Assessing Phosphorus Transportation and the High Risk Runoff Areas
The Cannon River Watershed, Southeastern MN

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ABSTRACT

The high content of algae in the Byllesby Reservoir in southeast Minnesota has causes concern in the local community and was recognized by the Minnesota Pollution Control Agency (MPCA) in 2000 as a pertinent environmental issue. The difficulty in correlating soil phosphorus amounts to the eutrophication of nearby surface waters leads scientists to use a more indirect method to determine this relationship by correlating soil phosphorus amount and the amount of phosphorus in runoff. This study examines the potential risk of phosphorus runoff in the Cannon River Watershed specifically above the Byllesby reservoir. Based on four variables (available phosphorus amount, slope, the K-factor, and land use), a composite map in ArcMap was derived defining five categories in the Watershed ranging from no risk to very high risk of phosphorus runoff. The most significant factors are clearly the K-factor and phosphorus amount. The results show the majority of the watershed is at high risk for phosphorus runoff with some specific areas around rivers and lakes being at very high risk. Areas of medium risk are found in small sections throughout the watershed, with a larger medium risk sections surrounding the Byllesby Reservoir. Areas of low risk in the composite map are disregarded because they correspond with areas of no data for either the phosphorus amount factor or the K-factor.

Key Words: phosphorus, runoff, GIS, eutrophication, algae, Minnesota, Reservoir

INTRODUCTION:

Byllesby Reservoir, located in the Cannon River Watershed (CRW) of southeastern Minnesota, suffers from extreme algal blooms for the majority of open water time (Watkins and Ganske, 2003). A probable culprit of this environmental problem is the nutrient phosphorus (P). Previously, phosphorus has been ignored as an important nutrient influencing algal blooms, with more focus on nitrogen. Recently, phosphorus has been more closely monitored and considered to be extremely relevant to eutrophication in aquatic ecosystems as a result of a better understanding of its mobility and chemistry (Schendel et al., 2004). Despite the ever increasing understanding of phosphorus, it still proves difficult to directly relate soil phosphorus amounts with that of phosphorus in surface waters and levels of eutrophication in these water bodies (Litke, 1999). Therefore, soil phosphorus amounts and eutrophication of waters must be related indirectly through soil runoff and the amount of phosphorus in runoff (Sibbesen and Sharpley, 1997).

This study locates areas in the CRW with high-risks for phosphorus runoff. Data were downloaded from the Minnesota Department of Natural Resources (DNR) and the Minnesota Land Management Information Center (LMIC) including soil phosphorus amount, slope, K-factor (erosion) and land use within the watershed. These variables are ranked and weighted based on studies such as Eghball and Gilley (2001) and best judgments. The factors are then added together forming a composite map of the watershed, which displays areas of high phosphorus runoff risks.

BACKGROUND:

What is phosphorus and why is it important?

Phosphorus the second most abundant nutrient in soil matter, it is essential to plant growth, seed formation, root development, maturity of crops and strength of crops(Stevenson and Cole, 1999). However, in comparison to other nutrients in the earth's crust it is relatively low in abundance (about 1100-1200mg kg-1) (Morgan, 1997) and the eleventh most common (Flaten et al., 2003). Its primary role is energy transfer in organisms (Busman et al., 2002). Though plants differ in nutritional requirements, generally small quantities of phosphorus are needed but essential (Stevenson and Cole, 1999). Without phosphorus, plants growth process slows and younger plants will have abnormally darker green to red or purple leaf pigments due to excess amounts of anthocyanin (Stevenson and Cole, 1999). The majority of phosphorus uptake by agricultural plants takes place in its first year (5-10% of the average amount of applied fertilizer in agricultural plants) and during the first few months of spring. However, it is essential to have a reserve pool of phosphorus in order to assure proper development of the plant because low phosphorus amount in the soil cannot immediately be compensated by phosphorus application. It takes time for phosphorus to be taken up by plant roots (Sibbesen and Sharpley, 1997).

Aquatically, phosphorus is the principle limiting nutrient in fresh water. It has no known direct toxic effects (Schendel et al., 2004), however, in excessive amounts, phosphorus causes unattractive and environmentally threatening algal blooms as well as potential drinking water problems. Algal blooms block light from entering water bodies, inhibiting photosynthesis, the basic process of life. Hence, algal blooms can eventually cause an entire aquatic ecosystem to collapse. The problem becomes more difficult to treat the larger it gets and the longer ignored. It has been estimated that after greatly reducing external sources of phosphorus from a lake which has been accumulating phosphorus in sediment for an extended period, the rivers and lakes will continue to release 22-400% of what was originally being contributed to the water system (Rehm and Schmitt, 2002a). This is a result of intrasystem cycling in an aquatic environment. Once phosphorus enters an ecosystem, it is highly recycled and can essentially be locked in lake waters. This can cause a permanent phase change (Camill, 2005). Algae growing as a result of excess phosphorus slow water movement, cause bacterial growth because they release dissolved organic carbon, and raise pH levels which then inhibit reactants used in treatment processes such as aluminate flocculent (Garnier et al., 2005). Microbial respiration breaking down dead algae will also consume dissolved oxygen, an element necessary for fish and without photosynthesis there is no oxygen replenishment (Busman et al., 2002; Camill, 2005).

For some time, scientists believed phosphorus was immobile and therefore contributed little to the excess nutrients causing algal blooms. Now, it is understood that although movement is slow and primarily through sandy, porous material, phosphorus is still a viable culprit because of its large role in life development (Schendel et al., 2004). One of the major contributions to excess phosphorus in water bodies and therefore algal blooms is erosion, which, in southwestern Minnesota, is primarily a result of agricultural practices. Livestock manure increases phosphorus levels and therefore the amount of phosphorus available for erosion (Jordan et al., 2005). Thus, phosphorus is a vital element supporting terrestrial life, yet excessive amounts can cause major environmental issues in aquatic systems.

Where does phosphorus come from?

Unlike nitrogen, which is primarily sourced from the atmosphere and then incorporated into earthen and aquatic environments, phosphorus is sourced from weathering minerals and has a more limited cycling processes (Camill, 2005; Flaten et al., 2003). For simplification purposes, contribution of phosphorus can be divided into non-point and point sources. Point sources are easier to quantify. These are when nutrients travel in waters emitted through a pipe (such as from a waste water treatment plant), with a known diameter and flow velocity. Non-point sources are much more difficult to trace and calculate as they are transported with waters traveling through land forms of varying areas, depths and porosities (Fetter, 1980).

Recognition of the effects of excess phosphorus in the environment and its sources have prompted efforts to reduce contaminants sourced from point sources, such as dish and laundry detergents, lawn fertilizers, and septic systems that are either poured down drains or run into stormwater drainage systems. These attempts have been generally successful since the 1960s (Sharpley and Rekolainen, 1997) and point source contamination has been greatly reduced as a result of waste water treatment plants. However, the region of this study has yet to prohibit certain threatening point sources such as dish detergent. Currently, more attention is directed toward non-point sources where pipes do not quantify phosphorus amounts. A main concern regards agricultural areas and their possible fertilizer application.

Phosphorus types and movement

Types:

The many forms of phosphorus influence its transportation and it is necessary to recognize these forms in order to reduce phosphorus runoff from non-point sources. The categories and sub-categories of phosphorus are mapped in Fig. 1. Phosphorus is only available to plant roots in specific forms. Unavailable phosphorus is stored in the soil as a reserve because plants are limited in the quantity of phosphorus they can absorb (Sharpley et al., 2001). Different crops are able to absorb varying amounts of phosphorus ranging from $1 g/m^2$ of cropland per season for crops such as alfalfa and wheat, to $3 g/m^2$ for crops such as celery and rice (Rendig and Taylor, 1989). Total phosphorus (TP) is the term used to describe all forms of phosphorus. Phosphorus available to plants is referred to as bioavailable P (BP) or Total Reactive Phosphorus (TRP). In non-point sources, TP is most easily measured and then broken into dissolved phosphorus (DP) and particulate phosphorus (PP). DP is composed of truly soluble P, orthophosphates, polyphosphates, pyrophosphates, colloidal P and organic excretion (Busman et al., 2002). In water, with Proper analytical methods can distinguish nine forms of phosphorus (Rehm and Schmitt, 2002a). Most commonly, phosphorus is present in orthophosphate ions ($H_2PO_4^-$ and $HPO^{2-}{}_4$). These are the soluble forms of phosphorus immediately available to plants (Stevenson and Cole, 1999). Dissolved phosphorus and particulate phosphorus are generally supplied from different land types. The majority of runoff from non-cultivated land, such as pastures and fields with little or no tillage, is in the form of DP and is one hundred percent available to plants (Natural Resources Conservation Service, 1994). PP includes phosphorus adsorbed to soil particles, phosphorus precipitates, as well as living

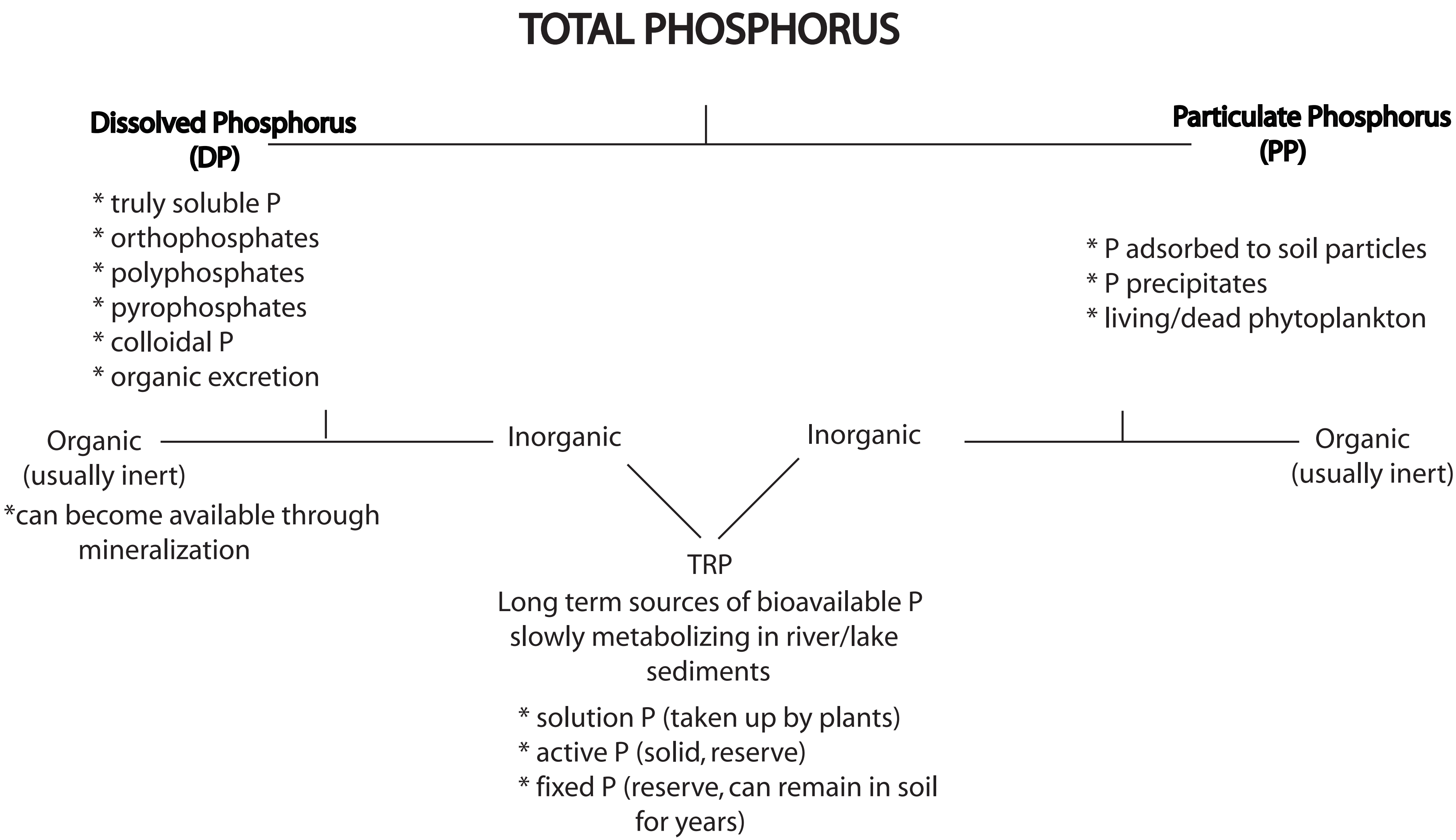


Figure 1. Map of Phosphorus Types

and dead phytoplankton in water bodies. Seventy five to ninety percent of phosphorus from cultivated land runoff is in the form of PP. It easily becomes less available to plants and algae depending on how it binds to other minerals and organic compounds in the soil (Natural Resources Conservation Service, 1994; Sharpley and Rekolainen, 1997). Both forms of phosphorus, DP and PP have subcategories of organic and inorganic phosphorus. Organic phosphorus is usually inert and unavailable to plants, but, can become available to plants through mineralization, a process where microorganisms break down organic phosphorus, releasing inorganic phosphorus (Busman et al., 2002; Rehm and Schmitt, 2002b). The inorganic forms of DP and PP are the more readily available and long term sources of bioavailable phosphorus/TRP (Flaten et al., 2003).

TRP can be divided into further categories. Solution P, the smallest pool, exists as an orthophosphate and is the only form plants can immediately absorb. Active P is a solid form, and though unacceptable for plant uptake, easily chemically reacts to become solution P. Finally, fixed P can remain in soils for many years undisturbed by microorganisms. However, with a series of more complicated chemical reactions, this too can be broken down (Busman et al., 2002).

As phosphorus moves over or through material, it is constantly changing forms. Exchanges can occur between DP and PP as well as organic P and inorganic P through mineralization. Mineralized phosphorus can adsorb to colloidal particles and will therefore be removed from a solution. Alternatively, it can precipitate as insoluble phosphates after fixation/bonding to other elements such as with Ca, Fe or Al (Stevenson and Cole, 1999).

The ionic concentration of soils also causes phosphorus forms to vary. Most all soils have aluminum and iron oxides and hydrous oxides, all which react with phosphorus (Stevenson and Cole, 1999). Chemical forms of phosphorus in soil depend on soil characteristics such as moisture, pH, texture and ionic content. Inorganic P (available P) can be divided into calcium phosphates and iron and aluminum phosphates. The most common calcium phosphates are $Ca_{10}O(PO_4)_6$ (oxyapatite), $Ca_{10}F_2(PO_4)_6$ (fluorapatite), $Ca_{10}OH_2(PO_4)_6$ (hydroxyapatite), and $Ca_{10}CO_3(PO_4)_6$ (carbonate apatite). Less soluble calcareous soil compounds are $Ca_2(HPO4)_2$ (di-calcium) and $Ca_3(HPO4)_2$ (tri-calcium) (Stevenson and Cole, 1999). Smaller amounts of phosphorus are found in compounds such as $FePO_{4*}2H_2O$ (strengtite) and $AlPO_4$*$2H_2O$ (variscite). Organic P is found in compounds such as inositol phosphates, phospholipids, nucleic acids, nucleotides and some sugar phosphates (Morgan, 1997). The exact amount of each type of phosphorus depends on the ions available in the soil.

The pH of a soil dictates how phosphorus binds to other compounds. Acidic soils precipitate phosphorus as insoluble Fe- or Al-phosphates. Phosphorus fixation is most successful at slightly acidic or neutral pH. Soils with a high content of Fe and Al are more likely to fix phosphorus at these lower pH ranges (below 6.5) and therefore precipitate Iron and Aluminum phosphates, while calcareous soils will fix phosphorus more readily at higher pH ranges (above 6.5) precipitating calcareous phosphates, though never as much as Fe and Al rich soils (Fig. 2). Fixation also increases with higher clay content because fine grained texture provides more particles to which phosphorus can adsorb (Sharpley and Rekolainen, 1997). The more fixation of phosphorus in a soil, the less available it is for plant uptake (Stevenson and Cole, 1999). Phosphorus uptake also

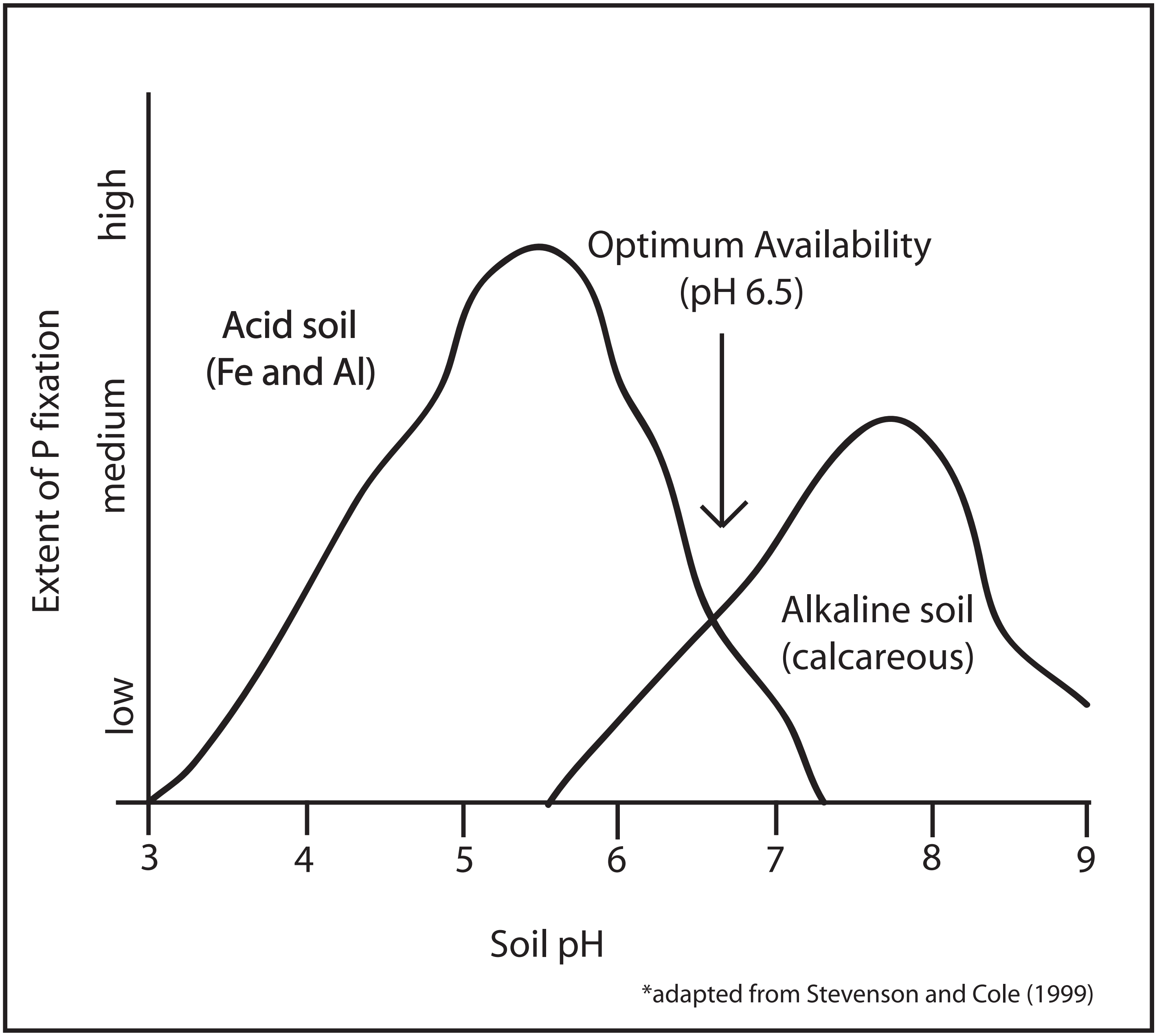


Figure 2. pH effect on the fixation of phosphorus.

increases with higher soil temperature, moisture, aeration and presence of specific nutrients (Sharpley and Rekolainen, 1997).

Movement:

The transportation of phosphorus is strongly dictated by the movement of water. There are three types of water movement. Overland flow is water flow over impermeable surfaces, such as pavement or over surfaces that have become so saturated they cannot hold more water. In Minnesota, this degree of saturation is rare, occurring only with heavy and prolonged precipitation (Tipping, 2005). However, in agricultural areas phosphorus may be capable of overland transportation despite unsaturated surfaces. PP adsorbs to soil particles and is therefore carried in turbid runoff traveling over the ground surface; a common occurrence in cultivated fields. DP is dissolved within water and therefore travels with waters carrying less sediment and can travel in subsurface flow where waters flow directly below the soil surface. The hydraulic conductivity determines the rate at which waters will flow through a medium. Water moves more rapidly through sandy soils or soils with macropores and earthworm tunnels as opposed to fine-grained and clayey soils. Phosphorus will move more efficiently through these soils based simply on faster transport of water. If the soil is saturated, water and phosphorus move even more quickly through soil because the lack of oxygen causes conversion of $Fe3+$ to $Fe2+$ and organic mineralization. Therefore, certain ion compositions and grain size dictate the amount of water and therefore phosphorus a soil can carry because of their hydraulic flow properties and the soils particle abilities for phosphorus sorption (Fetter, 1980; Sharpley and Rekolainen, 1997). All these factors make subsurface flow more difficult to analyze than surface flow.

The final form of phosphorus movement occurs in groundwater flow. This is generally a smaller portion of phosphorus transport and will not be addressed further in this paper, but in some cases can be up to 10-20% of phosphorus contribution (Litke, 1999). Another prominent influence in southeastern Minnesota is agricultural drainage methods, such as tiling which greatly aids phosphorus flow.

Measurement of phosphorus:

The numerous types of phosphorus and the equally numerous transportation mechanisms, make it difficult for scientists to measure phosphorus levels. There is no standard method to evaluate phosphorus amounts. In most literature, TP is measured and then divided into DP and PP. TP can be obtained from both soils and runoff. Soil sampling is tedious and difficult because of the many forms and modes of movement. It is difficult to determine how much of the soil phosphorus will contribute to eutrophication or pollution problems. When sampling soil for phosphorus amounts, problems such as, what form of phosphorus should be measured and is it practical to execute these procedures both financially and time wise? Furthermore, many tests are site specific, meaning they correctly correlate soil phosphorus and runoff phosphorus (that which is more apt to cause eutrophication) for one specific area and in another area a different technique or method of correlation may apply. In a test performed by Sharpley (Sharpley, 1995), iron oxide strips provided the most reliable information, whereas, in a study performed in the Minnesota River Basin a strong correlation was shown between soluble reactive phosphorus (SRP) extracted from the TRP in runoff and the methods of measurement which quantify phosphorus in terms of Mehlich-III, Olsen P and water extractable P (Fang et al., 2002). It is therefore very difficult to correlate soil phosphorus data to eutrophication. By using this data as one of many factors influencing phosphorus runoff amounts, scientists use a more indirect approach to determine how liable a soil is in contributing to eutrophication.

Soil P has a significant effect on total P runoff, but this does not eliminate other important factors such as land use, slope and precipitation which all affect soil P runoff. Recently, efforts have been made to create a universal equation with specific factors contributing to P loss in soils and surfaces. These factors are weighed and can be manipulated to be site specific. The results are equations such as the P Index to calculate amounts of P runoff in agricultural areas and RUSLE, a soil erosion potential equation.

The P Index /RUSLE:

The two important tools currently used to evaluate phosphorus runoff are the RUSLE (Revised Universal Soil Loss Equation) and the P Index. RUSLE is used to find annual expected erosion based on runoff, field slopes and cropping and management systems. Final units are in ton/acre/year and the equation is as follows:

$$A= R*K*L*S*C*P$$

Where:

A= spatial and temporal average soil loss per unit of area

R= rainfall and runoff

K= soil erosion factor

L= slope length

S= steepness of slope

C= land cover

P= land management

(Toy and Foster, 1998). This equation is often incorporated into the P Index, and is sometimes altered for certain regional circumstances. In Birr and Mulla's study (2001), USLE (Universal Soil Loss Equation), which does not have a C factor, was used because the area studied did not require such a factor (Birr and Mulla, 2001).

The P index is another tool to asses the risk of P movement through soils and into open water systems by considering both transport and source factors (Schendel et al., 2004). It was developed specifically to rank agricultural areas (Sharpley et al., 2001). Similar to RUSLE, certain factors are weighted depending on different locations to assess the vulnerability of an area for releasing P (Schendel et al., 2004). The variables considered are: sediment-bound phosphorus and soluble phosphorus from rainfall, as well as soluble phosphorus from snowmelt. These categories can be further broken down into sheet and rill erosion, manure factor, sediment delivery adjustment, sediment total phosphorus concentration, runoff volume, soluble phosphorus from soil, soluble phosphorus from applied fertilizer or manure, snowmelt runoff factor and phosphorus sources for snowmelt (Department of Soil Water and Climate, 2004).

In the past, there has been much debate regarding the validity of the P index on a national and regional scale. Recently, studies such as Sharpley's (Sharpley, 1995), which tested 30 fields using the P index then comparing the results to monitored P losses showed a strong relationship between the two measurements for a period of 16 years (r^2=0.70) (Birr and Mulla, 2001). The P index is an extremely detailed and complicated assessment of phosphorus runoff. In most cases it is used to assess a small area, specifically a crop field.

This study includes much more land (1.3% of Minnesota) than most P-Index studies as well as non-agricultural areas, which the P- Index was not designed for. The study therefore considers some alternate variables such as erosion potential, land use, slope and soil phosphorus amount, some of which are not considered in the P-Index. Phosphorus application methods such as fertilizers, either manure or inorganic, which are prominent in P-Index evaluations are not considered in this study because they are not applicable to all land types and data were not available (Department of Soil Water and Climate, 2004).

AREA SITE/GEOLOGICAL SETTING:

Byllesby Reservoir:

The Cannon River Watershed located in southeastern Minnesota, occupies 1.3% of the land in the state (733,393 acres or 296,804 hectares) (Fig. 3). Byllesby Reservoir is located at the eastern end of the watershed, and its dam was built in 1911. The CRW is comprised of multiple smaller watersheds, with three more generalized watersheds contributing most significantly to the reservoir, the Upper Cannon River Watershed

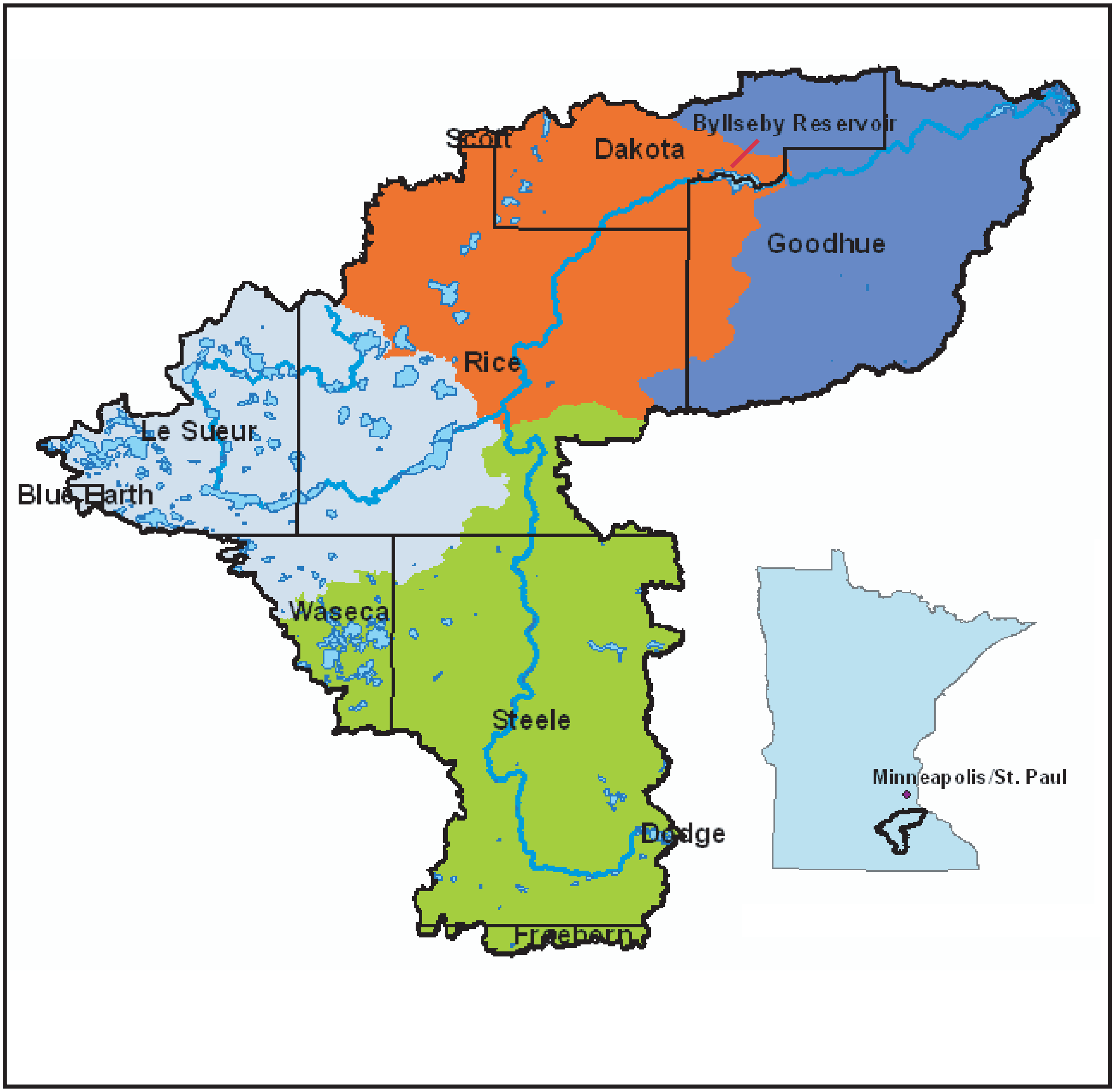


Figure 3. Location Map of the CRW showing county locations and watershed locations. Green is the Straight RIver Watershed (SRW), light blue is the Upper Cannon River Watershed (UCRW), orange is the Middle Cannon River Watershed (MCRW) and dark blue is the Lower Cannon River Watershed (LCRW).

(UCRW) and the Straight River Watershed (SRW) and the Middle Cannon River Watershed (MCRW) (Fig. 3).

The SRW contributes approximately 294,882 acres (119,339 hectares) of land with minimal water impediment, meaning that the water generally flows without slowing stopping or storing throughout this section. Only a few wetland areas potentially store water. This is not so for the UCRW (212,582 acres or 86,032 hectares) because it has multiple shallow lakes/basins along its path and as a result it may take days or months for water to move through this portion of the river as opposed to the hours or possible 3 days as is the case with the SRW. Once the rivers join in the center of the watershed, water storage is limited and flows can reach rates faster than the Straight River (Watkins and Ganske, 2003).

The two watersheds also differ in their surrounding land type and use. The SRW is mostly drained by man-made methods such as tiling and ditches, suggesting a more agricultural based land use. It contains only 30% of the total wetlands found in the UCRW, despite its enormous size. The UCRW is primarily composed of lakes and wetlands due to glaciation (Watkins and Ganske, 2003).

Byllesby Reservoir itself is 1,380 acres (558 hectares) of water but shallow, averaging 9 feet (2.7m) in depth. Its maximum depth, 50 feet (15.24m), is merely a small hole by the north end of the dam. The shallow waters make Byllesby susceptible to algal growth because algae thrive in sunlight and shallow waters permit sunlight to penetrate the entire depth of the Reservoir (Watkins and Ganske, 2003).

Soils and History:

The majority southwestern Minnesota soils are calcareous being of glacial origin and weathered limestone/dolostone till. Soil information specific to the CRW was difficult to source and is broadly described below. Soils in the western portion of the CRW are mainly well-drained loamy soils with some clays and have higher content of calcium carbonate indicating more calcareous soils (Fang et al., 2002). The most eastern portion of the watershed has a larger amount of rocky parent material and bedrock near the surface with thinner soil cover (Dakota County, 1999; ESRI, 2004). This is likely a result of river erosion from the Mississippi tributaries (Minnesota Department of Natural Resources, 2003). Bedrock material in this region is much older than western glacial material and has likely been leached of its carbonate material which can also be indicative of lower phosphorus amounts (Savina, 2005; Stevenson and Cole, 1999). The steeper terrain of the east also causes thinner soils than those of the west more susceptible to leaching (Morrison et al., 1997).

Many of the soils of southeastern Minnesota are classified as Mollisols by the U.S. Soil Taxonomy. Mollisols exhibit a thick, dark friable, fertile horizon and are found in grassland. They are generally high in organic carbon content, reducing erosion potential and are generally known to be high in many nutrients including phosphorus making them ideal for agriculture (Buol, 2003; Stevenson and Cole, 1999). Therefore, as is expected, soils in the CRW are also natively high in phosphorus (Carlson, 2005). Soils in the west are calcareous which usually results in higher pH promoting the fixation of phosphorus to calcium (Stevenson and Cole, 1999). As Fig. 4 shows, the pH of the soils in the CRW is mainly optimal for both calcareous and Fe and Al rich soils, falling between 5.1 and

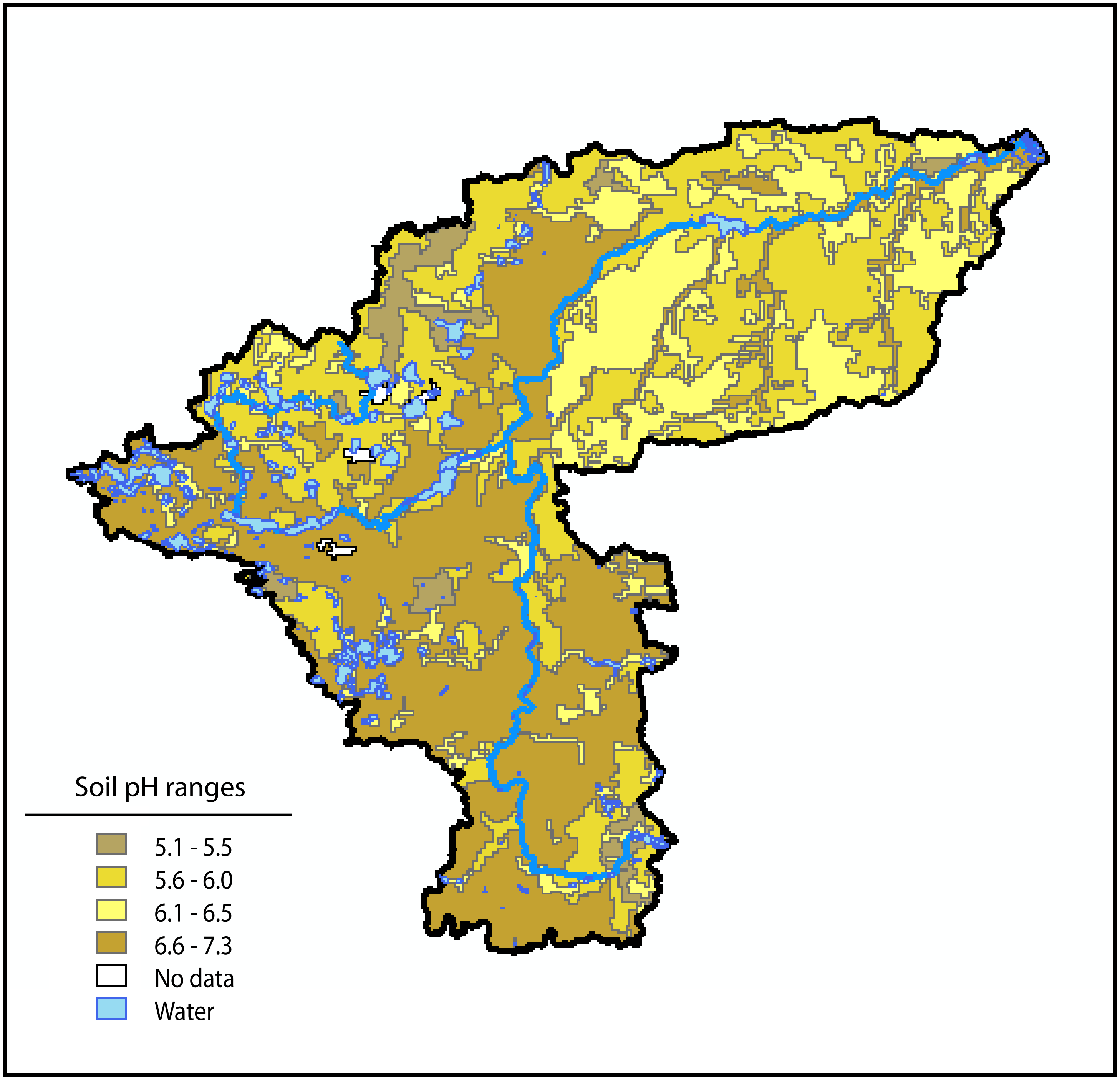


Figure 4. pH soil ranges in the CRW.

7.3, but it is evident that the higher pH values are located in the west (ESRI, 2004). Phosphorus in calcareous soils is highly available to plants and crops and therefore there is little concern with phosphorus application in fertilizers. In eastern Minnesota, the lower values of soil pH cause more phosphorus fixation through iron and aluminum. These forms of phosphorus are not as readily available to plants and crops which may result in phosphorus fertilizer application and environmental concerns (Rehm and Schmitt, 2002b).

Soils directly around the Byllesby Reservoir consist of wetland soils such as Aquolls (a branch of mollisols) and histosols (a highly organic soil) to the west. Well drained loamy, silty or sandy soils are found in the north, south and eastern directions. Calcareous mollisols are once again present to the far west of Byllesby (Buol, 2003; Morrison et al., 1997).

PROBLEM:

In 1996 the Minnesota Pollution Control Agency completed an assessment of the Byllesby Reservoir and four years later, in 2000, the CRWP (Cannon River Watershed Partnership) joined with the Pollution Control Agency in order to begin a more detailed assessment of the reservoir and its watershed with the goal of better understanding nutrient sources and improving water quality. Byllesby, for the majority of the year, is troubled by large amounts of algae, sediment and rough fish species, such as carp. These characteristics are aesthetically unpleasing, disliked by fisher people and swimmers and most importantly can be environmentally hazardous to the fish population of the Reservoir. Bodies of water downstream are also at risk, though generally water bodies downstream are much cleaner because the algae in Byllesby Reservoir acts as a filter releasing algae free water (Tipping, 2005; Watkins, 2005).

The ultimate goal of the CRWP is to complete a Total Maximum Daily Load (TMDL) for each sub watershed of the CRW with the help of the MPCA and funded by the Environmental Protection Agency (EPA). This will identify the water quality problem that the Byllesby Reservoir faces, such as the severity of pollution and its sources. Currently, a TMDL has been finalized for the Straight River, Cannon River and Prairie Creek, (a river in the LCRW which runs directly into the Reservoir). The studies found a large amount of bacteria, specifically fecal coliform assumed to be largely from the surrounding livestock and manured fields (Ganske et al., 2002). Other fecal matter sources could be both human and wildlife related such as septic systems and urban runoff (Brokman, 2004). With the combination of TMDLs for other section of the watershed, actions can be taken to meet the state's water quality standards (Watkins, 2005).

MATERIALS/METHODS:

Total phosphorus runoff potential was determined using ArcMap (ESRI, 2004). Four variables were taken into consideration for this calculation: soil phosphorus amount, slope, the K-factor from the RUSLE equation, and land use. The first three variables were available in a vector format, compatible with ArcMap, online from Land Management Information Center (LMIC) in the Minnesota Soil Atlas. The fourth, land use, was available through the Department of Natural Resources (DNR) data deli website sectioned in quads titled 'GAP Land Cover-vector'. All the data in the Minnesota Soil Atlas, though updated in 1998, was originally published in the 1970s and can vary in age, scale and resolution. The Minnesota Soil Atlas data were recorded in 40 acre parcels for the entire state of Minnesota. The map sources from which this data are based are commonly on a scale of 1:24,000. The oldest data (1960s) were formatted with a grid-cell overlay technique. The newer data use ARC/INFO to digitize the maps after converting them to 40-acre raster grid cells. ArcMap units are in meters (Maeder, 2004).

All three sets of data from the Minnesota Soil Atlas (slope, K-factor and phosphorus amount) are derived variables based on formulated ‘geomorphic regions’ and ‘soil landscape units’ if Minnesota. There are 94 ‘geomorphic regions’ characterized by similar topographic relief and parent material. There are 64 ‘soil landscape units’ characterized by similar drainage, soil color, and soil texture above and below the rooting zone. It is not clear how these data were combined to formulate the given values other than by ‘professional interpretation’ (Maeder, 2004).

The land use data from the DNR Data Deli were derived from six different data sources that cover different regions of the state. Each source is in a different format and legend. These were compiled into the 8-category system with 30 meter grid cells to produce the resulting quads. The six different data sources used to create the land use data are also of different ages ranging from 1987-1996. Units are in meters (Watson, 2004).

All data were available in vector format covering the entire state of Minnesota. The phosphorus, slope and K-factor data were clipped in ArcMap excluding all data outside of the CRW and then converted to raster format. The land use data was also available in vector format, but in quad sections. In this case it was more efficient to first convert the data to raster format and then use the mosaic tool to merge the quads.

These data came with information pertaining to the variable, such as slope percent or amount of phosphorus and was divided into levels of intensity. Each level held a corresponding value beginning with 0 and ending with the number of respective levels. The values were modified to reflect the amount of risk they posed to phosphorus runoff on a 0-4 scale in 5 categories of 0, 1, 2, 3 and 4. The higher the number, the more at risk the area was to phosphorus runoff (respectively none, low, medium, high and very high) (Tables 1-4). Each value was also assigned a weight to reflect its importance in contributing to phosphorus runoff. This model is based on the method of ranking when calculating the P-Index by Eghball and Gilley (2001). Their study modified a P-Index from Lemunyon and Gilbert (Lemunyon and Gilbert, 1993) which is similar to the P-Index developed for the western part of Washington State (Schendel et al., 2004). Modification was necessary because of different regional climates and soils. Eghball and Gilbert's study area was Nebraska and therefore more consistent in climate and soils to Minnesota than Washington (Eghball and Gilley, 2001). Though Nebraska is primarily dominated by ustolls and Minnesota is dominated by udolls, both are suborders of the Mollisol soil type described earlier. Western Washington does not contain Mollisol soil types (Schaetzl, 2005).

Eghball and Gilley (2001) value factors from 1 to 2 in 0.5 increments and weights range from 0.5 to 4 with the erosion factor 3 times greater than any other factor. Because ArcMap would not process values in decimals, values were multiplied by 2 to create whole numbers and the weight for each factor was halved to compensate.

***Phosphorus Amount*:**

The phosphorus amount is the total amount of available phosphorus within the rooting zone. These have been grouped into qualitative categories termed very-low to very-high. As with all the Minnesota Soil Atlas factors, phosphorus amounts were derived from geomorphic regions, soil landscape units and professional interpretations (Maeder, 2004). The phosphorus amounts, their original values and new values assigned for this study's model are shown in Table 1. Areas with no ratings were considered 0, and this should be noted in the final calculation of total P runoff.

Soil phosphorus measurements by Eghball and Gilbert were given a weight of 0.5. However, phosphorus is naturally high in the Cannon River Watershed region (Carlson, 2005) and so for this study the weight was raised slightly to 0.75 and then divided by 2 resulting in a 0.375 weight because the values were doubled to avoid decimals.

***Slope*:**

Slope is the "generalized slope" (Maeder, 2004) of the area. It has been broken into categories of percent. The slope percents, their original raster values and their new values for this study are shown in Table 2.

In the RUSLE equation, slope gradients are accounted by the SL (slope-length). In this study length is not considered because these data were not available in vector format. Fortunately, length is not as influential as gradient (Toy and Foster, 1998).

Assigning values and weights for slope is the most uncertain of the four variables. Many factors affect a slope's influence on erosion. Water transport (and therefore erosion) is variable based on qualities of the soil. Dry soil transports water differently than

Table 1. Phosphorus Values for the CRW
(shape, raster, new)

Amount P	Raster Value	New Value
water	0	0
low	1	1
low-medium	2	2
medium	3	3
varies (low-high)	4	4
no rating	5	0

Table 2. Slope Values for the CRW
(shape, raster, new)

Percent Slope (%)	Raster Value	New Value
water	0	0
0 to 2	1	1
2 to 6	2	2
2 to 12	3	2
6 to 12	4	3
6 to 45	5	4
12 to 45	6	4

Table 3. K-Factor Values for the CRW
(shape, raster, new)

K-factor	Raster Value	New Value
water	0	0
0.15 to 0.20	1	1
0.24 to 0.32	2	2
0.24 to 0.37	3	3
0.24 to 0.43	4	4
0.28 to 0.32	5	2
0.32 to 0.37	6	3
0.37 to 0.43	7	4
no rating	8	0

Table 4. Land Use Values for the CRW
(shape, raster, new)

Land Use	Raster Value	New Value
Water	83	0
Vegetated	82, 84-88	1
Crop/grassland	81	4
Non-vegetated	80	2

saturated soil transporting water despite a gradient because water moves to areas of lesser concentration (Rendig and Taylor, 1989). Soil permeability involving pore space, pore shape and soil texture will also contribute to runoff amount (Warrick, 2003). These characteristics of erosion are considered in the k-value factor which is heavily weighted, therefore, the slope factor is less heavily weighted. Furthermore, the percent slopes are so broadly classified, is difficult to assure the accuracy of the information. Slopes also fluctuate in gradient over their assigned area causing more complications along with gradient's effect on erosion varying with the land cover. On tilled land, soil will erode much more rapidly than on undisturbed land. The slope data are in 40 acre grid cells, however specific detail is lacking in actual length of a more determined percent slope. Despite this and for simplicity purposes, this study assumes an entire grid cell to be ranked with only one risk value.

The weight factor is assigned as 0.5 and divided by 2 to account for the doubling of the factor itself resulting in a 0.25 weight. The weight is small because of the relative insignificance of the variable and its uncertainty because of reasons mentioned above.

***K-Factor*:**

The K-factor is a factor from the RUSLE equation which represents soil erosion on the scale of 0 to1. It is the rate of soil loss per erosion index unit, with one unit being 72.6-ft (22.1-m) in length and uniform 9% slope in continuous clean tilled fallow. The K-factor is based on properties of the soil itself such as organic matter, texture, permeability and profile structure. It is also dependent on how climatically susceptible the area is to erosion due to regional precipitation (Toy and Foster, 1998). The exact units of the K-factor are unclear, but the finalized RUSLE equation, which includes the K-factor and other factors, expresses soil erosion on an agricultural field in ton/ac/year.

The K-factor, its original raster value and its new value for this study, are shown in Table 3. Areas of no data are ranked as 0 and should be considered in the final analysis of total phosphorus runoff.

Several P index studies, such as Sharpley's (Sharpley et al., 2003), and Birr's (Birr and Mulla, 2001) give a weight of 1.5 to the soil erosion factor. However, this was based on tons of soil per acre per year in Sharpley's study and Mg/ha/yr in Birr's, indicating that the erosion factor was the result of a complete RUSLE analysis and not just one of the 6 influencing factors such as the k-factor. The k-factor covers a smaller unit area (72.6ft or 21.1m in length with an unspecified, variable width). Therefore, in this study, the K-factor was given a weight of 3. Yet, because of the doubling of the factor itself, the weight was divided by 2 resulting in a 1.5 weight. This ensures that the proportions between the different factors are still similar to those of Eghball and Gilley's (2001) study.

***Land Use*:**

These data were in a different format than the previous three factors. They were compiled through scanning of maps and geocode matching. They are available in quads rather than on a state wide basis and are much more detailed. There are four levels dividing land use in this data, the fourth being the most detailed. For this project, the second data set was chosen and then further simplified to 3 values of phosphorus runoff.

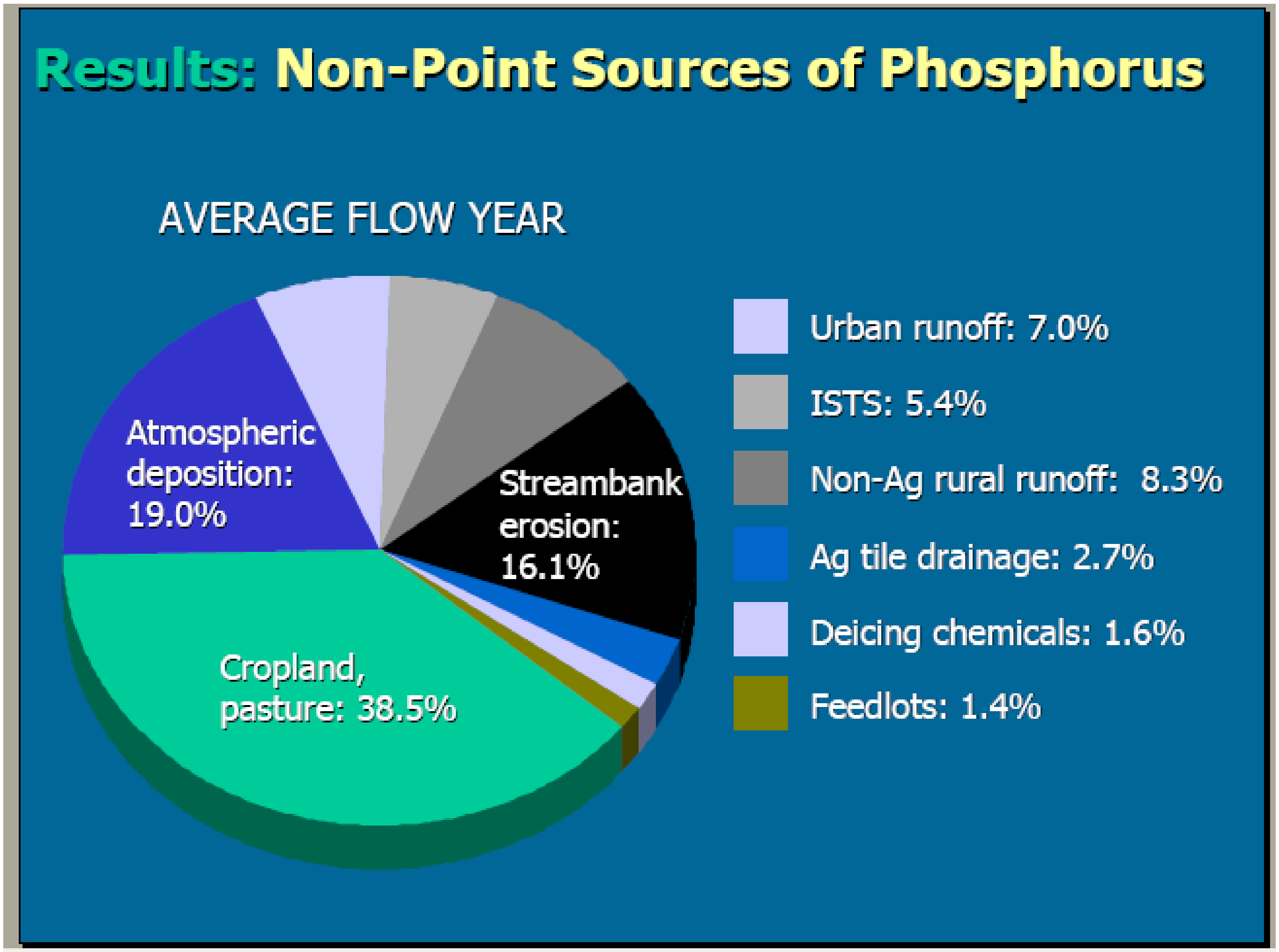
Table 4 shows the land use, its original raster value and the new value assigned for this study.

These values were assigned based on studies such as Gelbrecht's (Gelbrecht et al., 2005) who performed a study of two catchments in northeast Germany where one catchment was predominantly arable land (59%) and the second was predominantly forested land (81%). The results showed the specific discharge in the predominantly arable catchment to be significantly higher resulting in P runoff as 5 times greater (Gelbrecht et al., 2005). Wilson et al. (2005) also indicate cropland and grassland to be the most susceptible to phosphorus runoff in similar proportions. This Minnesota study showed that 38.5% of flow per year originates from cropland, with non-agricultural runoff contributing 8.3% and urban runoff contributing 7%. (Fig. 5) (Wilson et al., 2005). From the numbers/percentages in these studies, the ranking for the present study was derived where waters are ranked with 0 potential for runoff, forested areas ranked as 1, non-vegetated areas such as cities, ranked as 2 and crop/grassland as 4. The land use variable is weighed by 0.25 to exaggerate the difference between forested areas and crop/grassland.

***Combining the data*:**

After revaluing all four variables, they were compiled into an equation with their respective weights:

Phosphorus runoff potential =(K-factor value)(1.5) + (phosphorus amount value)(0.375) + (land use value)(0.25) + (slope value)(0.25)



*adapted from Wilson et. al. (2005)

Figure 5. Percents of non-point sources contributing to phosphorus runoff. ISTS is Individual Sewage Treatment Systems (unsewered communities)

The final equation produces areas with values ranging up to 9.5. P runoff risk is broken into 5 equal intervals following categorization based on the original P-index model (Eghball and Schendel): 0 is water, 0-2.375 is low, 2.375-4.75 is medium, 4.75-7.125 is high, and 7.125-9.5 is very high.

RESULTS:

Phosphorus

The phosphorus data shown in Fig. 6 show that available phosphorus is primarily located in the lower, northeast end of the watershed (red), in the Lower Cannon River Watershed (LCRW). A small, very high risk area also exists in the upstream area of the SRW and there are some high risk areas along the river, but the majority of the SRW does not contain an abundant amount of phosphorus. In the northeast, where lakes are abundant in the UCRW, high phosphorus content is also notable.

It should be noted that areas valued as 0 (white), are areas with no data. These areas become artificial areas of low risk in the overall assessment of total P runoff because they contribute no weight.

Slope

The slope data in Fig. 7 show the steepest slopes in the lower, northeast end of the watershed (red) in the LCRW similar to the phosphorus data.

Despite the highest slope areas being below Byllesby Reservoir, a significant portion above the reservoir is labeled as high slope (orange) with only a few smaller areas

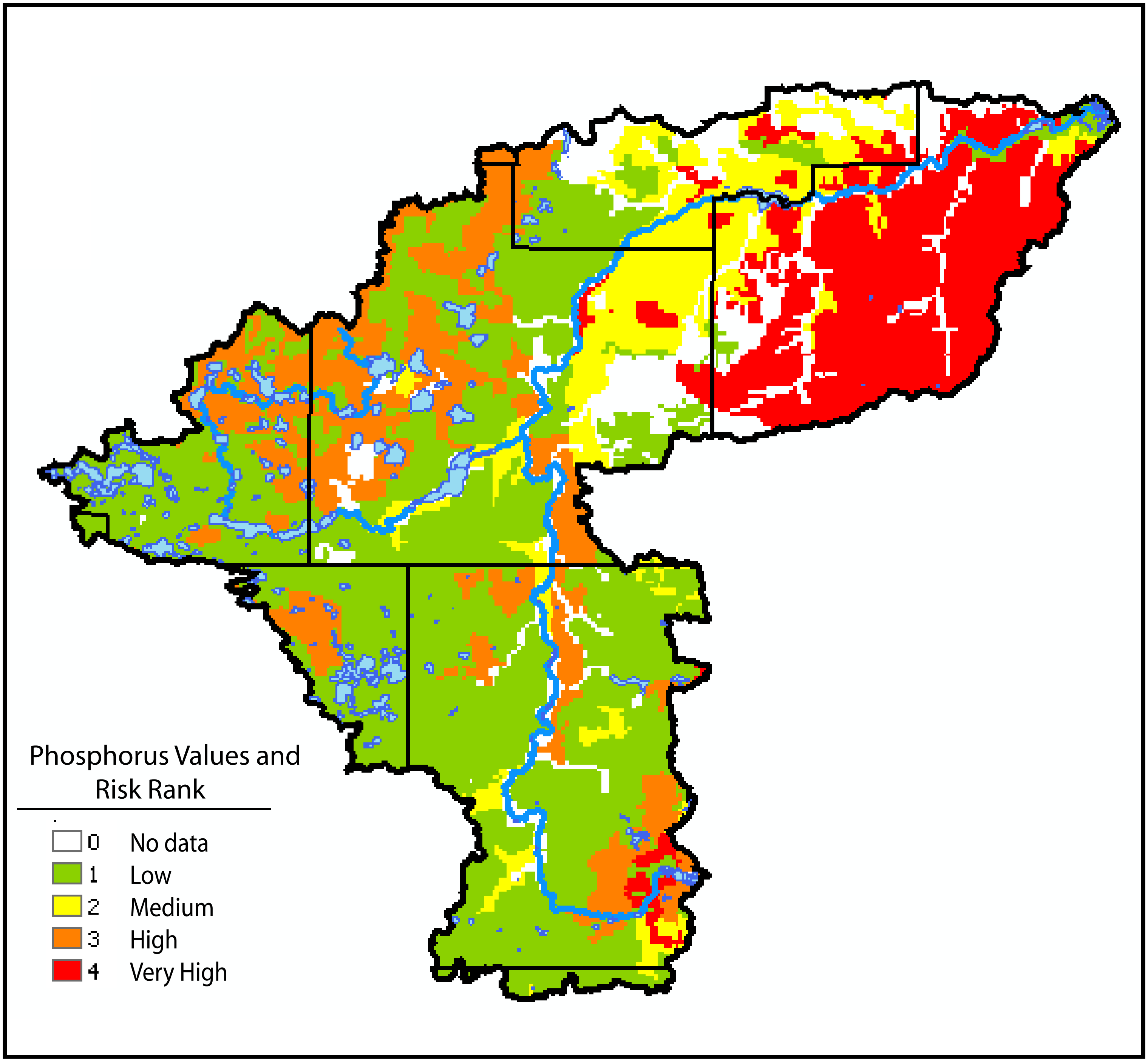


Figure 6. Available Phosphorus effect on phosphorus runoff in the CRW.

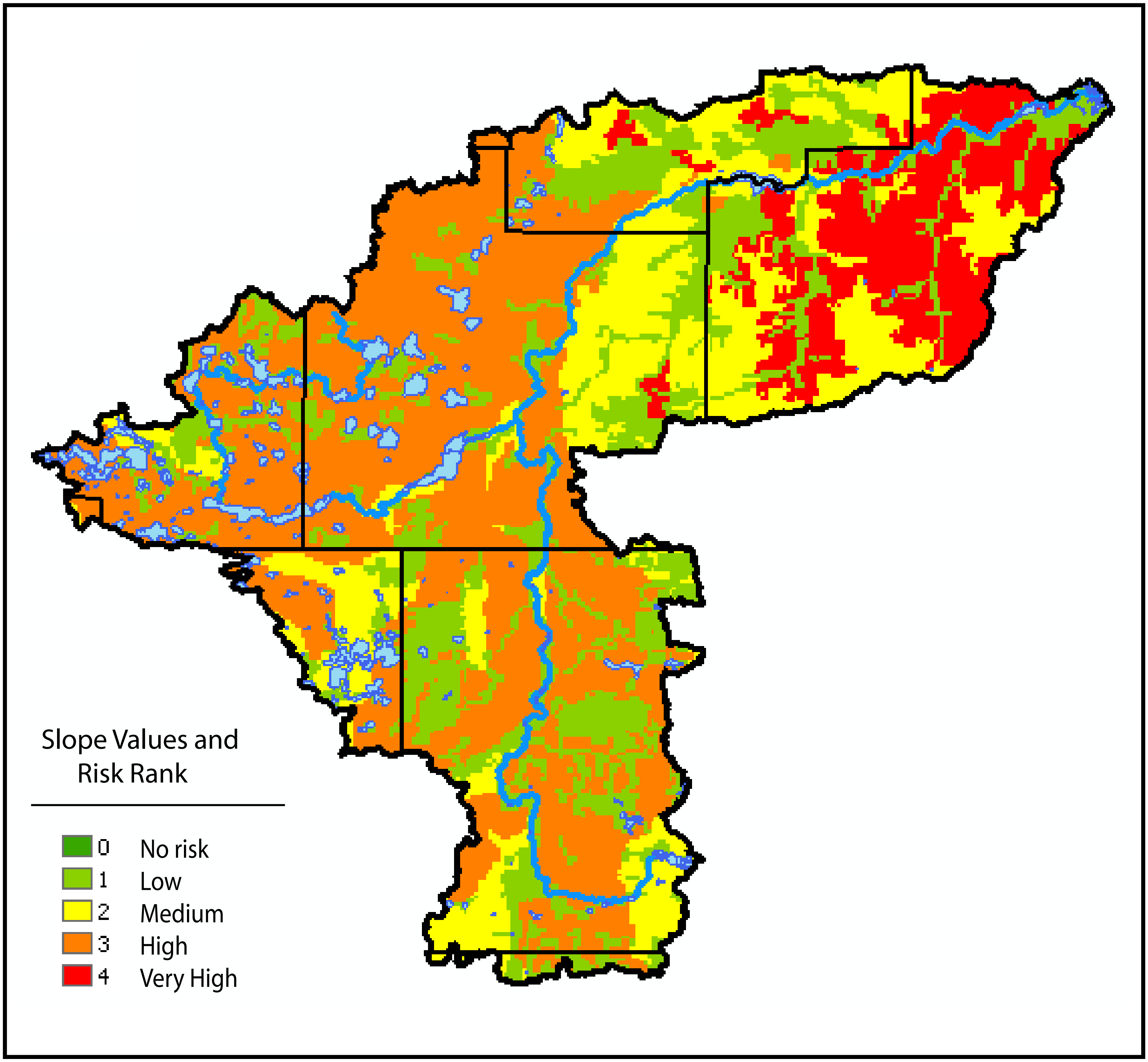


Figure 7. Slope effect on phosphorus runoff in the CRW.

shown as low (green). Along rivers, the slope tends to be either low or high. Only the eastern portion of the MCRW has a more general trend of medium slope values.

K-Factor

The K-factor data (Fig. 8) show areas most susceptible to erosion are scattered in the lower portion of the LCRW as well a small section of very high risk at the top of the SRW. The majority of the watershed is at medium risk (yellow) especially throughout the SRW. The UCRW exhibits some high risk areas to the north among the lakes. The white areas have no data and should be considered in the final analysis of total phosphorus runoff. These areas will be lower because of their value (0).

Land Use

The land use data (Fig. 9) classifies the majority of land in the watershed as cropland or grassland. There are small areas of urbanization and in the upper northwest corner in the LCRW scattered vegetated areas exist where risk for phosphorus runoff is less. Aside from this, it is obvious the CRW is at high risk for phosphorus runoff with the SRW contributing most in terms of land use.

Total Phosphorus Runoff

Total phosphorus runoff risk (Fig. 10),calculated by the equation:

Total Potential P runoff =
(K-factor value)(1.5) + (phosphorus amount value)(0.375) + (land use value)(0.25) + (slope value)(0.25)

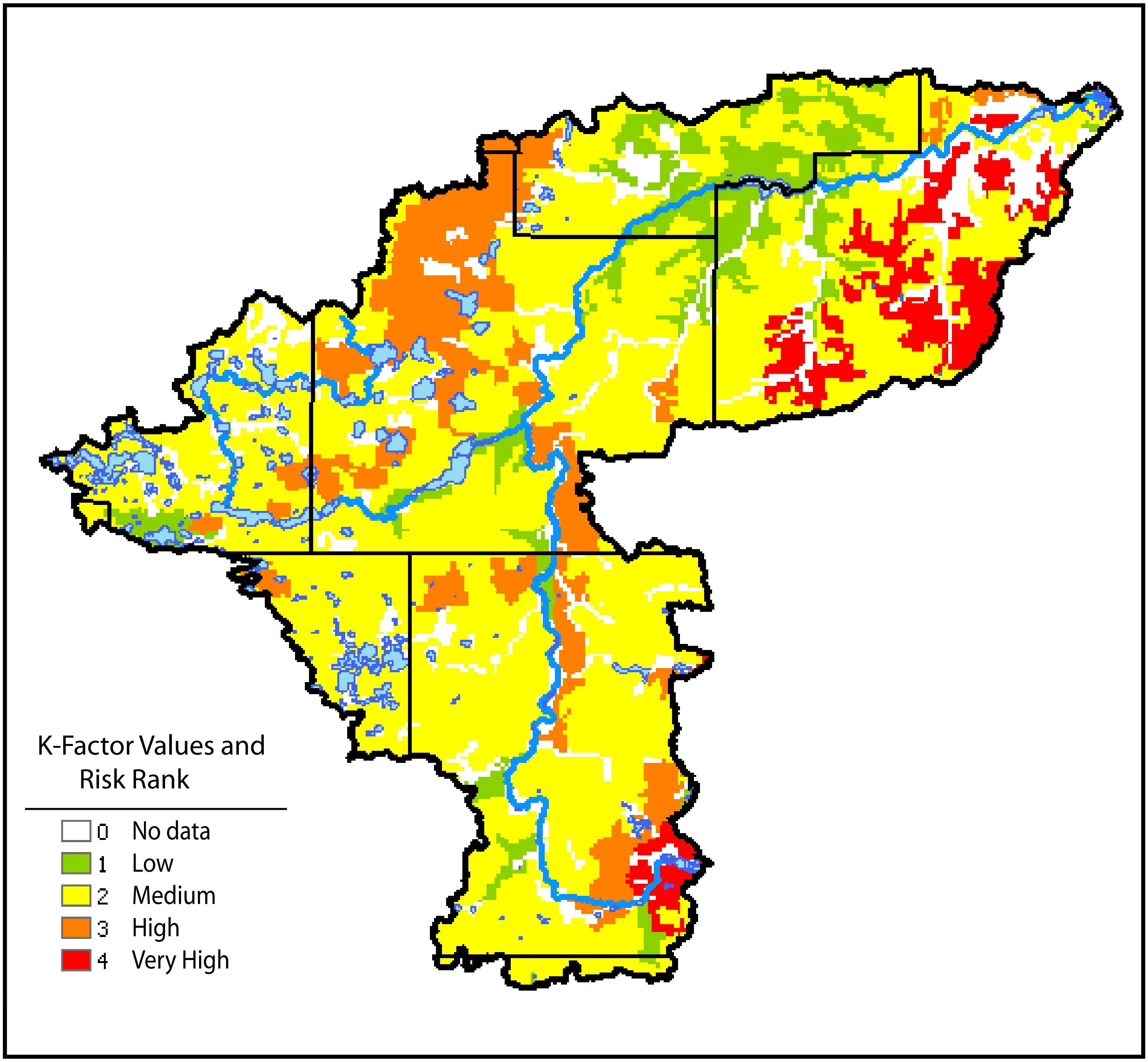


Figure 8. K-factor effect on phosphorus runoff in the CRW.

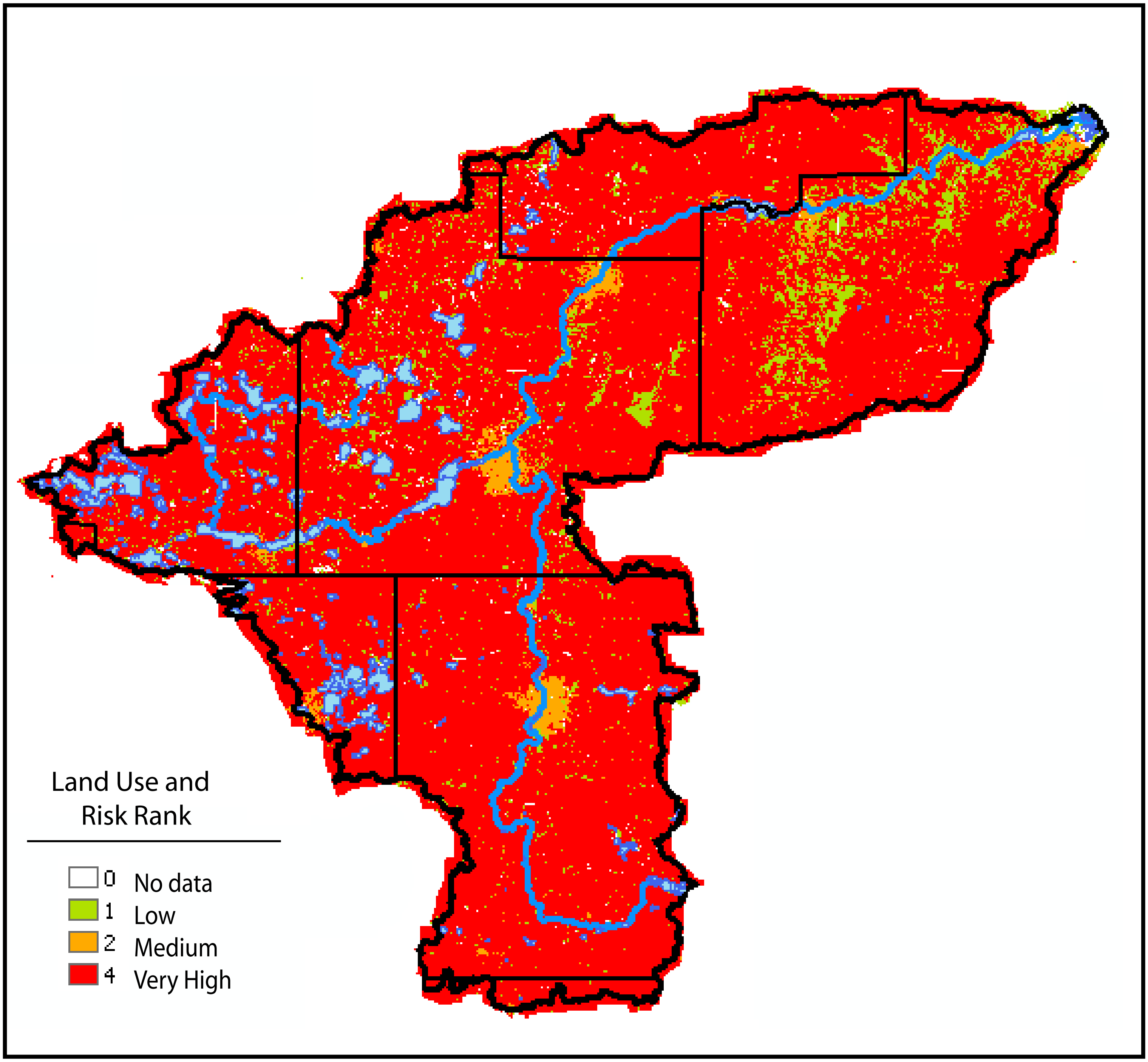


Figure 9. Land Use effect on phosphorus runoff in the CRW.

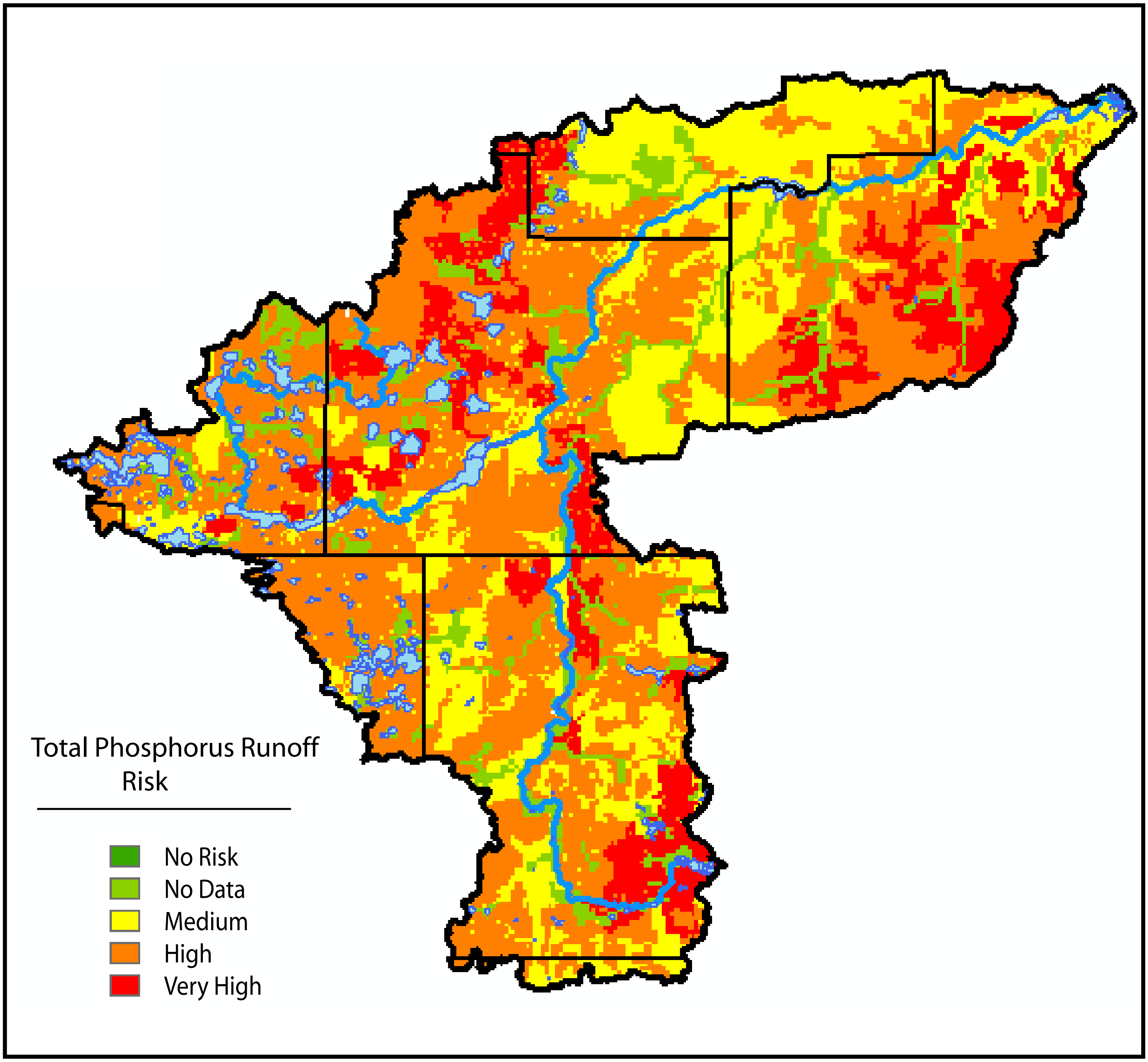


Figure 10. Total phosphorus runoff risk in the CRW based on available phosphorus amount, slope, k-factor value and land use.

shows no areas of low risk because the areas with low values are areas missing data from either the phosphorus or k-factor factors. Therefore, these areas are incorrectly represented at low risk and instead classified as no data. Very high areas (red) are found in the lower northeast section of the LCRW, in the upper southeast section of the SRW, throughout the UCRW, often near lakes, and the western portion of the MCRW, also near lakes.

The results from the ArcMap total phosphorus runoff raster calculation show the general trend in the three factors of slope, k-factor and P amount. Wherever these areas are highest individually, the compilation map shows a high risk. High-risk areas are generally found near bodies of water, rivers, streams or lakes, however, a body of water does not ensure a high risk area. A closer look at a portion of the Straight River shows this more clearly where the smaller tributaries are added to the map (Fig 11).

DISCUSSION:

The K-factor and the composite total phosphorus runoff map, correspond well, presumably because the K-factor has a weight of 1.5, the largest of any of the four variables. However, if the weight is halved, and, therefore even smaller in proportion to other factors than the original equation proposed by Egball and Gilley (2001), there is little change apart from high risk areas below the Reservoir. Values in this equation only reach 6.5 and are equally divided into five categories of risk: none, low, medium, high and very high. There is still a strong correlation between the K-factor and total phosphorus runoff (Fig. 12), indicating that the K-factor (erosion) has a major impact on phosphorus runoff.

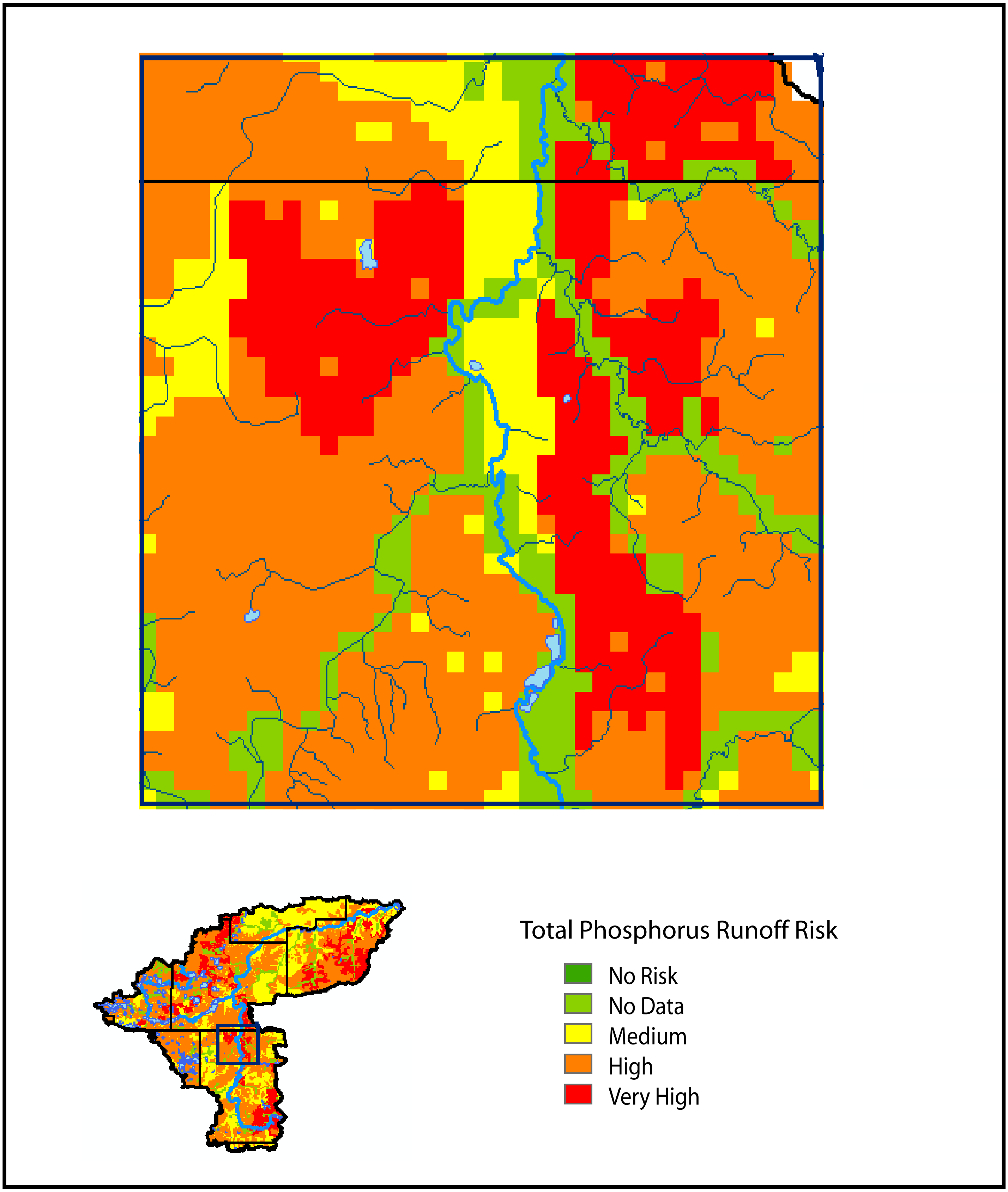


Figure 11. Close up section of a very high risk area along the Straight River with added tributaries.

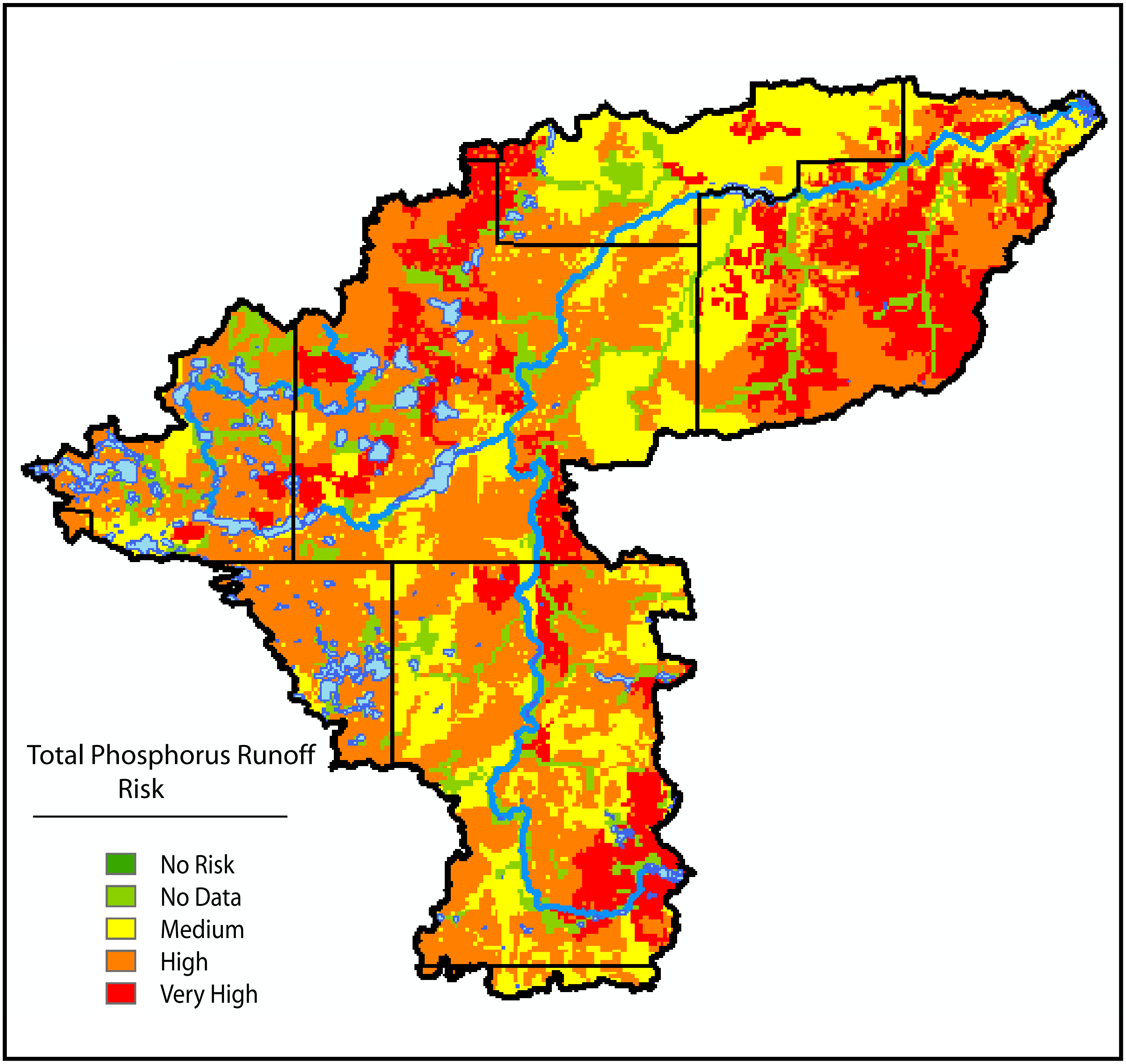


Figure 12. Total phosphorus runoff risk in the CRW based on available phosphorus amount, slope, k-factor value and land use with the k-factor weight halved.

Areas of very high to high risk near stream banks or lakes contribute phosphorus to water bodies more quickly, causing more immediate algal blooms and therefore are zones in need of more immediate attention. In addition to this, stream bank edges are generally steeper and more susceptible to erosion. Therefore, it would be expected that these areas show up on the composite map as high-risk zones. However, K-factor or phosphorus data are often missing from zones near water making them appear deceptively low. Despite the assumption that high risk areas would decrease farther from streams and rivers because of slope and erosion characteristics, the correlation between runoff values and distance from a stream is not consistently supported by the results in this study. Some sections support this theory, such as portions of the Straight River, Areas A and B (Fig. 13), showing, generally, less erosion at greater distances from the stream edge and some areas increase in risk farther from the stream even within these same sections. Still, others show no change in risk with distance from the stream. This is most likely a result of slope values combined with the K-factor. Slope values are too generalized and large scale to show contours leading to a river bed and therefore do not contribute to a steady decrease in runoff farther from the rivers. A more detailed contour map would be necessary to validate these assumptions. Again, the K-factor and phosphorus amount are the main influences these very high risk area. The Middle Cannon River Watershed (MCRW) and LCRW, Area C (Fig. 13), also show high runoff risk around lake areas. These areas show no outstanding slope values, but do correlate with the K-factor and phosphorus values.

Although there are areas where phosphorus runoff risk is associated with water bodies, not all streams and lakes fit this model of stream bank erosion. Some areas of

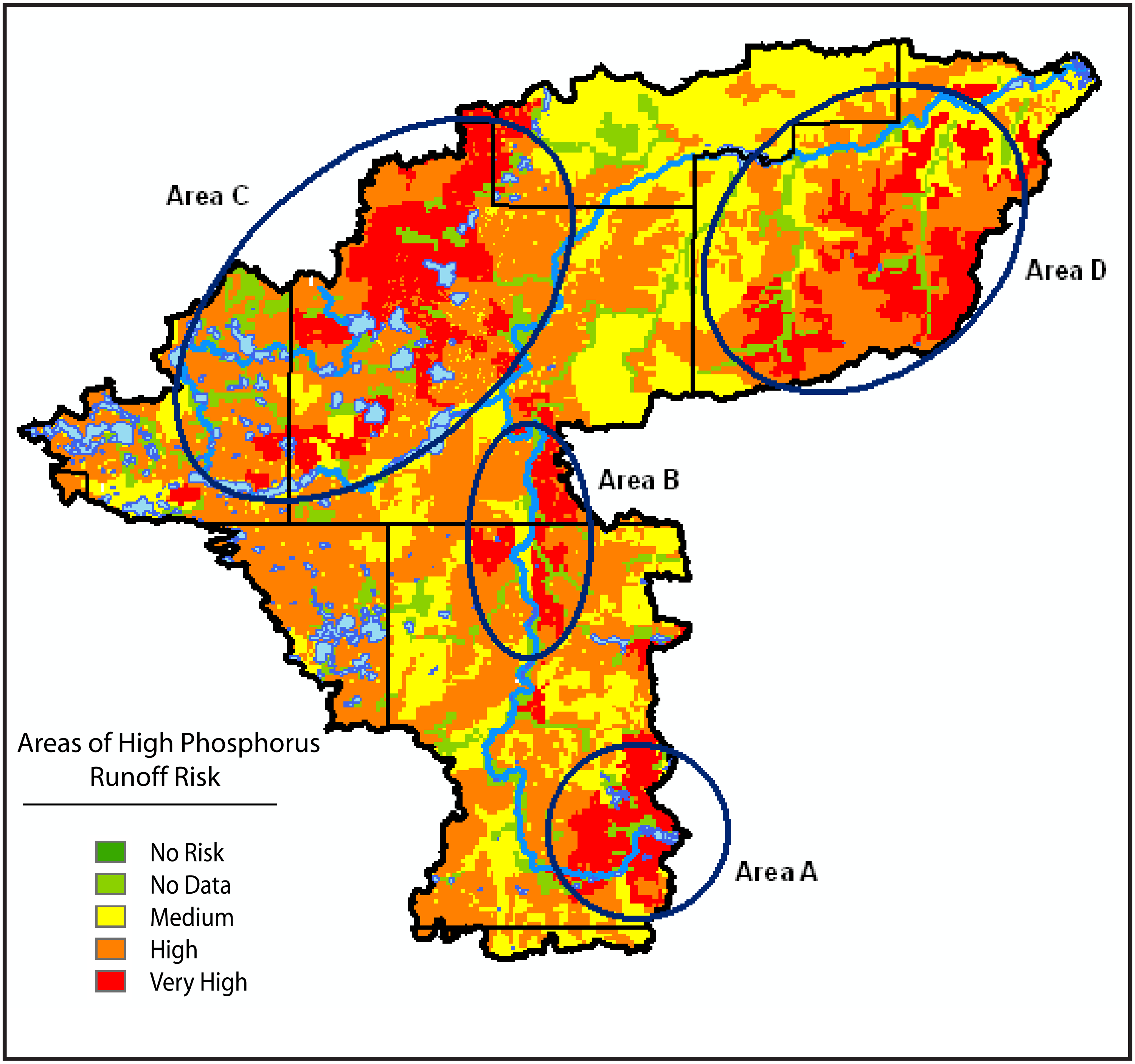


Figure 13. Areas of high phosphorus runoff risk divided in to Areas A,B,C and D in the CRW.

high phosphorus runoff risk are not near water bodies, such as Area D in Fig. 13, which is strongly impacted by high slope values. The lakes in the SRW, Section A, (Fig. 14) are not at as high a risk for phosphorus runoff as might be expected. These zones have more gradual slopes, but potentially higher phosphorus amounts. There is also a small amount of urbanized area to the west of the lakes lowering its risk potential. The lakes in the UCRW, Section B (Fig. 14) also show lower phosphorus runoff risk potential as a result of lower K-factor values and phosphorus values. There is no notable change in slope in comparison to other high risk areas and no significant change in land use.

The K-factor shows a stronger trend of higher phosphorus runoff risk closer to rivers, but again, is too general to ensure accuracy. To examine the phosphorus runoff risk in more detail, two smaller portions of the Watershed displaying high risk, one from the Upper Cannon River Watershed and one from the Straight Watershed, were isolated. Phosphorus runoff potential was calculated for these individual sections. Both areas show an overall increase in phosphorus runoff along the rivers and stream. This is especially true for the Upper Cannon River section (Fig 15a and b) where a large high-risk area appears near smaller tributaries. In the Straight River section (Fig. 16a and b), tributaries have less of an effect, but a larger high-risk area extends up the major river, again, attributed to the K-factor and higher erosion associated with stream banks.

A strange correlation exists between phosphorus runoff risk and land use. Some of the most susceptible areas to phosphorus runoff are forested, such as Area D in Fig 13, while areas of crop/grassland are only moderately at risk despite being almost 5 times greater in risk in terms of land use alone. This may be influenced by the lack of a phosphorus application factor, such as in fertilizer application. Another consideration is

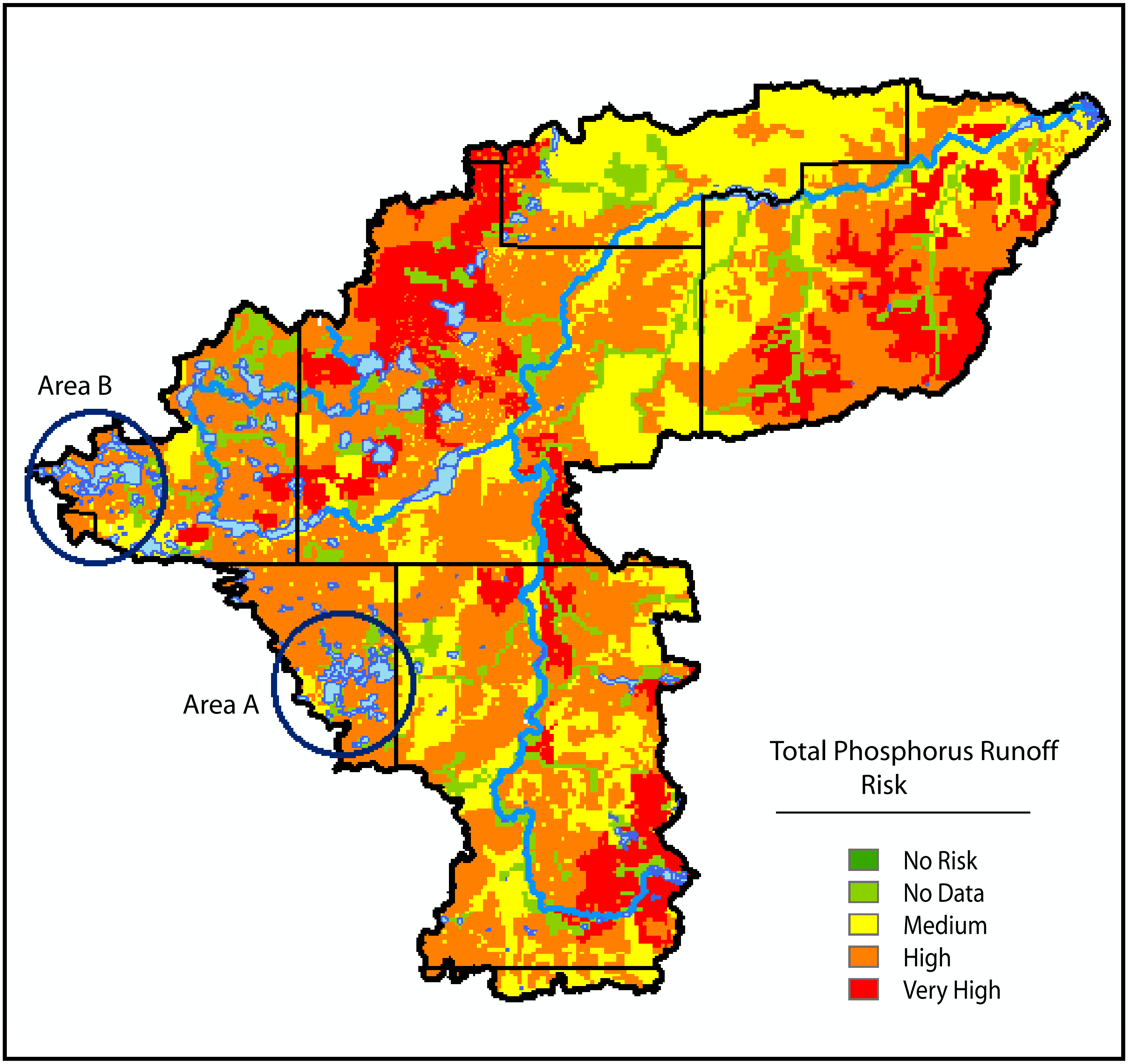


Figure 14. Unaffected lake areas divided into Areas A and B in the CRW.

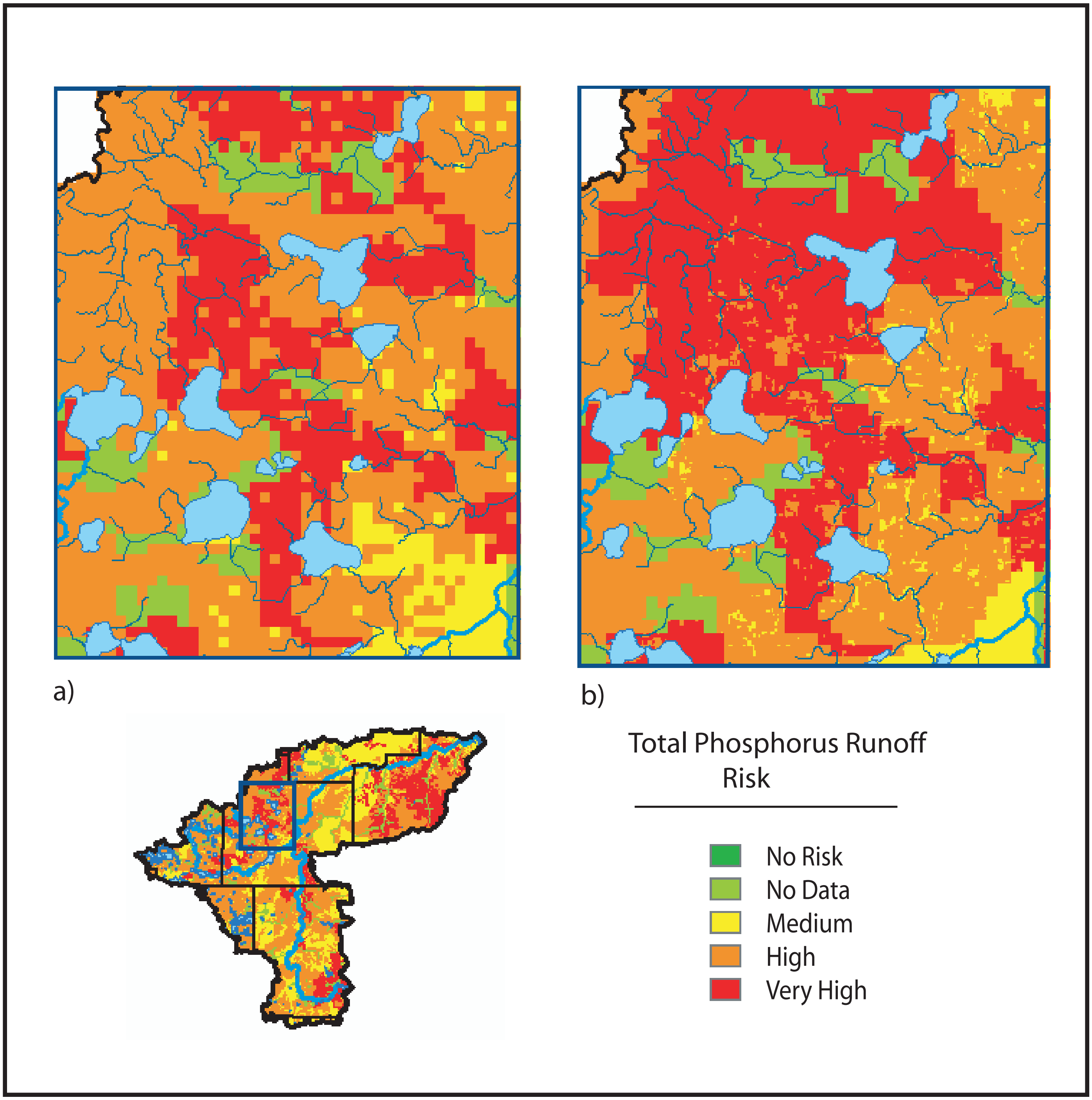


Figure 15. Zoomed UCRW high risk area with added tributaries a) original values b) revalued for zoomed area.

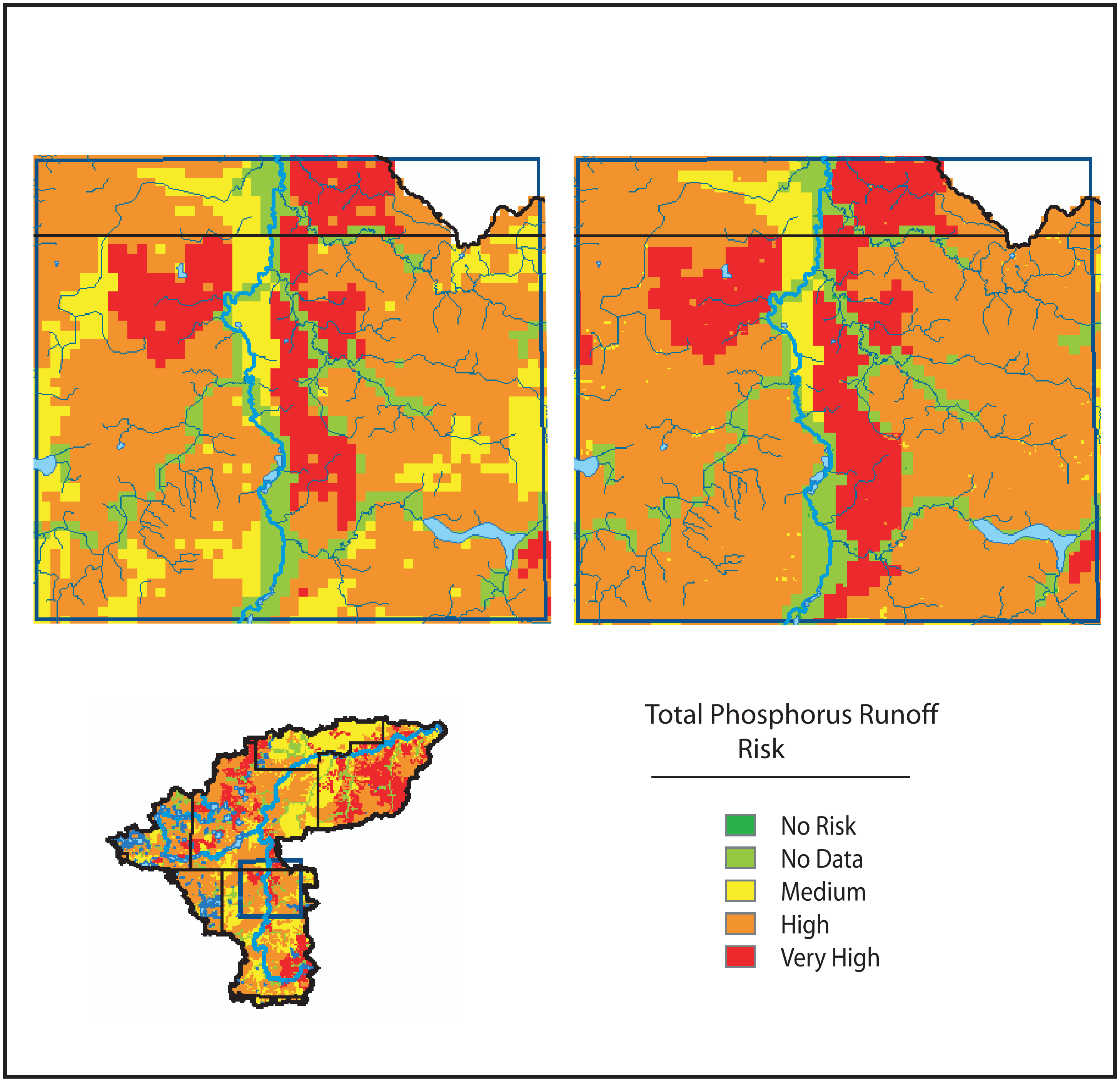


Figure 16. Zoomed SRW high risk area with added tributaries a) original values b) revalued for zoomed area

the correlation between these unsusceptible forested areas and their high slopes, which is likely one of the reasons these areas are not cultivated. The slopes of these areas could have a strong counteractive effect on the land use value, resulting in high risk phosphorus runoff areas. Again, it is difficult to say what causes high risk areas to be high risk because of the compilation and derivation of the data.

Explanation for skewed results:

Phosphorus data results show unexpectedly low phosphorus levels. The land below the Byllesby Reservoir in the LCRW is the only area classified as very high in phosphorus. This is surprising because soils in the CRW region are naturally high in phosphorus and it would be expected that the majority of the watershed above and below the reservoir would exhibit at least medium amounts of phosphorus instead of the low amounts shown (Fig. 6). A reasonable explanation for this may be land use. The majority of land above the Reservoir is crop/grassland and has likely been depleted of natural phosphorus amounts (Stevenson and Cole, 1999). Below the Reservoir, there is still vegetated area which has been allowed to keep its original phosphorus amount. Therefore, comparatively, the croplands have much less than the vegetated areas. The lack of phosphorus shown in the maps could also be due to the lack of consideration of phosphorus application on croplands which consists of both manure and commercial fertilizer application. Areas applying manure could be higher risk zones as it is more difficult to quantify phosphorus levels in this form of fertilizer. Unfortunately, data regarding phosphorus application was not available for this study (Carlson, 2005). Furthermore, methods of phosphorus application contribute differently to phosphorus runoff based on their source, method and the type of soil cultivated (Andraski et al., 2003). Comparing maps, including and excluding a phosphorus application variable, would demonstrate the influential of phosphorus application in the CRW.

There is also the possibility phosphorus is not the cause of extreme algal blooms in the Byllesby Reservoir. Of the 22 sites studied by Neal and Heathwaite (1997) , 20 displayed a significant downward trend in Total Nitrogen (TN) because of three variables: reduction in organic and inorganic fertilizers, reductions in ploughed or cultivated areas meaning more grassland or unmanaged land and finally because of farm management practice improvement. For TP, only two sites displayed a decrease in phosphorus runoff and there were also two upward trends, likely attributed to waste water treatment plants (Heathwaite, 1997). I propose an investigation of potential nitrogen runoff risk areas. Finally, the combination of the two nutrients together in proportional amounts could be the primary influence.

Validity Questions:

The source and format of the data used in this study have a significant impact on results. A primary concern is that three of the four factors were produced in the same manner using the same ‘geological regions’, ‘soil landscape units’ and ‘professional interpretation’. Therefore, there is almost certainly a predisposed trend in the composite total phosphorus runoff map because these three factors already have a similar pattern. Validity concerns within each factor are primarily a lack of precise quantitative data. Slope is strongly generalization (some categories ranging from 6-45%) and does not take into consideration the length the gradient covers, whereas more detailed equations such as the RUSLE equation do. Phosphorus runoff levels are qualitative, giving no indication of what type of phosphorus was measured or with what method. Furthermore, only the rooting zone phosphorus amount was measured and this brings questions of groundwater phosphorus which is not considered in this study. However, the majority of phosphorus contributing to surface waters such as Byllesby is mobilized by surface runoff (Lazzarotto et al., 2005) and the chosen variables are best matched for measuring phosphorus surface runoff because the phosphorus amount and K-factor are based on the tops of the soils. Finally, this study limits the classes of land use in the CRW. Although, similar, erosion properties on cropland verses grassland could be influential. In order to be more accurate the K-factor should be weighed more heavily on cropland and not as heavily on grassland (Eghball and Gilley, 2001). In addition, different crops and tillage methods cause differing degrees of erosion. Land use data also does not examine factors such as prior land use. If land was previously tilled, soil particles are looser and more susceptible to erosion.

Canopy cover, the height of plants and surface cover are other impacts on soil erosion. Larger, wide-leafed plants deflect rain and therefore reduce erosion. Taller plants also create a greater risk because water falls further, therefore hitting the soil with a larger force and disrupting the soil more. Surface cover, such as mulch or rock fragments may also hinder or help erosion (Toy and Foster, 1998).

Further Studies:

Phosphorus application to croplands is a complex but important component to phosphorus runoff, and, further studies concerning methods of application and types of phosphorus can be conducted to determine the most negatively impacting fertilizing techniques. There are many theories regarding which form of phosphorus causes the most phosphorus runoff, which is complicated by different responses to phosphorus in soil types. Organic applications (manure) have potential to increase phosphorus runoff, especially in well-drained silt loam soils (Andraski et al., 2003). These soils are characteristic of the lower portion of the CRW. The upper portion of the watershed is characterized by loam to clay loam and could also be susceptible to increased phosphorus runoff as a result of manure application (ESRI, 2004). Manure application is most common near area of livestock because it is difficult and costly to transporting heavy manure (Carlson, 2005). In Rice County, in the center of the CRW, Brad Carson, who is the County Extension Educator, believes that the majority of the County uses commercial fertilizer because of the difficulty in quantifying how much phosphorus is in applied manure. Farmers want to ensure proper plant growth and therefore are likely to apply too much. Carlson estimates that phosphorus amounts are likely sourced equally among the two types of fertilizer. In contrast to this, inorganic fertilizer produced the most TP runoff load compared to manure and slurry groups in a laboratory study performed by Heathwaite (Heathwaite, 1997). For more accuracy, a survey could be conducted determining what kind and method of phosphorus application is used in different parts of the Watershed.

Bedrock further contributes to erosional properties. Permeable rock will readily absorb water causing overlying soil to drain rapidly resulting in less erosion. Depth to bedrock is also important because a shallow soil layer becomes easily saturated. Shallow soils also have less compaction and cohesiveness (Tipping, 2005).

Despite the lacking influences mentioned above, this study provides a starting point for assessing phosphorus runoff. Investigations in response to this data could include examining areas indicated as very high or high risk in the field. For example: why is it that the east side of the Straight River is at more risk for phosphorus runoff than the west? And what are the characteristics (soil, bedrock, etc.) of the upper portion of the SRW making it so hazardous? Furthermore, why are the lakes on the west side of the CRW not at risk or are they? What is their algal content?

CONCLUSION:

Based on the composite map of potential phosphorus runoff, the majority of the CRW displays high risk for phosphorus runoff. The highest risk areas are found either along riverbanks or among lakes in the upper portion of the watershed. Beneath Byllesby Reservoir there is also a significant amount of very high-risk areas, however these areas do not contribute to the eutrophication of the Reservoir.

These data present potential expected correlations as well as unexpected. High phosphorus runoff along streams or around lakes could be a result of the erosion potential because the K-factor is strongly influential even when the weight is halved in the final equation. However, some areas near water bodies exhibit lower phosphorus runoff risk and do not support this theory. The unexpected correlation between very high phosphorus runoff risks in areas where land use risk is the least harmful can be explained by higher slopes also associated with these areas and likely the reason these areas were not cultivated.

Adding more variables to the equation would enhance the accuracy of this project. Phosphorus application though fertilizer, both organic and inorganic, can increase phosphorus levels highlighted areas of cultivation as very high risk. Underlying bedrock characteristics, including the depth to bedrock and the porosity of the bedrock, indirectly influence risk areas though impact on erosion potential. Accuracy would also increase with more complete data. Areas without data in this project have been distinguished as inaccurate risk representation. Despite uncertainties of this project, results can be used as base data to begin further investigations concerning areas susceptible to phosphorus runoff. Fieldwork validation and data expansion (more specific ranking of smaller areas) would prove to be very beneficial.

Overall, farming and fertilizer application should be monitored in the agricultural areas of the upper watersheds of the Straight River and Upper Cannon River. However, the lower portions of the watershed should not be neglected simply because they do not contribute to the Byllesby Reservoir. The steeper slopes and larger K-factors characteristic of these regions put them at risk for phosphorus runoff contributions into other watersheds along with the Mississippi River into which the Byllesby Reservoir eventually flows.

ACKNOWLEDGEMENTS:

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