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Assessing Phosphorus Sources with a GIS-Based Phosphorus Risk Index in a Mixed-Use, Montane Watershed

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A thesis submitted to the faculty of
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Master of Science

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ABSTRACT

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Elevated phosphorus (P) loading of freshwater lakes and reservoirs often results in poor water quality and negative ecological effects. Critical source areas (CSA) of P in the watershed can be difficult to identify and control. A useful concept for identification of a CSA is the P risk index (P Index) that evaluates the P risk associated with distinct source and transport pathways. The objectives of this study were to create a GIS model that adapts the Minnesota (MN) P Index for use at the watershed scale in a mixed-use, mountain environment, and to evaluate its effectiveness relative to field-based assessment. A GIS-based model of the MN P Index, adapted for montane environments and relying primarily on publicly available geospatial data, was created and applied in the Wallsburg watershed, located in the mountains of Central Utah. One necessary data input, P found in plant residue of common Utah ecosystems, was found lacking after literature review. We experimentally determined a range of observed values from multiple ecosystems to adapt and validate the GIS model. The GIS P Index was evaluated against the results of 58 field scale applications of the MN P Index conducted throughout the watershed. The field-scale analysis resulted in about 14% of the sites sampled being identified as high or very high risk for P transport to surface water. Spatially, these high risk areas were determined to be a geographic cluster of fields near the lower middle agricultural section of the watershed. The GIS model visually and spatially identified the same cluster of fields as high risk areas. Various soil test P scenarios were explored and compared to the known 58 site values. Soil test phosphorus had little effect on the GIS model's ability to accurately predict P risk in this watershed suggesting that high volume soil sampling is not always necessary to identify CSAs of P. Variable hypothetical livestock density scenarios were also simulated. The GIS model proved sensitive to variable P inputs and highlighted the necessity of accurate applied P source data. On average the model under-predicted the known field-site values by a risk score of 1.3, which suggests reasonable success in P assessment based on the categorical risk scores of the MN P Index and some potential for improvement The GIS model has great potential to give land managers the ability to quickly locate potential CSAs and prioritizing remediation efforts to sites with greatest risk.

Keywords: phosphorus risk index, phosphorus, GIS, Wallsburg, Utah, watershed, water quality, critical source area, plant residue, Minnesota

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CHAPTER 1

Creation and Evaluation of a GIS-Based Phosphorus Site Risk Index for a Montane Watershed

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ABSTRACT

Elevated phosphorus (P) loading of freshwater lakes and reservoirs often results in poor water quality and negative ecological effects. Critical source areas (CSA) of P can be difficult to identify and control. A useful concept for identification of a CSA is the P risk index (P Index) that evaluates the P risk associated with distinct source and transport pathways. The objectives of this study were to create a GIS model that adapts the Minnesota P Index for use at the watershed scale in a mixed-use, mountain environment, and to evaluate its effectiveness relative to field-based assessment. A GIS-based model of the MN P Index, adapted for montane environments and relying primarily on publicly available geospatial data, was created and applied in the Wallsburg watershed, located in the mountains of Central Utah. The GIS P Index was evaluated against the results of 58 in-field applications of the MN P Index conducted throughout the watershed. This field-site analysis resulted in about 14% of the sites sampled being high or very high risk. Spatially, These high risk areas were a cluster of fields near the lower middle agricultural section of the watershed. The GIS model visually and spatially identified the same cluster of fields as high risk areas. Various soil test P scenarios were explored and compared to the known 58 site values. Soil test phosphorus had little effect on the GIS model's ability to accurately predict P risk in this watershed suggesting that high volume soil sampling is not always necessary to achieve accurate results. Highly variable P sources in the form of

hypothetical livestock density scenarios were also simulated. The GIS model proved sensitive to highly variable P inputs but highlighted the necessity of accurate applied P source data. On average the model under predicted the known field-site values by a risk score of 1.3, which suggests that this method is a reasonable P risk assessment tool based on the categorical risk scores presented by the MN P Index. The GIS model has great potential to give land managers the ability to quickly locate potential CSA's and prioritizing remediation efforts to sites with greatest risk.

INTRODUCTION

Increased phosphorus (P) concentrations often results in eutrophication and poor water quality in freshwater lakes (Schindler, 1974). This is also the case for many water storage reservoirs found in the Rocky Mountains of the western United States (Gelder et al, 2003; Eckhoff et al., 2002; Utah DEQ-DWQ, 2007), which are susceptible to eutrophication from elevated nutrient inputs even when no point sources of P exist (Soballe and Kimmel, 1987). A point source is defined as a "clearly identifiable point of discharge" (Pierzynski et al., 2005). Nonpoint sources of P are more diffuse and often more difficult to assess and control (Carpenter et al, 1998). A nonpoint source of P found in a hydrologically active area results in disproportionately high amounts of P mobilization and is a critical source area (CSA) of P (Poinke et al., 2000). Identifying CSAs of P to these reservoirs is key to protecting and improving water quality.

A useful concept for identification of critical source areas of P is a phosphorus risk index (P Index). P indices take into account both P source and P transport risk factors specific to the site being evaluated (Buczko and Kuchenbuch, 2007). Inputs include things such as P fertilizer application, soil test P (STP), and P management practices (Buczko and Kuchenbuch, 2007). The first P Index was proposed in 1993 as an additive risk model that included P source and transport factors (Lemunyon and Gilbert, 1993). Since that time, development and application of P indices has been encouraged by natural resource agencies, such as the National Resources Conservation Service. Most U.S. states have developed independent versions of P Indices primarily for use in agriculturally dominant watersheds. Versions of P Indices vary in the approach and complexity of how inputs are weighted and combined to calculate an overall P risk score. The overall risk score is useful for prioritizing remediation efforts to sites with greatest risk.

Most P indices were developed for use and application at the scale of individual agricultural fields (Raney and Troxell, 2008, NRCS-Iowa, 2004). Because field specific inputs are obtained and used in the P Index calculations, it is reasonable to assume that indices employed at this scale are most appropriate for identification of site-specific best management practices. However, if water quality improvement at the watershed scale is the goal, field-by-field P index application can be tedious, time consuming, and costly. Some studies have successfully applied P indices at larger scales. For example, Birr and Mulla (2001) used a modified P Index to evaluate the risk of P movement from land to water from 60 watersheds in Minnesota. They showed good correlation of aggregated watershed level P Index scores with historic water quality data. However, Salvano et. al. (2009) showed that the same P index did not correlate well with water quality in 14 watersheds in the southern Manitoba prairie region of Canada. They highlight the need for P indices to be developed with attention to specific soil, landscape, and climate conditions. There is a significant and on-going effort to improve the utility of P indices for water quality protection (Ketterings et al., 2017; Nelson and Shober, 2012).

With the wealth of spatial data publicly available for use in geographic information systems (GIS) in the U.S., a GIS based P Index could bridge the gap between the field and regional scales by providing relatively accurate local input data in a watershed. Many GIS-based erosion prediction models have already been incorporated with P risk indices (Tattari et al., 2001), but independent GIS based P indices that examine multiple source and transport factors are rare (Tejero, 2015; Huang and Hong, 2010; Bolinder et al., 2000). A logical next step for P index based assessment would be to create a GIS model that adapts a field scale P index to a watershed scale in a complex environment, like a mixed-use, mountain environment.

For this study, the Minnesota Phosphorus Site Risk Index (MN P Index) was selected as the template for developing the GIS based model. The MN P Index is a field-based P index that incorporates P transport in three pathways: 1) P movement in particulate forms with soil erosion, 2) P movement in soluble forms in runoff from rainfall, and 3) P movement in soluble forms in snowmelt driven runoff ([2]Moncrief et al., 2006). This P Index was selected primarily because it incorporates P transport risk by snowmelt. In mountainous watersheds, spring snowmelt is the most significant annual hydrologic event and can transport a significant portion of the annual P load. The framework of the MN P Index is transferable to different locations and environments, but some factors within it need to be modified based on local conditions. The objectives of this study were to create a GIS model that adapts the MN P Index for use at the watershed scale in a mixed-use, mountain environment, and to evaluate its effectiveness relative to field-based assessment.

METHODS

STUDY AREA

The study was conducted using the Wallsburg watershed, a mixed-use watershed, located in the Wasatch Mountains in Central Utah, U.S.A. at 40.3877° N, 111.4224° W (Figure 1–1). A Total Maximum Daily Load (TMDL) study identifies the Wallsburg watershed's sole drainage channel, Main Creek, as a disproportionately high contributor of P to Deer Creek Reservoir, an important source of water for recreation, agricultural, municipal, industrial use, and as a cold freshwater fishery (Eckhoff, et al., 2002). Main Creek is fed by three perennial reaches: Main Creek itself (~24 km long), which originates in the southeast high elevation mountains of the watershed, Little Hobble Creek (~11.7 km), which originates in the southwestern high elevation mountains of the watershed, and Spring Creek (~5.3 km), a spring-fed stream in the center of Wallsburg proper, a small rural community home to about 303 residents (Boyd, 2012). Each of these waterways has contributing ephemeral streams, active only during snowmelt, and the Wallsburg watershed itself is made up of three sub-watersheds based on USGS classified hydrologic units (HUC12).

The watershed elevation ranges from 1,300 m at the outlet to 2,960 m above sea level at the highest peak. Average precipitation at the nearest weather station is 62 cm. The area is a graben, or a depressed area of land between parallel faults. The area contains high amounts of high-level alluvial fan-deposits. (Beik and Lowe, 2009). The total area is nearly 185 km^2. About 7.6% of the land area is used for agriculture. A mixture of grasses and shrubland ecotones make up 30.8% of land area and a mixed ecotone of big mountain sagebrush (*Artemisia tridentate var. vaseyana*), Gambel oak (*Quercus gambelii*), and forested woodlands make up the remaining 61.6% of the watershed area (Figure 1–2) (Boyd, 2012). The mixed-use nature of this watershed and its high P output make it an interesting site for development of a watershed scale, GIS P Index tool.

THE MINNESOTA PHOSPHORUS RISK INDEX

This study utilized the framework of the MN P Index ([2]Moncrief et al., 2006; Moncrief et al., 2017) as a template for developing the GIS P Index model. All modifications made to the MN P Index in order to better fit the mountain watershed environment are detailed below. The performance of the GIS P Index was tested against 58 field-site estimates of the MN P Index. The MN P Index estimates the risk of P delivery from field-site to water in three distinct pathways: Pathway 1) sediment bound P in rainfall induced runoff and erosion, Pathway 2) soluble P delivered in rainfall runoff, and Pathway 3) soluble P in snowmelt runoff. For each pathway, we followed a well-documented computational procedure that has been laid out for each individual pathway to obtain a risk score approximated as the mass of P per unit of land area ([2]Moncrief et al., 2006). Details for each pathway procedure are described below. The overall site risk is determined as the sum of the estimates for the three individual pathways. The overall risk is then interpreted according to the following: 0-1= Very Low Risk Level with no recommended management changes; 1-2 = Low Risk Level with minor management changes recommended; 2-4 = Moderate Risk Level with management recommendations that avoid risk increases; 4-6 = High Risk Level with management recommendations that reduce the P transport risk; >6 = Very High Risk Level with multiple and possibly large management improvements recommended.

Pathway 1 in the MN P Index estimates the transport risk of P bound to sediment through rainfall runoff and erosion ([2]Moncrief et al., 2006). It is calculated from the product of the average annual erosion rate, a distance based sediment delivery factor, a manure factor, and the site specific soil TP concentration. The average annual erosion rate is calculated from the Revised Universal Soil Loss Equation (RUSLE) (USDA, 2016). Cover factors were obtained for agricultural sites by matching available crop management templates from NRCS crop management zone 27. For range and forest sites where no template was available, either the conservation reserve program (CRP) template was used or a cover factor value was derived from published values (Montana DEQ, 2012). The conservation or support practice factor was left at the value of "1" for all sites. For the distance value input for calculating the sediment delivery factor, we calculated the flow path distance from individual sites to the outlet of Main Creek in the Wallsburg watershed. A manure factor of 1.0 was used for all calculations. A local equation was developed to predict soil total P concentration from extractable P and the local equation was substituted for the equation developed in the MN P Index. Pathway 2 in the MN P Index estimates the transport risk of soluble P mobilized through rainfall runoff events. This pathway is the product of a base annual runoff volume, a runoff adjustment factor to account for site specific soil drainage class and surface cover, and the sum of soluble soil P and applied P. For the MN P Index, base annual runoff volumes were estimated using the curve number method and ranged from 2.0-6.0 cm. The base runoff volume used for the Wallsburg watershed was 5.7 cm and was determined from an evaluation of 30 years of historic flow data on Main Creek at the outlet of the Wallsburg watershed, collected from 1984 to 2014, during June through November. Runoff during this period generally comes from rainfall and not snowmelt. Procedures for estimating soluble soil P and applied P followed those in the MN P Index. Pathway 3 in the MN P Index estimates soluble P transported by snowmelt. It is calculated as the product of the snowmelt runoff factor, fall soil condition factor, and the sum of residue P and surface applied P. Pathway

3 does not use soil P as an input based on the assumption that soils are frozen during snowmelt. Soluble P in Pathway 3 originates from plant residue P and surface applied P from manure application or outdoor winter feeding of livestock. The snowmelt runoff factor used for the Wallsburg watershed was 3.2 cm and was determined from an evaluation of 30 years of historic flow data on Main Creek at the outlet of the Wallsburg watershed, collected from 1984 to 2014, during December through May. Fall soil condition, livestock information, and fertilizer practices at each of the sample site locations were determined through discussion with landowners at each site. The practice of winter fertilizer application or manure application in the watershed is rare but some winter-feeding of livestock on pasture is more common. Stocking rates were determined based on an evaluation of wintertime high-resolution National Agriculture Imagery Program (NAIP) imagery from February of 2008, accessed through Google Earth Pro®. Livestock numbers were counted in each field where they were present and the area of the field was measured with a GIS. With this data, wintertime animal units per area (AUs) were determined for cows, sheep, and horses. The snowmelt pathway of the MN P Index incorporates the risk of P from plant residues moving into water during snowmelt. The MN P Index includes routines to estimate plant residue P as a function of crop type and fall tillage practice, but it does not have data for some of the native vegetation types in the Wallsburg watershed. Unknown plant residue P risk values were determined experimentally for primary vegetation types in the Wallsburg watershed. These values are represented in units of kilograms of P per hectare. A value of 2.6 kg ha^{-1} was used for aspen (*Populus tremuloides*) dominant forests, 4.9 kg ha^{-1} for Douglas fir (*Pseudotsuga menziesii*) dominated forests, 3.4 kg ha^{-1} for other conifers and deciduous woodland vegetation, 2.7 kg ha^{-1} for riparian woodland vegetation, 2.1 kg ha^{-1} for riparian shrubland vegetation, 1.2 kg ha^{-1} for wet meadow vegetation, 3.0 kg ha^{-1} for all

sagebrush (*Artemisia tridentate var. vaseyana, Artemisia tridentate var. cana, Artemisia tridentate var. tridentate, Artemisia tridentate var. wyomingensis*) dominated shrublands, and 1.8 kg ha^{-1} for grass dominated lands (See chapter 2 of thesis).

FIELD SITE DATA ACQUISITION

During the summers of 2014 and 2015, data collection was conducted at 58 field-sites (Figure 1–3) in order to calculate P Index scores for validation of the GIS based P Index model. The sampling locations were chosen in a stratified approach to include different land use classes (Figure 1–2), elevation zones, slopes, and proximity to waterways. However, the stratified random approach was significantly constrained by site accessibility. Many locations are privately owned and only accessible with permission and other sites are physically inaccessible. Spatial coordinates of each data collection site were obtained with a global positioning system (GPS) receiver or with the smartphone application Arc-Collector (Environmental Systems Research Institute, Redlands, CA). At each site, a surface soil sample (0-5 cm depth) was obtained by aggregating at least 15 individual 1.9 cm diameter cores from within a radius of 25 m. The dominant land cover at each location was documented and percentages of surface cover by vegetation and rocks were obtained using the line-transect method with transect points every 1.0 m over a 25 m length. Slope measurements were taken in the field by measuring the downslope elevation change from a string-levelled line over a 25 m length. A visual erosion score was recorded based on a scale ranging from 1 (no visual sign of surface soil movement) to 5 (erosional rills and gullies present). Digital photos were collected with digital smartphone cameras at each site for documentation and confirmation of field observations. Landowners and managers were consulted about site management practices and site history.

LAB ANALYSIS OF WATERSHED SOIL SAMPLES

Soil samples from all 58 sample locations were analyzed for extractable and total P (TP) concentrations. Collected soils were transported from the field on ice and then refrigerated at 4 °C until they were analyzed. Extractable soil P concentrations were determined from a sodium bicarbonate extract (Olsen et al., 1954) and analyzed colorimetrically using the ascorbic acid method on a Thermo Scientific GENESYS spectrophotometer (Murphy, 1962). Soil TP concentration was determined through microwave assisted nitric acid digestion and analyzed on the Thermo Scientific iCAP 7400 ICP-OES in the Brigham Young University Environmental Analytical Laboratory. A linear regression was performed to evaluate the relationship between soil TP concentrations to sodium bicarbonate extractable P concentrations in order to replace a similar equation used in the MN P Index with an equation derived from local soil data.

GIS P INDEX MODEL DEVELOPMENT

The goal of this project was to create a GIS model that adapts the MN P Index for use at the watershed scale. A practical model will utilize readily available spatial data, have a minimal requirement for field data collection, and will automate the calculations. The GIS P Index model was developed using Model Builder® in the software program ArcMap 10.4.1. (Environmental Systems Research Institute, Redlands, CA). All model inputs are supplied from the user, lookup tables in an embedded spreadsheet, and from web-accessible spatial data (i.e.: SSURGO database accessed through the NRCS's Web Soil Survey, the Utah Automated Geographic Reference Portal). Both the GIS P Index model and the field based P Index calculations use the MN P Index as a framework and many inputs are the same, but differ in the sources of some input data. Details of model inputs that differ between the field-site P Index and the GIS based P

Index are outlined in Table 1-1. The GIS P Index model joins the input data to geographic locations within the watershed based on common categories of land use and land cover types. Specifically, a spatial layer was created by merging two available data layers, Water Related Land Use and Land Cover, both accessed from the Utah Automated Geographic Reference Portal and prepared by the Utah Division of Natural Resources and the U.S. Geological Survey National GAP Analysis Program (USGS, 2015) respectively. The merged layer created relatively small polygons to which P Index input and output values could be assigned (Figure 1–4).

Four subroutines were created within the GIS P Index model, one for each pathway in the MN P Index and one that aggregates the three pathways into the overall risk score. The model was built for potential application to any watershed for which needed inputs are available, but this paper describes its performance only in the Wallsburg watershed.

MODEL SENSITIVITY TO SOIL TEST PHOSPHORUS AND LIVESTOCK DENSITY

Two of the P Index inputs that are not commonly available from public data sites are STP and livestock density. When applying the GIS P Index model, some soil testing and analysis is necessary, but the extent of sampling depends on how sensitive the model is to variation in soil P concentrations. The sensitivity analysis was performed by using the low, average, and high observed STP values as inputs for each land use class. The STP values were 7.6 mg kg^{-1}, 43.0 mg kg^{-1} and 82.8 mg kg^{-1} for low, average, and high scenarios, respectively for forested areas. The STP values were 8 mg kg^{-1}, 40.6 mg kg^{-1}, and 68.5 mg kg^{-1} for low, average, and high scenarios, respectively in shrublands. The STP values were 7.5 mg kg^{-1}, 24.6 mg kg^{-1}, and 69.7 mg kg^{-1} for low, average, and high scenarios, respectively for agricultural areas. Similarly, livestock density is an important input that generally cannot be obtained from GIS databases.

Livestock density can be obtained from landowner interviews, field observations, agricultural census data, or remote sensing. To understand the importance of this input for P risk calculations, a sensitivity analysis was performed by modelling three livestock density scenarios, low, average, and high. In the high livestock density scenario, all locations identified as "pasture" were assigned an animal density of 5.0 AUs per hectare for calculations in Pathway 2 and locations identified as grass hay were assigned an animal density of 6.1 AUs per hectare for Pathway 3. For the low livestock density scenario, livestock density in pastureland use was set at 0.05 AUs per hectare for Pathway 2 and the grass hay polygons at 1.2 AUs per hectare for Pathway 3. The average scenario used inputs for individual fields as determined from evaluation of remote sensing images.

GIS P INDEX MODEL VALIDATION

In order to evaluate whether the GIS P Index model is effective at identifying critical source areas of P in the watershed, the model predictions were compared to the 58 field-sites where the modified MN P Index calculations were performed. Both the GIS P Index model and the field based P Index calculations use the MN P Index as a framework and many inputs are the same, but differ in the sources of some input data (Table 1-1). Thus, the model validation did not test the model routines established in the MN P Index, but rather, tests how well the model's automated approach used to generate inputs for the P Index compare to generating inputs with site-by-site field visits. If the GIS P Index model performs similar to the field-based assessment, the approach is a much more effective way to scale up the P Index for watershed scale identification of CSAs. The validation is performed by comparing the P Index values for 58 field-sites to the GIS P Index values predicted for the corresponding raster output cell.

The following comparative validation statistics were used (Miner et al., 2013): (i) root mean square error (RMSE), which describes the magnitude of difference between the field scale P Index and the GIS P Index, with the same units as the P Index risk score, (ii) relative error (RE), which indicates directional bias of the GIS P Index model mean relative to the field-site P Index expressed as a percentage, and (iii) a normalized objective function (NOF), which indicates non-directional deviation between the GIS and field-site P Index values. The three validation statistics together provide a strong description of how well the field scale and GIS based P Index approaches correspond. The RMSE (Equation 1-1) describes the average difference between the two models being compared, with the magnitude in the same units as the P Index risk scores. For example, in this paper, a RMSE value of 1 for the total P Index score means that, on average, the GIS P Index model differs from the field-site P Index by a risk score of 1.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (P - O)^2}{n}}$$

Equation 1-1

The RE (Equation 1-2) shows whether the GIS P Index model generally under- or over-predicts the values obtained at the field-sites. If RE is negative it represents under prediction with the GIS P Index relative to the field based P Index. If it is positive, it represents over prediction. The combination of RE and RMSE allow for inferences about whether the model under- or over-predicts and by how much.

$$\mathrm{RE} = \frac{\left(\bar{P} - \bar{O}\right)}{\bar{O}} 100$$

Equation 1-2

NOF (Equation 1-3) measures the scale of model error relative to the mean and standard deviation of the data. When NOF has a value of zero, it indicates a perfect fit between the field-site data and the GIS P Index model results. If NOF is less than 1.0 it indicates that the model error is less than 1.0 standard deviation around the mean of field-site predicted P Index values. Each of these validation statistics was determined for each pathway of the P Index calculations and for all of the model sensitivity analysis scenarios.

$$\mathrm{NOF} = \frac{\mathrm{RMSE}}{\bar{O}}$$

Equation 1-3

RESULTS & DISCUSSION

The objectives of this study were to create a GIS model that adapts the MN P Index for use at the watershed scale in a mixed-use, mountain environment, and to evaluate its effectiveness relative to field-based assessment. Data, including soil test P concentration, were collected from 58 field-sites in the watershed. Soil P results were used as individual inputs for field-site P Index calculations, to modify aspects of the MN P Index for local application, and for obtaining average values used in the GIS based P Index model. Both the field-site P Index and the GIS P Index model were based on the same MN P Index framework, but the two approaches vary in the source of input data (Table 1-1). The field-site P Index values are used as validation points for the GIS based P Index model.

SOIL TEST PHOSPHORUS RESULTS

Extractable Soil Test P Results

Soil extractable P concentration from 58 field-sites in the Wallsburg watershed ranged from 7.5 to 82.8 mg kg^{-1}. Average soil extractable P concentrations by land classes were 22, 38, and 36 mg kg^{-1} for the agricultural, shrubland, and forest land classes with a wide range in concentration regardless of land class (Figure 1–5). One might assume that the range in soil P levels observed among the agricultural soils is due to variable history of fertilization or manure application. However, the similar range in soil P levels observed in shrubland and forest sites that have no history of fertilizer or manure application do not support that assumption. The relatively high average levels of soil P across all land classes suggest areas of P rich parent material. Some phosphate rich minerals are indicated in geologic maps of the watershed (Rupke, 2015) and some spatial patterns can be observed in the soil P data (Figure 1–6).

Correlation of Extractable Phosphorus and Total Phosphorus Concentrations

The MN P Index estimates transport risk of sediment bound P in rainfall induced runoff. One step in this calculation pathway converts extractable soil P concentration to total soil P concentration as an estimate of total P in eroded sediments. The MN P Index utilizes a conversion equation (TP = 3.338*STP + 453.8) derived from evaluation of 121 low CaCO3 Minnesota soils with TP concentration ranging from about 250 to 1,350 mg kg-1 ([1]Moncrief et al., 2006). For this study, we developed a similar correlation from the soils within and around the

Wallsburg watershed (Figure 1–7). Soil TP concentration ranged from 334 to 2,580 mg kg-[1]. Although there is significant scatter in the data, a linear fit was chosen for consistency with the equation in the MN P Index. The Wallsburg watershed conversion equation (TP= 9.9327*STP + 687.3) shows that the Wallsburg soils have a higher TP concentration than the MN soils at similar extractable P concentrations. This is likely due to higher $CaCO_3$ parent material in the study area, as described in SSURGO soils database, which can bind high levels of P.

Field Site Phosphorus Risk Index

Risk of P transport from land to water was calculated with the P Index for each of the 58 field-sites (Figure 1–8). The range in observed P Index risk scores was 0.7 to 18.3 with mean and median values of 3.2 and 1.5, respectively. About 70% of the field-sites were in the very low or low risk categories (41/58), while 16% where in the moderate risk level (9/58) and 14% were in the high or very high risk categories (8/58). This illustrates the potential value of a P Index for identifying sites and practices within a watershed responsible for the highest risk of P transport to surface water. All eight sites that were identified as high to very high risk are agricultural sites and five of those were sites with grazing or winter-feeding of cattle. P Index risk scores for forest and shrub land classes were uniformly low risk in rating.

For all 58 field-sites, the contribution of P risk through sediment-bound P transport (Pathway 1) ranged from 0 to 1 and averaged 0.17. These values are very low and indicate that P transport via upland erosion is not a major transport pathway in the Wallsburg watershed. This is reasonable for the Wallsburg watershed because nearly all land in the watershed has perennial plant cover without tillage. There are a small number of agricultural fields in the watershed with annual crops and tillage practices where erosion could be a concern, but none of those sites were among the 58 observed field-sites. The P Index approach does not evaluate the potential contribution of particulate P originating from streambank erosion, which has been identified as a concern in the Wallsburg watershed (Boyd, 2012).

The contribution of P risk as soluble P in rainfall runoff (Pathway 2) ranged from 0.002 to 16.7 and averaged 1.1. Pathway 2 has some of the highest individual pathway values observed in this study and makes up between 25% and 90% of the overall P Index score among the sites that rank as high and very high risk. As an example, field-site location 30 was among the highest risk sites with an overall P Index score of 18. For this site, the Pathway 2 risk score was 16.7. This is a site in permanent pasture, where erosion risk is low due to perennial vegetative cover, but high levels of soluble P are at the surface potentially due to high-density cattle grazing.

The contribution of P risk as soluble P in snowmelt runoff (Pathway 3) ranged from 0.44 to 12.6 and averaged 2.0. When considering all 58 field locations, the snowmelt pathway is the most important risk pathway for P transport in the Wallsburg watershed. This observation is logical because the annual snowmelt period is consistently the most hydrologically active period of the year. Even though the overall P Index risk ranks low for the forest and shrubland classes, the snowmelt pathway made up the major portion of the total risk. For the field-sites with high and very high P Index risk, the snowmelt pathway ranged from 10 to 96% of the total P Index score and averaged 58%. The highest snowmelt pathway risk scores correspond to pasture sites with high density of winter cattle feeding.

DEVELOPING AND EVALUATING THE GIS PHOSPHORUS INDEX MODEL

The objectives of this study were to create a GIS model that adapts the MN P Index for use at the watershed scale in the Wallsburg watershed and to evaluate its effectiveness relative to field-based assessment. The MN P Index is used as the framework for both the field-site P Index and the GIP P Index, but the two approaches vary in how input data for the model are obtained (Table 1-1). The intent of the GIS model was to develop an automated process and reduce the time and cost requirements of field-site assessment. The GIS P Index model was built to populate inputs for the P Index with information available through GIS databases and to automating the calculations. For this project, the GIS P Index model was created with four linked subroutines in the Model Builder® feature of ArcMap 10.4.1.

Model Pathway 1 - Transport Risk of Particulate P via Rainfall Runoff

The model was developed around the framework of Pathway 1 in the MN P Index, which multiplies the average annual soil erosion rate, manure factor, sediment delivery factor, and soil total P concentration ([2]Moncrief et al., 2006). The average annual soil erosion rate is calculated from procedures used in RUSLE. The model was created to query the user or available GIS data layers for inputs and prepare necessary output layers for the subsequent pathway calculations. The user is queried for inputs through ArcMap's tool dialogue box. Where appropriate, numeric input for constants are also present in the tool dialog box. The model scheme for Pathway 1 is the most complex among the three pathways (Figure 1–9). User inputs for this sub-routine include watershed layers for soils, digital elevation model, slope, land class, and a constant value for erosivity (R factor in RUSLE). Further, supportive look-up files needs to be in place that associates land classes with values for extractable P and total P concentrations.

All of the input parameters for RUSLE and P Index Pathway 1 were based on user defined input tables; the model runs the MN P Index to produce output in 10 m raster cells over the entire input area. This is accomplished by assigning each polygon in a water related land use and land cover layer specific, Pathway 1 information, converting it to 10 m rasters, and following the MN P Index calculations. Besides STP values, much of the input for Pathway 1 in the GIS model was the same as the field-site data. Soil TP concentration was assigned by the simple land use and land cover classifications shown in Figure 1–2. For the original model performance test, a random subsample of half of the observed STP values from each land use and land cover designation were used to create averages. These averages were assigned to all of the land use and land cover designations to be compared with the sample sites not used in the average calculation.

The LS, K, and C factors used in the model to calculate Pathway 1 components, as well as the Pathway 1 model's overall RUSLE estimates (A) for the watershed are displayed in Figure 1–10. The LS factor is by far the greatest driving factor in the RUSLE determination in this area. These figures are outputs of the model based on user input described in the methods section. The LS raster ranges from a low of 0 to a high of 119 with an average of 3.5. Higher slopes resulted in higher LS factor values. The K factor values range from 0.1 to 0.43. Higher K factors are shown in red and lower K factors are shown in green. Very rocky areas with limited data are shown in black. The mountain toe slopes tend to have higher K factors than the peaks and lowest valley areas. The C factor values range from 0 to 0.31. Natural cover factors increase in the higher elevations and agricultural cover factors change depending on the cropping system. As discussed in previous sections, P was set to 1, and R was set to 18. A, or the RUSLE results, range from 0 to 84 and average at 3.75. Some of the high output values on steep sloping areas could be a result of the RUSLE's inability to handle long slope lengths and very high slope steepness.

The GIS model output for Pathway 1 is shown in Figure 1–11. This output is based on the inputs most expected to mirror reality. Average soil test P was used to create this model output. Most of the watershed area is described as low and very low. Some of the high sloping, mountainous areas on the edges describe high and very high risk. This pattern follows the LS factor concerns discussed in the end of the previous paragraph. A different sediment bound P model might be more appropriate for the high sloping areas. In any case, these high sloping mountain areas do not lend themselves to practical P management strategies in many cases. Any reasonable management practices that reduce sediment erosion in these areas should be employed.

In order to examine the GIS tool outputs and how they compare with the field-sites in a sample-by-sample basis, the Pathway 1 GIS tool output at each field-site location was plotted against the respective Pathway 1 field-site values. Figure 1–12 shows that both the GIS tool outputs and field-site scores are low (less than 1.5). A perfect one-to-one relationship would represent perfect fit but, the relationship shows significant variability between the GIS tool output and field-site observations. The fact that the values are all so low means the lack of fit is not detrimental. All of the values are still within the very low and low risk categories defined in the MN P Index.

Model Pathway 2 - Transport Risk of Soluble P via Rainfall Runoff

Figure 1-13 shows the conceptual model framework of Pathway 2. The Pathway 2 output highlighted the effect of soluble P source risk in much different areas than Pathway 1. Where

Pathway 1 was high on the upper slopes of the watershed area, Pathway 2 was almost exclusively confined to agricultural areas. Figure 1–14 is the model output for Pathway 2. Specific fields and land use areas are highlighted as the higher risk areas. The output values ranged from a low of 0 to a high of 15. P application, mostly in the form of P associated with grazing livestock waste, had the biggest effect in driving specific field risk scores higher.

Field-site results and the GIS output followed a similar increasing trend when plotted against one another (Figure 1–15). In general, as the field-site observations increase, GIS tool output also increases. There is not a perfect one-to-one relationship but the GIS tool graphically appears to mirror field-site outputs. In the scale of the MN P Index, each point appears to be in or near the appropriate respective risk score categories. The highly variable source nature of Pathway 2 in agricultural areas could be tricky to model. This output is reassuring that the model can at least pick up on the general trends. It will likely be more accurate with data that are more accurate.

Model Pathway 3 - Transport Risk of Soluble P via Snowmelt Runoff

Figure 1-16 is the subroutine flowchart for Pathway 3. The GIS model produced some Pathway 3 hotspots and slightly higher overall scores, similar to the observed field-site results (Figure 1–17). Most of the Pathway 3 high risk areas were confined to fields where winter grazing was common. This output follows the same general trends found through field-site evaluation described spatially in Figure 1–8. This observation makes this output expectedly more similar to Pathway 2 than to Pathway 1. While many other areas are low, the addition of the other pathways could drive up the overall risk in some of the low areas. It is interesting to note that some of the high mountain areas of the watershed scored higher than the Pathway 2 scores at those locations. While these risks scores are low, they could combine with sediment erosion risk to create higher overall P loss issues.

In order to examine the GIS tool outputs and how they compare with the field-sites, the Pathway 3 GIS tool output at each field-site location was plotted against the respective Pathway 3 field-site values. Figure 1–18 shows the relationship between the two variables. Like the previous pathways, in general, as the field-site observations increase, GIS tool output also increases. Once, again, there is not a perfect one-to-one relationship but the GIS tool graphically appears to mirror field-site outputs with this pathway visually performing better than Pathway 1 and 2. In the scale of the MN P Index, each point appears to be in or near the appropriate respective risk score categories.

Model - Total Phosphorus Risk Index

The best estimate total P loss risk GIS tool output is shown in Figure 1–19. This output is very similar to the field-site results (Figure 1–8). Much of the land area of the watershed was in the low or very low category. The fields highlighted in Pathways 2 and 3 as high and very high risk areas are generally located in the agricultural areas towards the outlet of the watershed. High densities of grazing livestock in these areas likely drive the risk levels up. According to both models, these fields can be considered critical sources areas of P to Deer Creek Reservoir.

In order to further examine the GIS outputs and how they compare with the field-sites on a sample-by-sample basis, the GIS P Index model total P loss risk output at each field-site location was plotted against the respective Pathway 2 field-site P Index values. Figure 1–18 shows the relationship between the two variables. In general, as the field-site observations increase, GIS tool output also increases. There is not a perfect one-to-one relationship but the

GIS tool sample points graphically appears to mirror field-site outputs. In the scale of the MN P Index, each point appears to be in or near the appropriate respective risk score categories.

The comparative statistics (RMSE, RE, and NOF) for the means from each pathway and the total P index risk score is described in Table 1-2. These statistics described the GIS P Index model's general accuracy in comparison with the field-site P Index scores.

Pathway 1 had an observed mean of 0.17 and a GIS P Index mean of 0.18. The RMSE was 0.22, the RE was small at 4.58%, but the NOF was large at 1.31. As described in 3.3.1., all of the field-sites were found in very low and low risk areas for sediment-bound P loss. With such low values, the high NOF value is not a large cause of concern. Both the P Index and GIS P Index model described all of the sample points in the very low, and low risk categories. For all practical matters, in general, the GIS index is successful when compared with the field scores for Pathway 1.

Pathway 2 had an observed mean of 1.11 and a GIS P Index mean of 0.75. RMSE was 1.06, RE was the largest of the three pathways at -32.37%, and NOF was just inside of 1 standard deviation from the mean at 0.96. Pathway 2 is much more variable than Pathway 1, due to highly variable P sources (fertilizer application and livestock P inputs) therefore, while the means are relatively close, this variability affects the other comparative statistics. In general, the GIS P Index model will under predict P Index values for Pathway 2 by about 1 risk score. This is the largest of the three pathways and has the most effect on the overall total P Index risk score.

Pathway 3 had an observed mean of 1.96 and a GIS P Index mean of 1.63. RMSE was 0.56, RE was -16.95%, and NOF was just over one quarter standard deviation from the mean at 0.28. Similar to Pathway 2, Pathway 3 takes into account more variable P sources (fertilizer application and livestock P inputs) than Pathway 1. Yet, in the case Pathway 3, the GIS P Index was about 50% closer to the observed values.

The overall total P loss, or "P Index" pathway, as listed in Table 1-2, shows that the observed mean was 3.23 and the GIS P Index mean was 2.56. RMSE was 1.31, RE was -20.57% and NOF was 0.41. These comparative statistics suggest that the GIS P Index tends to under predict the field-site P Index by a little over 1 risk score value. This discrepancy could potentially result in misclassifications. For example, a high risk area could be classified as a medium risk area or a medium risk area as a low risk area. While such misclassifications could potentially cause underestimates, the GIS P Index outputs the actual numerical value associated with the general risk score classification. The user, knowing that the GIS P Index could be off by about 1, should take this into account when searching for high risk areas and rather than treating each score as a discrete value should realize that values near cut off points tend to blend.

MODEL SENSITIVITY TRIALS

Soil Test Phosphorus Scenarios

Soil test P is often thought of as an important indicator of P risk ([1]Moncrief et al., 2006). Ketterings et al. (2017) found STP to be less important than previously thought. To further test this idea and accomplish one of the objectives of this study, which was to test the GIS model's effectiveness against known MN P Index output at field-sites, we examined STP variability with the GIS model. STP is expectedly variable over the entire watershed, as shown in Figure 1–6, and could potentially cause the GIS model to err from field-site values. The lowest, an average, and the highest STP results were assigned in the GIS model based on land class to test its sensitivity to STP variation. The GIS model output of these tests is shown in Figure 1–21. The combination of the visual output maps and the comparative model statistics shown for each STP scenario (Table 1-3) describe the model's sensitivity. Pathway 1 was most influenced by changes in STP. High sloping areas experienced the greatest visual change between the low, average, and high STP model outputs. Using low STP values dropped the Pathway 1 risk score from the average STP score of 0.18 to 0.12, or by 33% on average. High STP values raised the Pathway 1 risk score from 0.18 to 0.23, or by 28% on average. Pathway 2 also experienced some slight effects from modifying STP inputs. Using low STP concentrations decreased the score from 0.75 to 0.67 or by 11% on average. High STP concentrations increased the score from 0.75 to 0.85 or by about 13% on average. These Pathway 2 changes go almost unnoticed without the aide of Table 1-3. Pathway 3 does not have a STP input so it is unaffected by changes in soil P. Low STP scores dropped the overall P Index score by only 0.12 from the average STP score. This decrease is only about a 5% decrease. The high STP overall P Index score increased on average by 0.16 from the average STP score, or a 6% increase. In general, STP modifications did not make the model less effective when compared with the field-site MN P Risk scores. This is consistent with the findings of Ketterings et al (2007). The Wallsburg watershed is not extremely susceptible to Pathway 1 P loss. In watersheds like Wallsburg, high volume soil sampling is likely not necessary to adequately apply this GIS P Index. Visually, the high slopes of the watershed were most influenced by STP modification. Watersheds with high erosion potential through rainfall runoff could experience more variable risk and more soil samples may be required to adequately apply this GIS tool.

Modified Animal Unit Densities

A potentially highly variable source of P comes from grazing livestock waste (Sharpley and Withers, 1994). Stocking densities often change from winter to summer in many mountain watersheds. Simple input changes to the GIS model were implemented to simulate low and high animal unit densities and evaluate the GIS model's sensitivity to changes. Because this test was simple in nature and was based off arbitrarily assigned values, no model comparison statistics were appropriate. The comparisons are simply visually assessed (Figure 1–22). Low AU's resulted in virtually no P risk for all of Pathway 2. Pathway 3 did display some high risk than Pathway 2, but the risk was still much less than the best estimate model. The overall P risk score was relatively low in the agricultural lowlands of the watershed and any risk came from Pathway 1, a pathway not concerned with AUs. High AUs on the other hand increase P risk in virtually every field assigned in both pathways 2 and 3. The overall P risk output was very high in much of the agricultural lowlands. The results from these tests show the sensitivity of the GIS model in predicting P risk under different AU scenarios. With accurate data, the GIS model can present highly variable P risk data. Healthy and productive grazing is achievable and depends on management strategies with take into account AUs (Bilotta et al., 2007). This tool could help determine an appropriate AU for each field to promote healthy water quality.

CONCLUSIONS

In summary, the field-based version of the MN P Index was evaluated at 58 watershed locations. This MN P Index was adapted for use in the mixed-use Wallsburg watershed in the Rocky Mountains. The GIS-based P Index was developed and applied to the watershed as well and validated against the field-based results. A sensitivity analysis was performed using the GIS P Index on different parameters, namely, STP and livestock density.

The application of the MN P index through GIS is a novel endeavor. This paper highlights that a GIS tool based on the MN P Index serves as a useful method for predicting P risk over watershed scale areas. The results of this this study suggest that snowmelt in lower elevations of the watershed is an important pathway for P transport. Agricultural fields with high surface levels of organic P or fertilizer P created some of the highest risk scores. Managing livestock density is a best management practice in the area has great potential to improve water quality.

The GIS P Index described in this paper provides a type of scaffolding to be tested in other areas, improved upon, and scrutinized to provide more accurate NPS P risk estimates. There are obviously some shortcomings of the model and potentially more work is necessary. More source and transport pathways could be built into the model to account for P loss through sub-surface flow, streambank erosion, and irrigation related runoff. More field-sites in some of the high elevation slopes of the watershed, areas described as high risk in Pathway 1 could also be useful to further test this GIS model's capabilities in mixed-use mountain watersheds. As it stands, this model is generally successful in predicting P risk with minimal field acquired data, relying instead on easy to acquire publicly available data. With cooperation form landowners and managers, this tool could use accurate data and save time and money by quickly narrowing down potential critical source areas.

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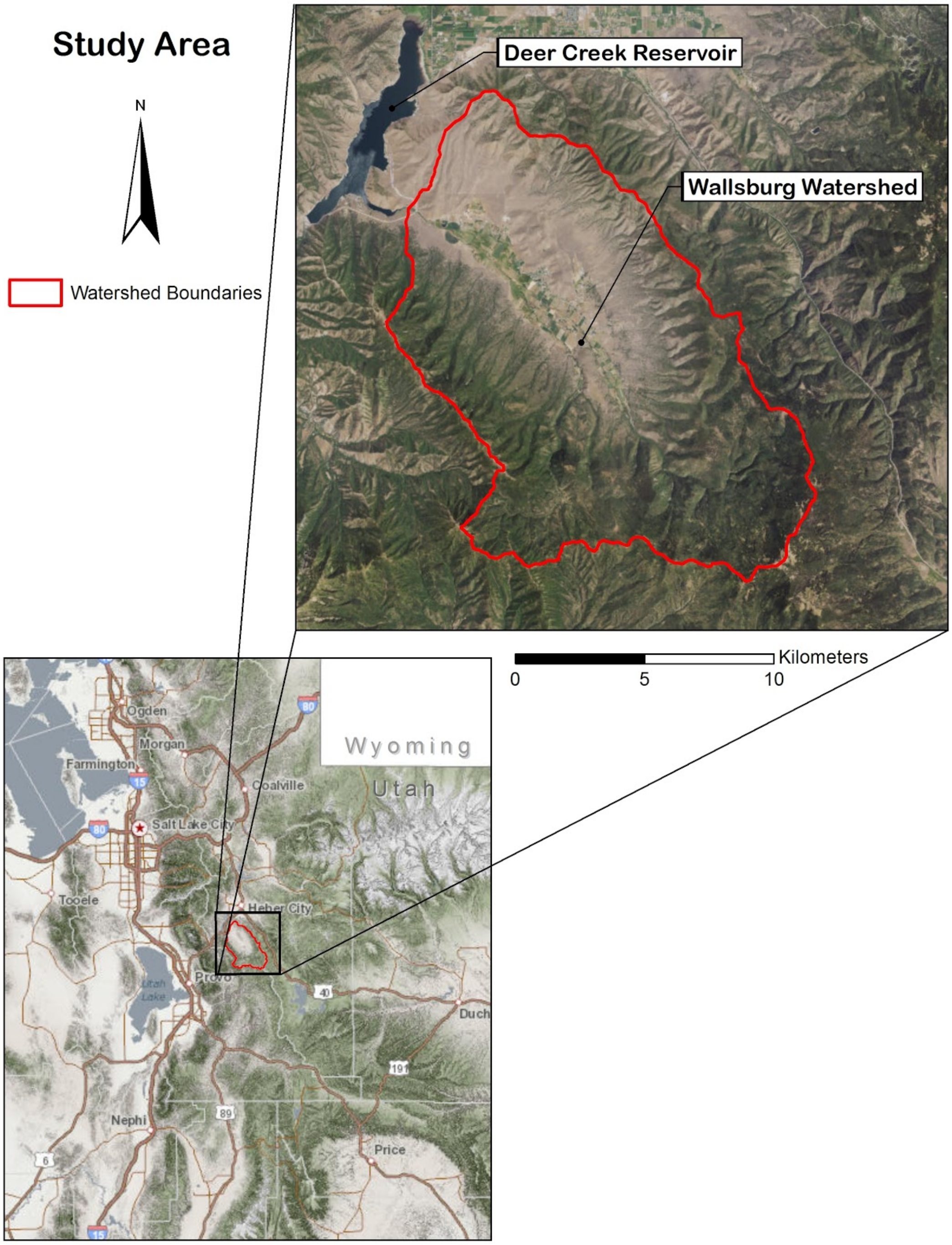

Figure 1–1. Study Area. The study was conducted in the Wallsburg watershed, a subwatershed of the Provo River Basin, located within the Wasatch Mountains of north central Utah, USA The watershed is outlined in red, encompasses 184 km^2, and drains into Deer Creek Reservoir.

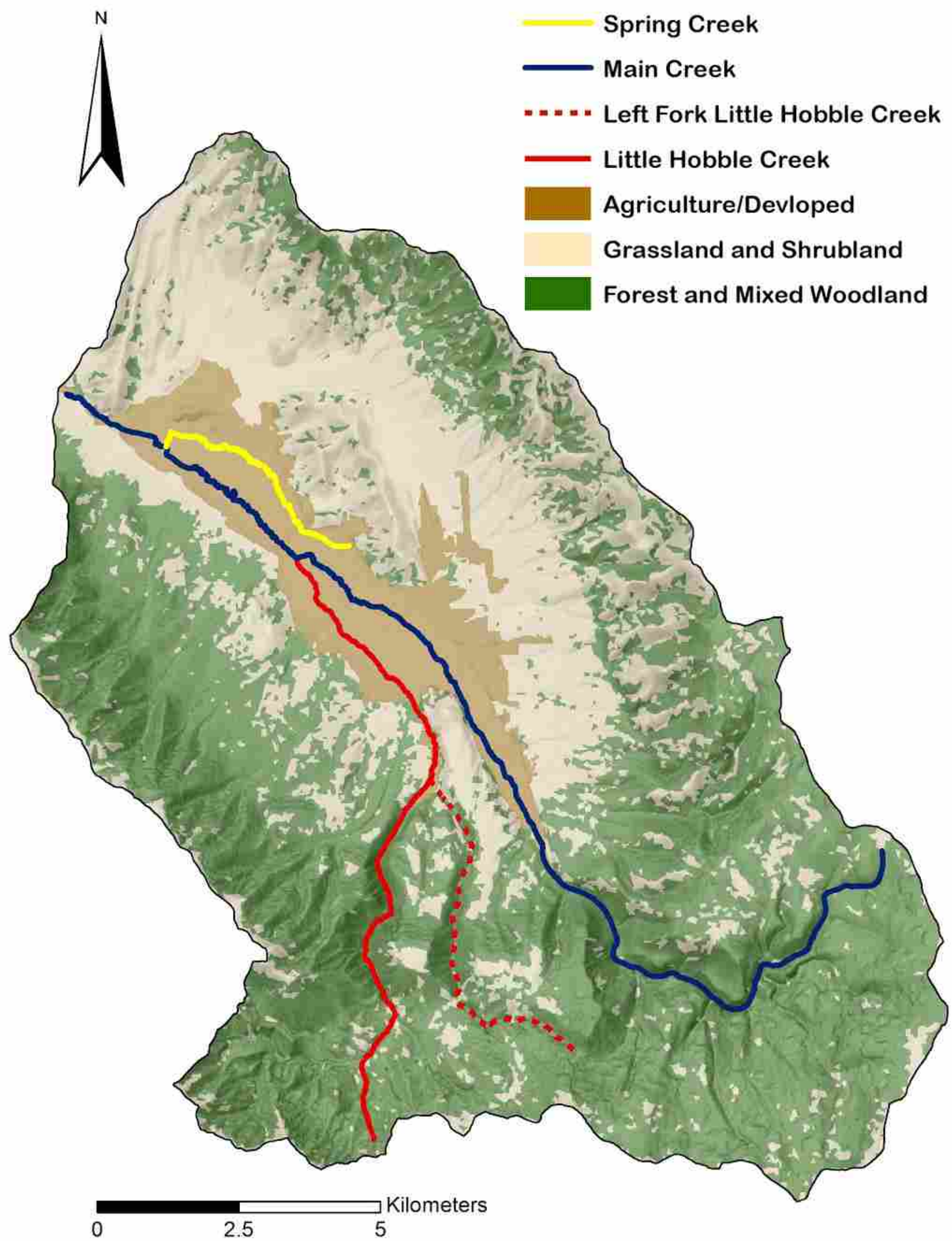

Figure 1–2. Land Use Classification and Perennial Streams in the Wallsburg Watershed. The watershed has three perennial streams, Little Hobble Creek (solid red and dashed red), Spring Creek (yellow), and Main Creek (blue). Land use in the area is classified as agriculture/developed lands (7.6%), grasslands and shrublands (30.8%), and forests and mixed woodland areas (61.6%).

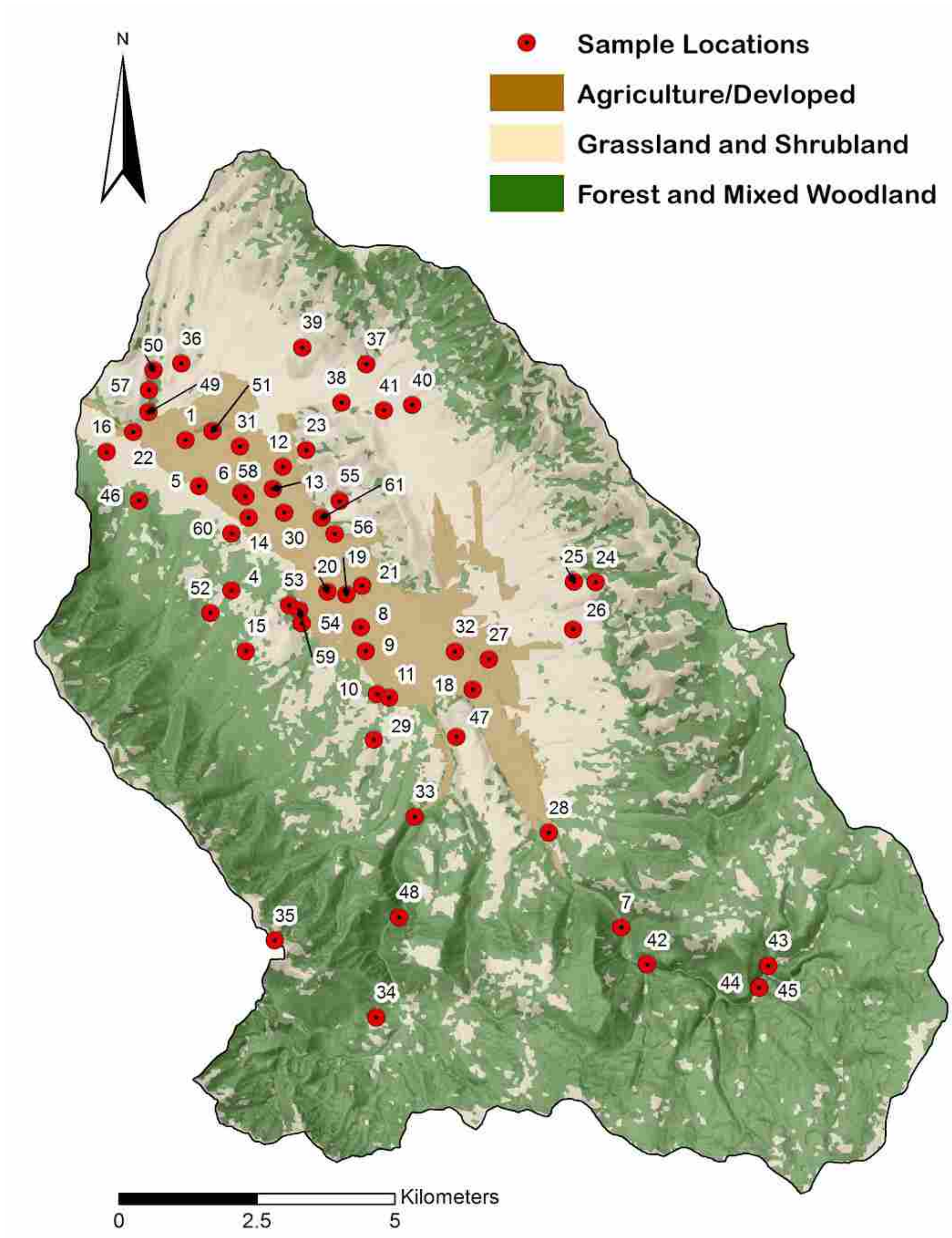

Figure 1–3. Sample Locations. Location of 58 field data collection sites within the Wallsburg watershed overlaid on a map of land use classification. A stratified sampling approach was used to identify sampling locations, but selection was constrained by site accessibility.

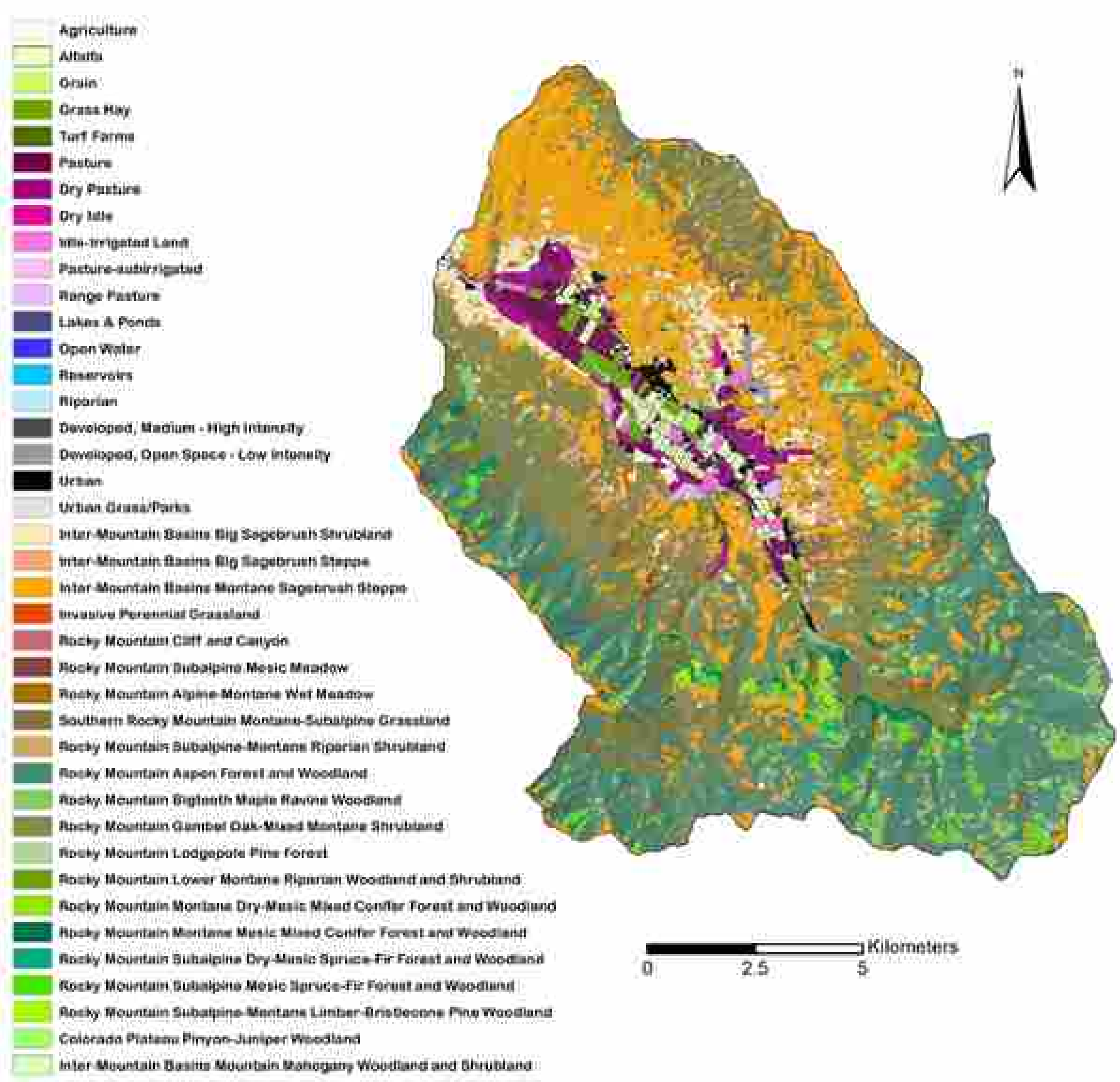

Figure 1–4. P Land Cover Map. Index inputs and output values are assigned to individual polygons shown in this map. The map was created by merging Water Related Land Use and Land Cover data layers obtained from the Utah AGRC and prepared by the Utah Department of Natural Resources and the U.S. Geological Survey National Gap Analysis Program. Green colors in the lower elevation/agricultural areas (the center of the watershed) are agricultural lands with different crops. Pinks and purples represent different types of dedicated pasture and idle lands. Blues represent water and riparian features. Blacks and greys describe different developed and urban areas. Oranges, browns, and yellows represent grasslands and shrublands. Greens located at the higher elevations (the outside edges of the watershed) represent woodlands and forests.

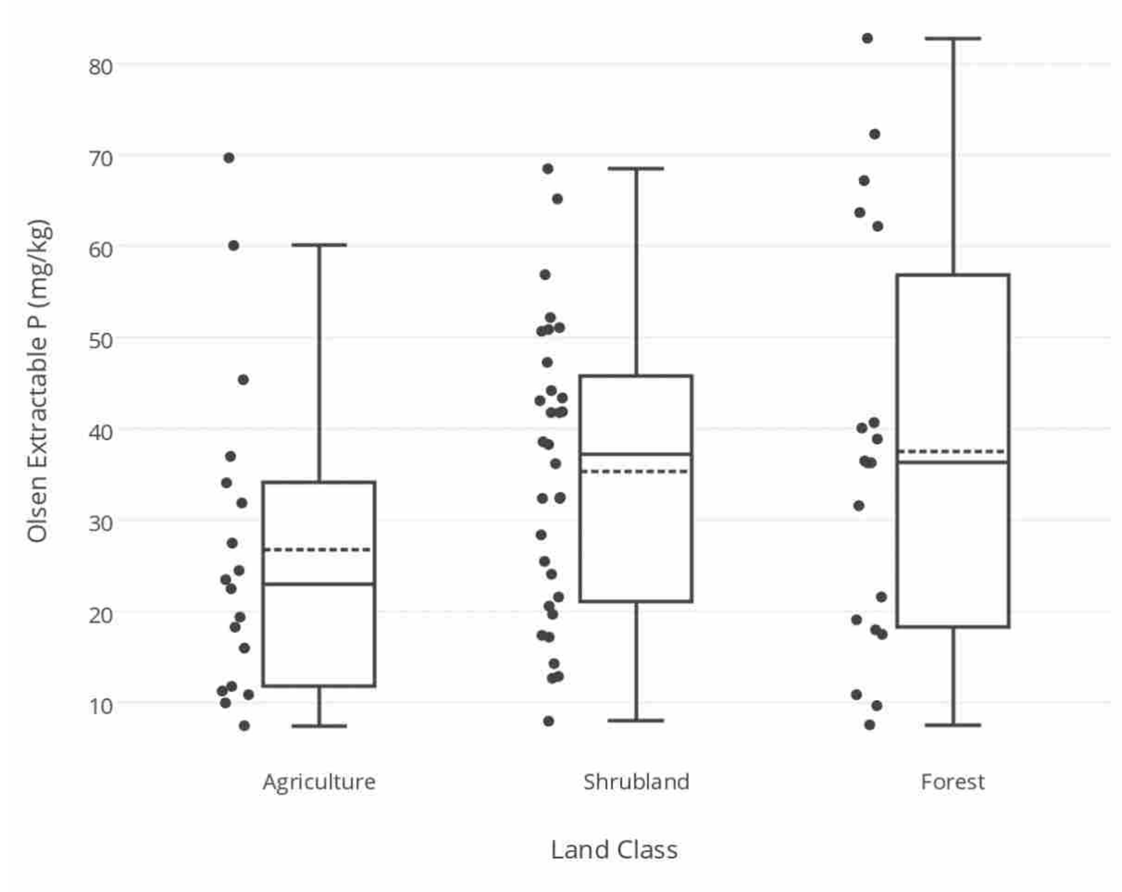

Figure 1–5. Concentrations of Sodium Bicarbonate Extractable Soil Phosphorus in the Upper 5 cm by Land Class. The box and whisker plots show how the data are distributed in quantiles, with each section containing 25% of the data. The solid centerline represents the median and the dotted line represents the mean. The points show the extractable soil phosphorus concentrations for each individual field-site by land class.

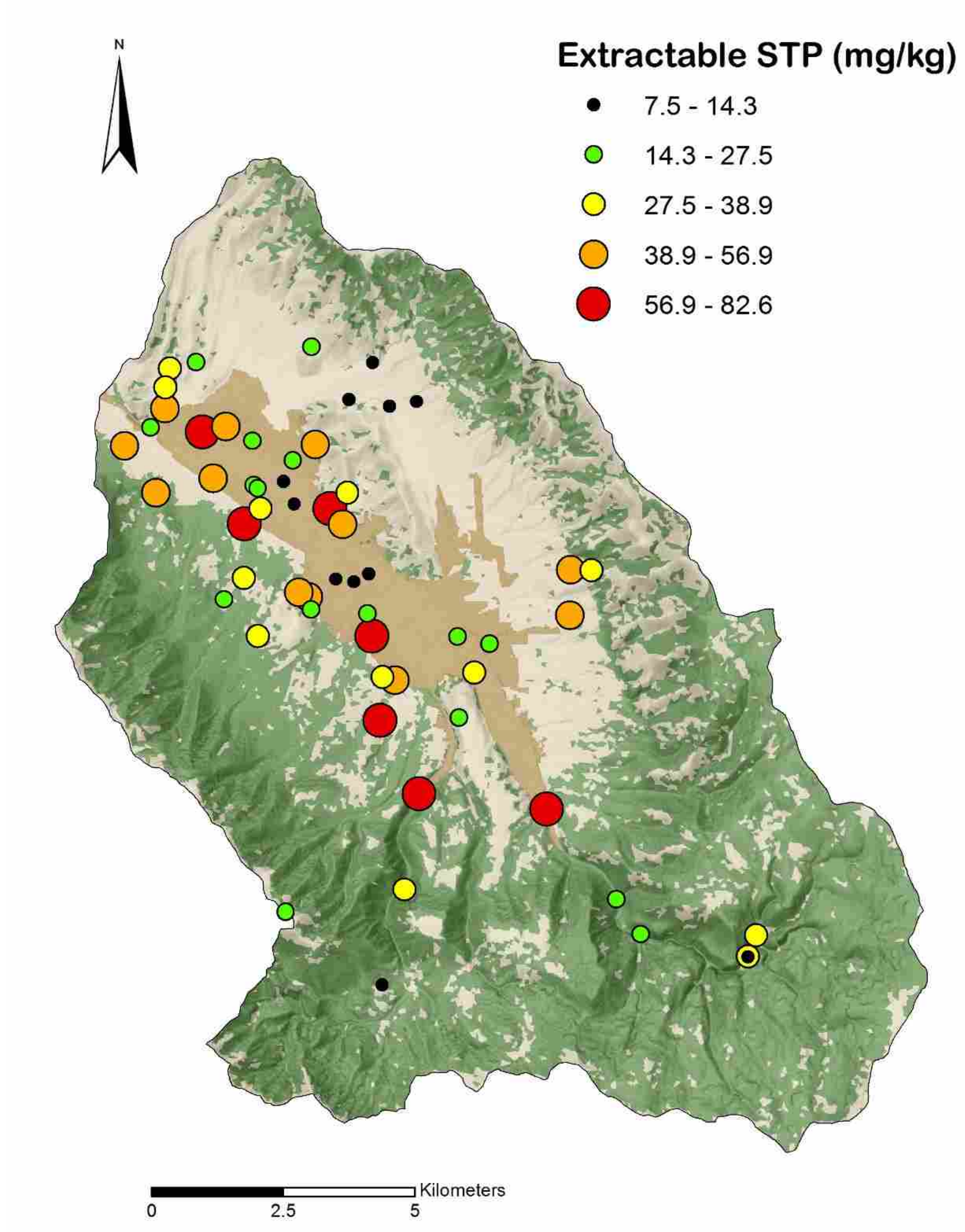

Figure 1–6. Extractable Soil P Observed at Each Field Site Location. Values range from as low as 8 mg kg^{-1} to as high as 83 mg kg^{-1}. The dot size distribution is classified into five categories by natural jenks. Soil P is highly variable, regardless of land class.

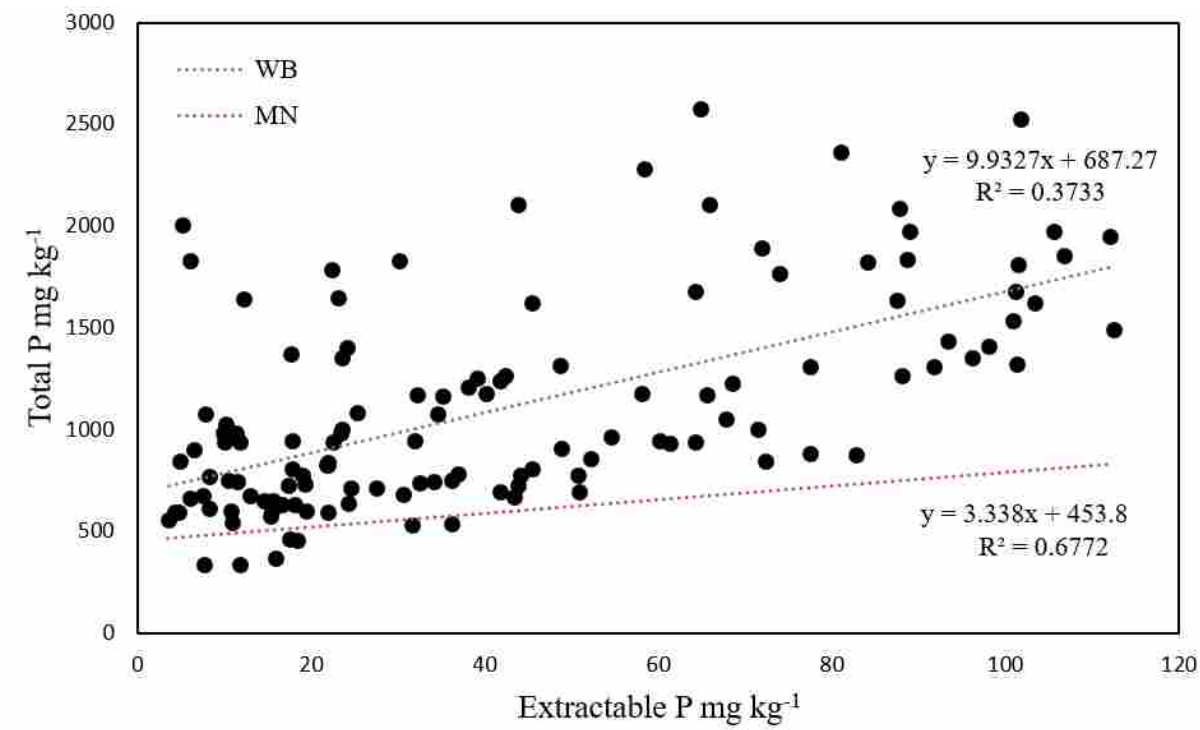

Figure 1–7. Observed TP vs. Observed Olsen Extractable P. Observed TP and Olsen STP were plotted against each other to acquire a linear equation that relates the two methods. The equation is: y = 9.9327x + 687.27. The MN P Index requires both TP STP and Olsen STP throughout its calculations. The blue line represents the correlation for the Wallsburg relationship and the red line represents the original MN relationship.

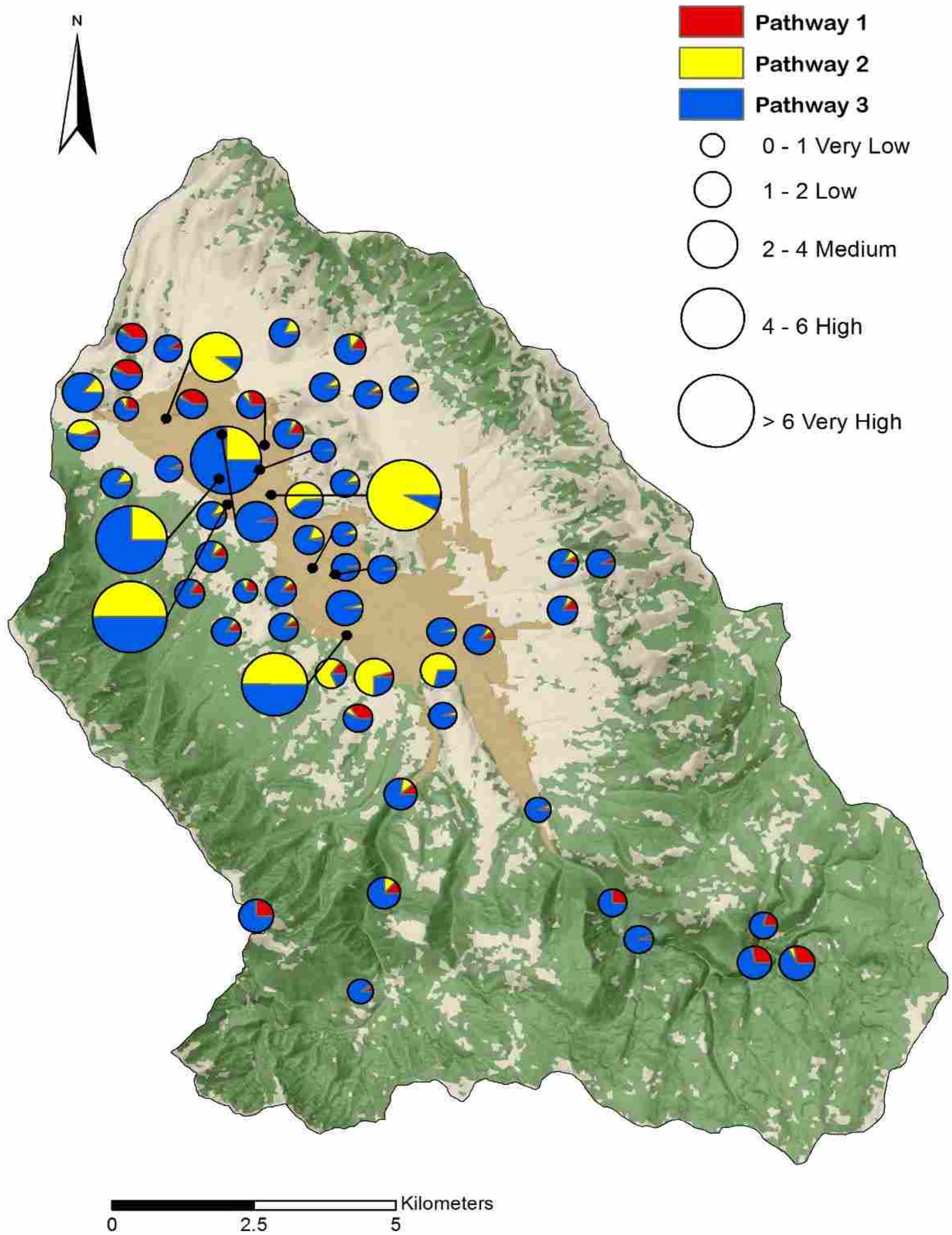

Figure 1–8. MN P Index 58 Field Site Results. The overall size of the circle corresponds with the overall P risk score; a larger circle represents a larger P loss risk. The colors define the relative proportion of each pathway's risk. Red is sediment-bound P loss through rainfall runoff, yellow is soluble P loss risk through rainfall runoff, and blue is soluble P loss risk through snowmelt. The largest risk areas are scattered throughout the agricultural lowlands of the watershed.

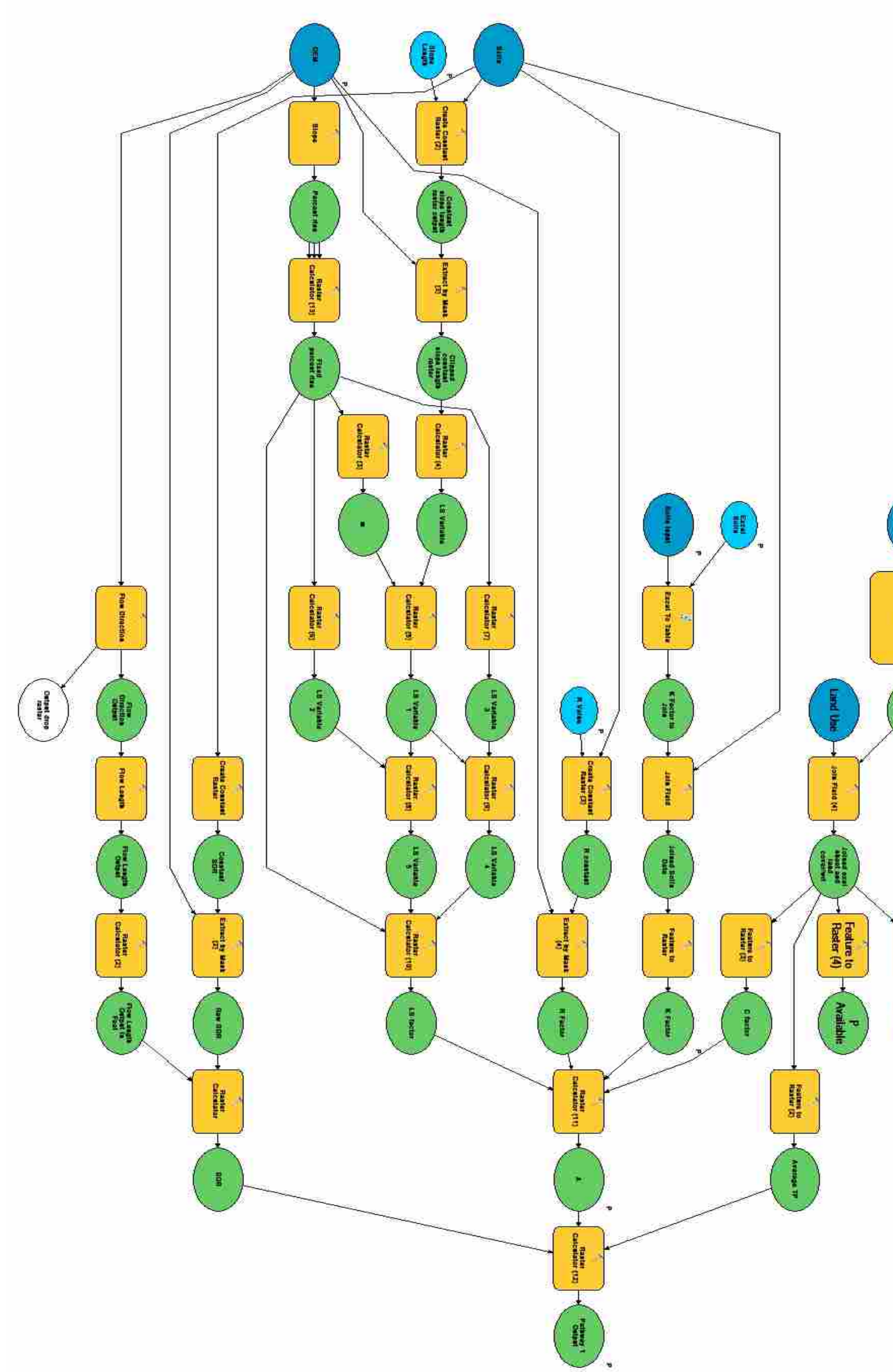

Figure 1–9. Pathway 1 Subroutine Flowchart. The GIS tool's Pathway 1 estimates the risk of particulate phosphorus transport in rainfall runoff. Blue ellipses are user defined inputs. The tools (yellow boxes) are processing commands that perform lookup and calculation commands and then generate output layers (green ellipses).

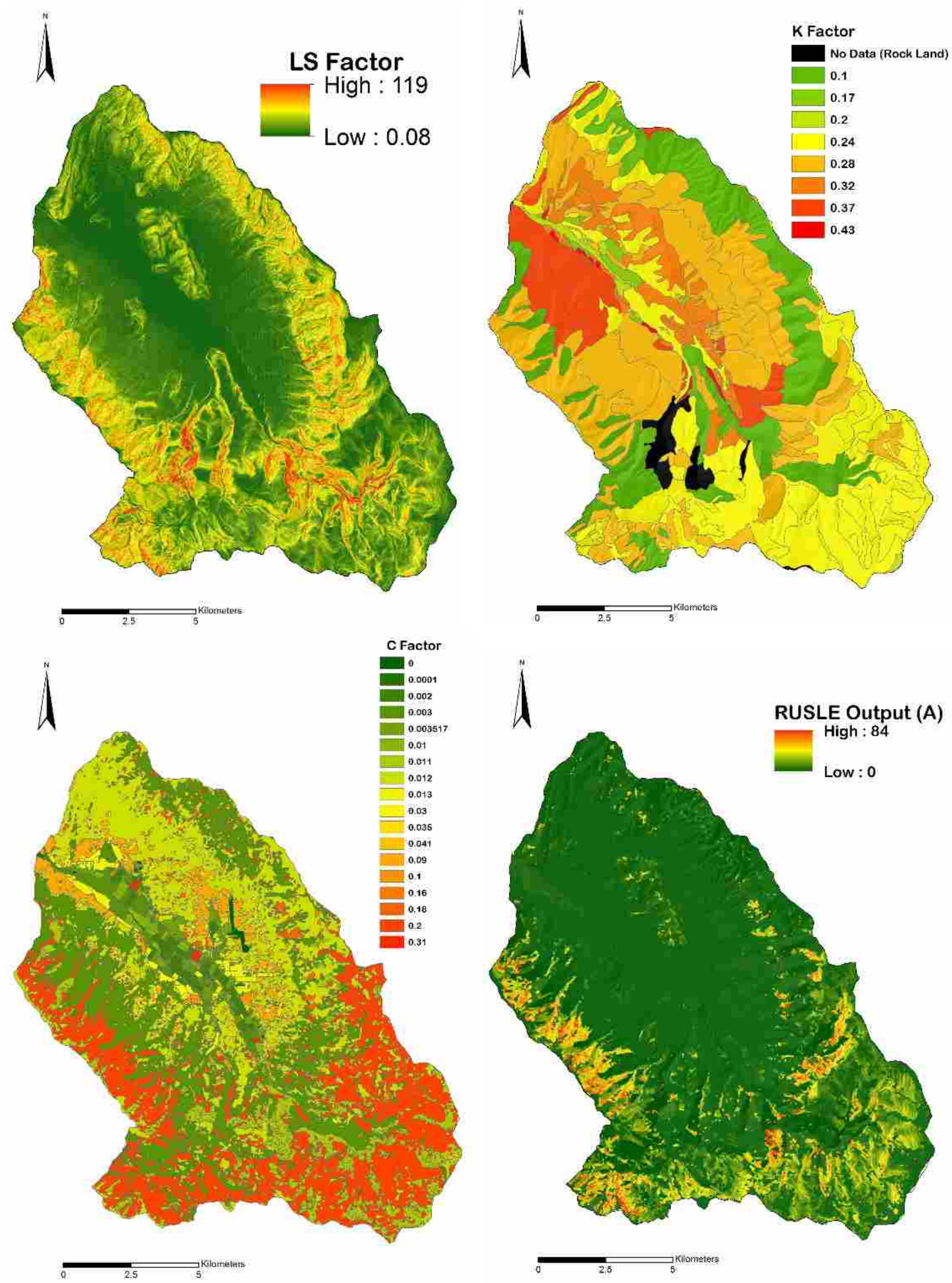

Figure 1–10. Various Pathway 1 Inputs. Spatial distribution of the length/slope factor (LS, top-left), the soil erodibility factor (k, top-right), and the cover factor (C, bottom-left), each of which are used in the Revised Universal Soil Loss Equation to calculate average annual soil loss (A, bottom-right).

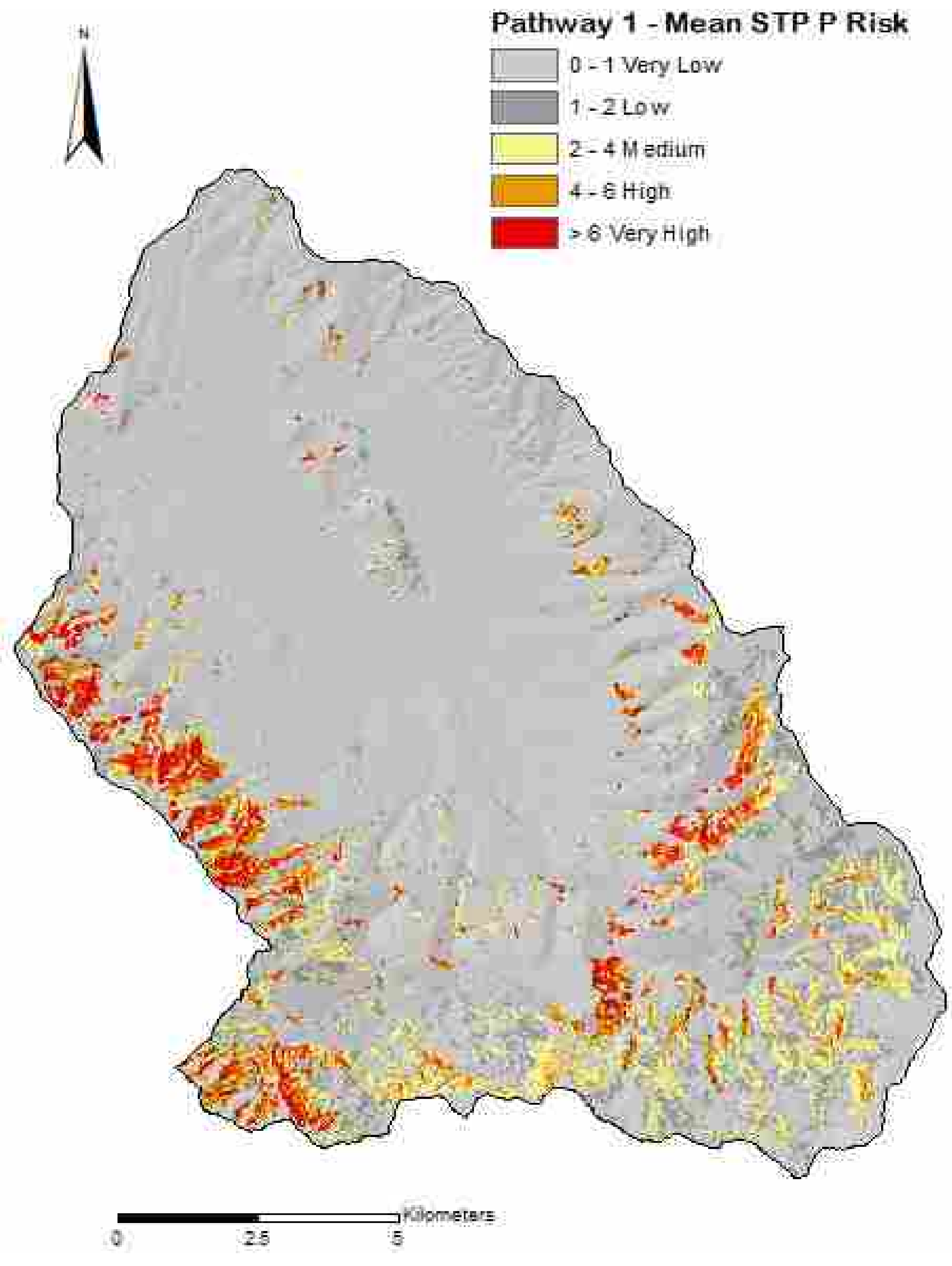

Figure 1–11. GIS P Index Pathway 1 Output. The best estimate values and mean STP were used to generate this model output. Output scores are classified by the MN P Index risk score categories. Scores of 0 to 1 represent very low P risk (light grey), 1 to 2 represent low P risk (dark grey), 2 to 4 represent medium P risk (yellow), 4 to 6 represent high P risk (orange), and greater than 6 represents very high P risk (red). The GIS Tool outputs for Pathway 1 range from 0 to 19.1. High values are on high sloping areas and are likely overestimated due to the RUSLE calculation.

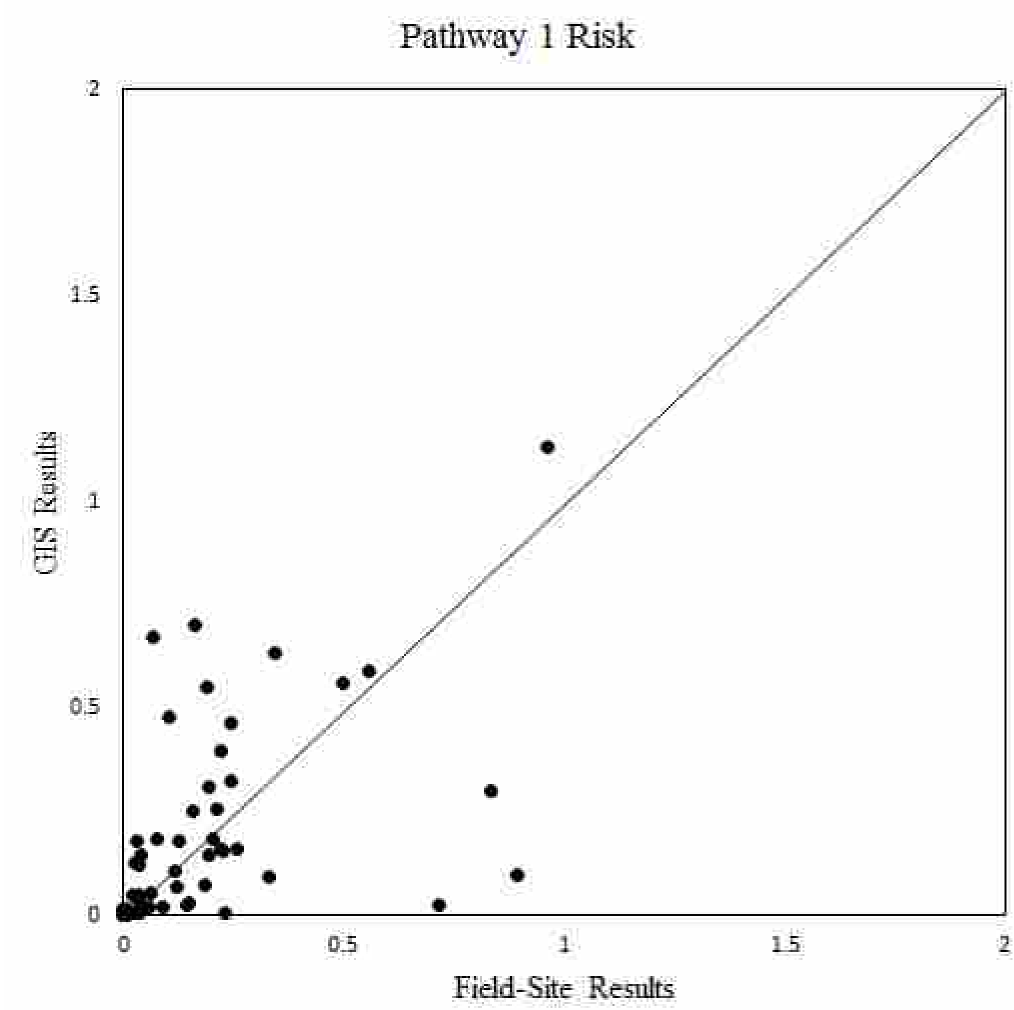

Figure 1–12. The Pathway 1 GIS Results vs. Field-Site Results. GIS output at each field-site location plotted against the respective Pathway 1 field-site values show that both the GIS Tool outputs and field-site scores are low (less than 1.5). There is great variability between the GIS Tool output and field-site observations. This chart represents a perfect one-to-one relationship (dotted blue line) but the values are scattered. The fact that the values are all so low means the lack of fit is not detrimental. All of the values are still within the very low and low risk categories defined by the MN P Index.

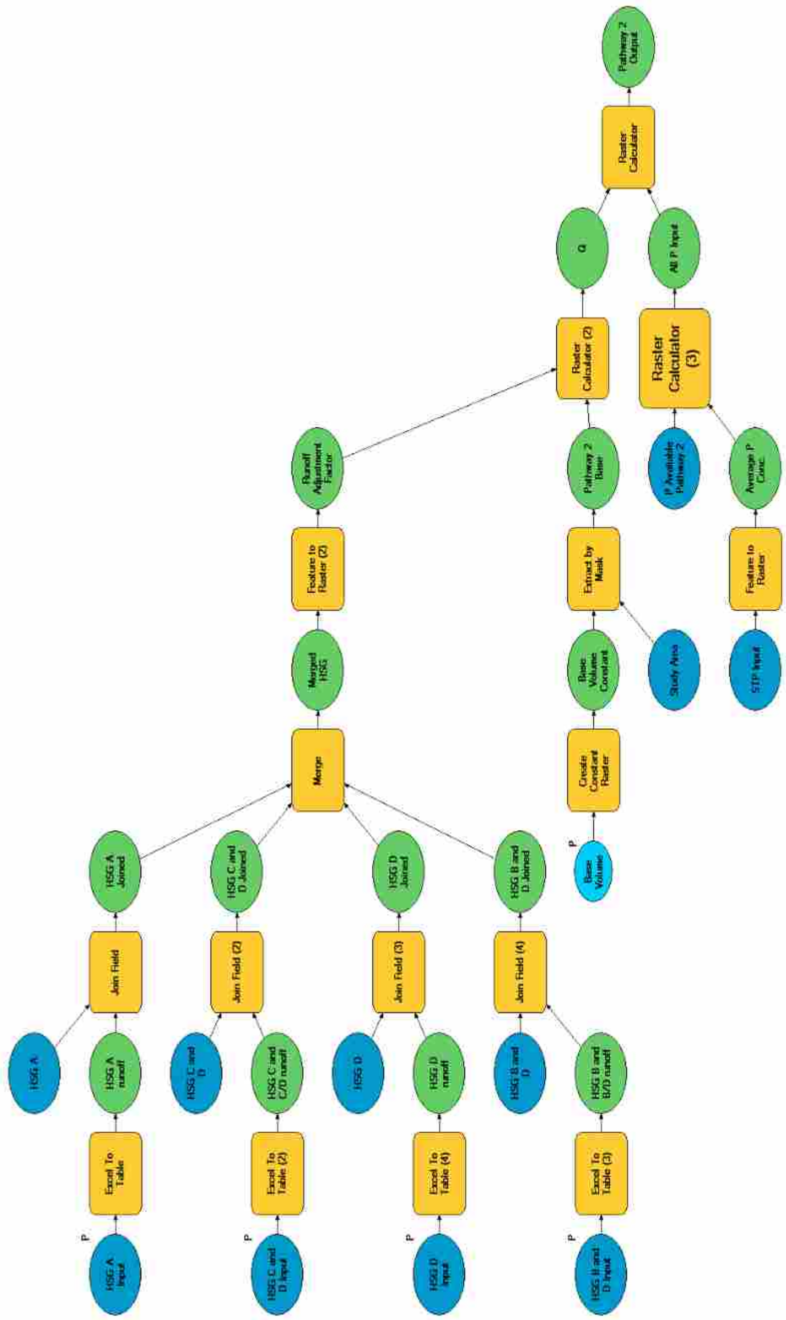

Figure 1-13. Pathway 2 Subroutine Flowchart. Blue ellipses are user defined inputs. The tools (yellow boxes) are processing commands that perform lookup and calculation commands and then generate output layers (green ellipses).

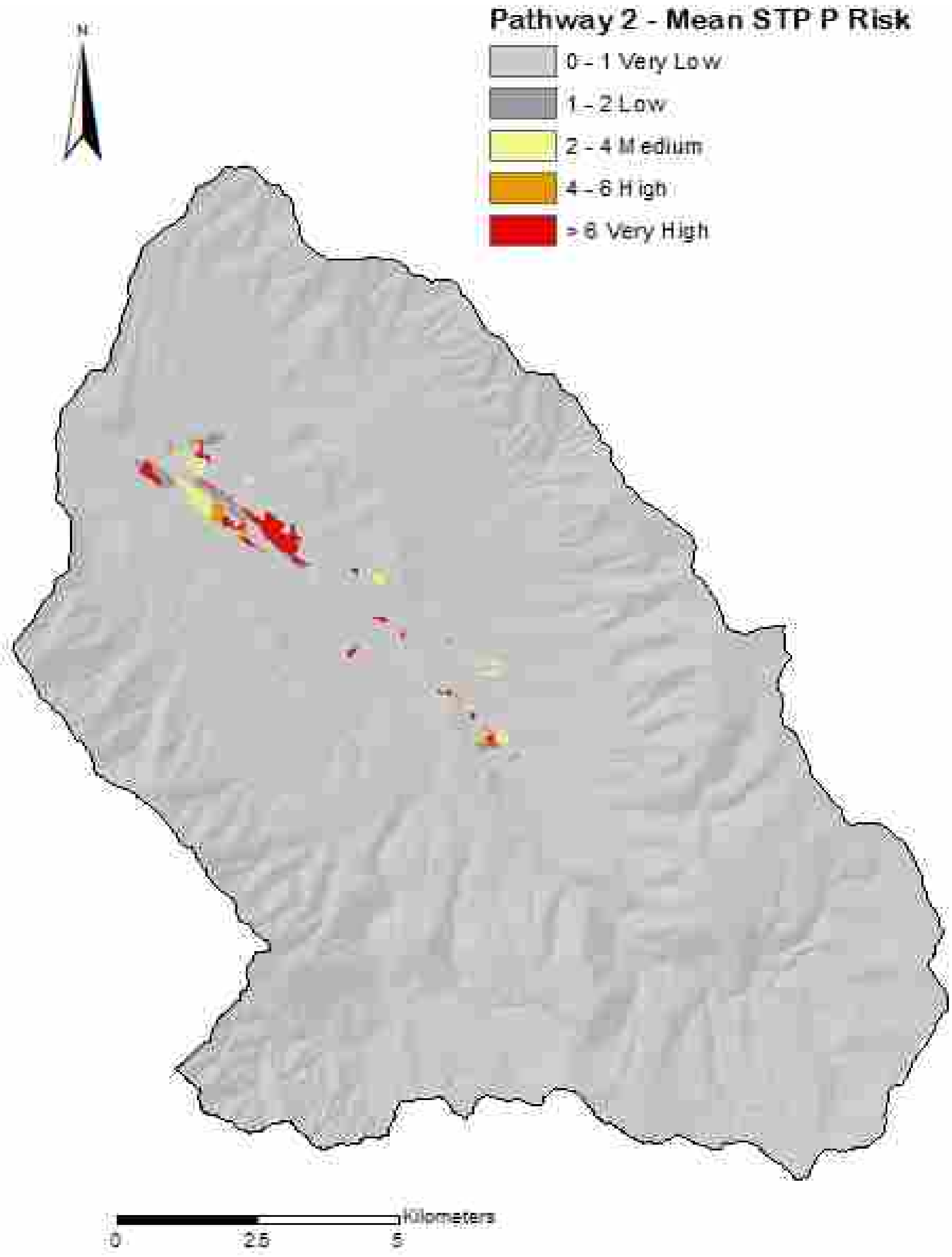

Figure 1–14. GIS P Index Model Pathway 2 Output. The best estimate values and mean STP were used to generate this model output. Artificial P application primarily in the form of grazing livestock waste had the largest impact in increasing Pathway 2 risk.

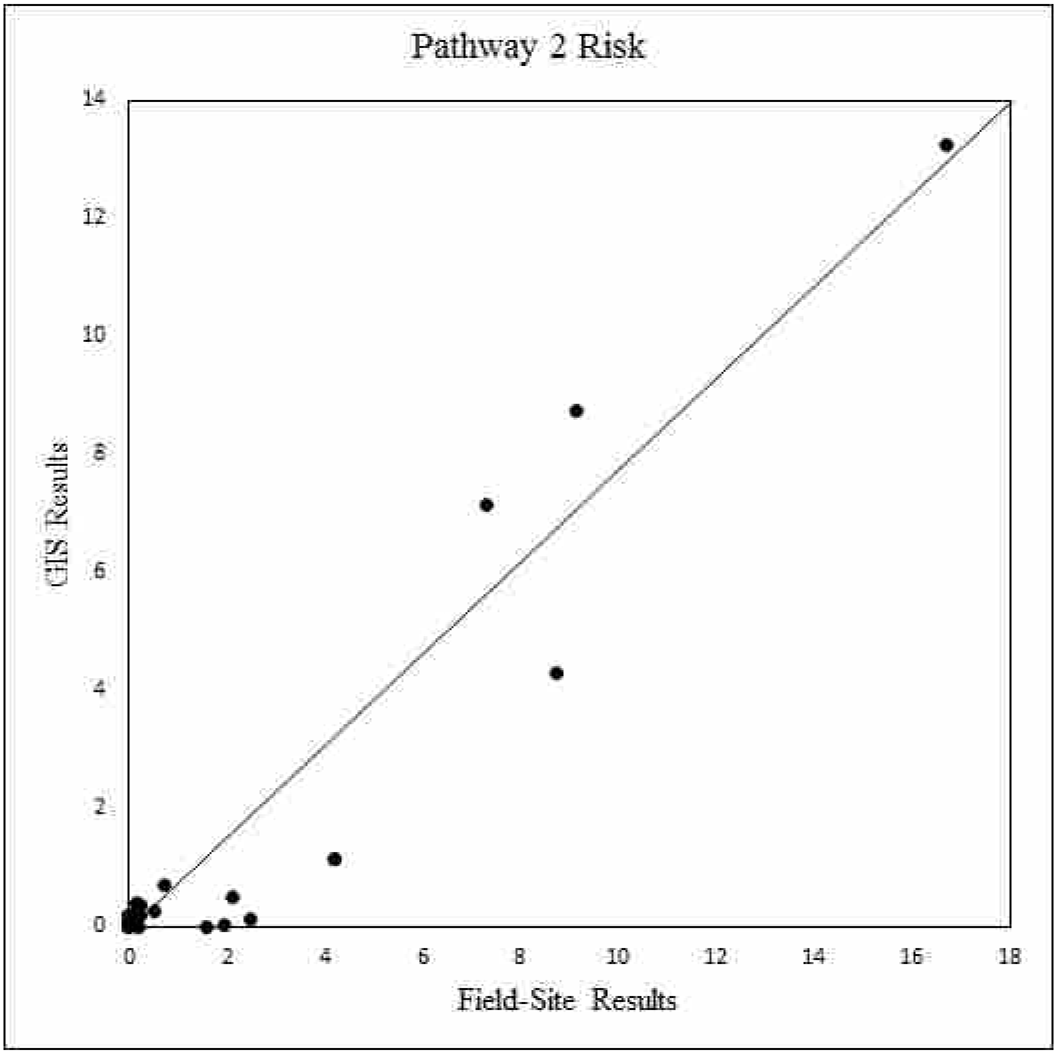

Figure 1–15. The Pathway 2 GIS Results vs. Field-Site Results. The Pathway 2 GIS Tool output at each field-site location plotted against the respective Pathway 2 field-site values. Both values seem to increase at similar rates. The GIS model appears to under predict slightly when compared with the field-site P Index.

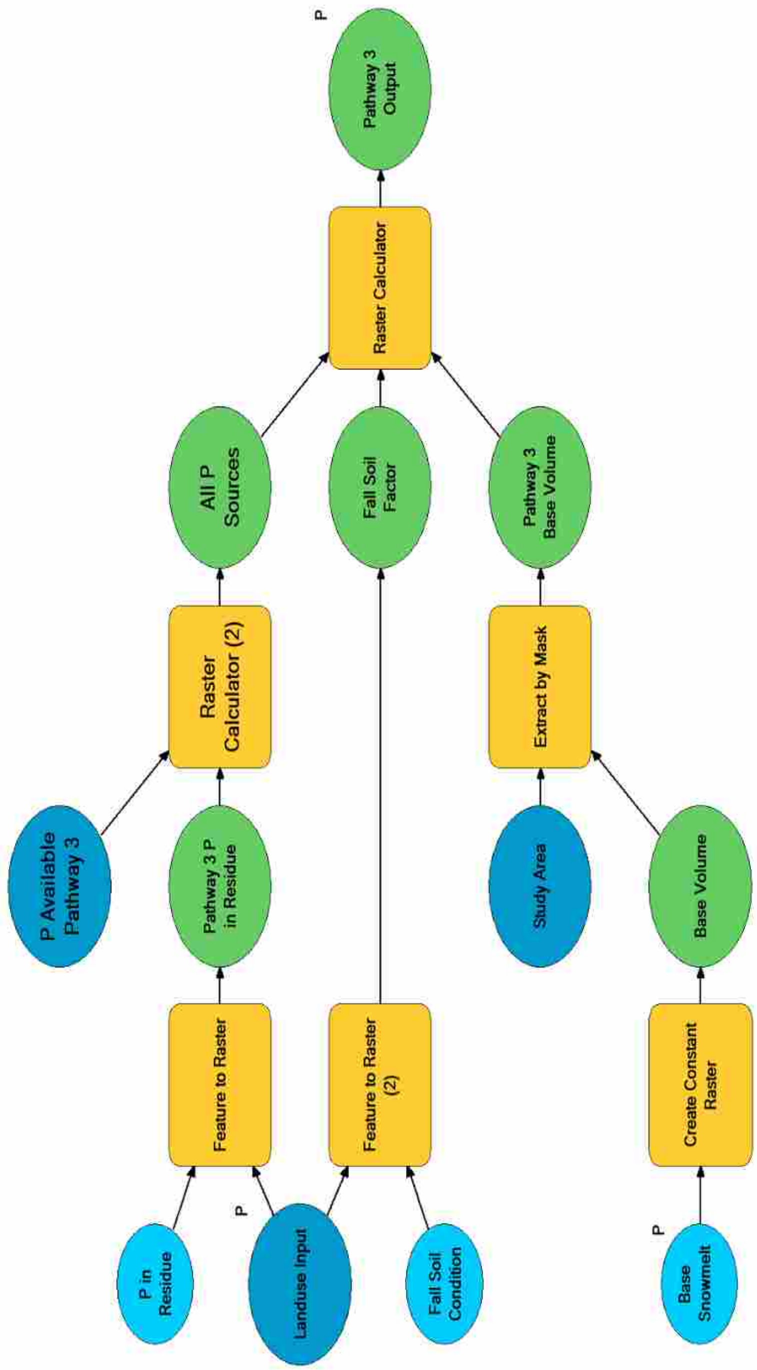

Figure 1-16. Pathway 3 Subroutine Flowchart. Blue ellipses are user defined inputs. The tools (yellow boxes) are processing commands that perform lookup and calculation commands and then generate output layers (green ellipses).

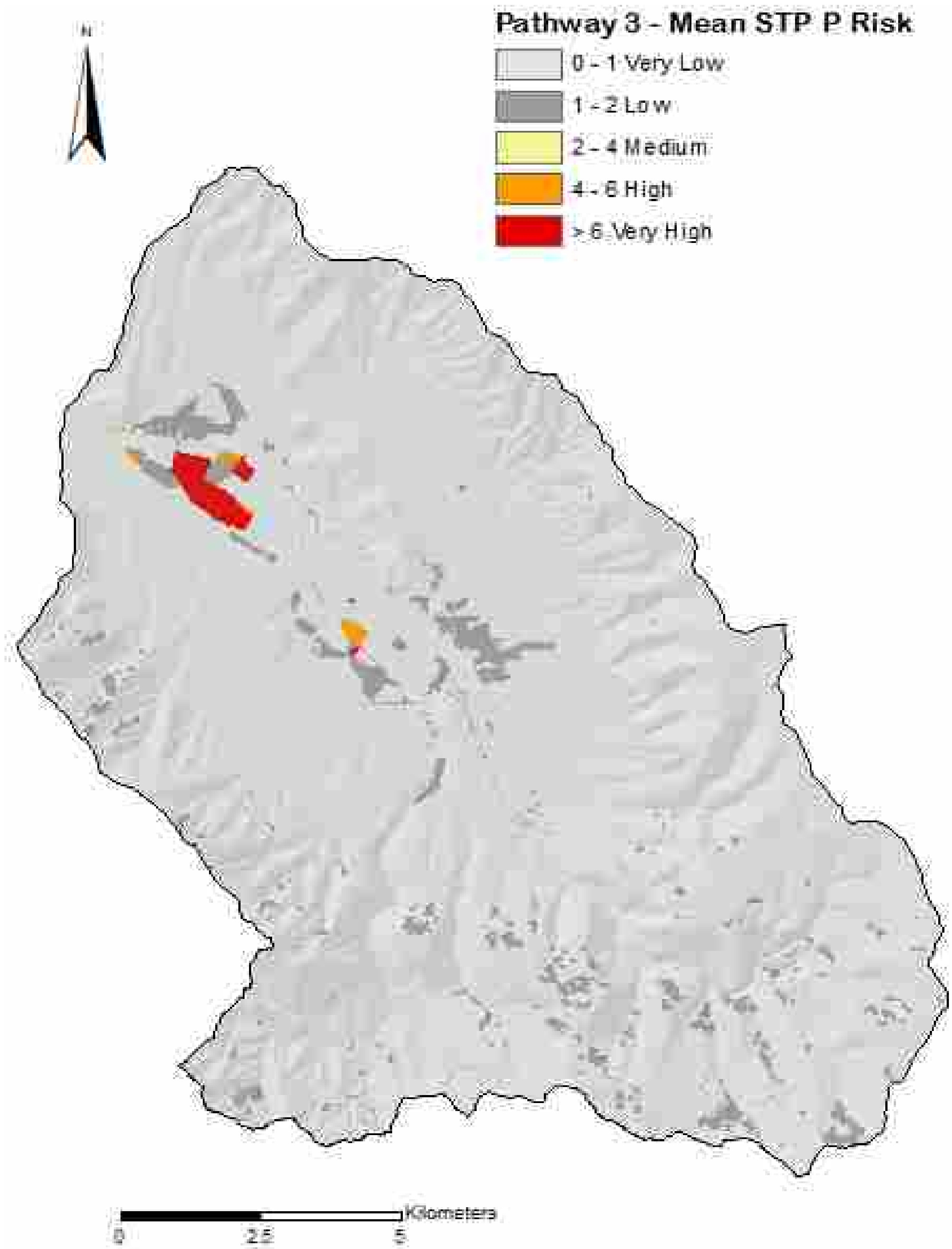

Figure 1–17. GIS P Index Model Pathway 3 Output. Results show hotspots in agricultural areas. These high risk areas predicted by the model follow similar spatial trends described by the in-field P Index calculations.

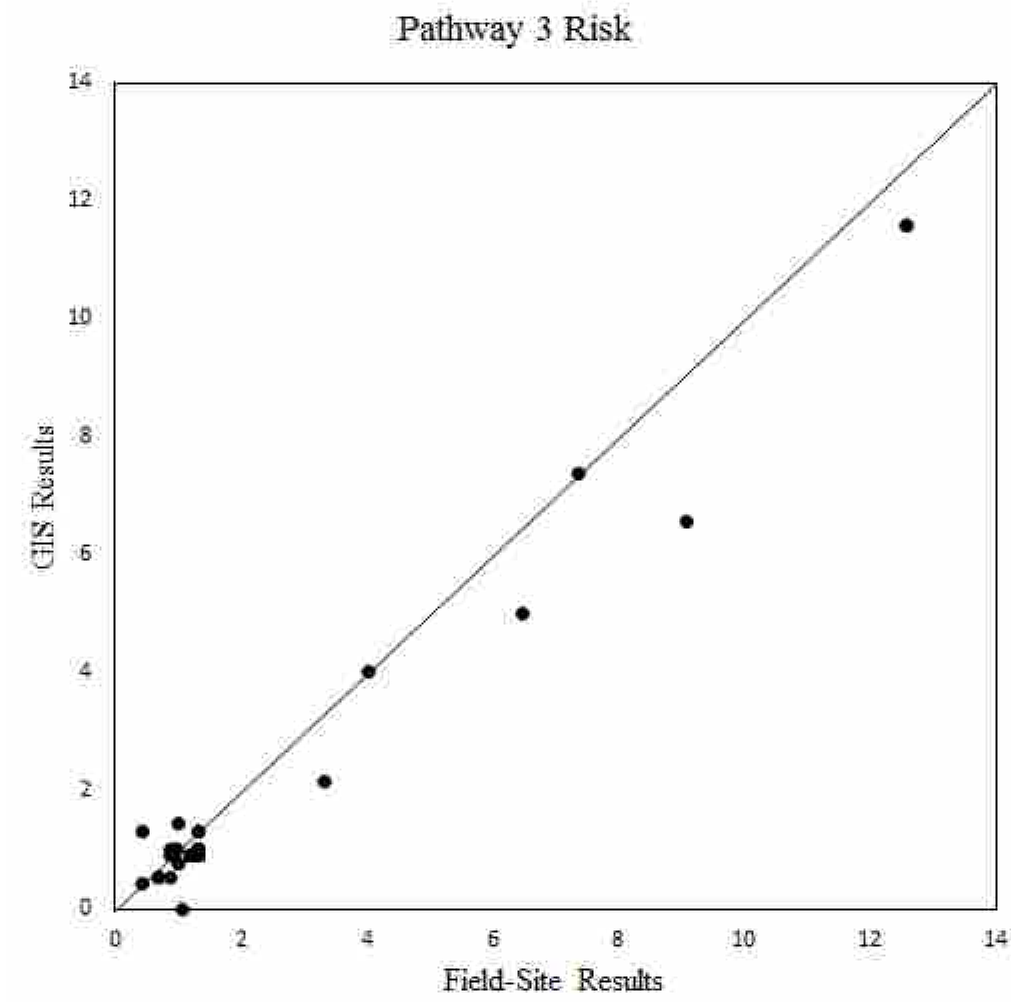

Figure 1–18. The Pathway 3 GIS Results vs. Field-Site Results. Pathway 3 comparisons between each field-site and the pixel value from the Pathway 3 GIS model output raster. Like Pathway 2, the GIS model appears to under predict when compared to a perfect one-to-one relationship. This pathway had good sample variation to test the model in low and high observed value situations.

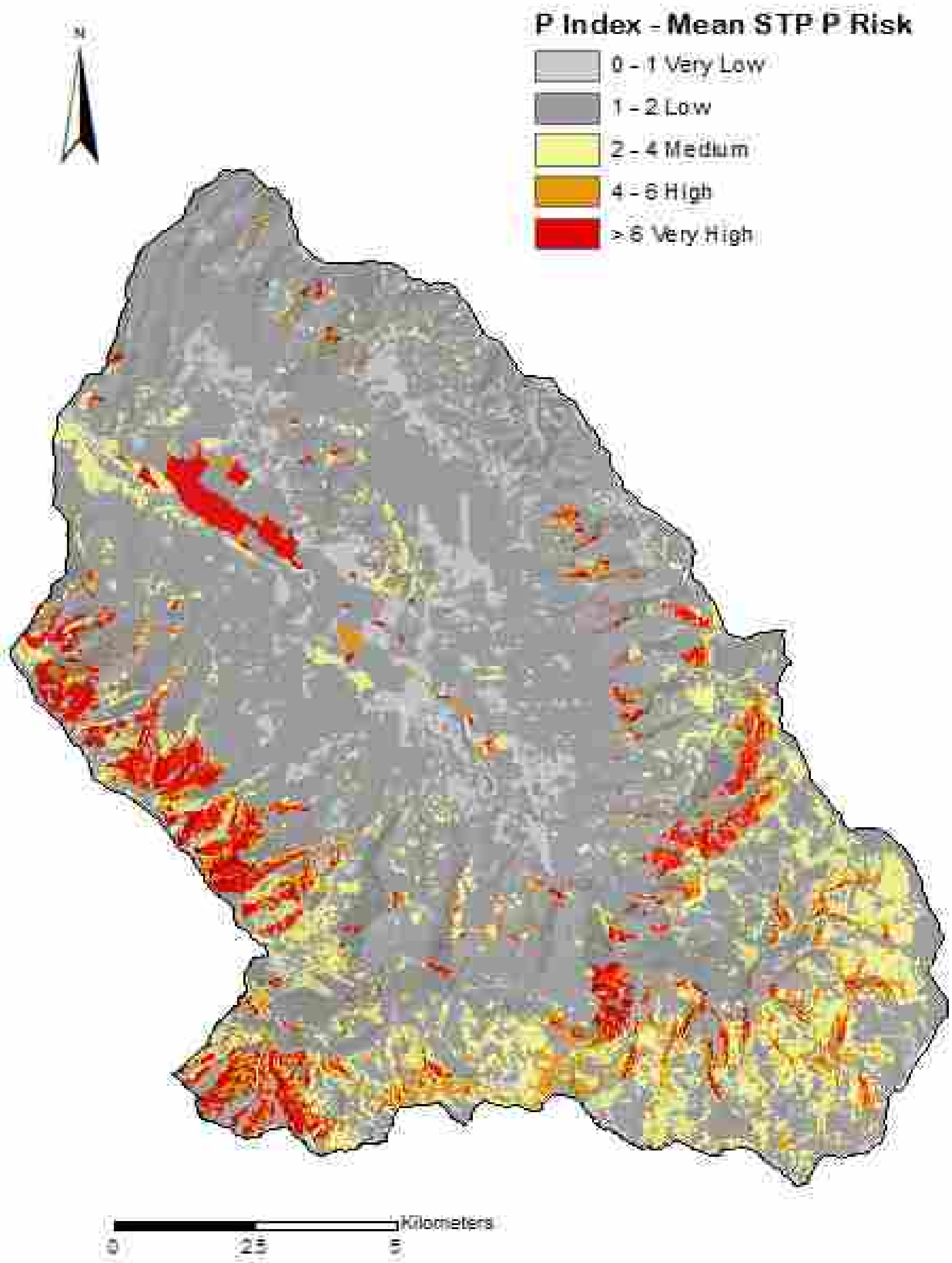

Figure 1–19. GIS P Risk Index Total Risk Output. GIS model output for the overall P Index risk scores. The map generally follows trends describe by the field-site analysis.

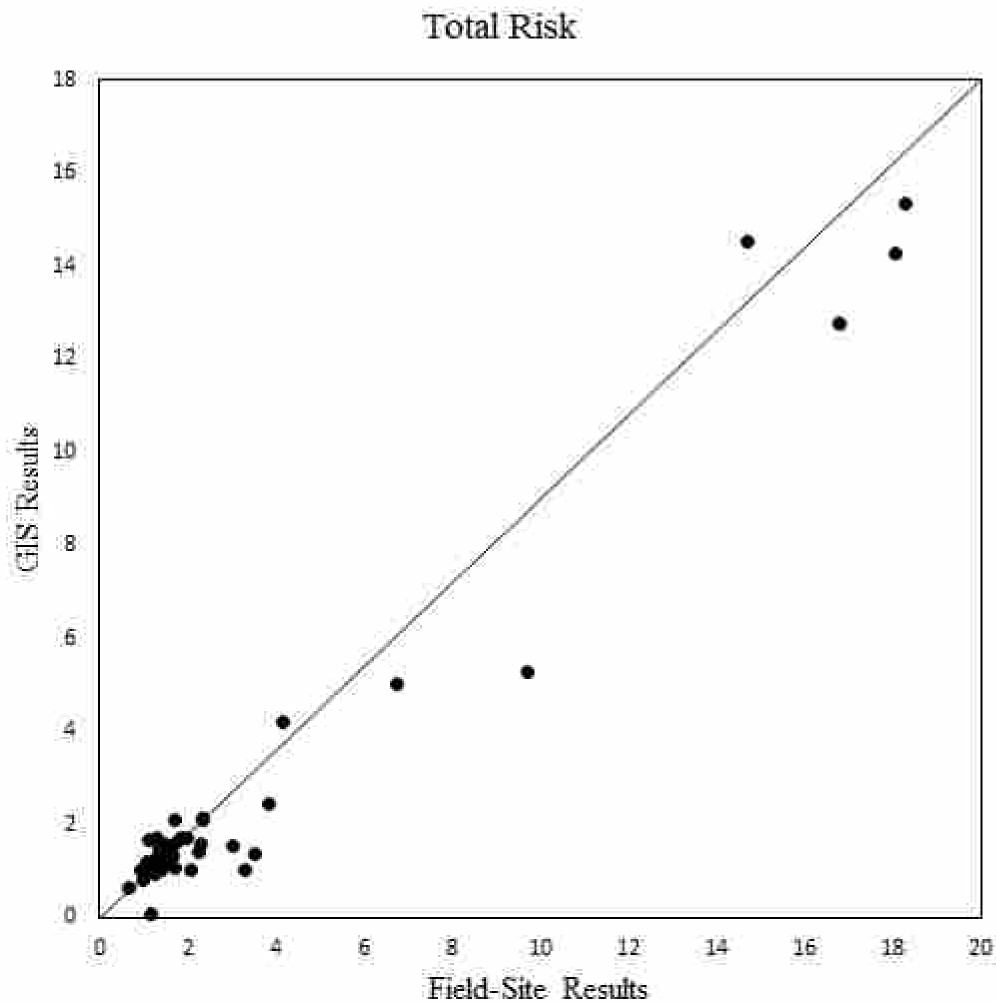

Figure 1–20. The Total P Risk GIS Results vs. Field-Site Results. Overall GIS P Index output compared to the observed field-site values. The general trend holds but the GIS sites tend to under predict.

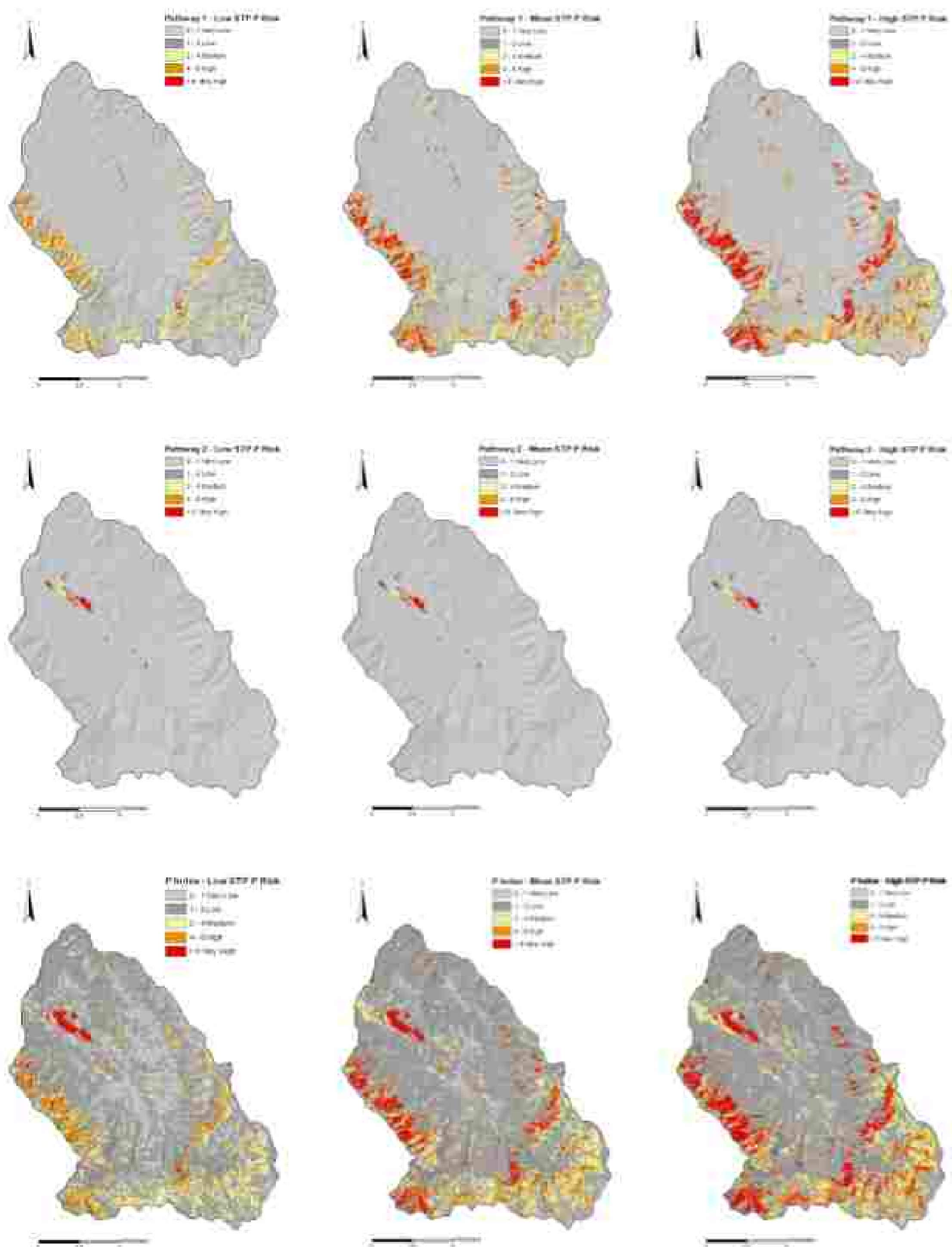

Figure 1–21. Soil Test P Tests. STP Scenarios of low, average, and high, based on observed soil test P concentrations and assigned to each land class and modeled. Pathway 1 was influenced most, especially in high sloping areas. Pathway 2 experienced very little change between scenarios. Pathway 3 has no STP input and was, therefore, unaffected and not included in this figure. The Overall P Index output shows slight increases in the lowlands and greater increases in the uplands as STP increases.

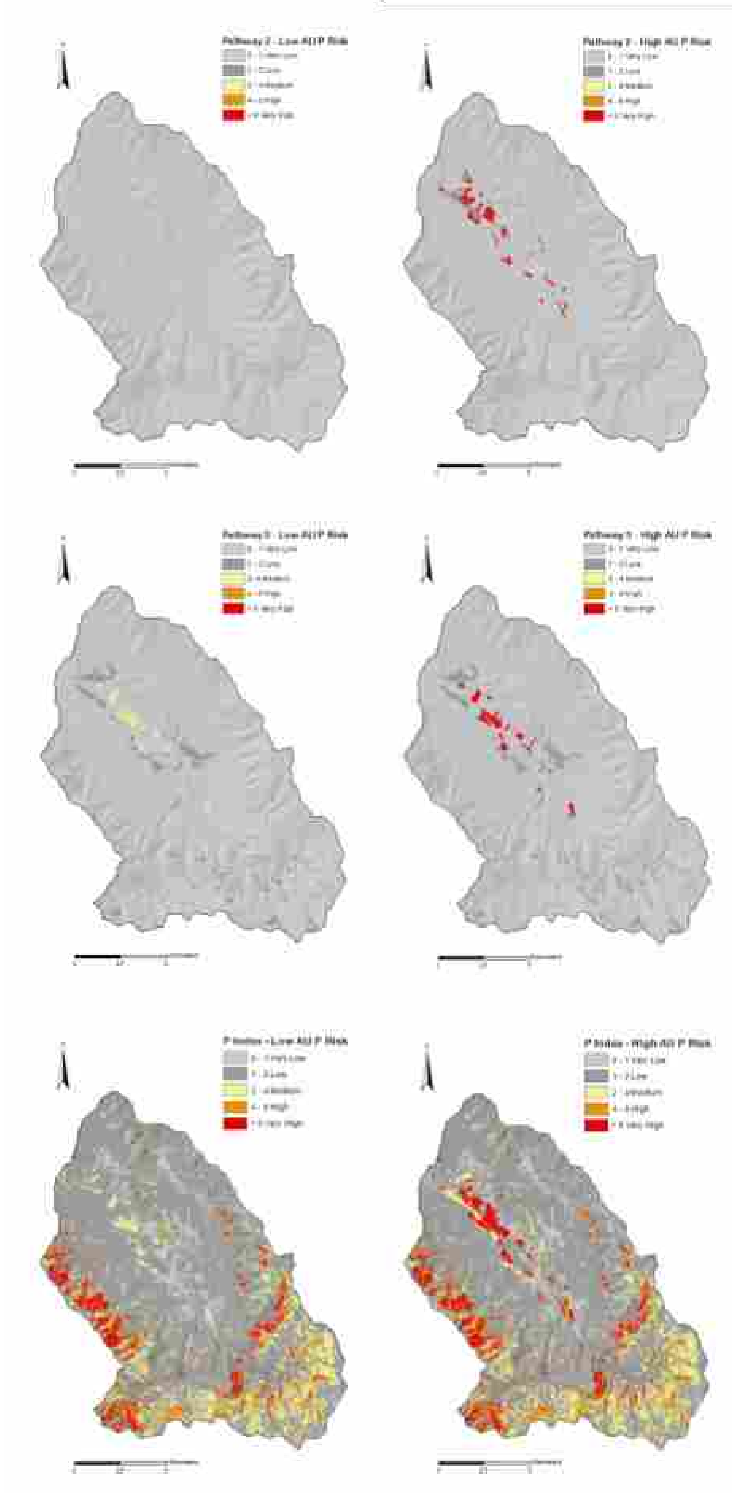

Figure 1–22. Animal Unit Density Tests. The GIS model was given low and high animal unit densities at arbitrary locations to test its sensitivity. This output shows that the model is sensitive to highly variable input data. Data inputs should be as accurate as possible to achieve the best outputs.

TABLES

Table 1–1. Inputs to the P Index models as calculated for either the field-sites approach or in the GIS based P Index model. This table highlights the differences in input sources.

Pathway	MN P Index Required Input	Sub-Input	Field-Site Data Source	GIS P Index Model Data Source
1	Sediment Delivery Rate	RUSLE C Factor	RUSLE2 Software Application-based on observed land management	RUSLE2 Software Application or C Factor Table - assigned by GIS Land Use layers
		RUSLE LS Factor (Slope Steepness)	Percent Rise measured at each sample site	USGS NED 10 m DEM
	Soil Total P	-	Soil Extractable P and TP relationship from each soil sample	Average of observed TP concentrations for each land class - assigned by GIS Land Use layers
2	Soluble Soil P	-	Soil Extractable P and MN P Index relationship at each field-site	Average of field-site relationships - assigned by GIS Land Use layers
	Surface Applied P	Applied Fertilizer and Livestock Waste	MN P Index, Site Observations, NAIP Imagery, and Landowner Surveys - assigned at each field-site	MN P Index, NAIP imagery, and generalizations based on Landowner Surveys - assigned by GIS Land Use layers
3	Crop Residue P	-	MN P Index and P in Residue Experiments - assigned by observed dominant vegetation	MN P Index and P in residue experiments - assigned by GIS Land Use layers
	Surface Applied P	Winter Applied Fertilizer and Livestock Waste	MN P Index, Site Observations, NAIP Imagery, and Landowner Surveys - assigned at each field-site	MN P Index, NAIP imagery, and generalizations based on Landowner Surveys - assigned by GIS Land Use layers

Table 1–2. Comparative statistics for the best estimate GIS P Index output and P Index observations. Overall, the GIS P Index is expected to under-predict by about 1.31 on average.

Pathway	**Observed Mean**	**GIS Tool Mean**	**RMSE**	**RE**	**NOF**
Units	MN P Index Risk Score Units			%	
Pathway 1	0.17	0.18	0.22	4.58	1.31
Pathway 2	1.11	0.75	1.06	-32.37	0.96
Pathway 3	1.96	1.63	0.56	-16.95	0.28
P Index	3.23	2.56	1.31	-20.75	0.41

Table 1–3. Comparative statistics for each STP scenario: low (top table), average (middle table), and high (bottom table). STP variation had little effect on model performance. Pathway 1 was the most affected in high slope, erosion prone areas. This observation none of the field-sites were in said areas so this observation could not be verified. Watersheds susceptible to high erosion risk likely require more soil samples to accurately characterize this unverified risk presented by the GIS model.

Pathway	**Observed Mean**	**GIS Tool Mean**	**RMSE**	**RE**	**NOF**
Units	MN P Index Risk Score Units			%	
Pathway 1	0.17	0.12	0.20	-25.94	1.18
Pathway 2	1.11	0.67	1.08	-39.19	0.98
Pathway 3	1.96	1.63	0.56	-16.95	0.28
P Index	3.23	2.44	1.36	-24.68	0.42

Pathway	**Observed Mean**	**GIS Tool Mean**	**RMSE**	**RE**	**NOF**
Units	MN P Index Risk Score Units			%	
Pathway 1	0.17	0.18	0.22	4.58	1.31
Pathway 2	1.11	0.75	1.06	-32.37	0.96
Pathway 3	1.96	1.63	0.56	-16.95	0.28
P Index	3.23	2.56	1.31	-20.75	0.41

Pathway	**Observed Mean**	**GIS Tool Mean**	**RMSE**	**RE**	**NOF**
Units	MN P Index Risk Score Units			%	
Pathway 1	0.17	0.23	0.28	36.27	1.64
Pathway 2	1.11	0.85	1.03	-23.02	0.93
Pathway 3	1.96	1.63	0.56	-16.95	0.28
P Index	3.23	2.72	1.25	-15.91	0.39

CHAPTER 2

Characterizing Phosphorus in the Vegetation of Montane Watersheds

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ABSTRACT

Elevated phosphorus (P) loading of freshwater lakes and reservoirs often results in poor water quality and negative ecological effects. Many critical source areas (CSA) of P are nonpoint sources that can be difficult to identify and control. A useful concept for identification of a CSA is the P risk index (P Index) that evaluates the P risk associated with distinct source and transport pathways. One potential source and transport pathway for P movement from landscapes is the leaching of P from plant tissues during snowmelt runoff. The purpose of this study is to examine plant residue P as either total P (TP) or water extractable dissolved reactive P (DRP) in living biomass and dead biomass during autumn months from mountain ecosystems, before winter snowfall and subsequent spring snowmelt runoff. These ranges will make it possible to adapt the Minnesota P Index to many Rocky Mountain watersheds in order to identify CSAs. Vegetation communities were divided into Upland Systems, Lowland Systems, and Wet Lowland Systems and samples were taken from each community. Average P density values to use in the MN P Index adaptation were 3.6 kg ha^{-1} for Upland Systems, 2.6 kg ha^{-1} for Lowland Systems, and 2.1 kg ha^{-1} for Wet Lowland Systems. These values differed greatly from the MN P Index default of 13.5 kg ha^{-1} for these areas suggested in the MN P Index allowing for greater accuracy in P risk assessment. Better inputs for the MN P Index will provided better outputs of overall P assessment and promote the automation of much of the P risk evaluation process.

INTRODUCTION

Since the implementation of the Clean Water Act, water quality improvements have been a serious focus of state and federal governments. Research shows that an increase in fresh water phosphorus (P) concentration often results in eutrophication and poor water quality (Schindler, 1974). In many cases, P additions to large water bodies, like lakes and reservoirs, come primarily through nonpoint sources (NPS) that are difficult to identify directly (Carpenter et al, 1998). Algal responses to elevated nutrient inputs in reservoirs can be similar to lakes and result in eutrophication (Soballe and Kimmel, 1987). Many of the large waterbodies in the Rocky Mountains of the western United States are reservoirs and many are susceptible to eutrophication (Gelder et al, 2003; Echkoff et al., 2002; Utah DEQ-DWQ, 2007). Efficiently identifying potential NPS of P to these reservoirs is key to improving water quality and fostering sustainable growth in the west.

A useful tool to evaluate NPS of P is a phosphorus risk index (P Index). The first P Index was proposed in 1993 (Lemunyon and Gilbert, 1993) and development of P indices by many U.S. states has been encouraged by government natural resource agencies, such as the National Resources Conservation Service (NRCS). P Indices vary among states, but most are empirical models addressing agricultural land uses and are often applied at the field scale (Raney and Troxell, 2008; NRCS-Iowa, 2004). They require specific information about the field, such as soil type, soil test P (STP), and P management practices ([1]Moncrief et al., 2006). The inputs are then categorized by degree of risk and weighted against other weighting factors to calculate an overall P risk score. P indices can be simple or complex but should take into account both P source and P transport risk factors specific to the site being evaluated. A robust index that can account for many source and transport pathways could be useful in many different environments.

The Minnesota Phosphorus Site Risk Index (MN P Index) focuses on quantifying many important sources and three main transport pathways. The three main pathways, 1) P movement in particulate forms with soil erosion, 2) P movement in soluble forms in runoff from rainfall, and 3) P movement in soluble forms in snowmelt driven runoff ([2]Moncrief et al., 2006), account for the main surface P transport pathways in virtually any landscape. This pathway approach makes the MN P Index robust and it could potentially be useful in identifying P risk areas in the watersheds that feed the montane reservoirs of much of the American West.

As described above, P indices must use inputs that accurately describe the study area. The MN P Index is no different. Much of the information necessary to apply the MN P Index is included in the Minnesota Phosphorus Site Risk Index Worksheet User's Guide ([2]Moncrief et al., 2006). Most of the information in the worksheet is from data derived in MN and new data about western montane areas is necessary to apply the index in the west. This paper focuses on acquiring input data from two western montane watersheds, the Wallsburg and Upper Strawberry River watersheds, found in central Utah. Both watersheds drain to large reservoirs and have been identified as contributors of NPS P (Utah DEQ-DWQ, 2007; Eckhoff, et al., 2002). The two watersheds share boundaries, many dominant vegetation types, parent geology, and experience similar climatic conditions. One of the main inputs missing to effectively apply the MN P Index to these areas is P transport in soluble forms from snowmelt driven runoff. Much of this P comes from plant residue on the landscape.

With respect to water quality, the leachable plant residue P found in relatively undisturbed watersheds, can be thought of as base, or background, NPS's of P. This potential source of P in watersheds is the P leached from plant tissue as they live out their life cycles. While not all of the P in plant tissue leaches out, P is a necessary plant nutrient and, in large watersheds, a sizable pool of P on the landscape is found in plant tissue (White and Brown, 2010; Mengel and Kirkby, 2001). P in the biomass residue of agricultural field crops is well documented ([2]Moncrief, 2006; Halsey, 1986; Wischmeier, 1973; Hanway and Olsen, 1980; Webb et al., 1992) but such information is limited with respect to native forest and range plants in montane ecosystems (Ste-Marie, et al., 2007). Wild plants are particularly dependent on the P found in the soils, as they have no artificial P inputs. P found in wild soils is effectively funneled to plants and potentially deposited on or near the surface when they die and decompose (Prescott, et al., 2000). Unlike agricultural crops, where plant tissue P is removed from cycling in the ecosystem at harvest, forest and range plants complete their lifecycles on the landscape allowing nutrients to return to the soil and cycle in the ecosystem over time. As P cycles through the ecosystem, it could be possible for relatively large amounts to leave the system and enter water bodies as it becomes more mobile at different stages of its biogeochemical cycling (Bünemann et al., 2012).

Researchers have examined the P movement with water through some of the compartments of these cycles (Loupe, et al., 2007; Gergans, et al., 2011). Most of the literature has focused on soils and P bound to soil particles that move with water in erosion and runoff events (Greene et al., 2013; Gergans, et al., 2011). Few studies characterize dissolved reactive P in natural ecosystems (Huang, and Schoenau, 1997; Loupe, et al., 2007). Another important aspect to examine is the time of year that P from plant residue is more likely to leach. According to the Minnesota Phosphorus Site Risk Index Technical Guide, aside from winter fertilizer application, winter sources of P can originate from crop residue and the type of crop, tillage practice, and crop yield should be taken into account when examining potential winter P sources. ([1]Moncrief, et al., 2006; Halsey, 1986; Wischmeier, 1973; Hanway and Olsen, 1980). Loupe et al. (2007) found that most P in organic residue tends to leach with the first large precipitation event. Thus, P found in fall vegetation residue is most indicative of potential P movement through snowmelt events.

The purpose of this study is to provide ranges of total P (TP) and water extractable dissolved reactive P (DRP) in living and dead biomass during autumn months, before winter snowfall and subsequent snowmelt runoff. The results in this paper do not represent means for vegetation sites but, rather, represent observations of possible values found in each ecosystem sampled. These data will supply useful inputs to a modified version of the MN P Index and further studies about how P in montane watersheds can affect water quality.

METHODS

STUDY AREA

The study area consists of two neighboring montane watersheds, the Wallsburg and Upper Strawberry River watersheds, located in north-central Utah, U.S.A (40.3877° N, 111.4224° W for Wallsburg and 40.1718° N, 111.1295° W for Strawberry Reservoir). Both watersheds drain to reservoirs located in the Wasatch Mountains in Central Utah and share a watershed boundary (Figure 2–1). Both watersheds are similar sizes, have similar climates and are located at similar elevations. Each watershed drains in the opposite direction to separate reservoirs.

The Wallsburg Watershed

The Wallsburg watershed (Figure 2–2), drains from the southern ends to the northwest of the watershed by feeding a tributary system of Deer Creek Reservoir. Deer Creek Reservoir serves as an important source of water for recreation, agricultural, municipal, industrial use, and as a cold freshwater fishery (Eckhoff, et al., 2002). A state Total Maximum Daily Load (TMDL) study identifies the single main tributary that drains Wallsburg, Main Creek, as a disproportionately high contributor of P to Deer Creek Reservoir (Eckhoff, et al., 2002). Main Creek is composed of three perennial reaches: Main Creek itself (~24 km long), which originates in the southeast peaks of the watershed, Little Hobble Creek (~12.5 km), which originates in the southwestern peaks of the watershed and is made up of the combination of both Left and Right Forks, and Spring Creek (~5.3 km), which springs from the ground in the center of Wallsburg proper, a small rural community home to about 300 residents (Boyd, 2012). Each of these waterways has contributing ephemeral streams and the Wallsburg watershed itself is made up of three sub-watersheds with United States Geological Service (USGS) classified hydrologic units (HU12).

The watershed elevation ranges from 1,300 m at the outlet to 2,960 m above sea level at the highest peak. Average precipitation at the nearest weather station is 62 cm (Boyd, 2012). The area is a graben, or a depressed area of land between parallel faults. The area contains high amounts of high-level alluvial fan-deposits. (Beik and Lowe, 2009). The total area is nearly 185 km^2. The land use and land cover of the watershed can be loosely categorized as about 7.6% of the land area used for agriculture or developed land, a mixture of grassland and shrubland as making up nearly 30.8% of land area and a mixed ecotone of more woody plants as making up the remaining 61.6% of the watershed area (Figure 2–2). These wildland ecosystems are common in both watersheds and many montane watersheds throughout the west. The grass dominated areas are typically dominated by species such as crested wheatgrass (*Agropyron cristatum*), Kentucky bluegrass (*Poa pratensis*), smooth brome (*Bromus inermis*) and cheatgrass

(*Bromus tectorum*). The shrublands are dominated by dryland sagebrush (*Artemisia tridentata* var. *vaseyana and Artemisia tridentate var. wyomingensis*) and silver sagebrush (*Artemisia tridentate var. cana)*, the forested areas are dominated by Douglas Fir (*Pseudotsuga menziesii*) and subalpine fir (*Abies lasiocarpa)* in conifer forest and aspen (*Populus tremuloides)* in deciduous forests. Other areas classified as wooded areas are dominated by Gambel oak (*Quercus gambelii*) stands. Agriculture in the Wallsburg watershed is of limited intensity. Much of the land kept in alfalfa, grass hay, or pasture grass for grazing.

The Upper Strawberry River Watershed

The Upper Strawberry River watershed (Figure 2–3) drains from the north to the south, emptying in the Strawberry Reservoir. The main and tributary and sole outlet of this watershed is the Upper Strawberry River (~30 km long). A Total Maximum Daily Load study (TMDL) study of the Strawberry Reservoir has identified P as a contaminant of concern and the Upper Strawberry River as a large contributor (Utah DEQ-DWQ, 2007). The Upper Strawberry River is also fed by the perennial Hobble Creek (~7 km) and Willow Creek (~12 km) systems.

The Upper Strawberry River watershed receives between 48 and 78 cm in average annual precipitation (Utah DEQ-DWQ, 2007). The watershed is approximately 226 km^2 in area and differs from the Wallsburg watershed mostly due to its lack of agriculture and urban development. The land use is predominantly divided into forested woodland and grasslands and shrublands with minimal development. Forested and woodland areas make up about 58% of the total area. Grasslands and shrublands make up nearly 16% of the land area. Strawberry Reservoir covers about 12% of the land area in the study area. The remaining 4% is divided up in urban development and riparian areas (Figure 2–3). The dominant species described in the Wallsburg watershed are still dominant players in the Strawberry watershed. These plant community designations only partially describe the vegetative classes found at the study site. Further designation necessary for the MN P Index are described in the Results section.

The majority of land area of the Strawberry watershed is under United States Forest Service (USFS) jurisdiction and is used for hunting, camping, and occasional grazing. The reservoir is used for recreation, irrigation, drinking water, and as a cold fresh water fishery (Utah DEQ-DWQ, 2007). The Utah Department of Natural Resources (DNR) and United States Forest Service completed extensive streambank restoration in recent years along the Strawberry River resulting in more stable riparian zones, resulting in narrower and more stable riparian channels, and increased riparian vegetation establishment in many areas along the river.

LAND COVER DESIGNATIONS

Ecosystems observed in both watersheds included in the study area were loosely split up into three general ecotypes: Upland Ecosystems (both deciduous and conifer forests as well as oak dominant stands), Dry Lowland Ecosystems (dominated by mixed shrubs and grasses) and Wet Lowland Ecosystems (dominated by riparian vegetation, grasses, and wet meadow forbes). These designations were implemented based on the types of vegetation found within 1 km of the Upper Strawberry River in the strawberry watershed, or described ecosystems unique to the Wallsburg watershed The land cover designations used in this study are meant to reflect general differences found at the various observed ecosystems, accounting for dominant vegetation types at each sample location.

SAMPLE LOCATIONS

Initial visualization of the study area through Utah's available vegetation maps and aerial photography were helpful in choosing potential sample locations in various dominant vegetation areas. 2014 National Agricultural Imagery Program (NAIP) imagery and Land Cover data layers obtained from the Utah AGRC and prepared by the Utah Department of Natural Resources and the U.S. Geological Survey National Gap Analysis Program were used (USGS, 2015). Sample sites in random locations in four different ecotypes, namely, riparian, wet meadow, forest, mixed dryland grasses and shrubs. These ecotypes were designated based on the general ecological conditions observed at each site location. All of the samples from the Strawberry Reservoir were chosen within 1 km to the Upper Strawberry River under the assumption that they will be more likely to have an effect on P concentrations in the River (Figure 2–4).

SAMPLE COLLECTION AND ANALYSIS

The purpose of this study was to determine P concentrations found in the residue of plants from ecosystems common to western mountain watersheds. During the fall of 2015 a total of 12 samples were collected in the chosen sample locations in both the Wallsburg and Strawberry watersheds (Figure 2–4). At each sample site was randomly selected from the observed ecosystems and a one meter square PVC quadrat was used to define a square meter. All living and dead biomass found in the square quadrat was clipped to within 2.0 cm of the soil surface, gathered, and separated into the respective categories and then placed in labeled paper bags. The sampling procedure was meant to characterize the plant community in the area, thus, the samples were not divided by species. All species from each site quadrat was placed into the bag.

Samples collected in wooded areas required tree density measurements to estimate tree biomass in the area. Tree density was determined by using the point quarter method described by Mitchell (2007). A tree corer was used to sample tissue from living and dead trees within the sample area. The core included all of the tissue from the outside bark to the center of the tree. These entire tissue samples were used to determine P content of trees and then to estimate P amounts for all trees on the landscape.

After collecting and weighing all of the living vegetation and dead biomass samples, a chipper-shredder was used to chop the samples to uniform, manageable sizes (~ 5 cm^3) and to mix the samples thoroughly. A representative subsample of each of the ground up samples was weighed for a wet weight. This wet weight was taken only to prepare compare with a dry weight after drying and was not used in results calculations.

After drying the samples until they measured a static weight, each sample was further mixed and ground down to 0.5 mm for microwave assisted nitric acid digestion and analyzed on the Thermo Scientific iCAP 7400 ICP-OES in the Brigham Young University Environmental Analytical Laboratory (EAL) A portion of the dry, chopped sample was used to determine water soluble P. Each sample was placed into a plastic container marked with a grid and shaken and spread evenly over the grid. A cell was chosen through a random number generator and then collected, weighed, and placed it into a 1 liter bottle. To each bottle was added a first dilution of water. The mixture was shaken on a soil shaker for one hour and then 5 mL of solution was extracted and further diluted to readable and filtered in a 0.45 micron filter analyzed colorimetrically using the ascorbic acid method on a Thermo Scientific GENESYS spectrophotometer (Murphy, 1962). Another sample of the filtered solution was analyzed on the EAL's ICP-OES mentioned above to acquire a total dissolved P measurement.

RESULTS

The results in this section are grouped into three categories: “Upland Systems,” “Lowland Systems,” and “Wet Lowland Systems.” This grouping describes the main visual differences between the sites in each grouping. The reasoning behind this grouping is to provide land managers using the MN P Index a quick and simple designation between different ecosystems. Perhaps the best presentation of this data, for quick reference is described in the three tables referenced in each section. The written results of this section describe each sample site, type of sample, and the following measurements: The total biomass in Mg ha^{-1} and the relative portions of the total from each sample type, the mean TP concentrations and individual sample type TP concentrations, the total mass per area of TP in kg ha^{-1} and mass per area of TP for each sample type, mean DRP concentrations and sample type DRP concentrations, and the total mass per area of DRP in kg ha^{-1} and individual sample type DRP concentrations. Photos of each site are included in the appendix, labeled by site number. Information about the dominant species found at each site is detailed in the Dry Matter Distribution in Ecosystems section. These same species made up the dominant portion of the samples described in the other analysis results described in the remainder of this paper.

The following abbreviations are used to describe each sample type: “LL” stands for any leaf litter, the duff layer, or any dead plant material, excluding wood, found on the surface within the sampling quadrat, “DW” represents any type of dead wood found in the quadrat, “T” stands for living trees, and “U” signifies any living understory or living vegetation excluding trees but including shrubs, grasses, and herbaceous plant species.

DRY MATTER DISTRIBUTION IN ECOSYSTEMS

Upland Systems

The results from the Upland sites are detailed in Table 2-1. Site 1 consisted primarily of mature aspen with a visibly high percentage of dead, standing trees. There were a few conifers, mostly subalpine fir, scattered throughout the site. Western yarrow (*Achillea millefolium*) and snowberry (*Symphoricarpos spp.*) were found among the sparse understory. At Site 1 the total dry biomass was measured at 284 Mg ha^{-1} with 270 Mg ha^{-1} of the total from T, 5 Mg ha^{-1} from LL, 5 Mg ha^{-1} from DW, and 4 Mg ha^{-1} from U. aspen biomass is much larger (~20 times greater) than all of the other categories combined at this site. There are many sites like this in Utah throughout the Rocky Mountains.

Site 2 was dominated by conifer species with a few aspen. The conifers at this site were mostly subalpine fir and Douglas fir. Snowberry and *Thalictrum spp.* Were also present among the understory. There were some dead standing trees but the majority were living. The dry biomass was measured at a total of 188 Mg ha^{-1}. 148 Mg ha^{-1} of that total was from T, 35 Mg ha^{-1} from LL, 3 Mg ha^{-1} from U, and 2 Mg ha^{-1} from DW. Like Site 1, the trees make up most of the biomass in this environment. Noteworthy at Site 2 is that the duff layer makes up almost 20% of the total mass. The duff layer was observed to be fairly uniform across the soil surface to a depth of about 10 cm. This site was likely made up primarily of aspen years ago but has since experienced a shift to conifers.

Like Site 1, Site 6 is another aspen dominated site. This site was located at a lower elevation and the tree diameters were noticeably smaller than the trees at Site 1. The understory at this site was more dominated by immature aspen shoots. Like site 1, snowberry and western yarrow were also present. The total dry biomass was measured to be 65 Mg ha^{-1}. 54 Mg ha^{-1}

came from T, 6 Mg ha^{-1} from U, and 5 Mg ha^{-1} came from LL. There was zero DW sampled at this site. While the trees at this site are much smaller than the trees at the other aspen site, the observed LL and U masses are similar to those at Site 1 but make up a larger percentage of the total biomass.

Site 12 was unique in that it was the only site dominated by Gambel oak. A few dryland sagebrush (*Artemisia tridentate var. wyomingensis and Artemisia tridentate var. vaseyana)* and cheatgrass were found at this site but, generally, Gambel oak dominated. The total dry biomass was measured to be 22 Mg ha^{-1}. 9 Mg ha^{-1} came from T, 9 Mg ha^{-1} from LL, and 4 Mg ha^{-1} came from DW and there was no understory sampled at this site.

Lowland Systems

The Lowland sites are detailed in Table 2-2. Site 5 was more of a grass and shrub dominated ecotone. The actual sample for this site included more grasses than shrubs. The dominant species at this site were Kentucky bluegrass, western wheatgrass (*Pascopyrum smithii spp.*), silver sagebrush, dandelion (*Taraxacum spp.)*, clover (*Trifolium spp.*), and western yarrow. There was basically no slope or tall canopy cover at this site. The total dry biomass measured at Site 5 was 5 Mg ha^{-1}. U added 5 Mg ha^{-1} and LL contributed 0.5 Mg ha^{-1}. The LL portion was much smaller than at many other sites perhaps due to the simple physiology of grass compared to shrubs and the vegetation in the other ecotypes sampled.

Site 7 was a sagebrush dominant site with some grass located on foothills on the west side of the study area. The dominant species at this site were silver sagebrush, big mountain sagebrush, western wheatgrass, clover, and dandelion. This site had a total dry biomass of 5 Mg ha^{-1} with 4 Mg ha^{-1}from LL and 1 Mg ha^{-1} from U. Site 7 was unique when compared to the other sagebrush sites in its dry biomass measurements. More biomass was found in LL than in U which was the opposite in both Site 9 and 11.

Like Site 7, Site 9 was a sagebrush dominated site. Site 9 was located furthest from the headwaters and near the Strawberry Reservoir itself. The dominant species at this site were silver sagebrush, Kentucky bluegrass, and bulrush. This site measured roughly the same mass of living biomass as dead biomass with living vegetation being slightly larger. The measured values are as follows: a total dry mass of 12 Mg ha^{-1} with 7 Mg ha^{-1} from U and 5 Mg ha^{-1} from LL.

Site 10 was a very dry and rocky grass dominated site on the northeastern side of the Wallsburg watershed. The dominant species were big mountain sagebrush and cheatgrass. The dry biomass totaled at 8 Mg ha^{-1} with 6 Mg ha^{-1} from U and 2 Mg ha^{-1} from LL. Like the other grass dominant site (Site 5) in the Upper Strawberry watershed, a much smaller proportion of mass was observed in LL than in U.

Site 11 was a sagebrush dominate in the Wallsburg watershed. The dominant species at this site were big mountain sagebrush, some Great Basin sagebrush, squirrel tail (*Elymus elymoides spp.*), and cheatgrass. This site showed a dry biomass total of 24 Mg ha^{-1}. 22 Mg ha^{-1} were from U and 2 Mg ha^{-1} were from LL. The dry biomass measurements from this site were very different than the other sagebrush sites measured in the Upper Strawberry River watershed. This observation points to the potential large variation possible in each ecotype.

Wet Lowland Systems

The Wet Lowland sites are detailed in Table 2-3. Site 3 was the first riparian site sampled along the Upper Strawberry River. Site 3 had relatively slow moving water with much of the river braided through the biomass. Much of the sample was made up of willows (*Salix spp.*), some snowberry, unidentified forbes (*Carex spp.),* and Kentucky bluegrass. The total dry biomass was 16 Mg ha^{-1}. 8 Mg ha^{-1} were from LL and 8 Mg ha^{-1} from U. It's noteworthy that almost exactly half of the mass came from LL and half from U.

Like Site 3, Site 8 was also a riparian site, sampled right next to the river. This site was much farther along the river and experienced more and faster moving water than site 3. The dominant species were willows and Kentucky bluegrass. Site 8 measured a total dry biomass of 22 Mg ha^{-1} with 17 Mg ha^{-1} from U and 5 Mg ha^{-1} from LL. Almost four times as much mass was measured in U than in LL. Perhaps the faster moving water took more of the LL downstream.

Site 4 was not a riparian site but more of a wet meadow. It was surrounded by smaller willows but primarily made up of grasses and forbs. The dominant grasses at this site were Kentucky bluegrass, bulrush, with some Nebraska sedge (*Carex nebrascensis*) among other less dominant grasses and forbes. The sample site was slightly raised when compared to the rest of the meadow but slopes were very gradual. The total dry biomass was 7 Mg ha^{-1} with 5 Mg ha^{-1} from U and 2 Mg ha^{-1} from LL. This site was interesting because it was fed by a groundwater seep and not the main Upper Strawberry River channel.

TOTAL PHOSPHORUS CONCENTRATIONS IN ECOSYSTEMS

Upland Systems

The Upland sites are detailed in Table 2-1. At the aspen dominated Site 1 the mean TP concentration was measured at 796 mg kg^{-1}. 1,130 mg kg^{-1} was measured in LL, 389 mg kg^{-1} in DW, 111 mg kg^{-1} in T, and 1,555 mg kg^{-1} in U. It is interesting to note that tree TP concentrations are relatively low when compared to U and LL especially when considering that the majority of LL is from aspen tree leaves.

At the conifer Site 2 the mean TP concentration was 1,237 mg kg^{-1}. 1,394 mg kg^{-1} were in LL, 428 mg kg^{-1} in DW, 1,529 mg kg^{-1} in T, and 1,596 mg kg^{-1} in U. The trees at this site had a much higher TP concentration than at the other sites. It is interesting to note that DW had similar concentrations (~ 400 mg kg^{-1}) at each site.

Site 6 had an average TP concentration 502 mg kg^{-1}, a LL concentration of 584, T concentrations of 111 mg kg^{-1}, and U concentrations of 810 mg kg^{-1}. There was not DW in the sample square at this site. P concentrations were much lower at this site than at the other aspen site, Site 1.

At the Gambel oak dominated site, Site 12, the average TP concentration was measured at 426 mg kg^{-1}. LL concentration was measured at 903 mg kg^{-1}, DW concentrations at 441 mg kg^{-1}, and T concentrations at 358 mg kg^{-1}, and there was no understory sampled at this site.

Lowland Systems

The Lowland sites are detailed in Table 2-2. The grass dominated site, Site 5 had an average TP concentration of 922 mg kg^{-1} between LL and U. The LL concentration was 1,121 mg kg^{-1} and the U concentration was 724 mg kg^{-1}. It's interesting that while there was little LL biomass at this site, the LL concentration was significantly higher than the U concentration.

Site 7, a sagebrush dominant site, measured a mean TP concentration of 1,122 mg kg^{-1} with 1,098 mg kg^{-1} in LL and 1,146 mg kg^{-1} in U. Both LL and U showed similar TP concentrations. This site observed the highest TP concentrations than at any of the other Lowland sites.

Site 9, another sagebrush dominant site, had a mean TP concentration of 893 mg kg^{-1}. LL was measured at 791 mg kg^{-1} and U at 995 mg kg^{-1}. Like Site 7, the LL and U TP concentrations were very similar to each other with slightly higher concentrations in the living vegetation.

The grass dominant site, Site 10, averaged 869 mg kg^{-1} for TP concentration. LL was measured at 799 mg kg^{-1} and U was measured at 939 mg kg^{-1}. This site was different than the other grass dominant site in that the LL and U concentrations were similar with U being slightly higher.

Site 11 was another sagebrush site. It averaged 781 mg kg^{-1} TP concentration. LL TP concentrations were 906 mg kg^{-1} and U concentrations were 655 mg kg^{-1}. This site was slightly different than the other sagebrush sites because the LL concentrations were measured higher than the U concentrations where the other sites displayed the opposite trend.

Wet Lowland Systems

The Wet Lowland sites are detailed in Table 2-3. Site 3 was a riparian site dominated by Willows that had an average TP concentration of 723 mg kg^{-1} with LL at 566 mg kg^{-1} and U at 881 mg kg^{-1}. This site experienced visibly slower moving water, less water, and less channelization than the other riparian site. Perhaps these conditions interacted to lower TP concentrations.

Like Site 3, Site 8 was a riparian, Willow dominant site. This site measured an average TP concentration of 1,348 mg kg^{-1} with LL at 1,894 mg kg^{-1} and U at 802 mg kg^{-1}. While the U pools for both of these sites were very similar, the LL concentrations were very different. It is interesting to note that Site 8 had less LL mass than Site 3 but the LL concentration of TP at Site 8 was almost three times higher.

Site 4 was the unique, wet meadow site. It averaged 887 mg kg^{-1} in TP concentration. LL was measured at 1,114 mg kg^{-1} and U at 660 mg kg^{-1}. While this site had many of the same grasses and Willows in either the Lowland or Wet Lowland Systems, the U pool was the lowest out of each of these sample types. (See Table 2-3 for more information about wet meadow sites).

TOTAL PHOSPHORUS DISTRIBUTION IN ECOSYSTEMS

Upland Systems

The Upland sites are detailed in Table 2-1. At the aspen dominated forest Site 1 the total sum of TP was 43.4 kg ha^{-1}. 5.7 kg ha^{-1} were from LL, 2 kg ha^{-1} from DW, 29.9 kg ha^{-1} from T and 5.9 kg ha^{-1} from U. While trees had much lower TP concentrations, they still made up about 70% of the total weight of TP at this site.

The conifer site, Site 2, summed to 280.1 kg ha^{-1} of TP. LL accounted for 48.3 kg ha^{-1}, DW for 0.9 kg ha^{-1}, T for 226.2 kg ha^{-1}, and U 4.7 kg ha^{-1}. Trees overwhelmingly accounted for the largest pool of TP mass at this site. It should be stated that the LL pool at this site was more than the entire mass of TP at Site 1.

Site 6 was the other aspen dominated forest site. The trees at this site were much smaller than at Site 1. Site 6 had a total sum of 14.1 kg ha of TP. 3.2 kg ha^{-1} came from LL, 6 kg ha^{-1} from T, and 4.9 kg ha^{-1} from U. This site did not have any DW. It's noteworthy that the U pool was very similar to Site 2 and Site 6.

Site 12, the Gambel oak site, had a TP mass of 36 kg ha^{-1}. The majority of that TP mass came from T at 25.9 kg ha^{-1}, 8.3 kg ha^{-1} came from LL, and 1.8 kg ha^{-1} from DW with none from U because no sample was collected at this site.

Lowland Systems

The Lowland sites are detailed in Table 2-2. Site 5, a grass dominant site, summed to 4 kg ha^{-1} TP. 0.6 kg ha^{-1} came from LL and 3.4 kg ha^{-1} came from U. This site had the least amount of TP by mass of the Lowland Systems measured. This is probably due to it being more of a grass monoculture when compared to the other sites. The vast majority of the TP measured here was found in U and only a very small portion came from LL.

The sagebrush dominated area at Site 7 had a total sum of 6.5 kg ha^{-1} TP with 4.8 kg ha^{-1} from LL and 1.7 kg ha^{-1} from U. The relative proportions in the LL and U pools at this site are almost the opposite when compared with the grassland sites with LL being a larger proportion and U being the smaller proportion.

Site 9 was also dominated by sagebrush. Site 9 had at total sum of 11 kg ha^{-1} TP with 4.2 kg ha^{-1} from LL and 6.8 kg ha^{-1} from U. Just like in the other measurements listed about Lowland Systems in the previous sections, the sagebrush sites seem to represent a lot of variation. The values and relative proportions for this site are very different than those recorded at the other sagebrush dominant sites.

Site 10 was primarily made up of grasses. This site had a total of 7.2 kg ha^{-1} TP with 1.3 kg ha^{-1} from LL and 5.9 kg ha^{-1} from U. A smaller portion was found in the LL pool and the majority of TP mass was found in U. This observation is consistent with the other grass site (Site 5).

Site 11, another sagebrush dominated site, had a total of 16.4 kg ha^{-1} TP with 1.7 kg ha^{-1} from LL and 14.7 kg ha^{-1} from U. This site displayed the largest masses of TP by far. The proportions represented by these results are more consistent with the grassland type sites, Site 5 and Site 10.

Wet Lowland Systems

The Wet Lowland sites are detailed in Table 2-3. The riparian, Willow dominant Site 3 had a total sum of 11.8 kg ha^{-1} TP. 4.6 kg ha^{-1} came from LL and 7.2 kg ha^{-1} came from U. An interesting observation at this site that is consistent with the other riparian site (Site 8) is that the mass of U is roughly double the LL mass.

The other riparian, Willow dominant site, Site 8, had a total sum of 22.6 kg ha^{-1} TP with 9.1 kg ha^{-1} from LL and 13.6 kg ha^{-1} from U. It is interesting to note that the TP at this site for each pool is consistently double that of Site 3. This observation is especially interesting when considering that the total LL biomass at this site was about half of Site 3 and the total U biomass was almost double.

The wet meadow site, Site 4, had a total sum of 5.8 kg ha^{-1} TP. 2.4 kg ha^{-1} came from LL and 3.4 kg ha^{-1} came from U. These numbers are more consistent with the grassland ecosystems that the riparian zones except for that the LL pool makes up a larger proportion of the total TP mass. Perhaps the constant addition of water to flush out the ecosystem does not have a large influence over TP presence.

DISSOLVED REACTIVE PHOSPHORUS IN ECOSYSTEMS

Upland Systems

The Upland sites are detailed in Table 2-1. At the aspen forest site, Site 1, the average DRP concentration was measured at 139 mg kg^{-1}. LL was measured at 247 mg kg^{-1}, DW at 89 mg kg^{-1}, T at 29 mg kg^{-1}, and U at 192 mg kg^{-1}. These concentrations, relative to each other, follow the same pattern as the TP concentrations in for each sample type. It is interesting to note that the DRP concentrations in DW and T both make up larger portions of the TP concentrations.

Site 2, the conifer dominant site, had a mean DRP concentration of 210 mg kg^{-1}. LL was measured at 74 mg kg^{-1}, DW at 38 mg kg^{-1}, T at 353 mg kg^{-1}, and U at 375 mg kg^{-1}. The trees and understory at this site were much higher than the dead biomass pools (LL and DW). The conifer trees also displayed much higher concentrations than the aspen trees.

Site 6, the younger aspen forest site, showed an average DRP concentration of 85 mg kg^{-1}. LL was 94 mg kg^{-1}, T was measured at 29 mg kg^{-1}, and U was measured at 132 mg kg^{-1}. The biggest noticeable difference between this site and Site 1 is that the LL concentrations are a lot lower at this site. The other measurements were somewhat similar.

Site 12, the Gambel oak site, had a mean DRP concentration of 98 mg kg^{-1}. LL was 289 mg kg^{-1}, DW was 9 mg kg^{-1}, T was 95 and no other living understory was collected at this site.

Lowland Systems

The Lowland sites are detailed in Table 2-2. The grassland site, Site 5, displayed a mean DRP concentration of 158 mg kg^{-1}. LL concentrations were found at 143 mg kg^{-1} and U concentrations at 173 mg kg^{-1}. It is perhaps interesting to note that the concentrations of DRP in the living grass is higher than that in the aspen trees but similar to aspen understory.

Site 7 was dominated by sagebrush and had a mean DRP concentration of 479 mg kg^{-1} with LL at 388 mg kg^{-1} and U at 571 mg kg^{-1}. The differences in concentrations between this site and the true grassland site (Site 5) are blatant. This sagebrush site has much higher concentrations that the grass and even higher concentrations than the aspen sites.

The other sagebrush site in the Upper Strawberry River watershed, Site 9, measured a mean DRP concentration of 278 mg kg^{-1} with LL at 324 mg kg^{-1} and U at 233 mg kg^{-1}. The noticeable drop in the U category points to the idea that there is a lot of variation between sites, even of the same ecotype.

Site 10 was the Wallsburg grass dominated site. It had a mean DRP concentration of 293 mg kg^{-1} with LL at 195 mg kg^{-1} and U at 391 mg kg^{-1}. The concentrations in U here are much higher than at Site 5. This could potentially be due to a more diverse species set found in the sampling quadrat when compared with Site 5's grass monoculture.

Site 11 was the only sagebrush site from the Wallsburg watershed. This site had a mean DRP concentration of 152 mg kg^{-1} with LL at 176 mg kg^{-1} and U at 127 mg kg^{-1}. This site is much lower in both pools when compared with the other sagebrush sites. This could be due to the fact that the samples are from different watersheds or another number of factors. Overall, this observation once again points to the potential for variation within the ecotypes sampled.

Wet Lowland Systems

The Wet Lowland sites are detailed in Table 2-3. Site 3, a Willow dominant riparian area, had an average DRP concentration of 92 mg kg^{-1} with LL concentrations at 75 mg kg^{-1} and U at 108 mg kg^{-1}. At this site, U appears to be higher than LL. This is consistent with the TP concentrations and masses observed here.

The other riparian, Willow dominant site, Site 8, had a mean DRP concentration of 188 mg kg^{-1} with LL concentrations at 236 mg kg^{-1} and U at 141 mg kg^{-1}. While different from Site 3, these DRP concentrations follow the same trend as this site's TP concentrations in that LL has a higher concentration than U.

Site 4, the wet meadow site, had a mean DRP concentration of 167 mg kg^{-1} with LL concentrations at 162 mg kg^{-1} and U at 173 mg kg^{-1}. Once again, these values were similar to those found in the dry Lowland grasslands further suggesting that the separation between this site and those sites might be somewhat arbitrary but useful when describing and categorizing the observed conditions.

DISSOLVED REACTIVE PHOSPHORUS CONCENTRATIONS IN ECOSYSTEMS

Upland Systems

The Upland sites are detailed in Table 2-1. The mature aspen forest site, Site 1, had a sum total of 10.18 kg ha^{-1} of DRP with 1.25 kg ha^{-1} from LL, 0.45 kg ha^{-1} from DW, 7.76 kg ha^{-1} from T and 0.72 kg ha^{-1} from U. Once again the largest contribution comes from T. It is interesting that while U recorded the second highest amount of TP, it shows the second lowest amount of DRP. The LL at this site is most likely the biggest concern for water quality at this site. Its LL TP recorded mass and DRP concentrations are higher than at Site 6 (the other aspen site) leading to larger DRP masses.

The conifer site, Site 2, had a sum total of 55.95 kg ha^{-1} of DRP with 2.56 kg ha^{-1} from LL, 0.08 kg ha^{-1} from DW, 52.19 kg ha^{-1} from T and 1.11 kg ha^{-1} from U. As expected, the largest contributor is from T. LL DRP mass at this site is much higher than at the other sites, even with a lower DRP concentration, pointing to the fact that larger masses of each sample type matter. In sites where DW was collected (this site and Site 1), it has a very small DRP mass.

Site 6, the younger aspen dominated stand, had a sum total of 2.88 kg ha^{-1} DRP. 0.53 kg ha^{-1} were from LL, 1.56 kg ha^{-1} were from T, and 0.8 kg ha^{-1} were from U. It is interesting that because the trees at this site were so much smaller than at the other sites so the total DRP mass was driven down. LL is also much smaller here potentially due to the more diverse subset of plant species at this site.

Site 12, the Gambel oak site, had a total DRP mass of 9.53 kg ha^{-1}. 6.85 kg ha^{-1} came from T and 2.64 kg ha^{-1} came from LL. The DRP mass in DW was virtually nonexistent at 0.04 kg ha^{-1} and there was no understory sample taken at this site.

Lowland Systems

The Lowland sites are detailed in Table 2-2. Site 5, one of the grassland systems, had a total of 0.9 kg ha^{-1} of DRP with 0.08 kg ha^{-1} from LL and 0.82 kg ha^{-1} from U. This site has some of the smallest recorded values for DRP mass of the sites sampled. The LL here is almost nonexistent to begin with and despite having a decent DRP concentration, the DRP mass is very minute. U is on the low end but consistent with the other U pools at other sites.

The sagebrush dominant site, Site 7, totaled 2.53 kg ha^{-1} of DRP with 1.69 kg ha^{-1} from LL and 0.84 kg ha^{-1} from U. DRP mass in LL makes up most of the DRP mass at this site. The value recorded for U is consistent with the other sites.

The other Upper Strawberry River watershed sagebrush site, Site 9, totaled 3.32 kg ha^{-1} of DRP with 1.73 kg ha^{-1} from LL and 1.59 kg ha^{-1} from U. This site has much more mass of DRP in U than Site 7. The LL value is similar to that of Site 7.

The Wallsburg watershed grassland site, Site 10, had a total of 2.79 kg ha^{-1} of DRP. 0.32 kg ha^{-1} came from LL and 2.47 kg ha^{-1} from U. Like the Site 5 grassland, this site displays little LL. It is a little higher, potentially due to the more heterogeneous sample. U at this site is much higher than all of the Strawberry samples but similar to the Wallsburg sagebrush site (Site 11).

The Wallsburg watershed sagebrush sample area, Site 11, had a total of 3.19 kg ha^{-1} of DRP with 0.32 kg ha^{-1} from LL and 2.87 kg ha^{-1} from U. It's interesting that the LL value here is the same at Site 10. U is the largest contributor of DRP mass at this site.

Wet Lowland Systems

The Wet Lowland sites are detailed in Table 2-3. Site 3, the upstream Willow dominant riparian site, had a total DRP mass measured at 1.5 kg ha^{-1} with 0.6 kg ha^{-1} from LL and 0.89 kg ha^{-1} from U. The DRP values at this site are lower than at many of the other sample sites but within the range observed at other sites.

The other, downstream Willow dominated riparian site, Site 8, totaled 3.51 kg ha^{-1} of DRP with 1.13 kg ha^{-1} from LL and 2.38 kg ha^{-1} from U. Much more DRP is found in the U pool at this site than at 3. Both LL and U are about double that of 3 which is consistent with the other measurements described in previous sections.

The wet meadow site, Site 4, had a total of 1.24 kg ha^{-1} of DRP with 0.35 kg ha^{-1} from LL and 0.89 kg ha^{-1} from U. This site displayed the smallest DRP mass of all of the Wet Lowland Systems sampled. Its values are, once again, similar to the grassland site (Site 5).

DISCUSSION

The ranges of results presented above show similar values to those found for many agricultural crops ([2]Moncrief et al., 2006). All of the values presented in this paper are much lower than the default 13.5 kg ha^{-1} described as the default value for all of these land cover types presented in the MN P Index ([2]Moncrief et al., 2006). With this information, land and water quality managers have a clearer picture of the amount of source P potentially leached from plant communities in parts of the Rocky Mountains similar to the study area.

In comparison with many agricultural crops, the values for the mountain ecosystems represented in this study are generally in the mid to low range. Perhaps the areas most likely to contribute P to water systems through overland flow are forested areas with either aspen or conifers dominating the landscape. Many papers have explored the role of aspen in changing soil chemistry and productivity (Buck and St. Clair, 2012; Wang, et al., 1995). Some have looked at conifers as well (Alban et al., 1978). Both aspen and conifers can increase soil nutrient concentrations and could potentially have the greatest effect on water quality as sources of P. This is most likely to occur during the first runoff event as described in Loupe et al. (2007).

The simplifying assignations of 3.6 kg ha^{-1} DRP for Upland Systems, 2.6 kg ha^{-1} DRP for Lowland Systems, and 2.1 kg ha^{-1} DRP for Wet Lowland Systems was determined. This assumption does not take into account trees because it is unlikely that trees leach as much P as the procedure used in this paper creates. Therefore, the high values for trees are left out and, rather, understory is counted twice to represent possible contribution of trees in first runoff events. This assumption was made to simply give a general range of values.

CONCLUSIONS

Greater understanding about expected ranges of P found in vegetation in western montane watersheds can help determine background NPS P. While the data presented in this paper do not represent statistical means, they do provide some expected ranges of P found in plant residue. In the particular case of the MN P Index, these data will provide more accurate evaluations of P risk comparisons.

Average values from the Upland, Lowland, and Wet Lowland Wystems were further split into dominant species types to use in the MN P Index adaptation. They were 2.6 kg ha^{-1} for aspen dominant forests, 4.9 kg ha^{-1} for Douglas fir dominated forests, 3.4 kg ha^{-1} for other conifers and deciduous woodland vegetation, 2.7 kg ha^{-1} for riparian woodland vegetation, 2.1 kg ha^{-1} for riparian shrubland vegetation, 1.2 kg ha^{-1} for wet meadow vegetation, 3.0 kg ha^{-1} for sagebrush dominated shrublands, and 1.8 kg ha^{-1} for grasslands. These values simply represent possible ranges of values for source P in plant residue for the ecotypes discussed in this paper and could be further modified to apply to the MN P Index. These values differed greatly from the MN P Index default of 13.5 kg ha^{-1} for these areas suggested in the MN P Index allowing for greater accuracy in P risk assessment.

P quantities for each vegetation type in many Rocky Mountain watersheds could be reasonably assigned from the data presented in this chapter. Statistical sampling methods form each of the ecosystems broadly explored in this study could provide even more accurate data without as much uncertainty. For the purposes of supplying reasonable ranges of values to automate the MN P index through GIS, the values presented in this paper are adequate.

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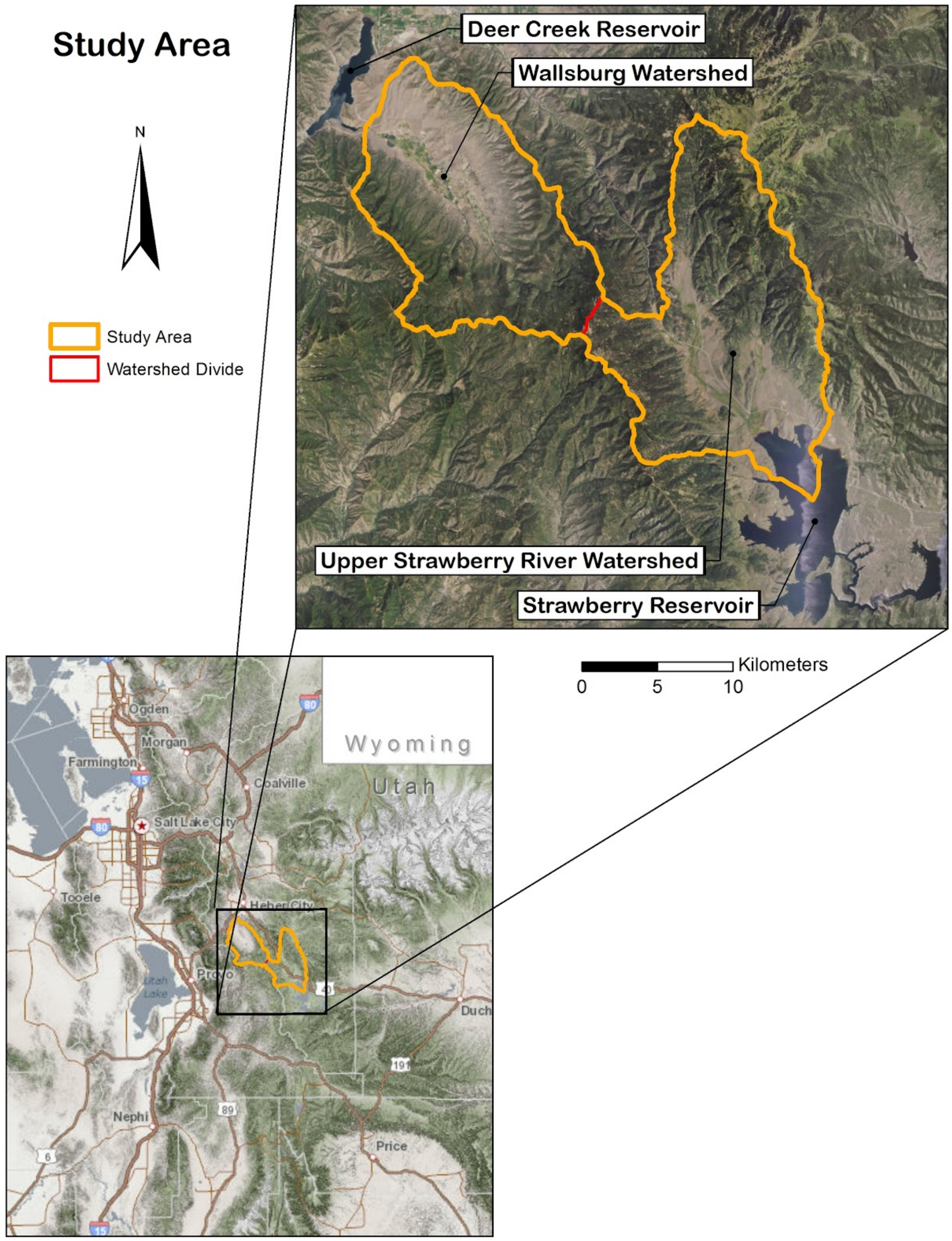


Figure 2–1. Study Area. The general location of the study area is described. The study area (orange outline) is divided into two watersheds: the Wallsburg watershed, located at the north end of the study area, and the Upper Strawberry River watershed, located at the south end of the study area. The watersheds share a boundary (red line) but drain to separate reservoirs. The Wallsburg watershed feeds Deer Creek Reservoir, located at the northwest corner of the map, and the Upper Strawberry River watershed feeds the Strawberry Reservoir, located at the southeast corner of the map.

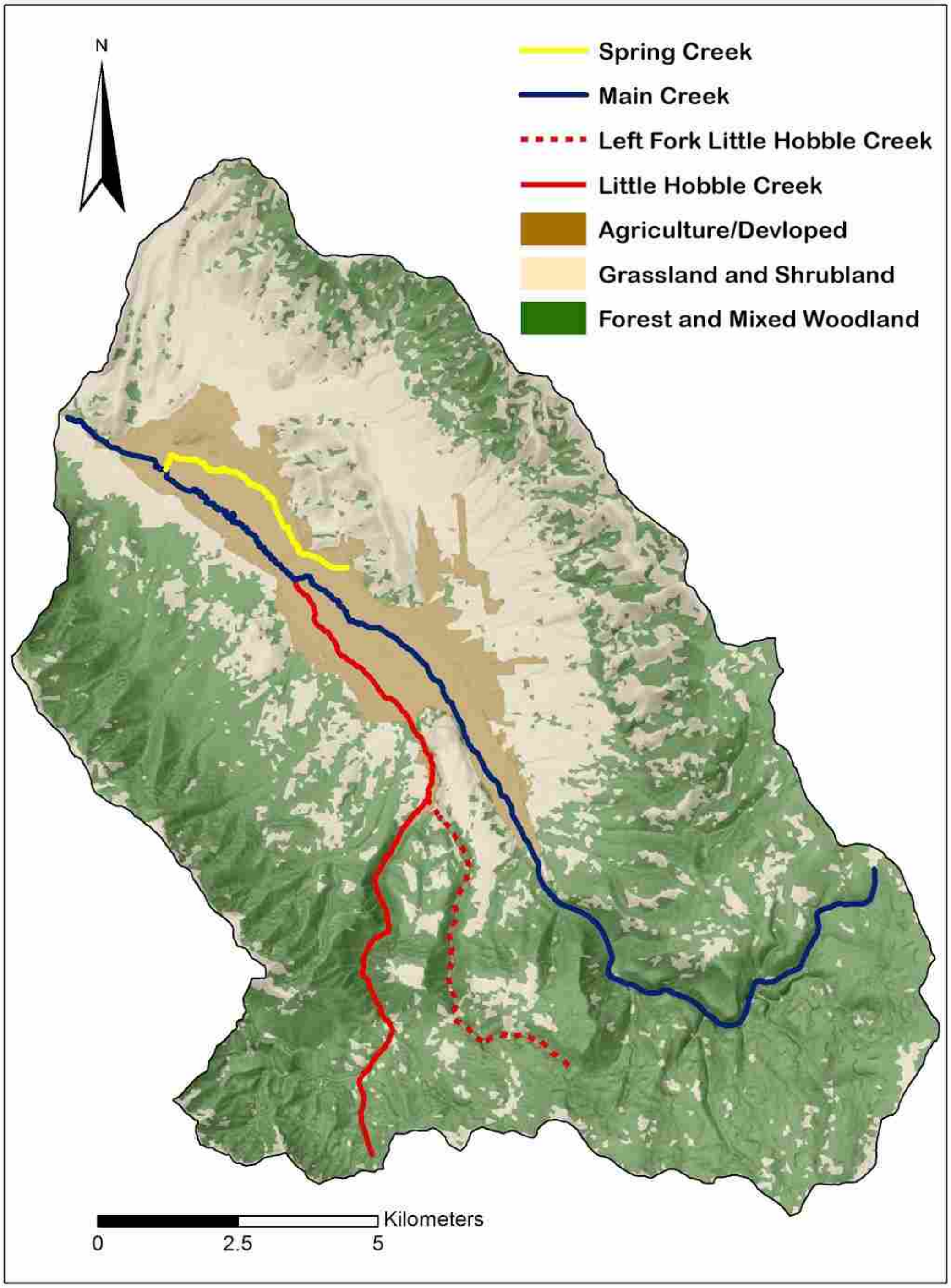


Figure 2–2. Wallsburg Watershed. The Wallsburg watershed encompases a drainage area of of approximately 185 km². The watershed drains to three main perennial streams: both forks of the Little Hobble Creek (solid red and dashed red), Spring Creek (yellow), and Main Creek (blue). Land Use in the area is divided up into agriculture/developed lands (~7.6% of the total land area), grasslands and shrublands (~30.8%), and forests and mixed woodland areas (~61.6%).

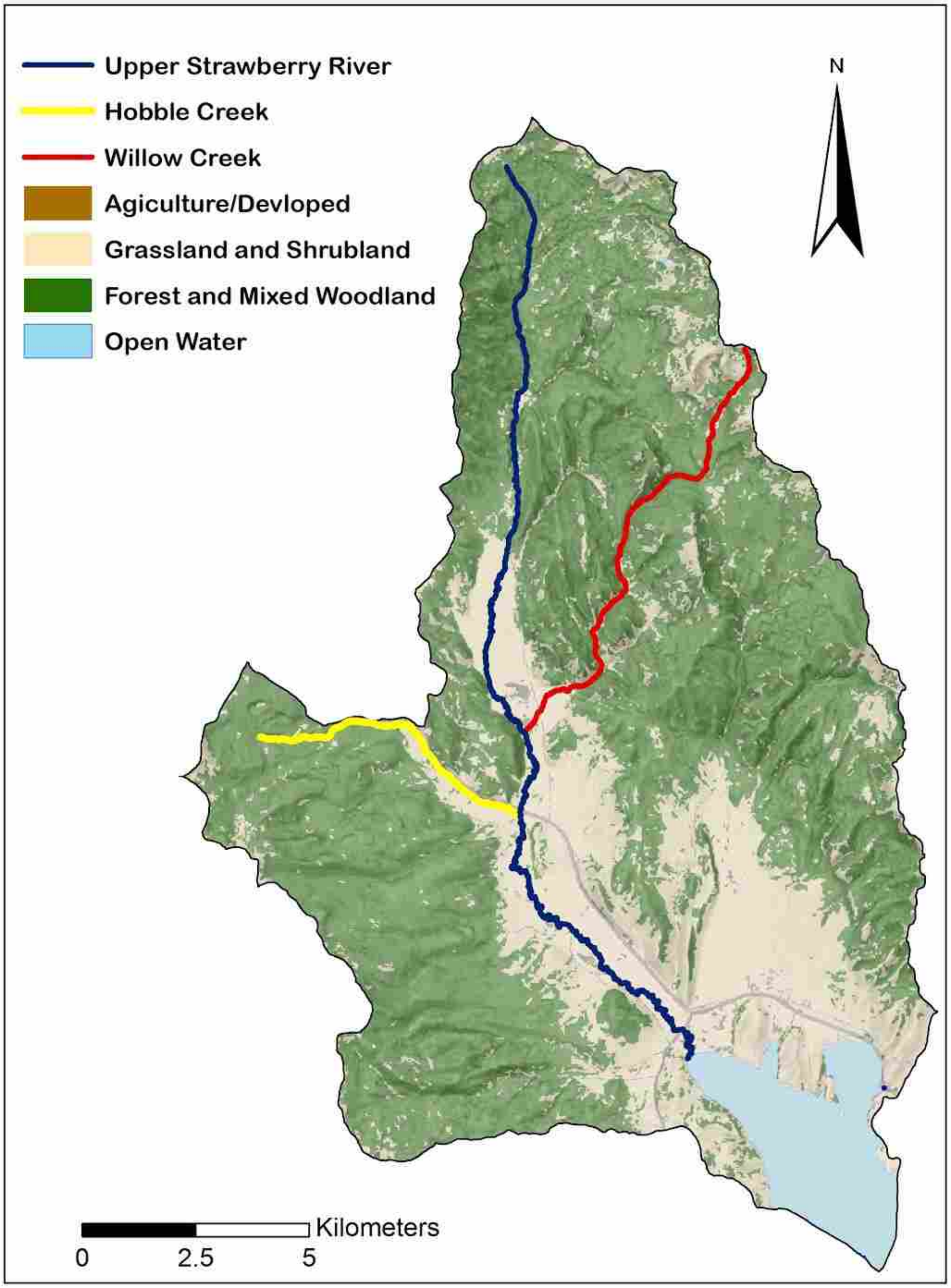


Figure 2–3. Upper Strawberry River Watershed. The Upper Strawberry River watershed encompasses a drainage area of approximately 226 km^2. The watershed drains to three main perennial streams: Hobble Creek (yellow), Willow Creek (red), and Upper Strawberry River (blue). Land Use in the area is divided up into agriculture/developed lands and riparian areas (~4% of the total land area), grasslands and shrublands (~16%), and forests and mixed woodland areas (~58%).

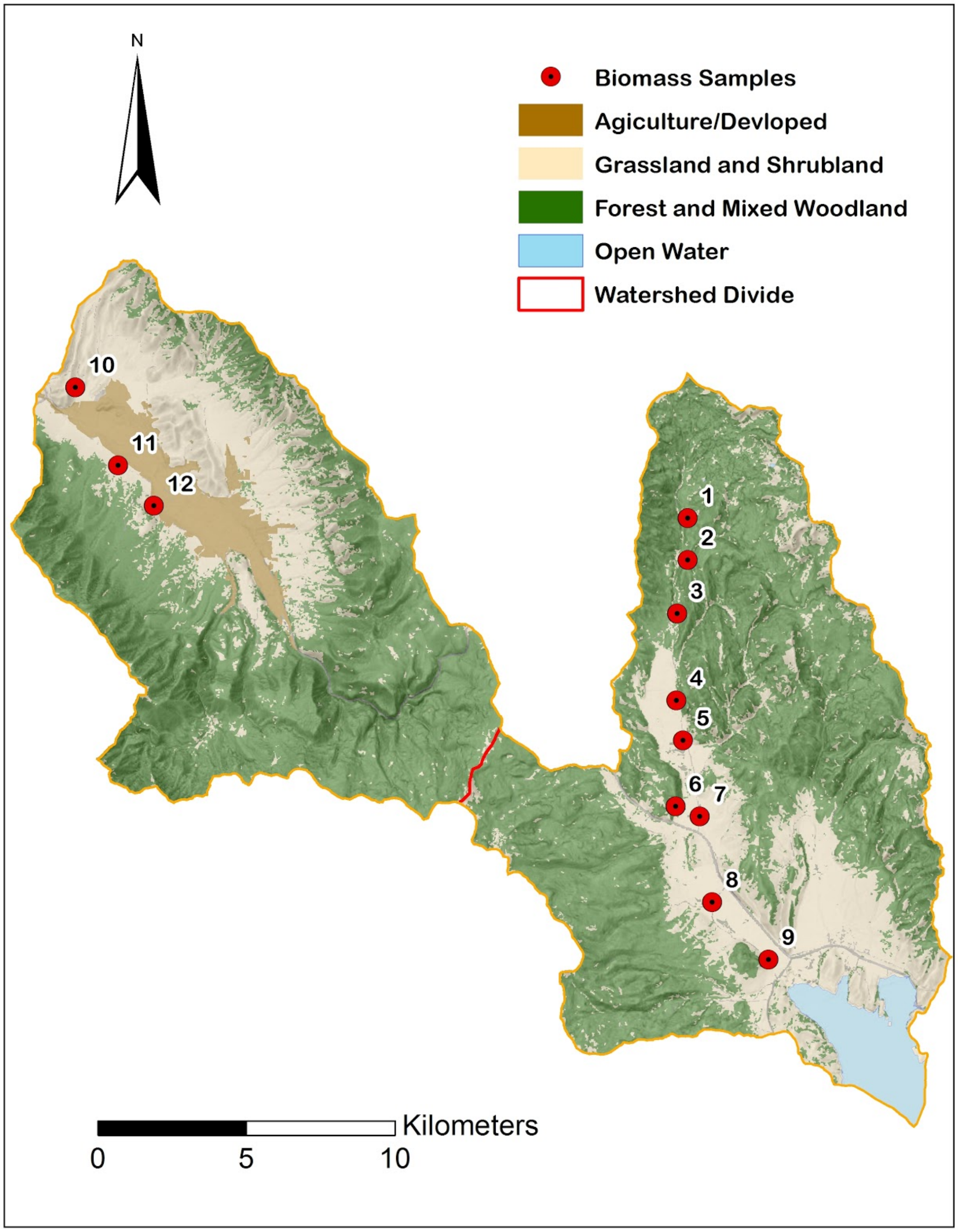


Figure 2–4. Sample Locations. A total of 12 samples were collected from the study area. Nine of the samples came from within 1 km of the Upper Strawberry River in the Upper Strawberry River watershed and the remaining three came from the Wallsburg watershed. The samples included all of the aboveground biomass in a square meter quadrat. The samples were divided into four different types: trees, living biomass, leaf litter or duff, and dead wood. Trees were sampled through tree bores and then their stand density was d The samples were divided into four different types: trees, living biomass, leaf litter or duff, and dead wood.

TABLES

Table 2–1. This table describes the results from sampling sites 1, 2, 6, and 12. All of these sites were found in upland wooded or forested areas. Upland sites displayed the highest values in virtually all of the tests.

Upland Sites								
Site	**Sub Category**	**Type**	**Biomass Mg ha^{-1}**	**TP mg kg^{-1}**	**TP kg ha^{-1}**	**DRP mg kg^{-1}**	**DRP kg ha^{-1}**
1	Aspen Dominant	Leaf Litter	5	1130	5.7	247	1.25
		Dead Wood	5	389	2.0	89	0.45
		Trees	270	111	29.9	29	7.76
		Understory	4	1555	5.9	192	0.72
		Mean	**-**	**796**	**-**	**139**	**-**
		Total	**284**	**-**	**43.4**	**-**	**10.18**
2	Conifer Dominant	Leaf Litter	35	1394	48.3	74	2.56
		Dead Wood	2	428	0.9	38	0.08
		Trees	148	1529	226.2	353	52.19
		Understory	3	1596	4.7	375	1.11
		Mean	**-**	**1237**		**210**	**-**
		Total	**188**	**-**	**280.1**	**-**	**55.95**
6	Aspen Dominant	Leaf Litter	5	584	3.2	94	0.52
		Dead Wood	0	-	0.0	-	0.00
		Trees	54	111	6.0	29	1.56
		Understory	6	810	4.9	132	0.80
		Mean	**-**	**502**	**-**	**85**	**-**
		Total	**65**	**-**	**14.1**	**-**	**2.88**
12	Scrub Oak Dominant	Leaf Litter	9	903	8.3	289	2.64
		Dead Wood	4	441	1.8	9	0.04
		Trees	72	358	25.9	95	6.85
		Understory	0	0	0.0	0	0.00
		Mean	**-**	**426**	**-**	**98**	**-**
		Total	**22**	**-**	**13.2**	**-**	**3.52**
	Means	Leaf Litter	14	1003	16.4	176	1.74
		Dead Wood	3	419	1.2	45	0.14
		Trees	136	527	72.0	126	17.09
		Understory	3	990	3.9	175	0.66
		Mean	**-**	**735**	**-**	**131**	**-**
		Total	**156**	**-**	**93.4**	**-**	**19.63**

Table 2–2. This table describes the results from sampling sites 5, 7, 9, 10, and 11. All of these sites were found in dry lowland grass or shrubland systems. These sites displayed little mass but comparable P concentrations to the other sites sampled in different ecotones.

Lowland Sites							
Site	**Sub Category**	**Type**	**Biomass Mg ha^{-1}**	**TP mg kg^{-1}**	**TP kg ha^{-1}**	**DRP mg ha^{-1}**	**DRP kg ha^{-1}**
5	Grass Dominant	Leaf Litter	0.5	1121	0.6	143	0.08
		Living Vegetation	5	724	3.4	173	0.82
		Mean	**-**	**922**	**-**	**158**	**-**
		Total	**5.5**	**-**	**4.0**	**-**	**0.90**
7	Sagebrush Dominant	Leaf Litter	4	1098	4.8	388	1.69
		Living Vegetation	1	1146	1.7	571	0.84
		Mean	**-**	**1122**	**-**	**479**	**-**
		Total	**5**	**-**	**6.5**	**-**	**2.53**
9	Sagebrush Dominant	Leaf Litter	5	791	4.2	324	1.73
		Living Vegetation	7	995	6.8	233	1.59
		Mean	**-**	**893**	**-**	**278**	**-**
		Total	**12**	**-**	**11.0**	**-**	**3.32**
10	Grass Dominant	Leaf Litter	2	799	1.3	195	0.32
		Living Vegetation	6	939	5.9	391	2.47
		Mean	**-**	**869**	**-**	**293**	**-**
		Total	**8**	**-**	**7.2**	**-**	**2.79**
11	Sagebrush Dominant	Leaf Litter	2	906	1.7	176	0.32
		Living Vegetation	22	655	14.7	127	2.87
		Mean	**-**	**781**	**-**	**152**	**-**
		Total	**24**	**-**	**16.4**	**-**	**3.19**
	Means	Leaf Litter	3	943	2.5	245	0.83
		Living Vegetation	8	892	6.5	299	1.72
		Mean	**-**	**917**	**-**	**272**	**-**
		Total	**11**	**-**	**9.0**	**-**	**2.55**

Table 2–3. This table describes the results from sampling sites 3, 4, and 8. All of these sites were found in riparian or wet meadow systems.

Wet Lowland Sites							
Site	**Sub Category**	**Type**	**Biomass kg ha^{-1}**	**TP mg kg^{-1}**	**TP kg ha^{-1}**	**DRP mg kg^{-1}**	**DRP kg ha^{-1}**
3	Willow Dominant	Leaf Litter	8	566	4.6	75	0.60
		Living Vegetation	8	881	7.2	108	0.89
		Mean	**-**	**723**	**-**	**92**	**-**
		Total	**16**	**-**	**11.8**	**-**	**1.50**
8	Willow Dominant	Leaf Litter	5	1894	9.1	236	1.13
		Living Vegetation	17	802	13.6	141	2.38
		Mean	**-**	**1348**	**-**	**188**	**-**
		Total	**22**	**-**	**22.6**	**-**	**3.51**
4	Grass Dominant	Leaf Litter	2	1114	2.4	162	0.35
		Living Vegetation	5	660	3.4	173	0.89
		Mean	**-**	**887**	**-**	**167**	**-**
		Total	**7**	**-**	**5.8**	**-**	**1.24**
	Means	Leaf Litter	5	1191	5.3	158	0.69
		Living Vegetation	10	781	8.1	141	1.39
		Mean	**-**	**986**	**-**	**149**	**-**
		Total	**15**	**-**	**13.4**	**-**	**2.08**

APPENDIX

The tables in this appendix show all data used for calculating P Index risk scores for each individual pathway and for the overall risk score for 58 field locations described in Chapter 1. The tables identify individual field-sites by a site numbers from 1 to 61 (total is 58 field-sites because three sites were eliminated either due to recording errors or being outside of the study area). Chapter two site photos are displayed following the tables.

Table A–1. Field-site descriptions for 58 locations in the Wallsburg watershed including site number, land class (agriculture, shrubland, and forest), slope, the type of livestock observed at any time in the year at each site, a visual erosion score, and the Olsen extractable P concentration (STP).

Site No.	Land Use Type	Slope %	Livestock Observed	Visual Erosion Score	Olsen STP mg kg^{-1}
1	Agriculture	0	-	0	69.7
4	Forest	23	Sheep	2	38.3
5	Shrubland	6	Sheep	1	52.2
6	Agriculture	0	Beef Cattle	0	23.5
7	Forest	15	-	1	17.5
8	Agriculture	4	Beef Cattle	0	22.5
9	Agriculture	6	Beef Cattle	1	60.1
10	Agriculture	7	Horses	4	34.1
11	Agriculture	9	Horses	3	45.4
12	Agriculture	0	-	1	19.4
13	Agriculture	6	-	0	11.2
14	Agriculture	2	Beef Cattle	2	31.8
15	Shrubland	13	-	2	32.4
16	Shrubland	11	Sheep	3	50.7
18	Agriculture	6	Horses	0	37.0
19	Agriculture	4	Beef Cattle	1	7.5
20	Agriculture	0	Beef Cattle	0	11.8
21	Agriculture	0	-	0	10.8

22	Agriculture	5	Horses	2	24.5
23	Shrubland	20	-	3	41.8
24	Forest	18	-	3	36.2
25	Shrubland	20	-	5	50.9
26	Shrubland	10	-	2	43.4
27	Agriculture	7	-	2	17.4
28	Forest	6	-	3	72.3
29	Shrubland	10	-	4	68.5
30	Agriculture	2	Beef Cattle	0	10.0
31	Agriculture	5	-	1	16.0
32	Agriculture	5	-	0	27.5
33	Forest	49	-	2	82.8
34	Forest	31	-	1	7.6
35	Shrubland	51	-	1	19.1
36	Shrubland	14	-	1	19.7
37	Shrubland	28	Beef Cattle	2	12.7
38	Forest	20	Beef Cattle	1	14.3
39	Shrubland	11	Beef Cattle	1	24.1
40	Shrubland	11	Beef Cattle	3	8.0
41	Shrubland	18	Beef Cattle	3	12.9
42	Forest	39	-	3	18.0
43	Shrubland	100	-	2	38.9
44	Forest	97	-	2	36.3
45	Forest	97	-	5	10.8
46	Forest	14	Sheep	1	44.2
47	Shrubland	14	-	1	25.5
48	Forest	39	-	1	36.5
49	Shrubland	27	-	0	43.1
50	Forest	33	-	0	38.6
51	Agriculture	21	-	0	56.9
52	Shrubland	28	-	0	21.6
53	Shrubland	24	-	0	41.8
54	Shrubland	27	-	0	20.6
55	Shrubland	26	-	0	28.4
56	Shrubland	25	-	0	51.1
57	Forest	38	-	0	32.4
58	Agriculture	5	-	0	18.3
59	Forest	19	-	0	41.9
60	Shrubland	9	-	0	65.2
61	Agriculture	10	Sheep	0	59.0

Table A–2. Phosphorus Index Pathway 1 field-site calculation data and risk scores for 58 field-sites in the Wallsburg watershed. Data includes the following inputs for the revised universal soil loss equation (RUSLE): soil erodibility (K), erosivity (R), practice factor (P), length/slope factor (LS), and cover factor (C). The average annual soil loss predicted by RUSLE (A) is given in tons/ac/yr.

Site No.	Sediment Delivery Rate RUSLE						Manure Factor	Weighted Sediment Delivery Factor	Soil Total P Concentration	Sediment-Bound P Loss Risk
	K	R	P	LS	C	A			mg kg-1	Pathway 1
1	0.43	18	1	0.2	0.008	0.011	1	0.16	2.8	0.0047
4	0.37	18	1	8.8	0.012	0.700	1	0.13	1.4	0.1924
5	0.32	18	1	1.2	0.013	0.089	1	0.15	1.4	0.0319
6	0.2	18	1	0.2	0.011	0.007	1	0.14	2.1	0.0019
7	0.28	18	1	2.7	0.140	1.880	1	0.11	2.4	0.3429
8	0.24	18	1	0.3	0.010	0.014	1	0.12	1.8	0.0031
9	0.24	18	1	0.7	0.010	0.033	1	0.12	1.7	0.0102
10	0.37	18	1	2.0	0.100	1.364	1	0.12	1.8	0.3327
11	0.37	18	1	0.9	0.100	0.599	1	0.12	2.6	0.1621
12	0.32	18	1	0.4	0.310	0.799	1	0.14	2.1	0.1937
13	0.2	18	1	0.2	0.011	0.007	1	0.14	2.3	0.0016
14	0.43	18	1	1.3	0.013	0.130	1	0.14	1.8	0.0361
15	0.37	18	1	2.5	0.038	0.642	1	0.12	1.6	0.1571
16	0.37	18	1	3.2	0.012	0.258	1	0.17	2.0	0.1052
18	0.32	18	1	0.3	0.003	0.005	1	0.12	2.0	0.0012
19	0.24	18	1	0.2	0.002	0.002	1	0.13	2.4	0.0003
20	0.24	18	1	0.2	0.002	0.002	1	0.13	2.9	0.0003
21	0.32	18	1	1.0	0.002	0.012	1	0.13	2.1	0.0024
22	0.2	18	1	0.8	0.003	0.009	1	0.18	1.5	0.0029
23	0.32	18	1	2.2	0.060	0.748	1	0.13	1.6	0.2210
24	0.28	18	1	6.2	0.012	0.376	1	0.11	1.6	0.0885
25	0.28	18	1	7.3	0.012	0.443	1	0.11	1.9	0.1196
26	0.28	18	1	2.1	0.070	0.750	1	0.11	2.2	0.1888
27	0.28	18	1	2.0	0.070	0.722	1	0.12	2.1	0.1446
28	0.32	18	1	1.1	0.013	0.082	1	0.11	2.4	0.0253
29	0.28	18	1	5.2	0.085	2.247	1	0.12	2.2	0.7155
30	0.28	18	1	0.2	0.010	0.009	1	0.13	1.7	0.0019
31	0.32	18	1	0.5	0.311	0.956	1	0.14	2.8	0.2321
32	0.32	18	1	1.0	0.002	0.011	1	0.12	2.7	0.0024
33	0.24	18	1	11.5	0.011	0.548	1	0.11	1.6	0.1853
34	0.24	18	1	9.0	0.011	0.427	1	0.10	1.7	0.0682
35	0.1	18	1	17.2	0.042	1.301	1	0.11	1.9	0.2429

36	0.32	18	1	2.2	0.038	0.483	1	0.14	3.0	0.1216
37	0.24	18	1	6.3	0.040	1.091	1	0.13	1.5	0.2257
38	0.32	18	1	6.6	0.003	0.114	1	0.13	1.8	0.0249
39	0.24	18	1	1.9	0.012	0.098	1	0.13	1.8	0.0238
40	0.28	18	1	3.1	0.012	0.184	1	0.12	1.6	0.0353
41	0.28	18	1	6.1	0.012	0.367	1	0.13	1.7	0.0761
42	0.1	18	1	16.7	0.011	0.330	1	0.10	1.9	0.0597
43	0.1	18	1	59.7	0.011	1.181	1	0.10	1.5	0.2558
44	0.24	18	1	55.1	0.011	2.619	1	0.10	1.6	0.5562
45	0.24	18	1	55.1	0.013	3.095	1	0.10	1.7	0.4988
46	0.37	18	1	5.1	0.003	0.103	1	0.15	2.1	0.0344
47	0.28	18	1	3.1	0.003	0.047	1	0.12	2.1	0.0101
48	0.28	18	1	17.7	0.011	0.981	1	0.11	1.6	0.2230
49	0.28	18	1	11.1	0.012	0.673	1	0.16	2.3	0.2447
50	0.28	18	1	14.1	0.038	2.691	1	0.14	1.9	0.8329
51	0.24	18	1	7.9	0.070	2.383	1	0.15	2.1	0.8951
52	0.37	18	1	11.6	0.012	0.929	1	0.13	2.2	0.2131
53	0.37	18	1	9.1	0.012	0.726	1	0.13	2.1	0.2026
54	0.24	18	1	10.9	0.012	0.566	1	0.13	2.5	0.1264
55	0.24	18	1	10.4	0.003	0.135	1	0.13	1.8	0.0339
56	0.24	18	1	9.9	0.003	0.128	1	0.13	2.2	0.0393
57	0.28	18	1	16.9	0.038	3.239	1	0.15	1.8	0.9635
58	0.2	18	1	1.0	0.010	0.036	1	0.14	1.9	0.0089
59	0.37	18	1	6.6	0.012	0.528	1	0.13	2.4	0.1471
60	0.37	18	1	2.1	0.012	0.170	1	0.14	2.0	0.0617
61	0.32	18	1	2.5	0.007	0.102	1	0.13	1.7	0.0342

Table A–3. Phosphorus Index Pathway 2 field-site calculation data and risk scores for 58 field-sites in the Wallsburg watershed.

Site No.	Base Runoff Volume	Runoff Adjustment Factor	Soluble Soil P and Applied P	Coefficient	Rainfall Runoff P Loss Risk Pathway 2
1	2.145	1.37	13.5	0.22	8.73
4	2.145	0.5	0.6	0.22	0.15
5	2.145	0.12	0.8	0.22	0.04
6	2.145	0.55	16.3	0.22	4.22
7	2.145	0.15	0.2	0.22	0.01
8	2.145	1.37	0.2	0.22	0.15
9	2.145	1.08	14.4	0.22	7.32
10	2.145	1.08	3.1	0.22	1.59
11	2.145	1.08	4.9	0.22	2.49
12	2.145	0.55	0.2	0.22	0.05
13	2.145	0.55	0.1	0.22	0.03
14	2.145	1.08	17.9	0.22	9.14
15	2.145	0.5	0.3	0.22	0.08
16	2.145	0.5	3.0	0.22	0.72
18	2.145	0.3	15.1	0.22	2.14
19	2.145	1.37	0.1	0.22	0.05
20	2.145	1.37	0.1	0.22	0.08
21	2.145	0.55	0.1	0.22	0.03
22	2.145	0.3	3.8	0.22	0.54
23	2.145	0.5	0.4	0.22	0.10
24	2.145	0.01	0.4	0.22	0.00
25	2.145	0.5	0.5	0.22	0.13
26	2.145	0.5	0.5	0.22	0.11
27	2.145	1.08	0.2	0.22	0.09
28	2.145	0.15	0.8	0.22	0.05
29	2.145	0.5	0.7	0.22	0.17
30	2.145	1.37	25.8	0.22	16.71
31	2.145	0.55	0.2	0.22	0.04
32	2.145	0.55	0.3	0.22	0.08
33	2.145	0.5	0.9	0.22	0.21
34	2.145	1.1	0.1	0.22	0.04
35	2.145	0.12	0.2	0.22	0.01

36	2.145	0.12	0.2	0.22	0.01
37	2.145	1	0.4	0.22	0.19
38	2.145	0.62	0.4	0.22	0.12
39	2.145	1	0.5	0.22	0.25
40	2.145	0.5	0.4	0.22	0.08
41	2.145	0.5	0.4	0.22	0.10
42	2.145	0.12	0.2	0.22	0.01
43	2.145	0.12	0.4	0.22	0.02
44	2.145	0.62	0.4	0.22	0.11
45	2.145	0.62	0.1	0.22	0.03
46	2.145	0.5	0.9	0.22	0.21
47	2.145	0.5	0.3	0.22	0.06
48	2.145	1.1	0.4	0.22	0.20
49	2.145	0.5	0.5	0.22	0.11
50	2.145	0.5	0.4	0.22	0.10
51	2.145	0.3	0.6	0.22	0.09
52	2.145	0.5	0.2	0.22	0.05
53	2.145	0.5	0.4	0.22	0.10
54	2.145	1	0.2	0.22	0.10
55	2.145	1	0.3	0.22	0.14
56	2.145	1	0.5	0.22	0.26
57	2.145	0.5	0.3	0.22	0.08
58	2.145	0.55	16.2	0.22	4.21
59	2.145	0.5	0.4	0.22	0.10
60	2.145	0.5	0.7	0.22	0.16
61	2.145	0.55	7.6	0.22	1.97

Table A–4. Phosphorus Index Pathway 3 field-site calculation data and risk scores for 58 field-sites in the Wallsburg watershed.

Site No.	Base Snowmelt Volume	Fall Soil Condition Factor	Residue P and Surface Applied P	Coefficient	Snowmelt Runoff P Loss Risk Pathway 3
1	2.45	0.75	3.0	0.18	0.99
4	2.45	1	3.0	0.18	1.32
5	2.45	1	2.7	0.18	1.19
6	2.45	0.75	38.0	0.18	12.58
7	2.45	1	2.3	0.18	1.01
8	2.45	0.75	12.2	0.18	4.02
9	2.45	1	16.7	0.18	7.38
10	2.45	1	1.0	0.18	0.44
11	2.45	1	2.0	0.18	0.88
12	2.45	0.4	2.5	0.18	0.44
13	2.45	0.75	3.0	0.18	0.99
14	2.45	1	20.6	0.18	9.08
15	2.45	1	2.7	0.18	1.19
16	2.45	0.75	2.7	0.18	0.89
18	2.45	1	2.0	0.18	0.88
19	2.45	1	3.0	0.18	1.32
20	2.45	0.75	3.0	0.18	0.99
21	2.45	1	3.0	0.18	1.32
22	2.45	1	7.5	0.18	3.32
23	2.45	1	2.7	0.18	1.19
24	2.45	1	3.0	0.18	1.32
25	2.45	1	2.7	0.18	1.19
26	2.45	1	2.7	0.18	1.19
27	2.45	1	3.0	0.18	1.32
28	2.45	1	2.5	0.18	1.08
29	2.45	1	2.7	0.18	1.19
30	2.45	1	3.0	0.18	1.32
31	2.45	1	14.7	0.18	6.49
32	2.45	1	3.0	0.18	1.32
33	2.45	1	3.0	0.18	1.32
34	2.45	1	2.3	0.18	1.01
35	2.45	1	1.6	0.18	0.71

36	2.45	1	2.7	0.18	1.19
37	2.45	1	2.7	0.18	1.19
38	2.45	1	3.0	0.18	1.32
39	2.45	1	2.7	0.18	1.19
40	2.45	1	2.7	0.18	1.19
41	2.45	1	2.7	0.18	1.19
42	2.45	1	3.0	0.18	1.32
43	2.45	1	2.3	0.18	1.01
44	2.45	1	3.0	0.18	1.32
45	2.45	1	3.0	0.18	1.32
46	2.45	1	3.0	0.18	1.32
47	2.45	1	2.7	0.18	1.19
48	2.45	1	3.0	0.18	1.32
49	2.45	1	1.6	0.18	0.71
50	2.45	1	3.0	0.18	1.32
51	2.45	1	3.0	0.18	1.32
52	2.45	1	2.7	0.18	1.19
53	2.45	1	1.6	0.18	0.71
54	2.45	1	2.7	0.18	1.19
55	2.45	1	2.7	0.18	1.19
56	2.45	1	2.7	0.18	1.19
57	2.45	1	3.0	0.18	1.32
58	2.45	0.75	38.0	0.18	12.58
59	2.45	1	3.0	0.18	1.32
60	2.45	1	2.7	0.18	1.19
61	2.45	1	3.0	0.18	1.32

Table A–5. Table A5. Summary of individual pathway and overall phosphorus index scores for 58 field-sites in the Wallsburg watershed.

Site No.	Sediment-Bound P Loss Risk Pathway 1	Rainfall Runoff P Loss Risk Pathway 2	Snowmelt Runoff P Loss Risk Pathway 3	Total P Loss Risk P Index
1	0.0047	8.73	0.99	9.7
4	0.1924	0.15	1.32	1.7
5	0.0319	0.04	1.19	1.3
6	0.0019	4.22	12.58	16.8
7	0.3429	0.01	1.01	1.4
8	0.0031	0.15	4.02	4.2
9	0.0102	7.32	7.38	14.7
10	0.3327	1.59	0.44	2.4
11	0.1621	2.49	0.88	3.5
12	0.1937	0.05	0.44	0.7
13	0.0016	0.03	0.99	1.0
14	0.0361	9.14	9.08	18.3
15	0.1571	0.08	1.19	1.4
16	0.1052	0.72	0.89	1.7
18	0.0012	2.14	0.88	3.0
19	0.0003	0.05	1.32	1.4
20	0.0003	0.08	0.99	1.1
21	0.0024	0.03	1.32	1.4
22	0.0029	0.54	3.32	3.9
23	0.2210	0.10	1.19	1.5
24	0.0885	0.00	1.32	1.4
25	0.1196	0.13	1.19	1.4
26	0.1888	0.11	1.19	1.5
27	0.1446	0.09	1.32	1.6
28	0.0253	0.05	1.08	1.2
29	0.7155	0.17	1.19	2.1
30	0.0019	16.71	1.32	18.0
31	0.2321	0.04	6.49	6.8
32	0.0024	0.08	1.32	1.4
33	0.1853	0.21	1.32	1.7
34	0.0682	0.04	1.01	1.1
35	0.2429	0.01	0.71	1.0

36	0.1216	0.01	1.19	1.3
37	0.2257	0.19	1.19	1.6
38	0.0249	0.12	1.32	1.5
39	0.0238	0.25	1.19	1.5
40	0.0353	0.08	1.19	1.3
41	0.0761	0.10	1.19	1.4
42	0.0597	0.01	1.32	1.4
43	0.2558	0.02	1.01	1.3
44	0.5562	0.11	1.32	2.0
45	0.4988	0.03	1.32	1.9
46	0.0344	0.21	1.32	1.6
47	0.0101	0.06	1.19	1.3
48	0.2230	0.20	1.32	1.7
49	0.2447	0.11	0.71	1.1
50	0.8329	0.10	1.32	2.3
51	0.8951	0.09	1.32	2.3
52	0.2131	0.05	1.19	1.5
53	0.2026	0.10	0.71	1.0
54	0.1264	0.10	1.19	1.4
55	0.0339	0.14	1.19	1.4
56	0.0393	0.26	1.19	1.5
57	0.9635	0.08	1.32	2.4
58	0.0089	4.21	12.58	16.8
59	0.1471	0.10	1.32	1.6
60	0.0617	0.16	1.19	1.4
61	0.0342	1.97	1.32	3.3

Chapter 2 – Site Photos

Site 1

Site 2

Site 3

Site 4

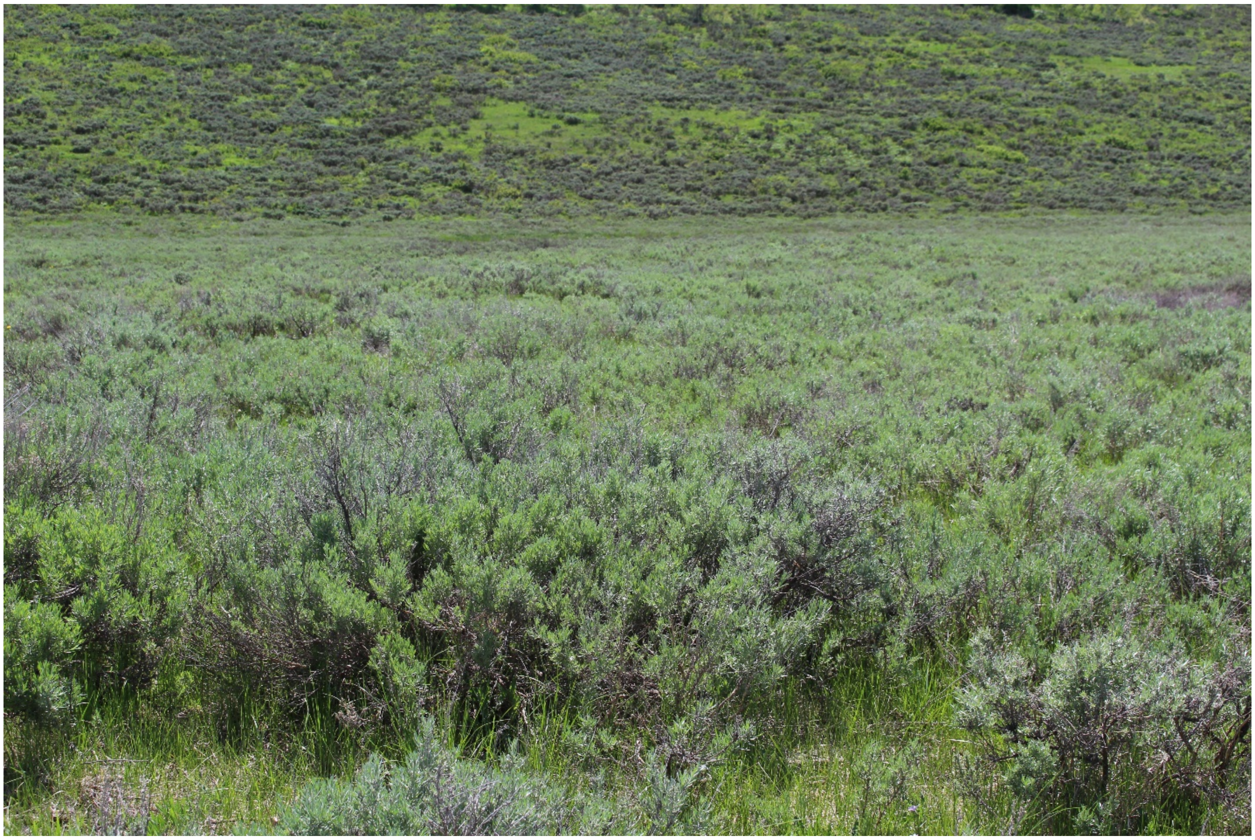
Site 5

Site 6

Site 7

Site 8

Site 9



Site 10

Site 11

Site 12