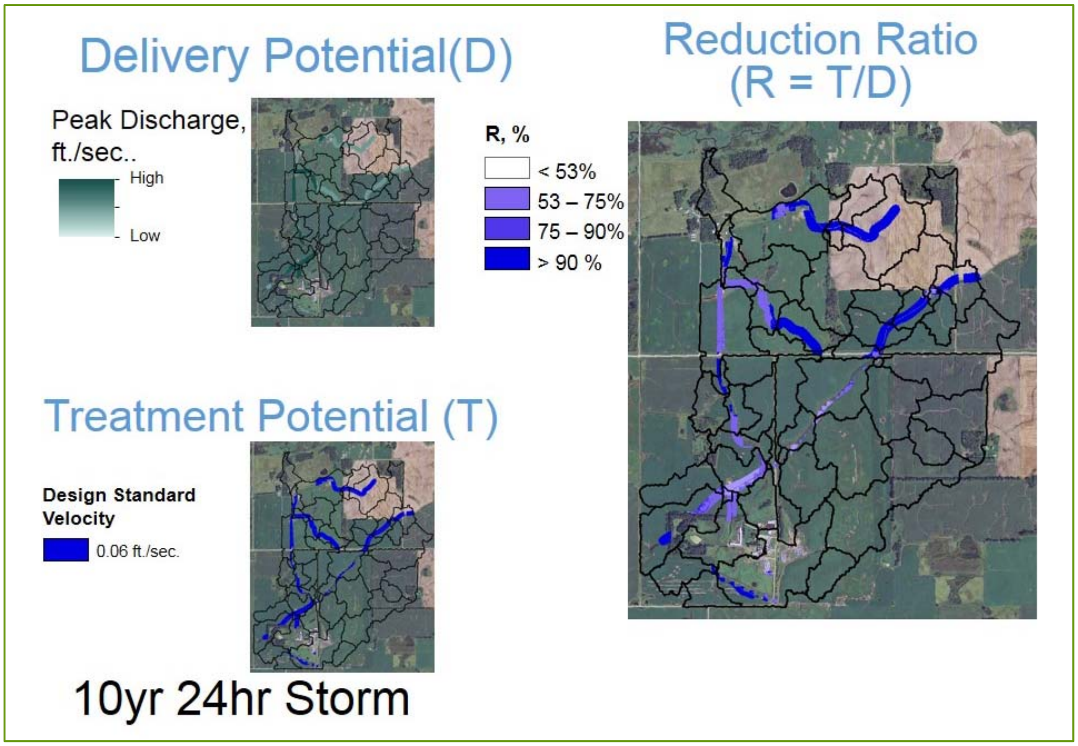



**Figure 4.** Example reduction ratio calculation for filtration practice treatment group.

### 5.6.2 ESTIMATING CONSTITUENT REMOVAL

**Table 11** shows an example of the empirical statistical distribution for sediment removal within the filtration treatment group and includes the resulting decay coefficient (*k*). The statistics are taken from the Minnesota Agricultural BMP database. **Figure 5** shows the resulting treatment decay results as a function of reduction ratios for filtration practices. By utilizing the range of observed treatment potential, the resulting treatment decay functions will account for uncertainty in BMP performance. **Figure 6** shows the output transformation of the reduction ratio to percent reduction in sediment for filtration practices using the median (Q2) observed value. PTMApp will use the percent reduction for each treatment group to "measure" load reductions (TP, TN, sediment and runoff) at the BMP and at the resource of concern.

**Table 11.** Empirical statistical distribution for sediment removal within the filtration treatment group and the resulting decay coefficient (*k*). Based on data from the MN Ag. BMP database.

| Treatment Group | Min, % | Q1, % | Q2, % | Q3, % | Max, % | k |
|---|---|---|---|---|---|---|
| Filtration | 0.44 | 0.54 | 0.75 | 0.91 | 1 | 0.74 |

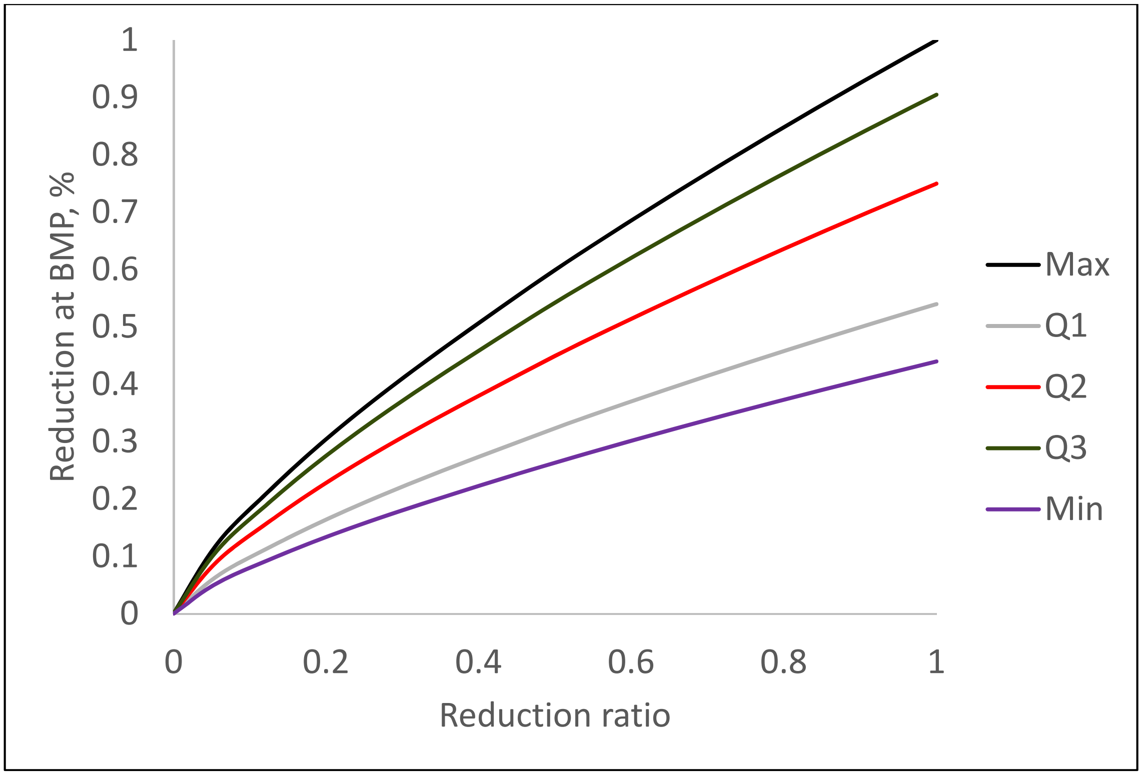



**Figure 5.** Treatment decay functions based on reduction ratios for filtration practices.

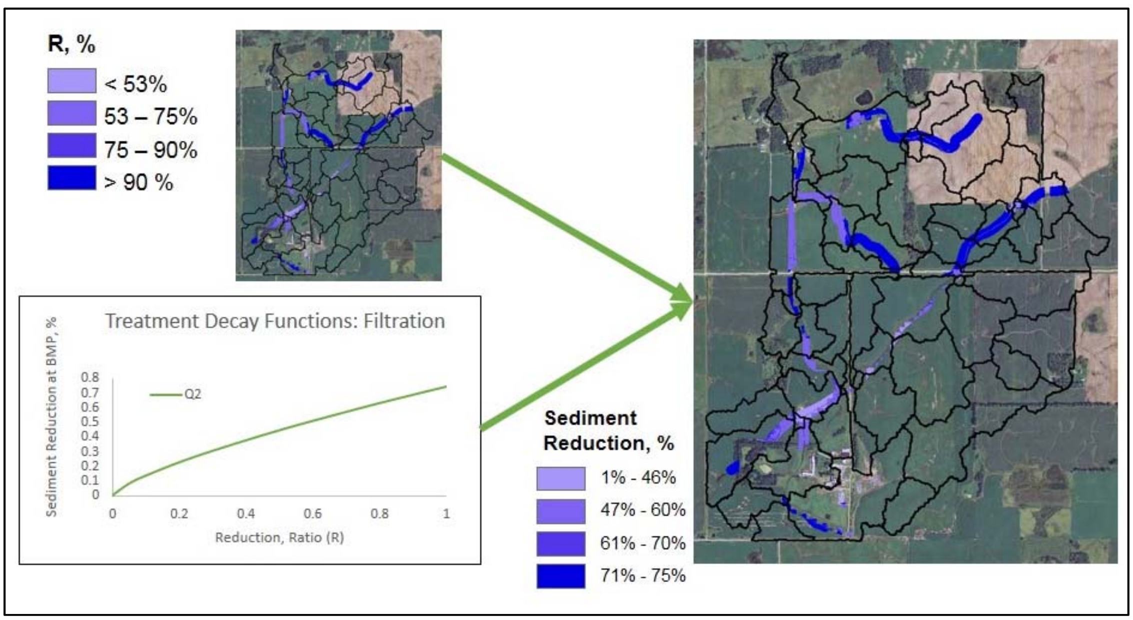



**Figure 6.** Conversion of the reduction ratio to a percent reduction in water constituent (sediment) using the treatment decay function for filtration practices.

### 5.6.3 ESTIMATING TREATMENT COST AND OPTIMUM TREAMENT

PTMApp estimates the potential cost associated with implementing BMPs and CPs on a per unit area, length or volume for each BMP treatment group. Each treatment group will have a default cost derived from best available information (i.e. NRCS EQUIP payment schedules). End user's will also have the option to override the default cost value based on local experience. For this example, it was assumed that filtration practices could be implemented at $1,000 / acre.

The percent sediment reductions calculated above (see **Figure 5**) were applied to sediment loading estimates delivered to a downstream resource of concern (i.e. main stem of the Sand Hill River). The sediment load delivered to the Sand Hill River was then scaled based upon the Hydrologic Simulation Program-Fortran (HSPF) model for the Sand Hill River watershed (meaning loads were adjusted from the terrain analysis products to match the calibrated HSPF modeled loads). PTMApp allows users to scale loading data based on existing models and/or gage (observed) data or other external knowledge. **Figure 7** shows the resulting treatment cost ($ / Ton of sediment reduced at the Sand Hill River impaired water) and total potential sediment reduction by field scale catchment. This information could be used during the development of targeted implementation plans to identify areas with the most cost-effective and highest potential for treatment of issues (TP, TN, sediment and runoff) impacting resources of concern. It could also be used to inform measurable goals and establish implementation strategies.

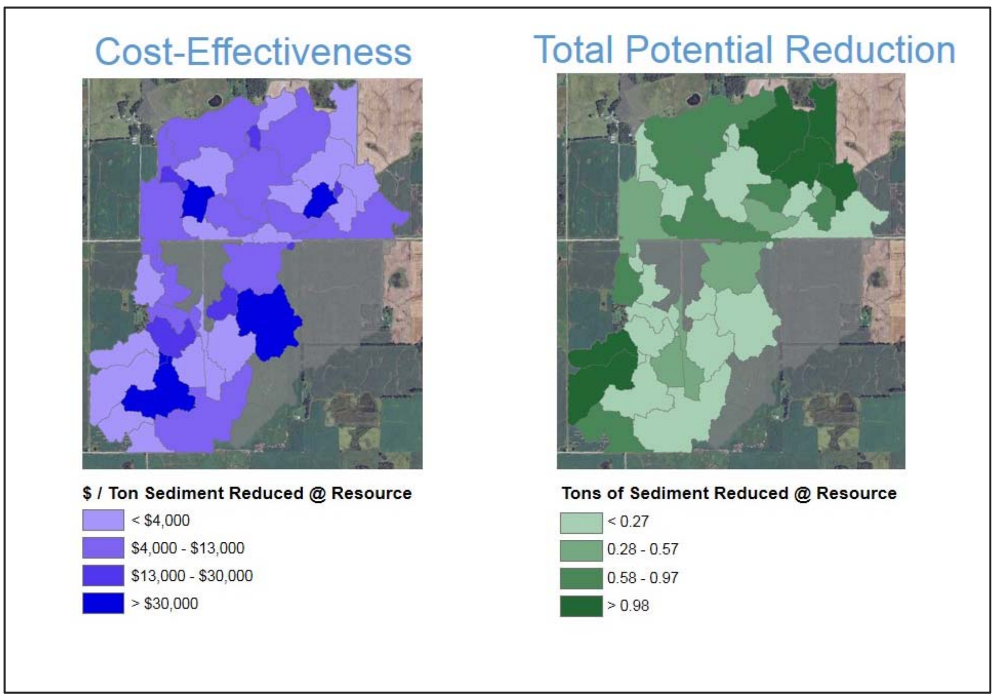



**Figure 7.** Dollars per ton of sediment reduced and total potential sediment reduction at the Sand Hill River. Grey catchments lack opportunities for filtration practices.

The BMP cost-effectiveness was then used to identify single practice implementation efficiency frontiers (**Figure 8**). In other words, the efficiency frontier identifies the minimum measured dollar investment needed to achieve a given amount of reduction in water constituent (TN, TP, sediment, and runoff) at a resource of concern. This output could serve to inform the potential efficiency (i.e. cost-effectiveness) of proposed implementation projects. Proposed projects that are close to the maximum possible efficiency should provide more cost-effective treatment relative to projects that are further away from the maximum possible efficiency.


**Figure 8.** Single treatment efficiency frontier for filtration practices. Frontier indicates the maximum reduction in sediment delivered to the main channel of the Sand Hill River relative to the implementation cost.

## 5.7 MODELING TREATMENT TRAINS

A treatment train is defined as two or more BMPs and CPs which treat a portion of the same runoff and load. The estimated treatment effectiveness of the BMPs and CPs are interdependent; i.e., the load arriving at a BMP or CP if modified by one located upstream. BMP treatment trains can occur in series and parallel, as well as a combination of series and parallel. **Figure 9** defines the conceptual range of potential interdependence[3] of BMPs and CPs.

[3] The treatment effectiveness of BMPs and CPs located in separate catchments are independent, and therefore their combined removal is multipliative moving downstream.

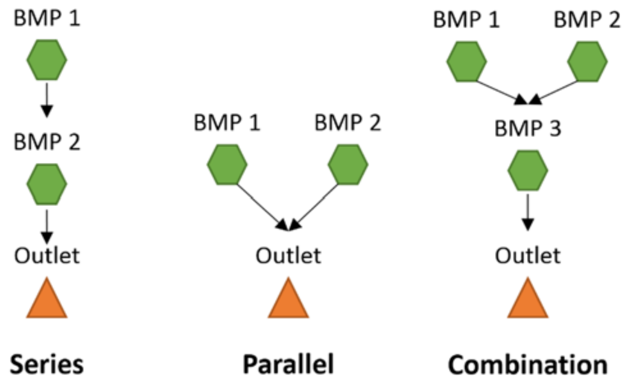



**Figure 9. Type of BMP treatment trains within PTMApp.**

The fundamental technical challenge when estimating the combined effectiveness (i.e., load reduction) of a treatment train in a geospatial environment lies in the ability to know the number and types of BMPs and CPs located upstream from a specific BMP/CP (i.e., network topology).

To estimate the load reduction at a BMP or CP, both the localized load (from the intervening drainage area between a specific BMP / CP and the next upstream BMP / CP) and the load delivered from upstream BMPs and CPs needs to be known. An example, highlighting this concept, is provided below. The computational steps necessary in a geospatial environment to estimate the combined load reductions can be complex. The approach used in PTMApp results in a reasonably efficient process by using the annual load rasters (3m x 3m rasters for TP, TN and sediment) for a catchment, where the load values are the mass delivered to the catchment pour point. Once load reductions to the catchment pour points are estimated, they can be "routed" to a downstream resource using pre-computed decay functions. A raster equal to one minus the pollutant reduction effectiveness (i.e. the BMP Delivery Factor) of the BMP / CP is applied to the annual load raster for a catchment. The BMP Delivery Factor is utilized to track the load remaining rather than the load reduced. This methodology eliminates the need for routing loads through BMPs as the routing to the catchment outlet or priority resources is already performed at the raster cell scale. The following section describes how treatment trains (series, parallel, and combinations) are handled within PTMApp.

### 5.7.1 TREATMENT TRAINS: CALCULATING LOAD REDUCTIONS

The general equations used to estimate the annual load reduction from a treatment train are as follows:

Series

$$L_O = L_{BMP1}d_1d_2 + L_{BMP2}d_2$$

Parallel

$$L_O = L_{BMP1}d_1 + L_{BMP2}d_2$$

Combination

$$L_O = L_{BMP1}d_1d_3 + L_{BMP2}d_2d_3 + L_{BMP3}d_3$$

where $L_O$ is the annual load delivered to the catchment pour point after being reduced by the combined effectiveness of the upstream BMPs, $L_{BMPn}$ is the annual load delivered to BMP $n$ from its upstream drainage area, and $d_n$ is the proportion of the load reaching the $n$ th BMP (BMP $n$) that is delivered to catchment pour point (i.e., BMP delivery factor). The structure of these equations requires that in order to estimate the overall load reduction at the catchment pour point (or a priority resource), the annual load raster for the catchment of an individual BMP must have the BMP delivery factor applied to the raster. Likewise, if the cell of a raster falls within the drainage area of multiple BMPs (i.e. overlapping BMPs) then the BMP delivery factor are applied multiplicatively. Treatment train costs are estimating using the EQIP estimates in **Table 10**. These payments do not necessarily reflect the true total cost of installing and maintaining BMPs and CPs. If better costs become available, it is suggested that **Table 10** be updated.

### 5.7.2 APPLYING TREAMENT TRAINS IN PTMAPP

Within PTMApp the process for applying this theory is as follows:

1. Develop a raster of annual loads delivered to the catchment pour point for the catchment in which the BMP is located;
2. Develop BMP delivery factor rasters, based upon the median and interquartile range of the BMPs estimated effectiveness, for the upstream contributing drainage area for each BMP (i.e. all cells within the catchment given the BMPs BMP delivery factor value) in the catchment;
3. Multiply BMP delivery factor rasters grids together to create an overall BMP delivery factor grid.
4. Multiply the overall BMP delivery factor raster grid by the loading grid to create an applied BMP treatment train loading grid (i.e. the load that is not treated by the BMPs).

Within PTMApp, the nutrient and sediment load reductions to areas that receive treatment from BMPs, are based upon each BMP's individual effectiveness. Treatment of nutrients and sediment is estimated by calculating load reductions for the areas treated by each BMP or CP (**Table 12**). For example, Storage practice reductions are applied to nutrients and sediment delivered to the BMP from its' watershed, whereas Source Reduction practice (e.g. Nitrogen Management Plans) reductions will be applied to the area where the BMP is implemented. For all practice types, costs (per unit area based upon EQIP payment schedule) and benefits (i.e. load reductions) will be estimated relative to catchment pour point or resource of concern. An example calculation is provided to illustrate the proposed treatment train methods for use in PTMApp.

**Table 12.** Method for applying reductions by treatment group.

| | Storage | Filtration | Bio-Filtration | Infiltration | Protection | Source Reduction | User Defined |
|---|---|---|---|---|---|---|---|
| **Method for applying load reductions** | Reductions applied to BMP watershed | Reductions applied to BMP watershed | Reductions applied to BMP watershed | Reductions applied to BMP watershed | Reductions applied area where BMP is implemented | Reductions applied area where BMP is implemented | User selects method (from those to left) |

### 5.7.3 EXAMPLE TREATMENT TRAIN CALCULATION

A catchment with high sediment delivery to the Middle Branch Root River was selected for an example treatment train calculation. Information about the potential locations for various BMPs and CPs is expected to be available either based on the BMP Suitability analysis (see *5.3 BMP suitability*) or the user. The treatment potential of each BMP considered in this example is shown in **Table 13**. Note, a portion of the catchment does not receive treatment by these BMPs. For illustration purposes it is assumed there are opportunities for Source Reduction and Filtration practices (show in blue cross hatch on **Figure 10**) within the catchment. **Figure 10** shows the potential location for filtration practices. The red boundary in **Figure 10** is an area that is suitable for a source reduction practice. The black line shows the catchment boundary. These boundaries are automatically generated using the PTMApp-Desktop. Catchments are delineated based upon surface hydrology and have an average size of 40 acres (see *5.1.1 Catchments*).

**Table 13. Treatment potential of the individual BMPs.**

| Treatment Group | Area Treated, acres | Sediment Treatment Effectiveness (Median), % |
|---|---|---|
| **Filtration** | 65 | 76% |
| **Source Reduction** | 83 | 76% |

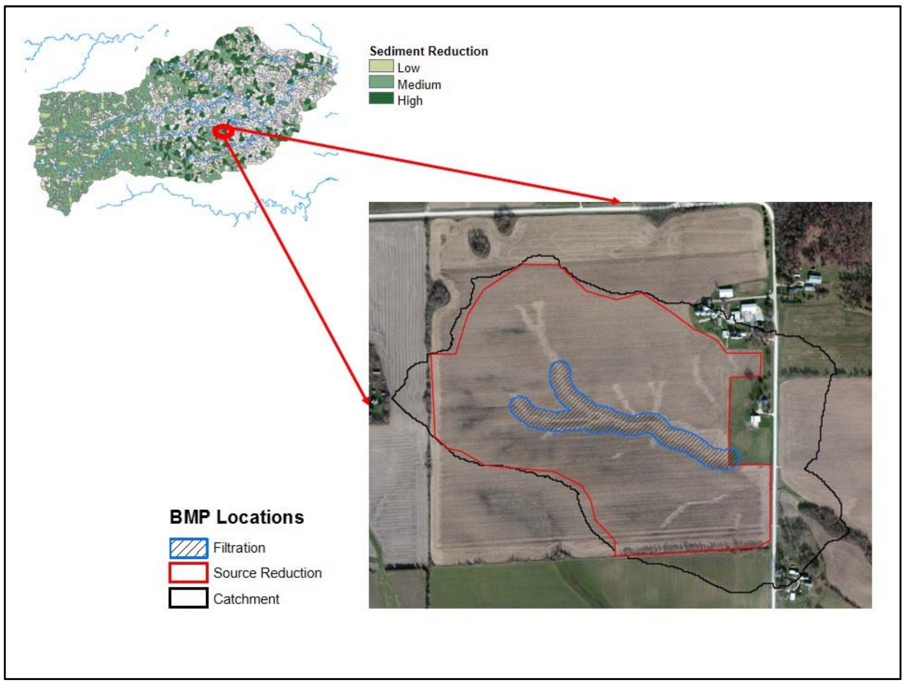



**Figure 10. Targeted catchment showing opportunities for BMPS.**

The contributing drainage area to each BMP / CP is identified using geospatial processing tools (**Figure 11**) according to the methods outlined in **Table 12**. The grey area within **Figure 11** represents the catchment boundary, the black area the location of source reduction practices within the catchment, the blue line the location of proposed filtration practices and the green area the upstream drainage area contributing runoff to the filtration practices. The individual BMP efficiencies were estimated using the methods described in *5.4 Benefits analysis*. For this example calculation the median efficiencies were used for each BMP. These BMP efficiencies were then converted to a BMP Delivery Factor (described in *5.7.1 Treatment trains: Calculating load reductions*) and applied to the areas of the watershed treated, assuming multiplicative reductions (**Figure 12**). The treatment train scenario indicated that the practices would result in a 13 Tons/year reduction in sediment delivered to the downstream resource and a total EQIP cost of $6,300, giving a treatment cost of $485/ton/year (**Figure 13**). To better illustrate how these calculations are performed, a 5 row X 7 column set of values were extracted from the treatment effectiveness, BMP Delivery Factor and RUSLE sediment yield rasters to so the measured yield remaining after the treatment was applied (**Figure 14**).

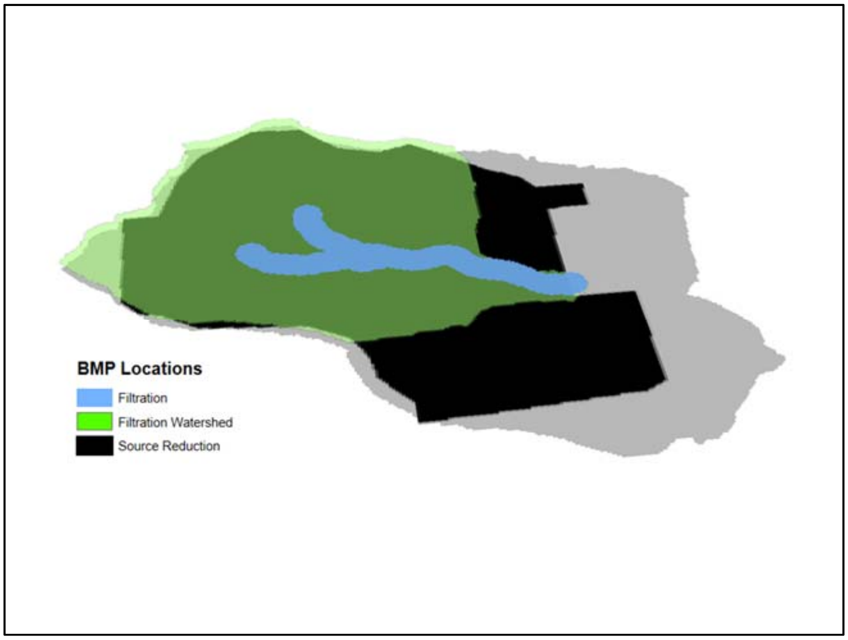



**Figure 11.** Areas of the watershed treated by the selected BMPs.

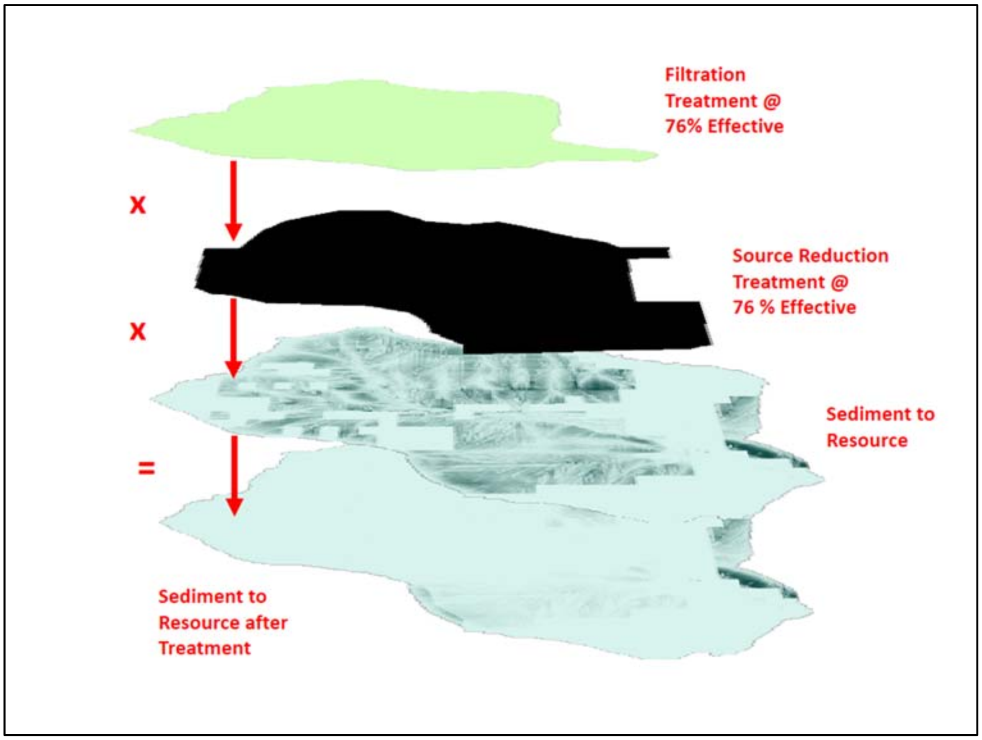



**Figure 12.** BMP effectiveness applied to the area of the watershed treated by the BMPs for sediment delivered to the downstream resource.

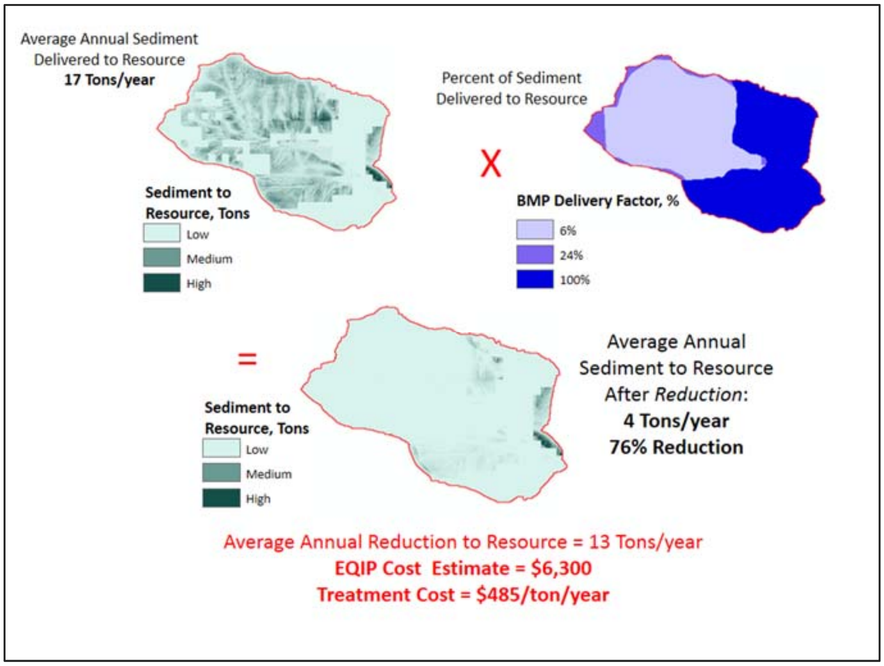



**Figure 13.** Resulting treatment cost of the treatment train scenario.

**BMP 1: BMP Delivery Factor: Filtration (1 - Efficiency)**

| | | | | | | |
|---|---|---|---|---|---|---|
| 24% | 24% | 24% | 24% | 24% | 100% | 100% |
| 24% | 24% | 24% | 24% | 24% | 24% | 100% |
| 24% | 24% | 24% | 24% | 24% | 24% | 100% |
| 24% | 24% | 24% | 24% | 24% | 24% | 24% |
| 24% | 24% | 24% | 24% | 24% | 24% | 24% |

**BMP2: BMP Delivery Factor: Source Reduction (1 - Efficiency)**

| | | | | | | |
|---|---|---|---|---|---|---|
| 24% | 100% | 100% | 100% | 100% | 100% | 100% |
| 24% | 24% | 24% | 100% | 100% | 100% | 100% |
| 24% | 24% | 24% | 24% | 100% | 100% | 100% |
| 24% | 24% | 24% | 24% | 24% | 100% | 100% |
| 24% | 24% | 24% | 24% | 24% | 24% | 24% |

x

=

**Treatment Train: BMP Delivery Factor (Percent untreated )**

| | | | | | | |
|---|---|---|---|---|---|---|
| 6% | 24% | 24% | 24% | 24% | 100% | 100% |
| 6% | 6% | 6% | 24% | 24% | 24% | 100% |
| 6% | 6% | 6% | 6% | 24% | 24% | 100% |
| 6% | 6% | 6% | 6% | 6% | 24% | 24% |
| 6% | 6% | 6% | 6% | 6% | 6% | 6% |

**Raster No. 1 - RUSLE Sediment Yields Delivered to the Catchment Outlet (tons/acre)***

| | | | | | | |
|---|---|---|---|---|---|---|
| 7.3 | 6.4 | 5.0 | 4.9 | 4.1 | 5.3 | 4.4 |
| 5.5 | 5.5 | 7.3 | 6.2 | 4.5 | 3.1 | 6.8 |
| 8.5 | 14.2 | 11.6 | 10.2 | 5.8 | 4.3 | 2.6 |
| 4.7 | 10.0 | 13.6 | 12.9 | 4.4 | 3.4 | 2.3 |
| 16.3 | 15.2 | 14.8 | 13.0 | 8.9 | 5.4 | 3.2 |

* Load delivery is estimated using a sediment delivery ratio and is described by HEI (2015).

x

=

**RUSLE Yield (tons/acre) Raster After Treatment**

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.4 | 1.5 | 1.2 | 1.2 | 1.0 | 5.3 | 4.4 |
| 0.3 | 0.3 | 0.4 | 1.5 | 1.1 | 0.7 | 6.8 |
| 0.5 | 0.8 | 0.7 | 0.6 | 1.4 | 1.0 | 2.6 |
| 0.3 | 0.6 | 0.8 | 0.7 | 0.3 | 0.8 | 0.6 |
| 0.9 | 0.9 | 0.9 | 0.7 | 0.5 | 0.3 | 0.2 |

**Figure 14.** Illustration of treatment train calculations showing raster cell values that result from applying the BMP Delivery Factor to RUSLE sediment yields.

# 6 TARGETED IMPLMENTATION PLANS: PUTTING THE DATA TO USE

This section provides examples of the business workflows that can be accomplished using PTMApp-Desktop (**Figure 15**). This example was provided courtesy of Sauk River Watershed District (SRWD) and shows the result of a PTMApp-Desktop analysis conducted through an Accelerated Implementation Grant for Ashley Creek within the Sauk River Watershed (SRW). The purpose of the project was to further target conservation efforts following the development of an HSPF model, and estimate the water quality benefits of the targeted BMPs and CPs. In other words, Sauk River Watershed District had a business need to develop a targeted implementation plan that was Prioritized, Targeted, and would likely result in Measurable water quality improvements.

The graphics below walk through the different data products available through PTMApp-Desktop and used to address the business need of Sauk River Watershed District.

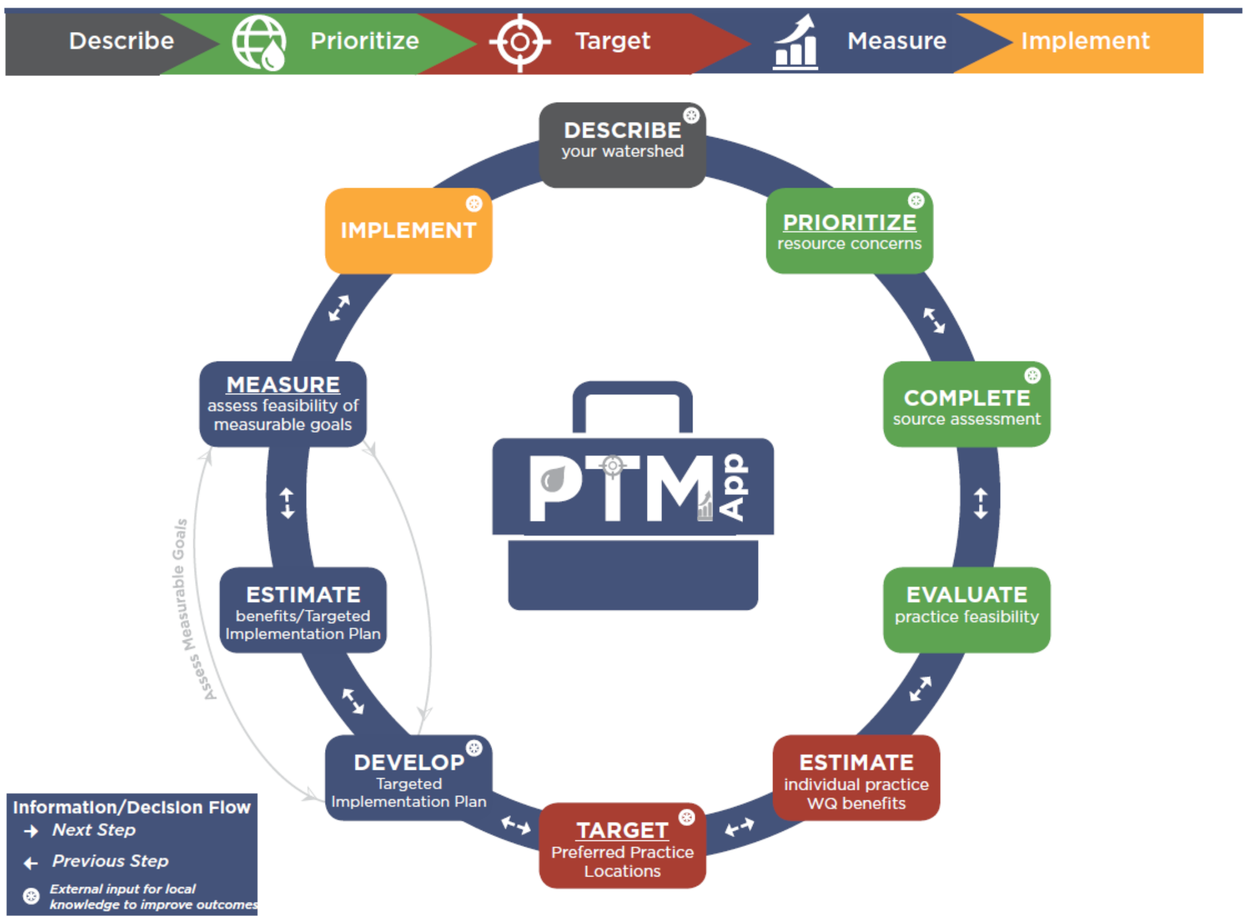
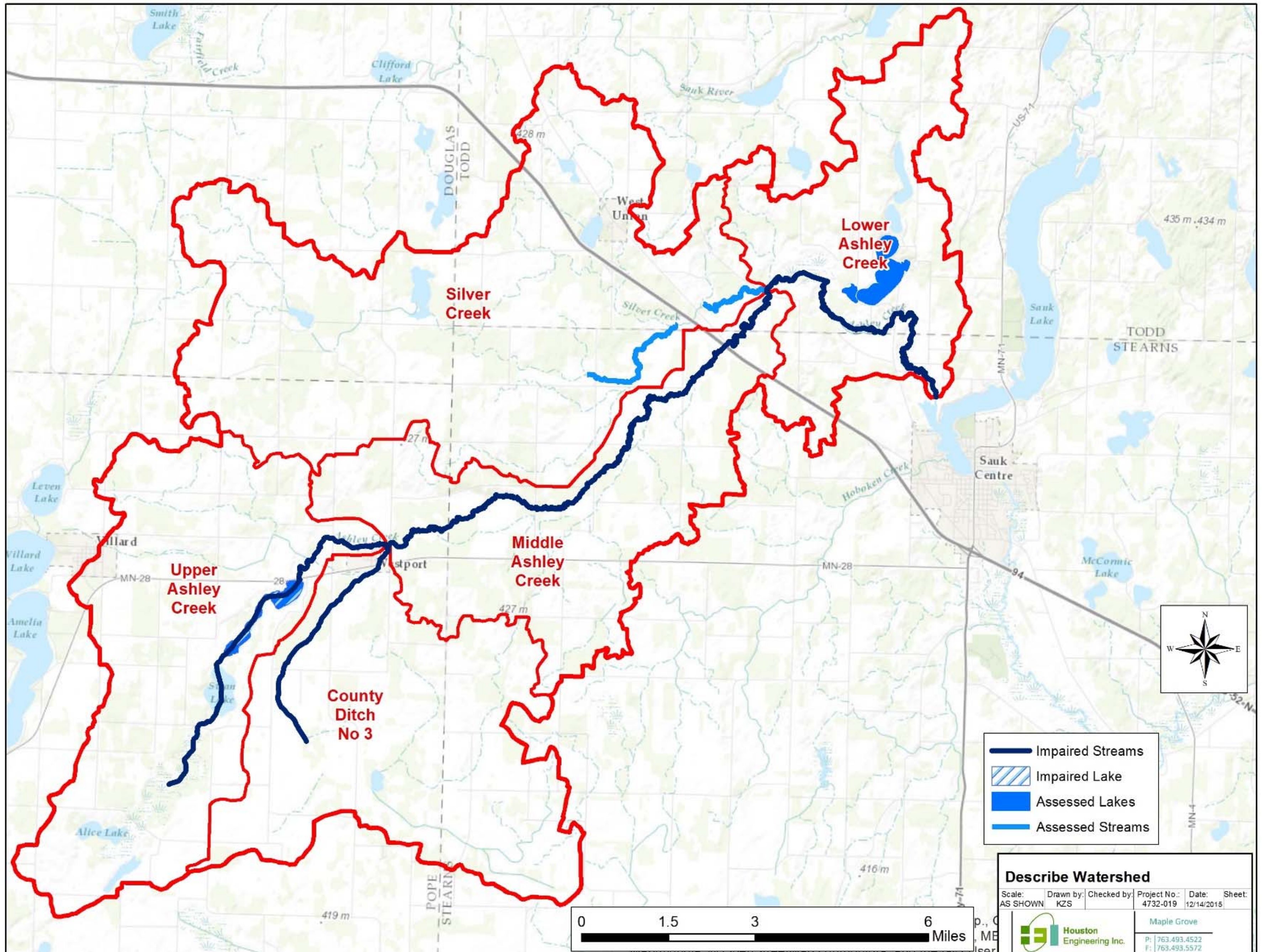



**Figure 15.** Business workflows addressed by PTMApp Desktop.

## 6.1 DESCRIBE YOUR WATERSHED

Describe your watershed is this process of identifying and describing important resources, features, and factors (e.g. socioeconomics) associated with your watershed. PTMApp provides base outputs of publicly available statewide data that are set to the extent of your watershed, such as watershed boundaries of different scales, assessed streams and lakes, impaired streams and lakes, ecological regions, and monitoring locations. This information is intended to simplify the process of gathering and summarize some of the common information needs associated with watershed management. **Figure 16** below is an example in the SRW for Ashley Creek where assessed and impaired lakes and streams are displayed based upon current geospatial data from the Minnesota Pollution Control Agency. This data can help to visualize and summarize the number of impaired waters and assessed waters within the study area.



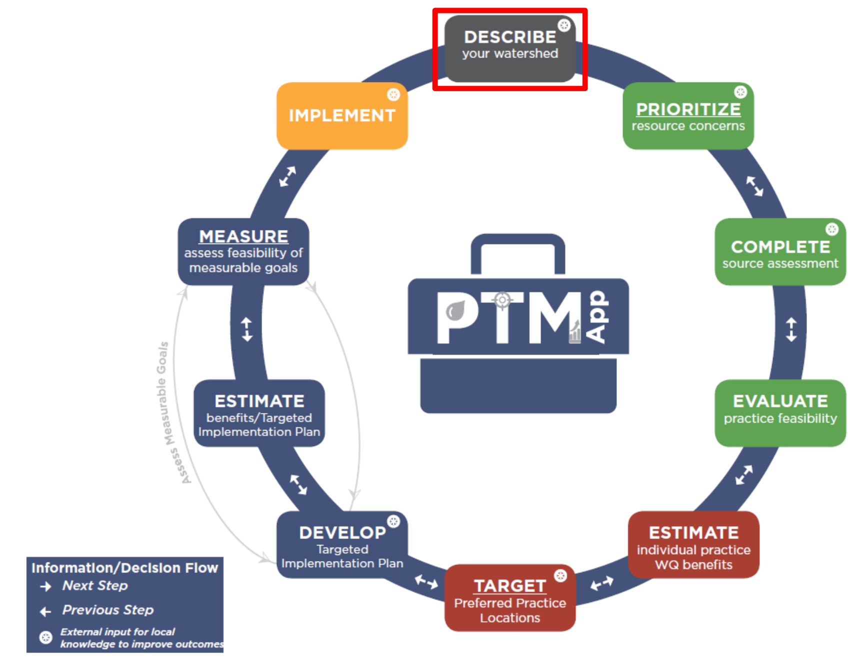




**Figure 16.** Assessed and impaired streams draining to Ashely Creek in the Sauk River Watershed.

## 6.2 PRIORITIZE RESOURCE CONCERNS

Prioritizing resource concerns is the process by which practitioners establish the relative importance of resources within their area of management. Frequently in Minnesota, water quality is a potential resource concern included in prioritization processes. Products from PTMApp can be used in conjunction with other information, such as Hydrologic Simulation-Fortran Program (HSPF) models and zonation, to aid in the process of prioritizing resource concerns. For example, PTMApp outputs can be used to show the ranks of field scale catchments based upon their delivery of sediment and nutrients, called a water quality index (50% sediment and 50% nutrients), to areas of channelized flow (**Figure 17**). These ranks can aid the prioritization in types of resources that are selected as priorities and locations in which management actions are undertaken.

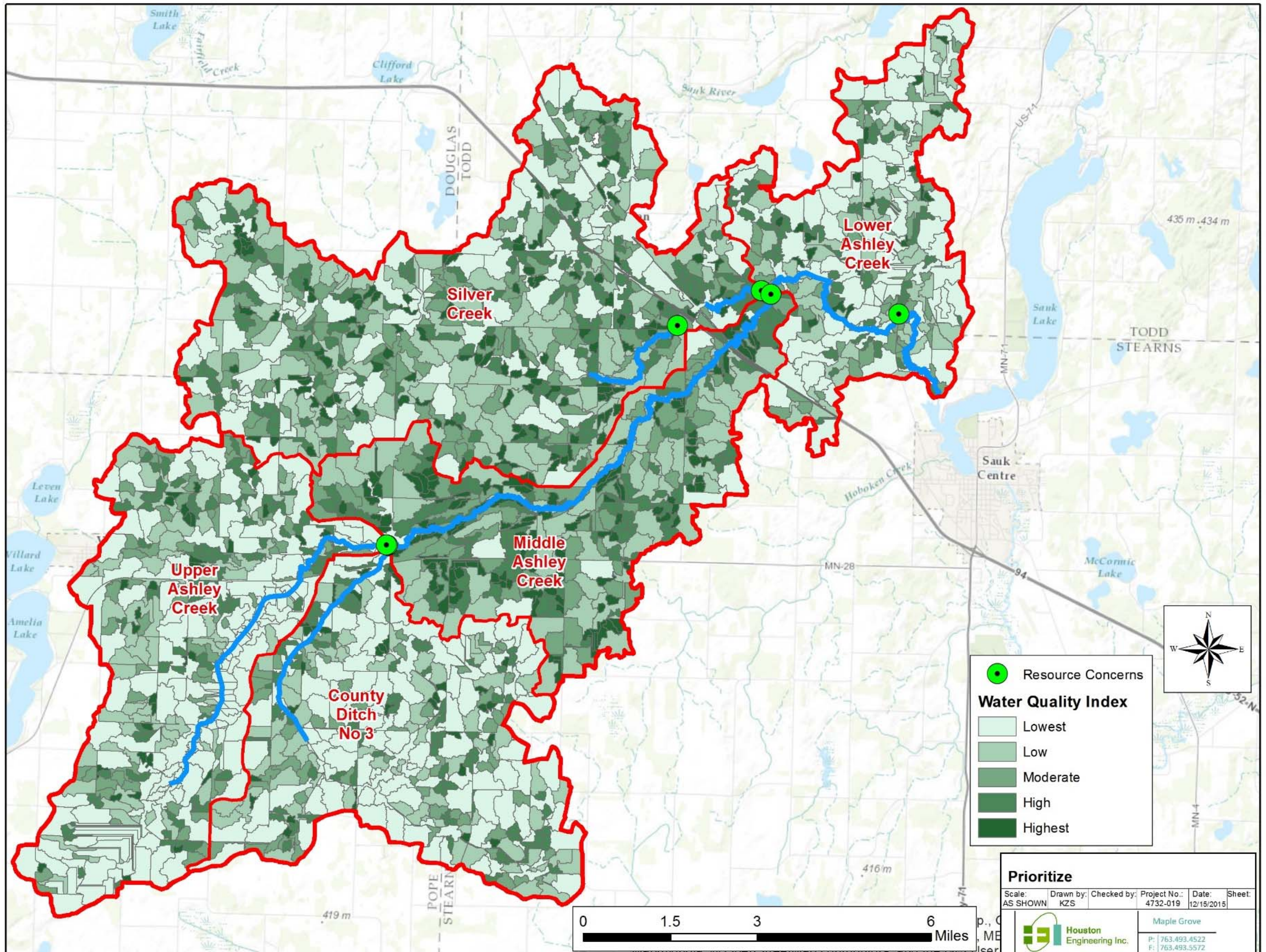
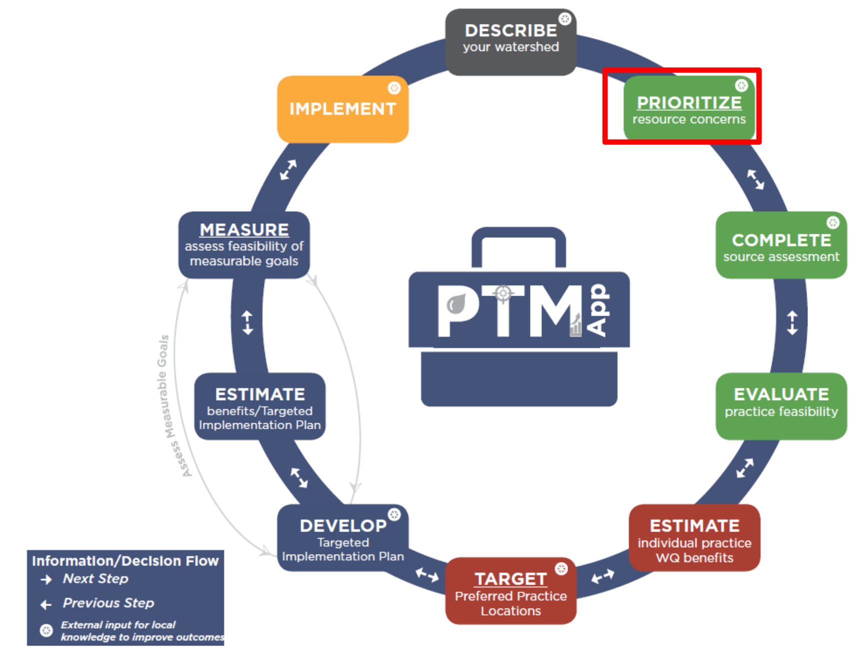
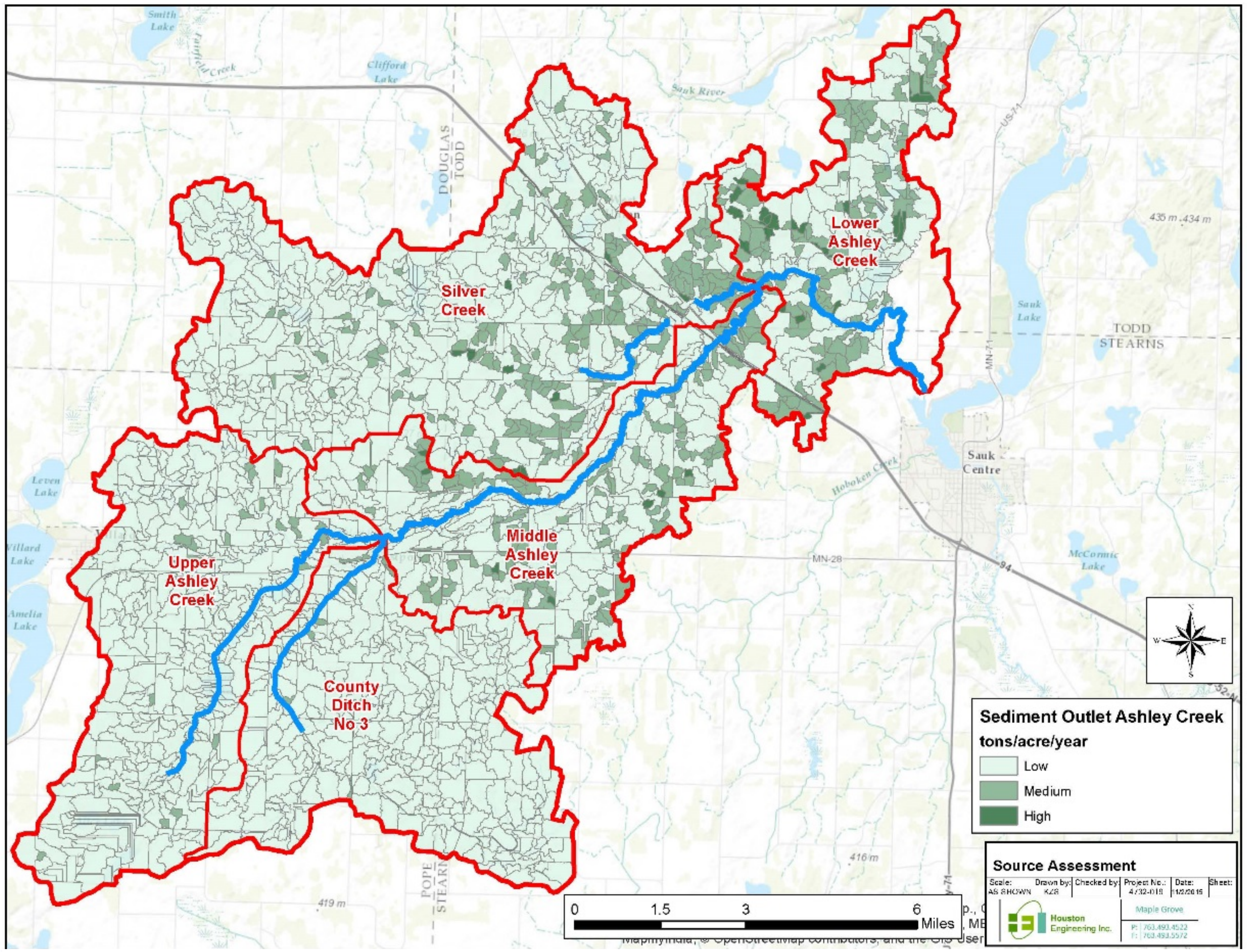



**Figure 17.** Water quality index (50% sediment and 50% nutrients) for sediment, total nitrogen, and total phosphorus delivered to areas of channelized flow draining to Ashley Creek within the Sauk River Watershed.



## 6.3 COMPLETE SOURCE ASSESSMENT

The source assessment identifies the magnitude and spatial distribution of potential pollution sources across the landscape. PTMApp – Desktop creates three source assessment products; i.e., load and yields leaving the landscape, delivered to a waterway, and delivered to a downstream resource of interest (e.g., lake or river reach). By completing a source assessment an understanding of how various parts of the watershed affect a resource is obtained and problem BMP and CP locations identified. The sediment yield (tons/acre/year) delivered to the outlet of Ashley Creek that have been scaled (i.e. forced to match) relative to a HSPF model for SRW (RESPEC, 2014), within the Ashley Creek study area are shown in **Figure 18**. Similar products can be developed for TN and TP for any priority resource point input during processing. The results indicate that the highest areas of sediment loading to the outlet of Ashley Creek are within Lower Ashley Creek (9070102020205), with additional areas in Silver Creek (070102020204) and Middle Ashley Creek (070102020203). For strategies aimed at reducing sediment delivered to the outlet of Ashley Creek, the “High” sediment yield areas would provide ideal locations to target practices. However, we first must evaluate the feasibility of implementing BMPs and CPs in those areas. In other words, the highest loading (sediment, TN, or TP) areas on the landscape, might have limited opportunities for implementing a practice to address the issue.



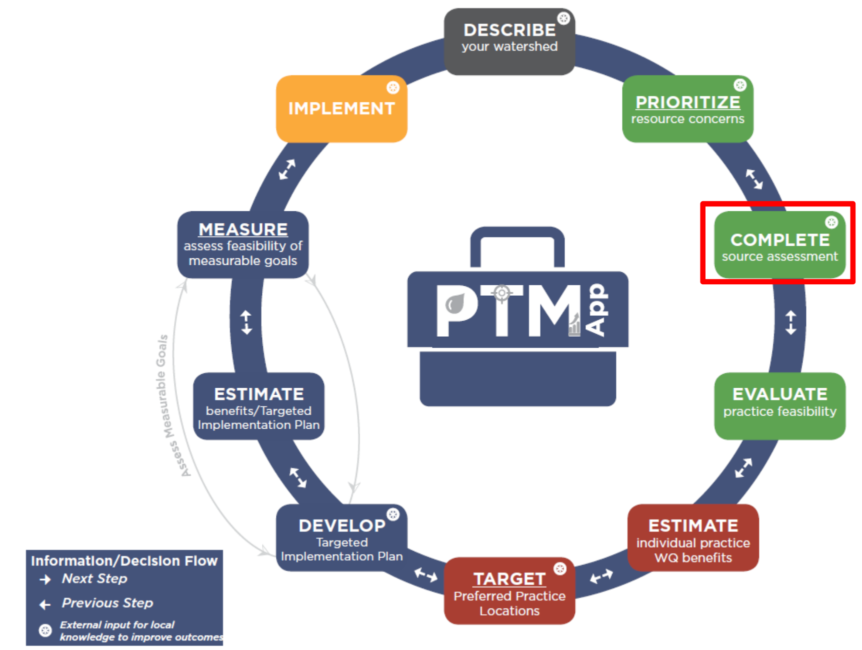
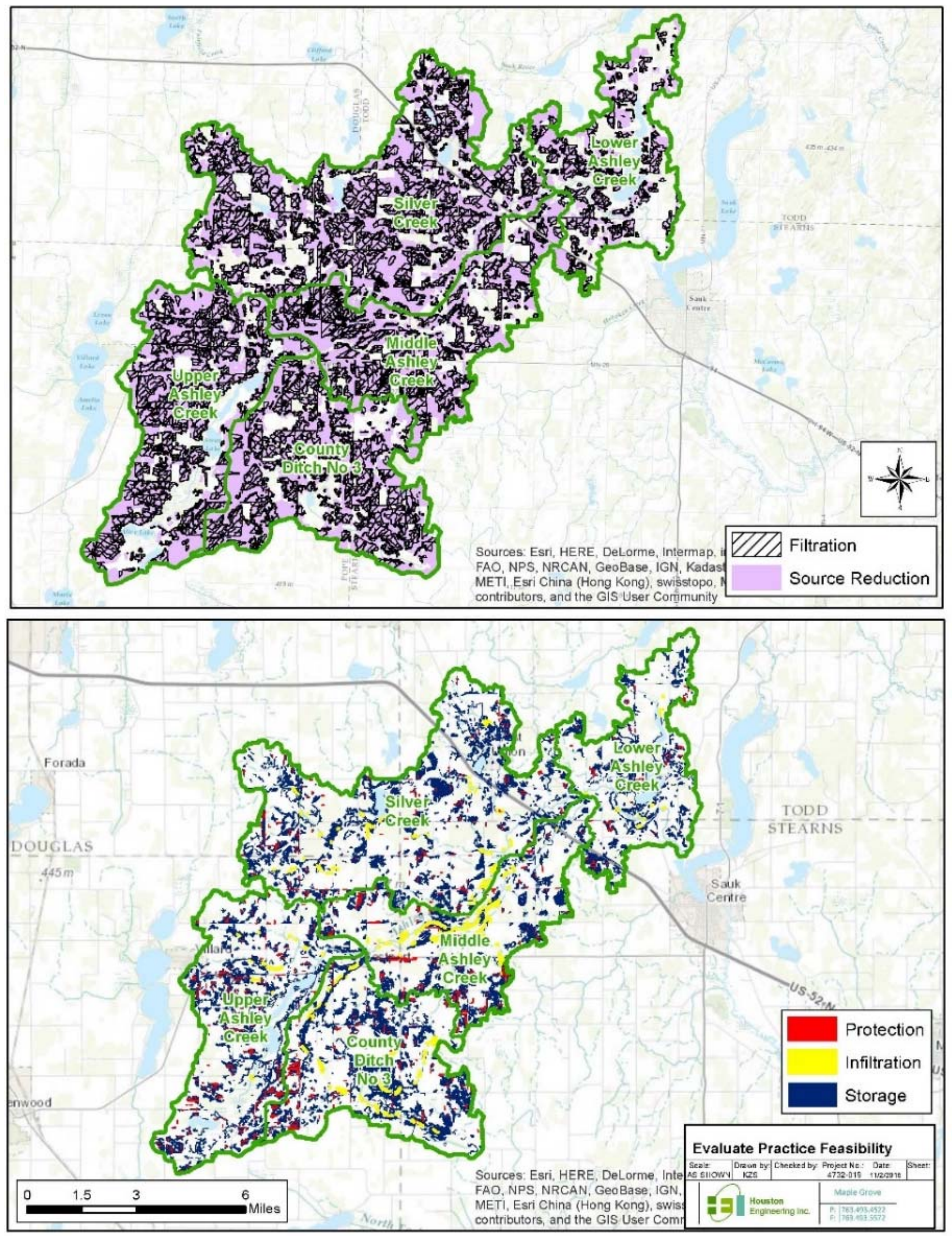




**Figure 18.** Ashley Creek source assessment for sediment yield delivered to the outlet of Ashley Creek. Total Nitrogen and Total Phosphorus were also assessed (not shown in map).

## 6.4 EVALUATE PRACTICE FEASIBILITY

The feasibility of placing a BMP or CP on the landscape depends on several factors. These factors include the size of the contributing drainage area, the land slope, the type of flow regime, and local topography. Practice feasibility is based solely on technical factors largely based on field office technical guides developed by the NRCS, and excludes social factors like landowner willingness. Locations shown as “feasible” are candidates for implementing practices and require further technical evaluation to confirm feasibility. The potential opportunities for BMPs and CPs within the Ashley Creek study area are shown in **Figure 19**. The opportunities are displayed by PTMApp treatment group (HEI, 2014b). It’s important to note that that these are only potential locations at this point in the business workflow. Local knowledge is still needed to refine the locations to identify a realistic set of targeted practices. These BMP and CP opportunities can be combined with the source assessment data in PTMApp to estimate the “measurable” water quality benefits for implementing the practices.



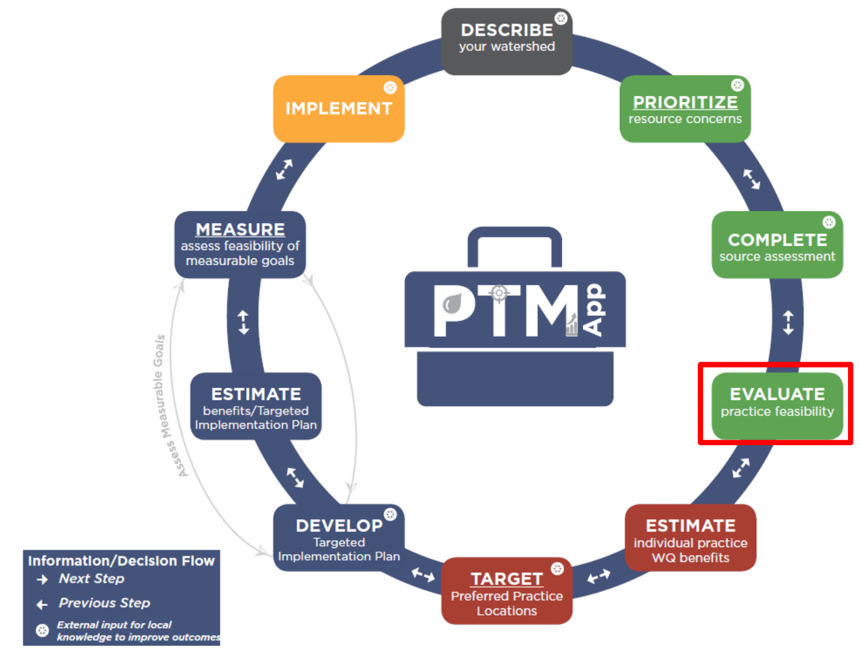
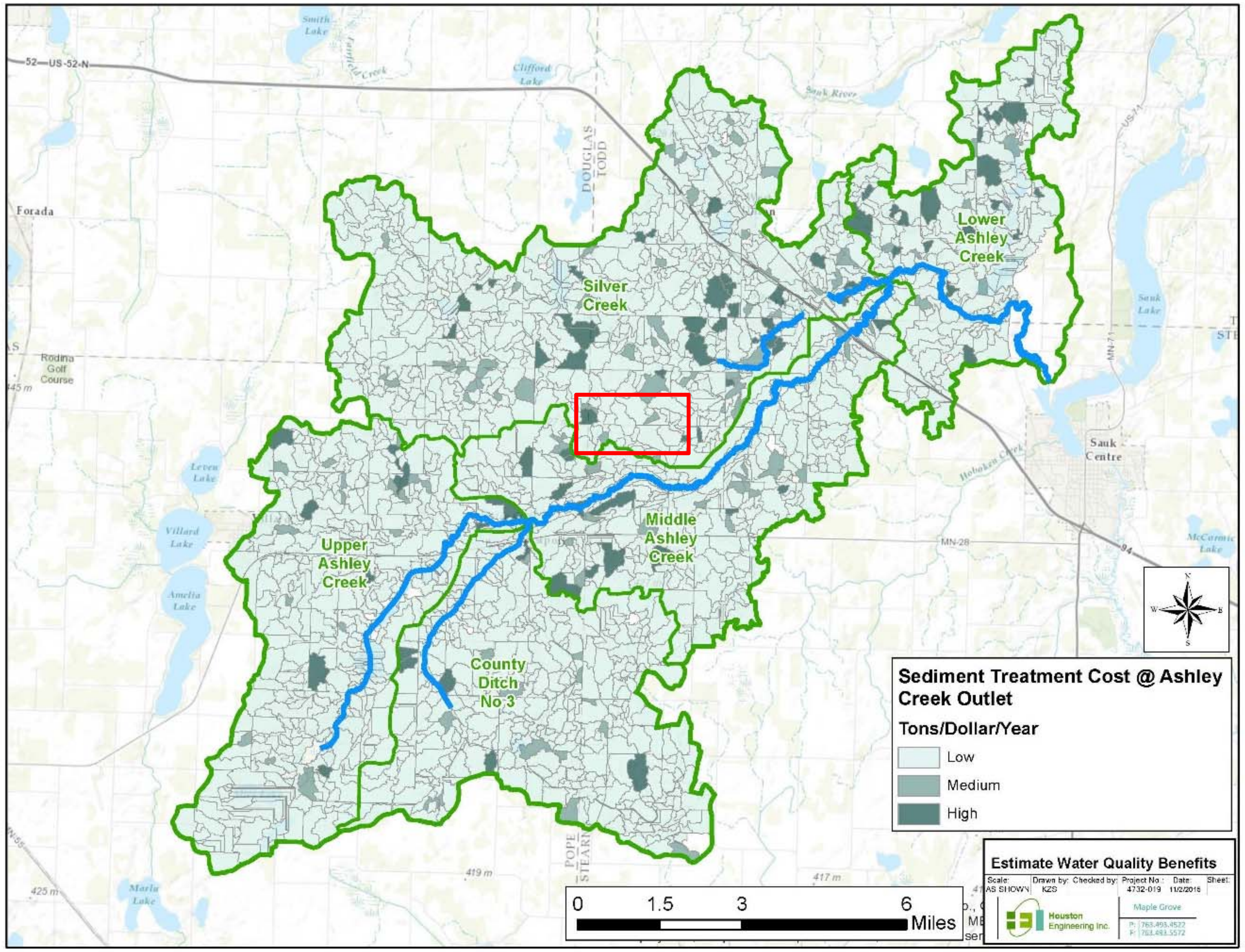




**Figure 19.** Potential opportunities for BMPs and CP within the Ashley Creek Study Area.

## 6.5 ESTIMATE WATER QUALITY BENEFITS

One of the means of selecting specific practices for implementation is based on their probable benefits. The probable benefits of a practice can be described by either the amount of a parameter like sediment or phosphorus removed, or the cost to remove one unit of the parameter (e.g., dollars per pound of phosphorus annually reduced). Practice benefits can be estimated at the location of the practice or the resource. The estimated benefits at a lake or river are more valuable from a decision making perspective. The treatment cost, tons/year/dollar spent, of reducing sediment to the outlet of Ashley Creek are shown in **Figure 20**. The areas providing the largest "bang for the buck" are in the High category. The most cost-effective areas for sediment reductions do not correspond exactly to the highest source load areas (see **Figure 18**). These results can be used to target practice locations to implement BMPs and CPs that provide the most cost-effective avenue to make progress towards local, state, and regional water quality management goals.



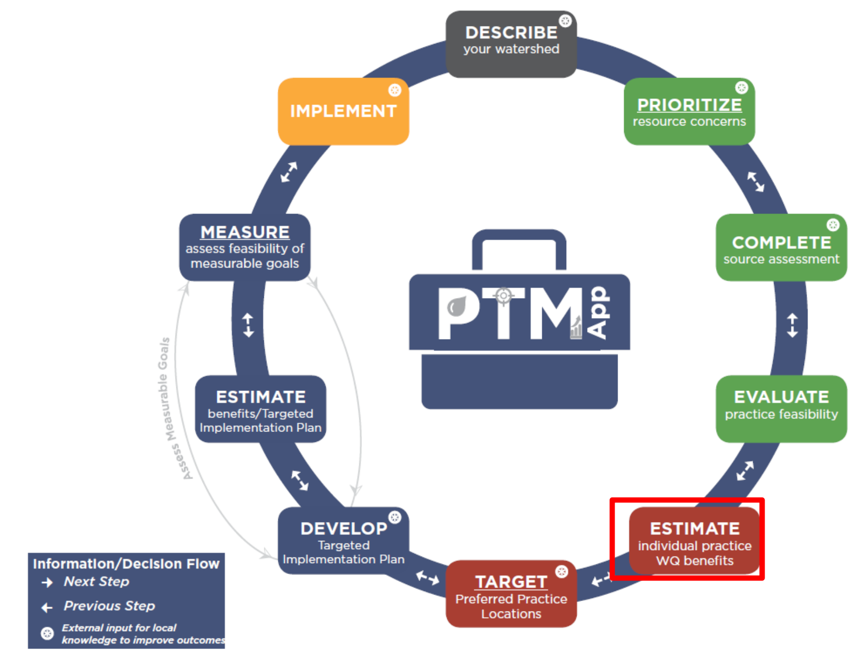
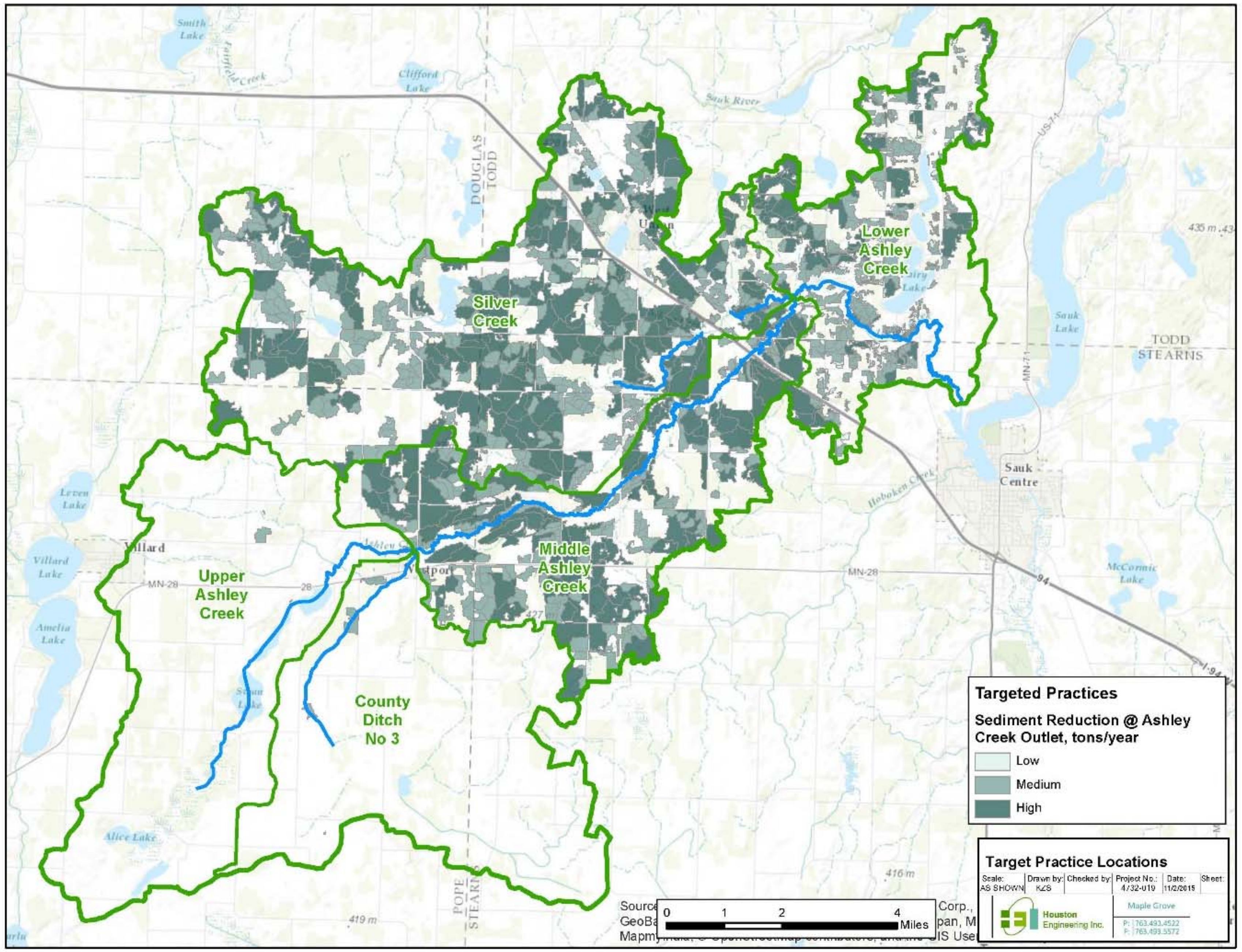




**Figure 20.** The treatment cost (tons/year/dollar spent) of reducing sediment delivered to the outlet of the Ashley Creek study area. Similar products can be developed for total nitrogen and total phosphorus.

## 6.6 TARGET PREFERRED PRACTICE LOCATIONS

Once possible BMP and CP locations are identified based upon technical feasibility, the potential locations need to be assembled into an implementation approach to evaluate their combined effectiveness. The range of BMP and CP locations based solely on technical feasibility is reduced, by applying conditions like a minimum size requirement, minimum treatment effectiveness, or minimum cost effectiveness. The BMPs and CPs targeted for Scenario 2 within the Ashley Creek study area shown in . Scenario 2 focused on targeting practices that provided the most cost-effective reductions in sediment at TP to the outlet of Ashley Creek. This step in the business workflow is based upon queries of the data generated by PTMApp. It is intended to provide feasible locations for implementing practices that will provide measurable water quality improvements for local priority resources. However, there are a number of factors that might influence the practices which end up being implemented such as, existing practices already in place or willingness of the landowner to participate. The inclusion of such factors is discussed in the next business workflow section, Develop Targeted Implementation Plan.



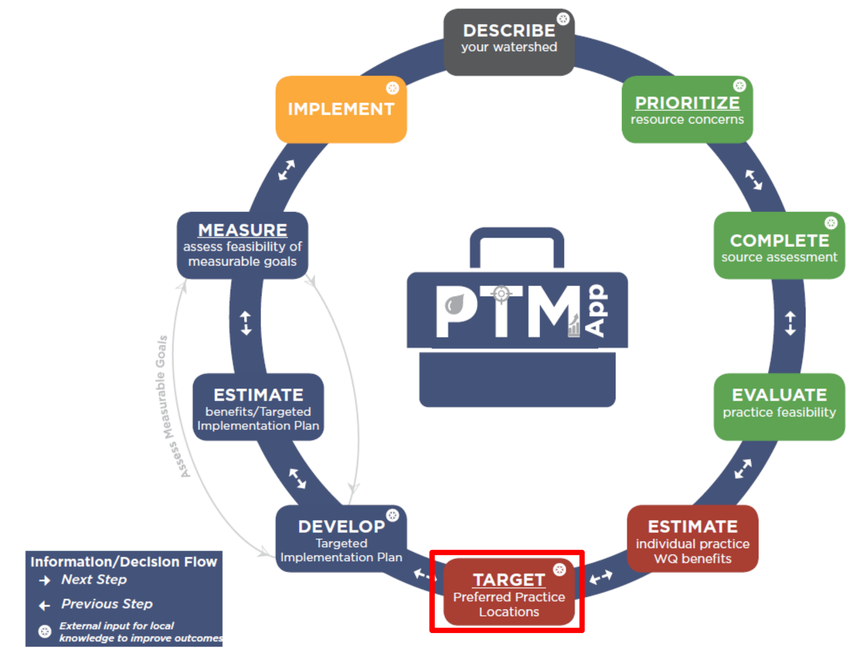
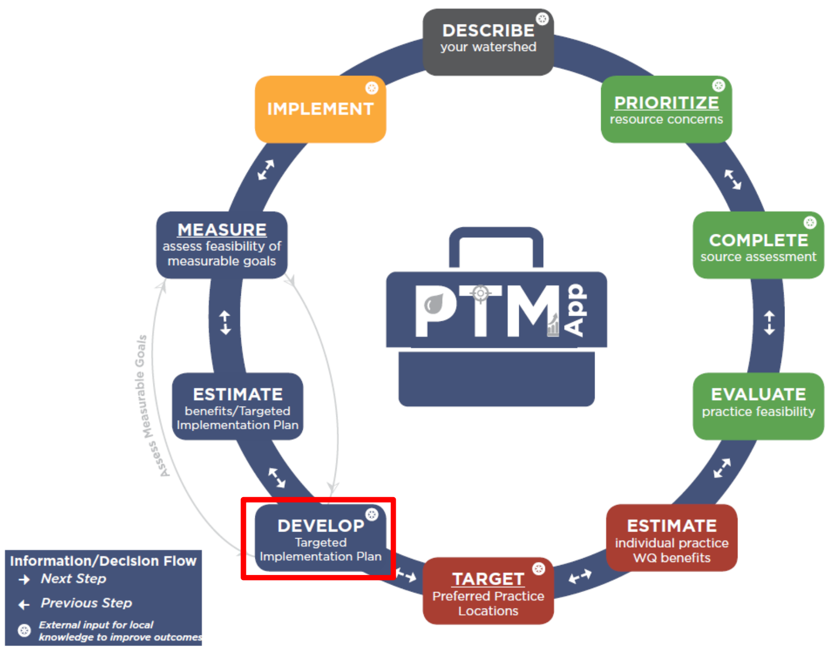




**Figure 21.** Practices targeted for implementation during the development of Scenario 2 for the Ashley Creek Study Area.

## 6.7 DEVELOP TARGETED IMPLMENTATION PLAN

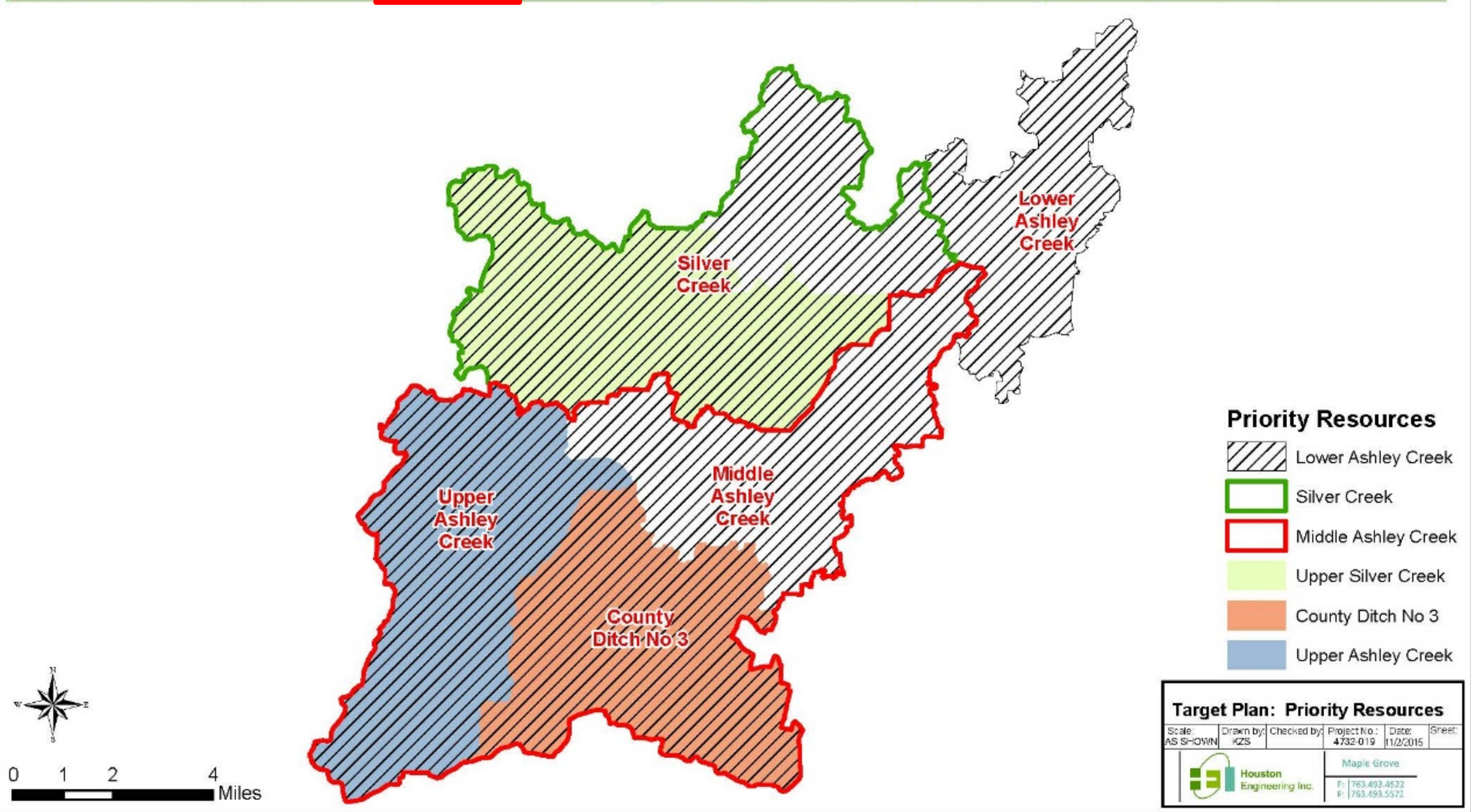
Specific locations to place practices need to be targeted based on other factors, including practical and social factors. Practical factors include for example landowner acceptance of specific types of practices and landowner willingness to place a practice on a field. Additional information can be incorporated to refine the practices targeted based upon PTMApp data. It's likely that many areas in watersheds might already have numerous BMPs and CPs implemented, lack landowners who are willing to participate in additional BMPs and CPs, or have benefits outside of water quality (water quantity, wildlife habitat, aquatic habitat, etc...) that adjust the targeted locations for BMPs and CPs. For example, local knowledge was used for the Adley Creek study area scenarios to restrict targeting to the Adley Creek (070102020404) 12-digit HUC subwatershed, as this area was identified by SRWD as a priority subwatershed for practice implementation.



## 6.8 ESTIMATE BENEFITS OF TARGETED IMPLMENTATON PLAN

The combined benefits expressed as the amount of load reduction at the resource location being restored or protected can be compared to a measurable goal. The measurable goal may be the load reduction necessary to reach the loading capacity for an impaired surface water or the existing load. Because the benefits of one or more practices depends on the amount of distance between the practice and the lake or river, practices benefits are a function of their position within and size of the watershed. Practice benefits tend to decline moving downstream as the drainage area increases. Although a practice may be intended to restore or protect the closest lake or river reach, benefits are also realized further downstream. The combined benefits of many practices can be used to assess the effectiveness of the targeted implementation plan. The annual load reduction estimates for TN, TP, sediment based upon Scenario 2 for the Ashley Creek study area are shown in **Figure 22.** The load reductions are calculated at each priority resource point within the Ashley Creek study area and can be used to assess progress towards and feasibility of a measurable water quality goal. This information can be used directly within a targeted implementation plan.

| Priority Resource | Original Load | Remaining Load | Load Reduction | Original Load | Remaining Load | Load Reduction | Original Load | Remaining Load | Load Reduction |
|---|---|---|---|---|---|---|---|---|---|
| | Sediment, tons/year | | | TP, lbs/year | | | TN, lbs/year | | |
| Lower Ashley Creek | 559 | 267 | **292** | 331 | 130 | **201** | 6,148 | 2,945 | **3,203** |
| Silver Creek | 340 | 146 | **194** | 213 | 113 | **100** | 4,087 | 3,133 | **955** |
| Middle Ashley Creek | 308 | 186 | **122** | 274 | 115 | **158** | 4,277 | 2,756 | **1,521** |
| Upper Silver Creek | 259 | 117 | **142** | 200 | 98 | **102** | 4,100 | 3,141 | **959** |
| County Ditch No. 3 | 164 | 158 | **6** | 182 | 175 | **6** | 3,514 | 3,470 | **44** |
| Upper Ashley Creek | 208 | 201 | **7** | 245 | 225 | **20** | 4,944 | 4,538 | **405** |



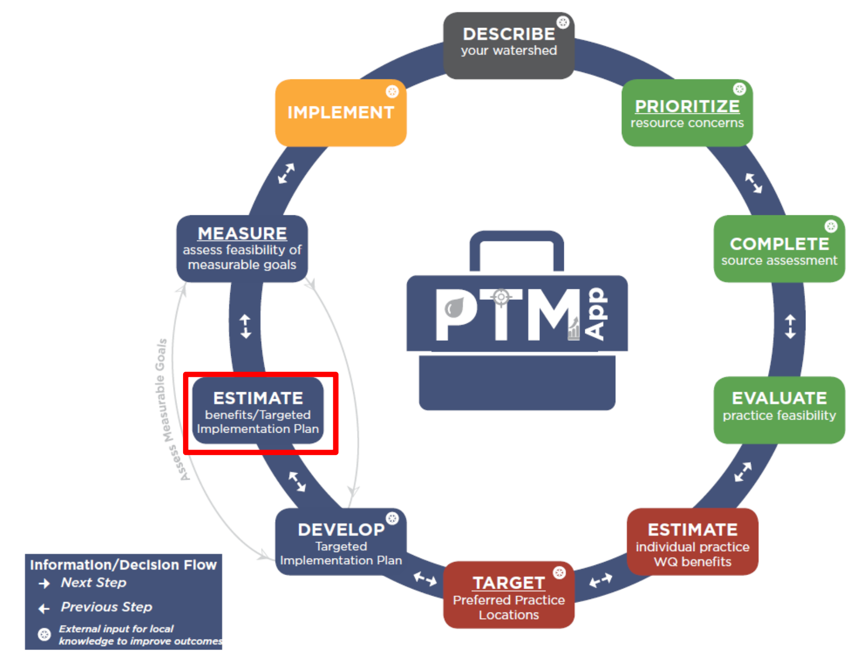
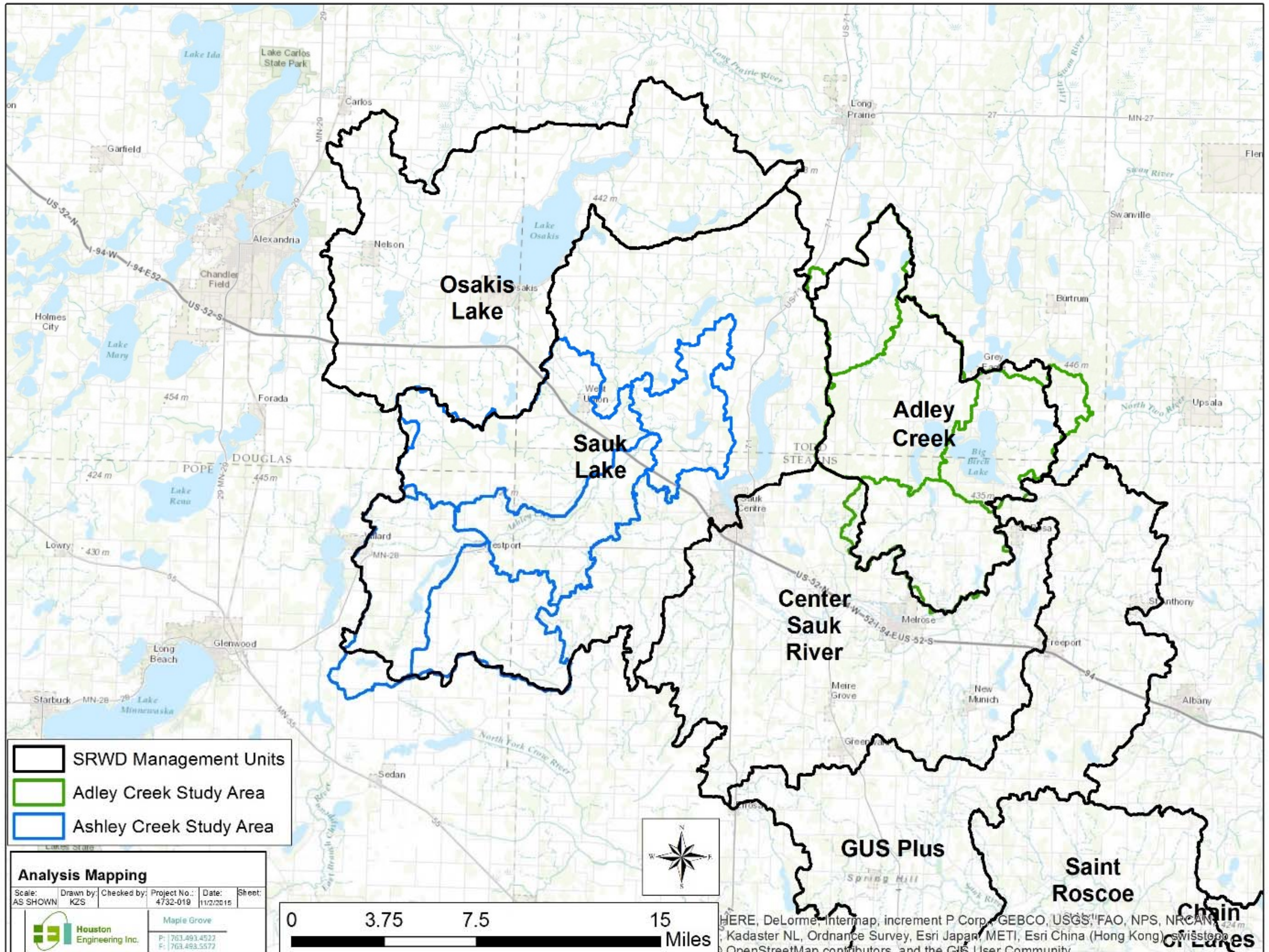




**Figure 22.** Sediment, TP, and TN reductions based upon Scenario 2 for Ashely Creek.

## 6.9 ASSESS FEASIBILITY OF MEASURABLE GOALS

A measurable goal may be the load reduction needed to restore a lake or river reach or a maximum load to protect a resource. The benefits of the implementation plan can be compared to the measurable goals at one or more locations. The estimated benefits of the targeted implementation plan can be compared to water quality goals from watershed, state, or regional strategies, such as those found in the States Nutrient Reduction Strategy or the Sauk River Watershed WRAPS. For example, a study completed during the Sauk River Watershed WRAPS development (RESPEC, 2014) identified an achievable total suspended solids (TSS) reduction for SRWD Sauk Lake Management Unit of 1,486 tons/year using BMPs and CPs in agricultural areas. The Ashley Creek study area only makes up a portion of the Sauk lake Management Unit. The results of this project suggest that implementing Scenario 2 would provide 18% of the reductions needed for this goal assuming that TSS is a surrogate for suspended sediment.



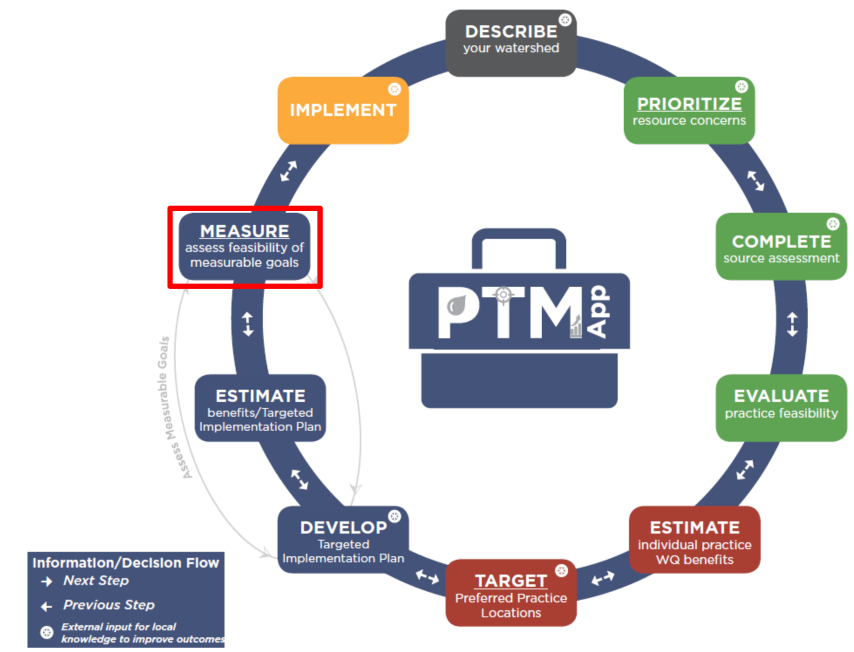




**Figure 23.** Sauk River Watershed District Management Units relative to the study areas used in this project.

# 7 DEVELOPMENT RESULTS AND CONCLUSIONS

PTMApp was developed to meet multiple business needs of LGUS and BWSR (see **Figure 15**). Specifically, it was developed with the goal of providing a tool for rural LGUS to target BMPs and CPs and measure the water quality benefits associated with implementing BMPs and CPs. The original purpose for PTMApp was to serve as a tool to support LGUs for Comprehensive Watershed Managements and Ongoing Local Implementation within the Minnesota 10 year cycle Water Quality Framework (**Figure 24**). However, PTMApp can also be used to provide information for Restoration and Protection Strategy Development, Water Resource Characterization & Problem Investigation, and Monitoring and Assessment.


**Figure 24.** Minnesota Water Quality Framework showing the 10 year watershed cycle.

It is important to note that PTMApp is in no way intended to replace other tools (e.g. ACPF Framework, Zonation), actual monitoring, or models (e.g. HSPF, SWAT) within the Minnesota Water Quality Framework. Rather, it was developed to complement or integrate with the other efforts.

# 8 REFERENCES CITED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# 9 APPENDICES

## 9.1 APPENDIX A: WORKSHOPS

## 9.3 APPENDIX C: PTMAPP-WEB WIREFRAMES

## 9.4 APPENDIX D: CURVE NUMBER TABLE

| Hydrologic Soils Group | ID | NLCD Value | NLCD Class Name | Join | CN |
|---|---|---|---|---|---|
| A | 1 | 11 | Open Water | 1101 | 100 |
| B | 2 | 11 | Open Water | 1102 | 100 |
| C | 3 | 11 | Open Water | 1103 | 100 |
| D | 4 | 11 | Open Water | 1104 | 100 |
| A/D | 5 | 11 | Open Water | 1105 | 100 |
| B/D | 6 | 11 | Open Water | 1106 | 100 |
| C/D | 7 | 11 | Open Water | 1107 | 100 |
| A | 1 | 12 | Perennial Ice/Snow | 1201 | 100 |
| B | 2 | 12 | Perennial Ice/Snow | 1202 | 100 |
| C | 3 | 12 | Perennial Ice/Snow | 1203 | 100 |
| D | 4 | 12 | Perennial Ice/Snow | 1204 | 100 |
| A/D | 5 | 12 | Perennial Ice/Snow | 1205 | 100 |
| B/D | 6 | 12 | Perennial Ice/Snow | 1206 | 100 |
| C/D | 7 | 12 | Perennial Ice/Snow | 1207 | 100 |
| A | 1 | 21 | Developed, Open Space | 2101 | 45 |
| B | 2 | 21 | Developed, Open Space | 2102 | 65 |
| C | 3 | 21 | Developed, Open Space | 2103 | 76 |
| D | 4 | 21 | Developed, Open Space | 2104 | 82 |
| A/D | 5 | 21 | Developed, Open Space | 2105 | 45 |
| B/D | 6 | 21 | Developed, Open Space | 2106 | 65 |
| C/D | 7 | 21 | Developed, Open Space | 2107 | 76 |
| A | 1 | 22 | Developed, Low Intensity | 2201 | 60 |
| B | 2 | 22 | Developed, Low Intensity | 2202 | 74 |

| Hydrologic Soils Group | ID | NLCD Value | NLCD Class Name | Join | CN |
|---|---|---|---|---|---|
| C | 3 | 22 | Developed, Low Intensity | 2203 | 82 |
| D | 4 | 22 | Developed, Low Intensity | 2204 | 86 |
| A/D | 5 | 22 | Developed, Low Intensity | 2205 | 60 |
| B/D | 6 | 22 | Developed, Low Intensity | 2206 | 74 |
| C/D | 7 | 22 | Developed, Low Intensity | 2207 | 82 |
| A | 1 | 23 | Developed, Medium Intensity | 2301 | 77 |
| B | 2 | 23 | Developed, Medium Intensity | 2302 | 85 |
| C | 3 | 23 | Developed, Medium Intensity | 2303 | 90 |
| D | 4 | 23 | Developed, Medium Intensity | 2304 | 92 |
| A/D | 5 | 23 | Developed, Medium Intensity | 2305 | 77 |
| B/D | 6 | 23 | Developed, Medium Intensity | 2306 | 85 |
| C/D | 7 | 23 | Developed, Medium Intensity | 2307 | 90 |
| A | 1 | 24 | Developed, High Intensity | 2401 | 92 |
| B | 2 | 24 | Developed, High Intensity | 2402 | 94 |
| C | 3 | 24 | Developed, High Intensity | 2403 | 96 |
| D | 4 | 24 | Developed, High Intensity | 2404 | 96 |
| A/D | 5 | 24 | Developed, High Intensity | 2405 | 92 |
| B/D | 6 | 24 | Developed, High Intensity | 2406 | 94 |
| C/D | 7 | 24 | Developed, High Intensity | 2407 | 96 |
| A | 1 | 31 | Barren Land | 3101 | 77 |
| B | 2 | 31 | Barren Land | 3102 | 86 |
| C | 3 | 31 | Barren Land | 3103 | 91 |
| D | 4 | 31 | Barren Land | 3104 | 94 |
| A/D | 5 | 31 | Barren Land | 3105 | 94 |
| B/D | 6 | 31 | Barren Land | 3106 | 9 |
| C/D | 7 | 31 | Barren Land | 3107 | 94 |

| Hydrologic Soils Group | ID | NLCD Value | NLCD Class Name | Join | CN |
|---|---|---|---|---|---|
| A | 1 | 41 | Deciduous Forest | 4101 | 36 |
| B | 2 | 41 | Deciduous Forest | 4102 | 60 |
| C | 3 | 41 | Deciduous Forest | 4103 | 73 |
| D | 4 | 41 | Deciduous Forest | 4104 | 79 |
| A/D | 5 | 41 | Deciduous Forest | 4105 | 79 |
| B/D | 6 | 41 | Deciduous Forest | 4106 | 79 |
| C/D | 7 | 41 | Deciduous Forest | 4107 | 79 |
| A | 1 | 42 | Evergreen Forest | 4201 | 30 |
| B | 2 | 42 | Evergreen Forest | 4202 | 55 |
| C | 3 | 42 | Evergreen Forest | 4203 | 70 |
| D | 4 | 42 | Evergreen Forest | 4204 | 77 |
| A/D | 5 | 42 | Evergreen Forest | 4205 | 77 |
| B/D | 6 | 42 | Evergreen Forest | 4206 | 77 |
| C/D | 7 | 42 | Evergreen Forest | 4207 | 77 |
| A | 1 | 43 | Mixed Forest | 4301 | 30 |
| B | 2 | 43 | Mixed Forest | 4302 | 55 |
| C | 3 | 43 | Mixed Forest | 4303 | 70 |
| D | 4 | 43 | Mixed Forest | 4304 | 77 |
| A/D | 5 | 43 | Mixed Forest | 4305 | 77 |
| B/D | 6 | 43 | Mixed Forest | 4306 | 77 |
| C/D | 7 | 43 | Mixed Forest | 4307 | 77 |
| A | 1 | 52 | Scrub/Shrub | 5201 | 35 |
| B | 2 | 52 | Scrub/Shrub | 5202 | 56 |
| C | 3 | 52 | Scrub/Shrub | 5203 | 70 |
| D | 4 | 52 | Scrub/Shrub | 5204 | 77 |
| A/D | 5 | 52 | Scrub/Shrub | 5205 | 77 |

| Hydrologic Soils Group | ID | NLCD Value | NLCD Class Name | Join | CN |
|---|---|---|---|---|---|
| B/D | 6 | 52 | Scrub/Shrub | 5206 | 77 |
| C/D | 7 | 52 | Scrub/Shrub | 5207 | 77 |
| A | 1 | 71 | Grassland/Herbaceous | 7101 | 30 |
| B | 2 | 71 | Grassland/Herbaceous | 7102 | 58 |
| C | 3 | 71 | Grassland/Herbaceous | 7103 | 71 |
| D | 4 | 71 | Grassland/Herbaceous | 7104 | 78 |
| A/D | 5 | 71 | Grassland/Herbaceous | 7105 | 78 |
| B/D | 6 | 71 | Grassland/Herbaceous | 7106 | 78 |
| C/D | 7 | 71 | Grassland/Herbaceous | 7107 | 78 |
| A | 1 | 81 | Pasture/Hay | 8101 | 49 |
| B | 2 | 81 | Pasture/Hay | 8102 | 69 |
| C | 3 | 81 | Pasture/Hay | 8103 | 79 |
| D | 4 | 81 | Pasture/Hay | 8104 | 84 |
| A/D | 5 | 81 | Pasture/Hay | 8105 | 84 |
| B/D | 6 | 81 | Pasture/Hay | 8106 | 84 |
| C/D | 7 | 81 | Pasture/Hay | 8107 | 84 |
| A | 1 | 82 | Cultivated Crops | 8201 | 61 |
| B | 2 | 82 | Cultivated Crops | 8202 | 71 |
| C | 3 | 82 | Cultivated Crops | 8203 | 78 |
| D | 4 | 82 | Cultivated Crops | 8204 | 81 |
| A/D | 5 | 82 | Cultivated Crops | 8205 | 61 |
| B/D | 6 | 82 | Cultivated Crops | 8206 | 71 |
| C/D | 7 | 82 | Cultivated Crops | 8207 | 78 |
| A | 1 | 90 | Woody Wetlands | 9001 | 78 |
| B | 2 | 90 | Woody Wetlands | 9002 | 78 |
| C | 3 | 90 | Woody Wetlands | 9003 | 78 |

| Hydrologic Soils Group | ID | NLCD Value | NLCD Class Name | Join | CN |
|---|---|---|---|---|---|
| D | 4 | 90 | Woody Wetlands | 9004 | 78 |
| A/D | 5 | 90 | Woody Wetlands | 9005 | 78 |
| B/D | 6 | 90 | Woody Wetlands | 9006 | 78 |
| C/D | 7 | 90 | Woody Wetlands | 9007 | 78 |
| A | 1 | 95 | Emergent Herbaceous Wetland | 9501 | 85 |
| B | 2 | 95 | Emergent Herbaceous Wetland | 9502 | 85 |
| C | 3 | 95 | Emergent Herbaceous Wetland | 9503 | 85 |
| D | 4 | 95 | Emergent Herbaceous Wetland | 9504 | 85 |
| A/D | 5 | 95 | Emergent Herbaceous Wetland | 9505 | 85 |
| B/D | 6 | 95 | Emergent Herbaceous Wetland | 9506 | 85 |
| C/D | 7 | 95 | Emergent Herbaceous Wetland | 9507 | 85 |

## 9.5 APPENDIX E: MAPPING BMPS TO TREATMENT GROUPS