A Comparison of the Iowa Phosphorus Index, the Wisconsin Phosphorus Index, the Minnesota Phosphorus Index, and the Barr Engineering Phosphorus Index: Using Cottonwood River Watershed-based Soil Tests

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Project Vision and Scope

History:

The Cottonwood River Restoration Project and the Redwood River Clean Water Project are managed by the Redwood-Cottonwood Rivers Control Area Joint Powers Organization. Both projects have approved Watershed Implementation Plans prioritizing different reaches of the watersheds based on their disproportionate share of pollutant loadings. Pollutant loadings are a result of current contiguous water quality monitoring programs extending over a period of thirteen years. Total Maximum Daily Loading (TMDL) impairments are being assessed based on these water chemistry results, the Plans and priority areas have been adjusted to reflect those impairments in order to re-focus best management practice implementation. The need for accurate pollutant reduction estimation tools, based on current research, is an urgent priority. We need to have the ability to accurately credit implementation projects and correlate those reductions to water quality trends in order to delist current and future impairments.

The ensuing debate in Minnesota on what reduction credits can be attributed to open tile intake replacements with rock inlets and slotted risers has been the catalyst for this comparison project. Making the jump from treatment efficiencies and life expectancies of alternative tile intakes (ATIs) to the phosphorus indices has been a logical step with the Lower Minnesota River (DO) TMDL and the focus on phosphorus reductions. Using the indices and actual project site soil samples collected using University of Minnesota protocols, we can quantify the phosphorus delivery in pounds per acre per year.

Vision:

It is our intention to utilize the indices as a platform for pre-site evaluation and post practice pollutant reduction estimation based on commonly installed structural/non-structural best management practices. With this comparison using watershed specific parameters, we have created a preliminary phosphorus delivery calculator. We have already begun using the treatment efficiencies of various ATI replacements to figure net reductions of total phosphorus. We intend to expand this to other historical best management practices implemented in the Cottonwood and Redwood River Watersheds. After refinement of our methods using peer-review feedback, we will distill our efforts to create a calculator that can be both predictive and reactive. New project requests will have a preliminary assessment done to determine net pollution reduction return on investment. This will serve as a project ranking. This assessment will also serve as the reported pollutant reduction on successfully funded projects. This information is needed for grant reporting purposes and entry into the E-link database. As new research refinements emerge, we will update the calculator to reflect those refinements.

Request:

Please take the time to review our comparisons and offer feedback. We are compelled to ensure that each index has been properly represented and any assumptions made do not conflict with research findings.

James Doering, Executive Director, Redwood- Cottonwood Rivers Control Area

Abstract

Redwood-Cottonwood Rivers Control Area (RCRCA) is a joint powers organization charged with improving the water quality of the Cottonwood River, which drains into the Minnesota River. One of the pollutants degrading the water quality of the Cottonwood River and the Minnesota River is phosphorus. Installation of various best management practices (BMPs), including alternative tile intakes (ATIs), can reduce the amount of phosphorus entering the Cottonwood River.

The purpose of calculating and comparing various phosphorus indices is to determine how much phosphorus pollution is reduced by BMP implementation. Historical and current methods of assuming one pound of phosphorus reduction per intake per year may not be accurate. RCRCA wanted to confirm or improve this current reporting procedure. Soil samples from the Cottonwood River watershed were collected and tested and were used in calculating the Barr Engineering Index, the Iowa Phosphorus Index, the Wisconsin Phosphorus Index, and the Minnesota Phosphorus Index. The indices' results were compared to see how well the Cottonwood River watershed was represented by each index.

The results of the indices for Barr, Minnesota, Iowa, and Wisconsin were variable. One of the reasons for this is that each index uses different factors and equations to calculate their P Index value. Barr's, Wisconsin's, and Iowa's Indexes give results in pounds of P/ acre/ year. Iowa, Wisconsin, and Minnesota give a P Index value and a risk ranking category. All four procedures used RUSLE (soil erosion factor) and a sediment delivery ratio factor.

This paper is the second of a proposed series of articles to calculate phosphorus reduction by various BMPs, including ATIs. The last article discussed the phosphorus index calculations; this article will discuss phosphorus reduction by ATIs and will include a software program to calculate phosphorus reductions. The software package also includes a user's guide to assist the conservation professional in operating the software application. The next article in this series will include a "best-fit" hybrid RCRCA Phosphorus Index for the Cottonwood River watershed.

Introduction/Background:

Redwood-Cottonwood Rivers Control Area (RCRCA) is a joint powers organization charged with improving the water quality of the Cottonwood River. The Cottonwood River originates near Balaton, MN in the Coteau des Prairie, a glacial formation, in southwestern Minnesota. The Minnesota River receives the water from the Cottonwood River at New Ulm, Minnesota. The Minnesota River is on the State of Minnesota's impaired waters Clean Water Act 303d list (Minnesota Pollution Control Agency, 2004). One of the pollutants degrading the water quality of the Cottonwood River and the Minnesota River is phosphorus. An excess amount of phosphorus encourages algae blooms, which consumes the dissolved oxygen and stresses aquatic life. This stress contributes to fish kills. Installation of various best management practices (BMPs) can reduce the amount of phosphorus entering the Cottonwood River. BMPs include, but are not limited to, vegetative filter and buffer strips, riparian corridor restoration, erosion control (by conserving the soil, the phosphorus attached to the soil particles remains on the land), and alternative tile intakes (ATIs) that replace traditional tile intakes.

ATIs have a variety of designs to choose from; the most common design involves placing perforated tile within a trench filled with pea-rock. The theory behind ATIs is that surface water percolates into the soil and pea rock, which filters out contaminants, including phosphorus; cleaner water enters the tile line, which carries excess water to nearby surface waters that drain into the Cottonwood River. Removal of excess water within agricultural crop land in less than 24 hours prevents drowning of cash crops, mainly corn and soybeans. ATIs benefit the farmer by preventing crop mortality by drowning; ATIs help improve water quality and meet the conservation goals of cleaner water.

The purpose of calculating and comparing various phosphorus indices is to determine how much phosphorus pollution is reduced through the implementation of BMPs, including ATIs. The extent of phosphorus reduction by ATIs isn't fully understood. Historical and current methods of assuming one pound of phosphorus reduction per intake per year may not be accurate. RCRCA's goal is to confirm or improve this current reporting procedure. Soil samples were collected and tested; these test results were used in calculating the Iowa Phosphorus Index, the Wisconsin Phosphorus Index, the Minnesota Phosphorus Index, and the Barr Engineering Phosphorus Index. The indices were adjusted to meet the parameters of the Cottonwood River watershed. The indices' results were compared against one another to see how well the Cottonwood River watershed was represented.

This paper is the second in a series of articles to calculate phosphorus reduction by various BMPs, including ATIs. This article discusses the phosphorus index calculations and phosphorus reduction by ATIs. A separate package will include a software application to calculate phosphorus reductions, a User's Guide for the software application, and Sample Problems to help the user familiarize his/herself with the software application.

Methods/Procedure:

RCRCA contacted landowners of ATIs installed within the Cottonwood River watershed. RCRCA received permission to sample soils of 86 ATIs in southwestern Brown, northern Cottonwood, southeastern Lyon, northeastern Murray, and southern Redwood counties. Please check the Appendix to view the GIS maps created by RCRCA of the ATI locations. Due to time, crop harvest, and weather constraints, only 64 of the 86 ATIs were soil-sampled in the fall of 2003. GPS coordinates for all ATI sites were obtained with a Garmin GPS for later reference. A soil-sampler was used to obtain a 1-inch diameter, 16-inch long soil sample. Four soil samples, one on each side of the rock inlet, were taken and placed into a pail. The four samples were mixed to obtain one composite soil sample. This composite was sent to the Soils Testing Lab of the South Dakota State University at Brookings, South Dakota for analysis of coarse soil texture, pH, soluble salts, nitrogen (NO_3), total nitrogen, phosphorus-Olsen, and potassium.

Each of the ATI locations were recorded with the Unites States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) GPS backpack and Garmin GPS Map 76 unit. The backpack unit was set on NAD 83 with UTM Zone 15. All of the ATI locations had a differential of less than 10 feet; many were less than 6 feet. Differentials were observed during recording to verify accuracy while at the location.

The GPS coordinates were entered into ArcView 3.3 GIS software for ATI watershed analysis. The land that drains into each ATI forms the watershed of each ATI. Watersheds were delineated using the USGS 7.5' topographical maps, aerial photos, field observations, and USDA soil survey maps. Please check the Appendix to view RCRCA's Maps 1 through 5 to see the GIS maps outlining the watershed and soils of select ATI watersheds. The Appendix also includes RCRCA's Table 2, which has the GPS coordinates, field location information, sampling information, and soils information. The watershed and soil characteristics were used to calculate the Revised Universal Soil Loss Equation (RUSLE) value. GIS was used to identify the soils within each ATI watershed in order to calculate the RUSLE, which was used in all phosphorus index and phosphorus reduction calculations. Other characteristics, such as watershed slope, were also calculated using GIS.

The ATI watersheds ranged from 1.68 acres to 109.03 acres. The mean, median, and standard deviation values of the ATI watersheds are 18.22, 11.75, and 20.17 acres, respectively. The acreage for all 64 ATI watersheds totals 1,165.94 acres. The majority of the ATIs are located within agricultural land, including land under corn and soybean farming systems, field edges, and building site edges. The majority of the ATIs are maintained by farmers without livestock; mostly commercial fertilizer is used on the crops rather than manure. Many of the fields have conservation tillage; only a few are no-till or conventionally tilled. For the purpose of phosphorus index calculations, RCRCA used a corn-soybean rotation with chisel conservation tillage.

RUSLE was calculated for each ATI watershed, using the USDA-NRCS RUSLE guidelines found in the Technical Guide (USDA-NRCS, 1996). The RUSLE equation is $A=R*K*LS*C*P$ where A is the annual soil loss in tons soil loss / year. The R (rainfall) factor varies by county: 115 for Murray county, 110 for Redwood county, 120 for Cottonwood county, and 115 for Brown county. The K (soil erodibility) and LS (slope length and steepness) factors vary by soil type. The K and LS factor values were weighted according to their proportion of the entire watershed for each ATI. Since the majority of the ATIs are found in agricultural land, the C (cover and management) factor was determined to be 0.20 from average-yielding grain corn to be planted on soybean stubble with 20% residue cover from fall mulch tillage. The P (supporting practice) factor was set at 1 since it is impractical to locate and estimate each supporting practice in each ATI watershed. The RUSLE values ranged from 0.78 tons soil loss/ ATI/ year to 12.02 tons soil loss/ ATI/ year. The median, mean, and standard deviation RUSLE values are 1.57 tons soil loss/ ATI/ year, 2.13 tons soil loss/ ATI/ year, and 1.73 tons soil loss/ ATI/ year, respectively. The total RUSLE value for all 64 ATIs is 136.05 tons soil loss/ all ATIs/ year.

Once the background information of soils, slope, watershed size, and current land use were determined, phosphorus reduction and loss rankings were calculated using the Barr Engineering, Iowa Phosphorus Index, Wisconsin Index, and Minnesota Index. In addition to the Minnesota Index, the Iowa and Wisconsin Indices were considered since they border Minnesota and their soils, vegetation, and landforms are similar to Minnesota's landscape. The results of the various indices are shown in RCRCA's Figures 1 through 10 in the Appendix.

Barr Engineering Index Calculations:

The Barr Engineering Index (Phosphorus Trade Crediting Calculations…) is an assessment tool developed for the Southern Minnesota Sugar Beet Cooperative for phosphorus trade credit calculations. SMSBC participants have agricultural land in southwestern Minnesota, including the Cottonwood River watershed. The Barr Index uses RUSLE, soil types, treatment efficiency, and a delivery ratio to calculate the amount of phosphorus entering and leaving ATIs. Barr assumes that the phosphorus content of the soil is dependent upon soil types. For example, clay loam is 1.15 lb P/ Ton and silty soil is 1.00 lb P/ Ton. The delivery ratio for ATIs is 0.2 or 20%. Barr's calculations call for 50% treatment efficiency; Wilson's research indicates that ATIs have a treatment efficiency of 88.1% (Wilson, et al, 1999). RCRCA calculations used 88.1% treatment efficiency for the purposes of this comparison.

The Sediment Delivery Ratio "before ATI" uses the equation RUSLE * Delivery Ratio. This value is put into the equation $(7.4(SDR*2241.66)^{-0.2})$ to calculate the enrichment factor. This value is used in the equation Enrichment Factor * Soil Phosphorus Content * "before ATI" Sediment Delivery Ratio to determine the Phosphorus content of the Sediment Delivered to the ATI in lbs P/ ac/ yr. This value is multiplied by the watershed size to determine the amount of phosphorus delivered in the sediment to the ATI from its watershed. These variables are calculated again, this time modified by the treatment efficiency of 88.1% to determine the amount of phosphorus reduction due to treatment by the ATI. The result of the second calculation gives the phosphorus delivered after the implementation of the ATI. The "before" – "after" results in the total phosphorus savings or reduction for that particular ATI's characteristics.

The Barr Phosphorus Index ratings ranged from 0.01 lbs P/ ATI/ yr to 62.46 lbs P/ ATI/ yr with a mean of 6.16 lbs P/ ATI/ yr. The Phosphorus Index median and standard deviation values are 3.42 and 9.12, respectively. The Barr Index does not assign a risk level to its values; it only calculates an estimated phosphorus reduction.

Iowa Phosphorus Index Calculations:

The Iowa Index (USDA-NRCS, Iowa, 2001) is an assessment tool to determine risk for phosphorus transport away from its source of origin. The Iowa index considers RUSLE, phosphorus soil test results, the use of buffers and BMPs, runoff and precipitation, and the use of subsurface drainage systems. The results are given in pounds of phosphorus per acre and ranked into very low to very high risk categories.

The Index rating is calculated from the following formula: Erosion Component + Runoff Component + Subsurface Component = Phosphorus Index

The Erosion Component of the Iowa index is calculated by: Gross Erosion * (Sediment Trap Factor or Sediment Delivery Ratio) * Buffer factor * Enrichment Factor * Soil Test P Erosion Factor = Erosion Component

The Gross Erosion is the sum of RUSLE and gulley erosion estimates. The sediment trap factor is taken from Iowa Index Table 1. ATIs function similar to a water and sediment control basin, which has impounded water and tile to drain the pond. ATIs temporarily pond the water and allow the tile to slowly drain off the impounded water. Iowa also says that water and sediment control basins have a trapping factor of 0.2 (or 20%), which matches the trapping factors determined by Ranaivoson's research (Ranaivoson, 2001) and the Minnesota Index. The Sediment Delivery Ratio was taken from Iowa Index Figure 2. The distance to surface water for ATIs are less than 10 ft (once runoff water enters the ATI, the water is carried directly to surface water), so the value from Figure 2 is one. The buffer factor is taken from Iowa Index Table 2. There are no buffers for ATIs, so the buffer width of 0-19 feet has a factor value of 1. The enrichment factor is taken from Iowa Index Table 3. RCRCA assumed there is no buffer and that tillage is performed, so the factor value is 1.1. The Soil Test P (STP) Erosion factor is taken from Table 4 of the Iowa Index and is based off of the soil test results and ranged from 0.15 to 3.52.

The Runoff Component of the Iowa Index is calculated by: Runoff factor * Precipitation factor * (STP Runoff Factor + P Application Factor) = Runoff Component

The Runoff factor uses the Natural Resources Conservation Service (NRCS) Runoff Curve Number (USDA-NRCS, 1993). The RCN values are typically in the mid-70s, with 75 being a common RCN for agricultural land in southwestern Minnesota. For RCRCA's purposes, an RCN value of 75 is used. The RCN value is inputted into Iowa Index Figure 3, which returns the factor of 0.175. This table modifies the traditional RCN in that the calculated RCN is entered into the table to obtain a factor. One important consideration is that Iowa research shows that one-half of all rain events in Iowa do not produce runoff. Iowa research shows that rainfall must meet or exceed 0.75 inches to produce runoff. Therefore this runoff factor is cut in half to account for the runoff behavior. Please note that in RCRCA graphs and figures, the term "one-half RCN" leaves the original Iowa Index runoff factor intact. The RCRCA term "full RCN" doubled the table results to obtain full Runoff impact. The Precipitation factor is taken from the Minnesota Hydrology Guide Chapter 1 Figure 1-1 of 26 inches. Twenty-six inches is divided by 4.415 to convert inches of rain to million pounds of water/acre. A Precipitation factor value of 5.89 is used. The Figure 4 of the Iowa Index is not used since Iowa precipitation differs from the Cottonwood River watershed precipitation levels. The STP Runoff Factor is the amount of total dissolved phosphorus concentration in runoff, estimated from the STP results in Iowa Index Table 5. Table 5 returned values ranging from 0.09 to 0.80. The P Application Factor is obtained from by using 50 pounds P_2O_5 incorporated within one week to receive a value of 0.02 from Iowa Index Table 6. The STP Runoff Factor and the P Application Factors are added together and then entered into the Runoff Component equation.

The Subsurface Drainage Component is calculated by: Precipitation Factor * Flow Factor * STP Drainage Factor = Subsurface Drainage Component.

The Precipitation Factor value is the same as the Precipitation Factor of the Runoff Component, 5.89. The Flow Factor value from is 0.1 since tile is known to be present as part of the ATI design. The STP Drainage Factor is either 0.1 or 0.2. 0.1 is used if the STP value is less than 60 ppm for Olsen test. 0.2 is used if the STP value is greater than or equal to 60 ppm for Olsen test. RCRCA test results used both 0.1 and 0.2. The Subsurface Drainage Components ranged from 0.06 to 0.12.

The Erosion Component, Runoff Component, and Subsurface Drainage Components are added together to obtain the Phosphorus Risk Index. The Phosphorus Index ratings ranged from 0.32 to 4.48 lbs P/ ac/ yr with a mean of 0.78 (using Iowa's original one-half RCN factor). The one-half RCN Phosphorus Index median and standard deviation values are 0.62 and 0.55. The majority of the ATIs were rated very low or low risk. Iowa's full RCN ratings ranged from 0.43 to 5.32 lbs P/ ac/ yr with a mean of 1.07. The full RCN Phosphorus Index median and standard deviation values are 0.88 and 0.67. Again, the majority of the ATIs were rated very low or low risk.

The Index values are helpful, but for RCRCA's purposes, they do not answer the question on the amount of phosphorus reduction for ATIs. The Phosphorus Index rating for each ATI needed to reflect treatment efficiencies to answer this question. Bruce Wilson's research indicates that rock inlet ATIs have a treatment efficiency of 88.1% compared to no treatment (Wilson, et al, 1999). Flush pipe (a standard tile intake) has a treatment efficiency of 66.6% when compared with no treatment. Many of the ATIs studied for this comparison are conversions from a flush pipe to a rock inlet ATI. The actual "net gain" for phosphorus reductions is obtained by subtracting 88.1% - 66.6% = 21.5% to reflect the actual changes wrought by the tile intake conversion.

For the Iowa Full RCN Phosphorus Index "net gain" conversion reductions, the ratings ranged from 0.31 to 35.26 lbs P/ ATI/ yr with a mean of 4.34. The full RCN Phosphorus Index "net gain" conversion median and standard deviation values are 2.53 and 6.12.

Wisconsin Phosphorus Index:

The Wisconsin Phosphorus Index (Good, 2004) is an assessment tool to estimate the risk of phosphorus transport from an agricultural landscape into surface waters. The Wisconsin Index considers particulate phosphorus, soluble phosphorus, acute phosphorus losses from manure or fertilizer, and a total phosphorous delivery ratio. Particulate phosphorus (PP) is dependent on the amount of soil eroded from the field, the bulk soils phosphorous concentration, and sediment phosphorous enrichment. Soluble phosphorus (SP) considers phosphorus dissolved in runoff and is dependent on runoff volume, soil soluble phosphorous, and soil test extraction efficiency. The acute phosphorous loss from manure or commercial fertilizer equation uses a worst-case runoff event approach to estimate phosphorous loss from surface applications. The total phosphorus delivery ratio (TPDR) is determined by slope and flowpath length from field edge to surface waters. The Wisconsin Index uses the Bray phosphorus test results. Since RCRCA's soil testing laboratory used the Olsen test, the Olsen ppm was converted to Bray by dividing the Olsen P ppm result by 0.6.

The Wisconsin index is calculated by: [PP + SP + Acute P Losses from surface manure or fertilizer] * TPDR = Phosphorus Index

Particulate phosphorus (PP) is calculated by the formula: Sediment Delivery * Bulk Soil P Concentration * Sediment P Enrichment * 0.002 = PP. The Sediment Delivery is the RUSLE value. The Bulk Soil P Concentration is -15 + (154*SOM%) + (1.7*Adjusted crop year surface Bray P). The Soil Organic Matter percent (SOM%) used is 3.8, an average value for medium organic matter values taken from University of Minnesota Extension Service (University of Minnesota Extension Service, 1998). The adjusted crop year surface Bray P is derived from a series of calculations, described as follows. The adjusted surface Bray P accounts for soil stratification and is calculated by Initial Surface Bray P = Bray ppm * Stratification Factor. The stratification factor is based off of the subsoil fertility group which is given for Wisconsin soil series (Kelling et al, 1998). When comparing soils found in the publication and in the Cottonwood River Watershed, only 8 local soils were listed. Five of the eight were listed as subsoil fertility group B. The other three were in groups A, E, and O. The B category was used for the purposes of this comparison. The stratification factor for A & B subsoil fertility group is

1.2, so the Initial Surface Bray P = Bray ppm * 1.2. This value is used in the Adjusted Crop Year Surface Bray P equation which accounts for new phosphorous additions. Adjusted Crop Year Surface Bray P = Initial Surface Bray P + [(Total P incorporated (lb/ac))/18] + [(Total P broadcast (lb/Ac))*(0.42)]. The total P incorporated is 174 lb/Ac as calculated for the other indices and the total P broadcasted is zero so this equation is reduced to Adjusted Crop Year Surface Bray P = Initial Surface Bray + 9.67 + 0. The Sediment P Enrichment factor is set as 1 as a placeholder by the Wisconsin Index due to their research that shows a dilution of total Phosphorus. Wisconsin is waiting for additional research to prove or disprove this preliminary finding. Wisconsin has a concern on the soils testing methodology that could have influenced the test results.

The Soluble Phosphorus (SP) factor for the Wisconsin Phosphorus Index is calculated by Annual Runoff volume * Soil soluble P * Extraction efficiency * 0.2265 = SP. The annual runoff volume is taken from the Minnesota Hydrology Guide figure 7-1 which gives 3.5 inches. Soil soluble P is taken from the subsoil fertility group, which is B for this comparison: Soil soluble P = 0.012*(Adjusted Surface Bray P) + 0.08. The extraction efficiency uses the hydrologic soil group, which is also B for this comparison, and is 0.7 from the Wisconsin Index table.

The Acute Phosphorus Loss from surface manure or fertilizer is calculated from Non-frozen Ground $P_{surface}$ = (Soluble P in surface fertilizer * Soluble P Single Storm Loss factor) + Total P in Manure Applied in Fall) * Fall Particulate P Single Storm Loss factor. Soluble P in surface fertilizer = ((174lb/Ac fertilizer applied)/18) * Water Solubility factor = 9.67* 1. There was no value given for water solubility for fertilizer, only manure in Table 2 of the Wisconsin Phosphorus Index; assuming all of the fertilizer is water soluble. Soluble P Single Storm Loss factor is a factor based on the hydrologic group of the soils: A and B soils with a spring application are 0.005. For this comparison no fall manure was applied, so the Total P in Manure Applied in Fall is zero. The Fall Particulate P Single Storm Loss factor is a constant with a value of 0.03.

The Total Phosphorus Delivery Ratio (TPDR) is the last portion of the Wisconsin Phosphorus Index equation. It is influenced by the dominant slope and the flowpath length to surface waters which is listed in Wisconsin’s Table 3. When distance to water is less than 250 feet (as with ATIs), the value is 1, regardless of slope. The three phosphorus sources are added together and then multiplied by the TPDR. This final value calculates a gross estimate of P loss (lb/ac/yr) on a field scale.

The majority of ATIs have an acceptable Wisconsin Index rating. A value less than 6 lb/ac/yr is considered to be an acceptable Phosphorus loss risk; a value higher than 6 is not acceptable. Six sampling sites exceeded 6.0; the remaining 58 were less than 6.0. The mean Index ranking is 3.28 lb/ac/yr with a range of 1.24 to 22.27 lb/ac/yr. The standard deviation and median are 2.89 and 2.44, respectively.

The Index values are helpful, but again for RCRCA's purposes, they do not answer the question on the amount of phosphorus reduction for ATIs. Again, the treatment efficiencies were considered as in the Iowa Index and calculated to determine the "net gain" for treating each ATI watershed by converting flush pipes to rock inlet ATIs.

For the Wisconsin Phosphorus Index "net gain" conversion reductions, the ratings ranged from 0.97 to 138.26 lbs P/ ATI/ yr with a mean of 13.04. The Phosphorus Index "net gain" conversion median and standard deviation values are 6.30 and 21.15, respectively.

Minnesota Phosphorus Index:

The Minnesota Index (Minnesota…, 2002) calculates the risk of phosphorus movement off of the land and into the surface waters. The Minnesota Index is based on the concept of multiple pathways of phosphorus movement from land to water. The pathways are sediment-bound phosphorus from rainfall runoff (Pathway 1), soluble phosphorus from rainfall runoff (Pathway 2), and soluble phosphorus from snowmelt runoff (Pathway 3). The phosphorus index is: Pathway 1 + Pathway 2 + Pathway 3 = Phosphorus Index

The first pathway, sediment-bound phosphorus from rainfall runoff, is calculated by: RUSLE * Manure Factor * (the lesser of Sediment Trap Factor or Sediment Delivery Ratio) * Soil Total Phosphorus Concentration = Pathway 1

The RUSLE values are the same for all of the indices and were calculated with GIS and Excel spreadsheets. The Manure Factor was found in Minnesota Table 1; a factor of 1 was used because no manure was applied. The Sediment Trap Factor and the

Sediment Delivery Ratio are compared; the lesser of the two is used. Minnesota Index Table 2 has the Sediment Trap Factors; a gravel inlet structure has a trapping efficiency of 0.1 and a surface tile inlet has a trapping efficiency of 0.2. Minnesota Figure 1 has the sediment delivery ratio with a value of 1 because the flow distance from edge of field is 1. For rock inlets, 0.1 is used. For traditional tile intakes, a factor of 0.2 is used. The Soil Total Phosphorus Concentration is calculated by Minnesota Table 3. Table 3 uses the Olsen phosphorus test in the following equation: Total Phosphorus Concentration (lb P/ton) = (0.0067 * Olsen test) + 0.92.

The second pathway, soluble phosphorus from rainfall runoff, is calculated by: Base Runoff Volume * Runoff Adjustment Factor * (Soluble Soil P + Applied P) * 0.22 = Pathway 2

The Base Runoff Volume value of 1.5 is determined from Minnesota Figure 2 of the index. The Runoff Adjustment Factor is determined by Minnesota Table 4 to be 1 by using soil hydrologic group B, 5-20% surface cover, and row crops. The Soluble Soil P is calculated in Minnesota Table 3's Soluble Soil P Concentration (lb P/ton) = 0.0106 * Olsen test. The Applied P value is calculated in Minnesota's Table 5, which considers amount of phosphorus in fertilizer and tillage multiplied by a constant of 0.044. RCRCA used the tillage factor of 0.35, with straight chisel incorporation.

The third pathway, soluble phosphorus from snowmelt runoff, is calculated by: Snowmelt Runoff * Fall Soil Condition * (Residue P + Surface Applied P) * 0.18 = Pathway 3.

The Snowmelt Runoff is determined using Minnesota Figure 3 with a value of 0.75 (midway between the 0.5 and 1.0 data lines). The Fall Soil Condition is 0.6 by considering chisel plow tillage up and down the slopes. The Residue P value from Minnesota Table 7 is 3.2, taken from Surface Residue P after Fall Tillage column, CP (chisel plow) tillage, crop of corn at 100 bu/ac yield. These conditions are common to the Cottonwood River watershed.

The three pathways were added together for each of the ATI sampling sites. This value is a relative ranking and is unitless. The ranking values range from 1.53 to 3.51. The mean and median values are 1.76 and 1.66, respectively. The standard deviation value is 0.27. Fifty-seven ATIs were rated low and 7 ATIs were rated to have medium risk according to the Minnesota Index risk categories.

The treatment efficiencies for converting the flush pipe to a rock inlet ATI could not be calculated using the Minnesota Index since the Minnesota Index is unitless.

Comparisons Between Indices:

The results of the indices for Minnesota, Iowa, and Wisconsin were variable. One of the reasons for this is that each index uses a variety of factors and equations to calculate their P Index value. Barr's, Wisconsin's, and Iowa's indices gave results in pounds of P/ acre/ yr. Iowa, Wisconsin, and Minnesota give a P Index value and a risk ranking category. All four procedures use RUSLE (soil erosion factor), and a sediment delivery ratio factor. All of the state indices use soil test P, fertilizer P application rates, organic P (manure) application rates, organic P application method, runoff, distance to waterbody, buffer strips, precipitation, and soluble P factors. Having the same factors does not mean the same equations were used, however. A summary of the different factors is given in the Comparison of Indexes table found in RCRCA Table 1 in the Appendix.

All of the indices have strengths and weaknesses. None of the indices included examples to help the user verify whether or not the index is calculated correctly. Some of the directions for calculating the indices are vague and open to interpretation. Some of the factor tables do not include all possible field scenarios.

For example, the Iowa Index does not include sediment trapping efficiency factors (Table 1) for ATIs, grassed waterways, or filter strips. The enrichment factor (Table 3) considers all tillage under one category—moldboard plow tillage will vary from ridge tillage for phosphorus enrichment just by the differences in each tillage practice. The Minnesota Index (Table 5) does consider the differences between tillage concerning applied phosphorus and in management practices. The Minnesota Index also appeared to have typos in its worksheet which prompted some assumptions on RCRCA's part. Also, the Minnesota Index look-up map for snow precipitation appears to have been modified from another source and the map is difficult to read due to differing numerical values.

One of the strengths that the Iowa Index has is that it considers a phosphorus enrichment factor. The Iowa Index also quantifies the amount of phosphorus at risk for leaving the field and entering the surface water or tile. The Wisconsin Index strengths include consideration of hydrologic group, subsoil fertility, snowmelt runoff, extraction efficiency, plow layer, and slope. The Minnesota Index utilizes many of the factors of the Iowa and Wisconsin Indices. Minnesota's Index also considers the total phosphorus in the field while Wisconsin does not.

Conclusions:

Each of the various indices include different aspects of sources, transport, and loss of phosphorus from the agricultural field setting. Some of the factors, such as snowmelt runoff, slope, tile presence, and sediment delivery ratio influence how much phosphorus enters surface waters, including the Cottonwood River. A user-friendly software program has been developed by RCRCA to reflect the various indices. This software's purpose it to help the conservation professional determine the amount of phosphorus reduction performed by rock inlet ATIs and later, other BMPs. This software can also help determine the "bang for the buck" economic and water quality return value for various BMPs. It may also assist the landowner in determining the most "bang for the buck" return when comparing various conservation practices and influence their conservation management decisions. The next step in the Phosphorus Index for the Cottonwood River is to receive feedback from the developers of the various indices and develop a hybrid Phosphorus Index that covers the specific parameters of the Cottonwood River watershed in southwestern Minnesota. Once the hybrid is finalized, the user-friendly software program will be finalized and developed for use by RCRCA and its partners to assist in phosphorus management and reduction within the Cottonwood River watershed. Only then can the question of ATIs – and other BMPs -- phosphorus reduction abilities be answered.

Appendix

Table 1: Comparison of Indexes & Formulas

Item	**Barr Engineering**	**Iowa Phosphorus Index**	**Wisconsin Phosphorus Index**	**Minnesota Phosphorus Index**
Source Factors				
Soil Test P		X	X	X
Fertilizer P Application Rate		X	X	X
Fertilizer P Application Method		X	X	X
Organic P Application Rate		X	X	X
Organic P Application Method		X	X	X
Sediment Delivery Ratio	X	X	X	X
Enrichment Factor	X	X		
Others	Dominant Soil w/ P content		Extraction Efficiency, Subsoil Fertility, Application Timing	
Transport Factors				
Soil Erosion	X	X	X	X
Runoff		X	X	X
Leaching Potential			Soil Hydrologic Group	
Distance to Water Body		X	X	X
Buffer Strip		X		X
Subsurface Drainage		X		
Precipitation		X	X	X
Total P		X		X
Soluble P		X	X	X
Snowmelt Runoff			X	X
Others			Plow Layer, Slope	
Index Mathematical Processing		Additive	Additive	Additive

Parts taken from GEIS for Animal Agriculture in MN by Moncrief & Bloom

Table 2: ATI Location, Sampling Information, and Soils Information

ATI #*	LAT	LONG (-)	COUNTY	TWP NAME	T # N	R # W	SEC	1/4	SAMPLED	ELEV	SOIL SYMBOL	SOIL SERIES
1E	44.20164350	95.45088507	REDWOOD	N. HERO	T109N	R38W	32	SW 1/4	27-OCT-03 11:14	1255	241, 345	Letri CL, Wilmonton CL
2EP	44.20158181	95.44678599	REDWOOD	N. HERO	T109N	R38W	32	SW 1/4	27-OCT-03 11:35	1238	149B, 241	Everly CL 2-4, Letri CL
3T	44.19890413	95.44234794	REDWOOD	N. HERO	T109N	R38W	32	SW 1/4	27-OCT-03 11:56	1225	392	Biscay L
4T	44.20631248	95.45222157	REDWOOD	N. HERO	T109N	R38W	31	NE 1/4	27-OCT-03 10:39	1252	241	Letri CL
5T	44.20343857	95.45337911	REDWOOD	N. HERO	T109N	R38W	31	NE 1/4	27-OCT-03 10:51	1248	1897, 241	Seaforth-Wilmonton CL, Letri CL
6T	44.04618787	95.38385952	COTTONWOOD	WESTBROOK	T107N	R38W	27	NE 1/4	19-NOV-03 15:13	1409	241	Letri CL
7T	44.04347624	95.38119315	COTTONWOOD	WESTBROOK	T107N	R38W	27	SE 1/4	14-NOV-03 09:53	1410	114	Glencoe CL
10TI	44.26074665	95.58180847	REDWOOD	SPRINGDALE	T109N	R39W	7	SE 1/4	23-OCT-03 14:16	1271	894B2, 149B, 241	Everly Storden Cplx, Everly CL, Letri CL
11TI	44.25852603	95.57898662	REDWOOD	SPRINGDALE	T109N	R39W	7	SE 1/4	23-OCT-03 14:33	1272	241	Letri CL
12T	44.30717812	95.53382711	REDWOOD	GALES	T110N	R39W	28	NW 1/4	23-OCT-03 11:37	1167	86	Canisteo CL
13T	44.30502053	95.53565755	REDWOOD	GALES	T110N	R39W	28	NW 1/4	23-OCT-03 12:20	1160	86	Canisteo CL
14T	44.30523427	95.53723033	REDWOOD	GALES	T110N	R39W	28	NW 1/4	23-OCT-03 12:09	1159	241	Letri CL
15T	44.30709933	95.53741406	REDWOOD	GALES	T110N	R39W	28	NW 1/4	23-OCT-03 11:57	1177	241	Letri CL
16T	44.30688291	95.53636716	REDWOOD	GALES	T110N	R39W	28	NW 1/4	23-OCT-03 11:51	1174	241	Letri CL
17T	44.29891147	95.56934609	REDWOOD	GALES	T110N	R39W	29	SW 1/4	23-OCT-03 11:03	1148	269	Millington SICL
18T	44.12435747	95.05095175	BROWN	STATELY	T108N	R35W	28	SW 1/4	14-NOV-03 14:47	1189	113	Webster CL
19T	44.12342727	95.05346686	BROWN	STATELY	T108N	R35W	28	SW 1/4	14-NOV-03 14:34	1183	113	Webster CL
20T	44.12387931	95.05770548	BROWN	STATELY	T108N	R35W	28	SW 1/4	14-NOV-03 14:17	1184	113	Webster CL
21T	44.12606120	95.05439870	BROWN	STATELY	T108N	R35W	28	SW 1/4	14-NOV-03 15:14	1174	113	Webster CL
27E	43.94707924	95.40304821	COTTONWOOD	ROSE HILL	T106N	R38W	33	NE 1/4	19-NOV-03 12:14	1495	884	Webster Delft CL
29T	44.09458439	95.48929330	MURRAY	DOVRAY	T107N	R39W	2	E 1/2	22-OCT-03 13:03	1438	594	Jeffers CL
30T	44.09545460	95.48245895	MURRAY	DOVRAY	T107N	R39W	2	E 1/2	22-OCT-03 13:22	1450	241	Letri CL
31E	44.09859521	95.48841840	MURRAY	DOVRAY	T107N	R39W	2	E 1/2	22-OCT-03 13:58	1458	345	Wilmonton CL
32E	44.10047687	95.48594532	MURRAY	DOVRAY	T107N	R39W	2	E 1/2	22-OCT-03 14:11	1455	149B, 594	Everly CL 2-6, Jeffers CL
33T	44.10339670	95.48967862	MURRAY	DOVRAY	T107N	R39W	2	E 1/2	22-OCT-03 15:00	1455	594	Jeffers CL
34T	44.10321498	95.48559085	MURRAY	DOVRAY	T107N	R39W	2	E 1/2	22-OCT-03 14:53	1454	345	Wilmonton CL
35T	44.10350550	95.48456155	MURRAY	DOVRAY	T107N	R39W	2	E 1/2	22-OCT-03 14:42	1461	345	Wilmonton CL
37T	44.10710729	95.48249013	MURRAY	DOVRAY	T107N	R39W	2	E 1/2	22-OCT-03 15:54	1433	594	Jeffers CL
38T	44.10874662	95.49031807	MURRAY	DOVRAY	T107N	R39W	2	E 1/2	22-OCT-03 16:11	1444	594	Jeffers CL
40T	44.10876573	95.48736714	MURRAY	DOVRAY	T107N	R39W	2	E 1/2	22-OCT-03 16:05	1451	345	Wilmonton CL
42T	44.00707447	95.36281707	COTTONWOOD	ROSE HILL	T106N	R38W	11	NE 1/4	14-NOV-03 13:14	1421	113	Webster CL
43T	44.00676931	95.36587511	COTTONWOOD	ROSE HILL	T106N	R38W	11	NE 1/4	14-NOV-03 13:25	1432	113	Webster CL
44T	44.08058686	95.40056507	COTTONWOOD	WESTBROOK	T107N	R38W	10	SW 1/4	14-NOV-03 11:31	1392	149B, 241	Everly CL 2-4, Letri CL
45T	44.09263124	95.39495308	COTTONWOOD	WESTBROOK	T107N	R38W	10	NW 1/4	14-NOV-03 12:12	1381	211	Lura SIC
46T	44.09330760	95.39480955	COTTONWOOD	WESTBROOK	T107N	R38W	10	NW 1/4	14-NOV-03 11:58	1389	211, 594	Lura SIC, Jeffers CL
47T	44.09426750	95.39455259	COTTONWOOD	WESTBROOK	T107N	R38W	10	NW 1/4	14-NOV-03 11:50	1383	211	Lura SIC
49T	43.97369622	95.38648733	COTTONWOOD	ROSE HILL	T106N	R38W	22	NE 1/4	19-NOV-03 11:37	1431	595C, 114	Swanlake L 6-12, Glencoe CL
50T	43.97351023	95.38647006	COTTONWOOD	ROSE HILL	T106N	R38W	22	NE 1/4	19-NOV-03 11:28	1429	595C, 114	Swanlake L 6-12, Glencoe CL
51T	44.19241277	95.44341613	COTTONWOOD	ANN	T108N	R38W	6	NE 1/4	27-OCT-03 12:32	1260	589	Jeffers Variant CL 2-4
52T	44.19456666	95.44529560	COTTONWOOD	ANN	T108N	R38W	6	NE 1/4	27-OCT-03 12:13	1262	589	Jeffers Variant CL 2-4

ATI #	LAT	LONG	COUNTY	TWP NAME	T # N	R # W	SEC	1/4	SAMPLED	ELEV	SOIL SYMBOL	SOIL SERIES
53T	44.01694112	95.43294408	COTTONWOOD	ROSE HILL	T106N	R38W	5	NW 1/4	19-NOV-03 13:09	1435	35	Blue Earth mucky SIL
54T	44.06042738	95.44350397	COTTONWOOD	WESTBROOK	T107N	R38W	19	NE 1/4	14-NOV-03 10:30	1445	884	Webster Delft CL
55T	44.06036183	95.44340791	COTTONWOOD	WESTBROOK	T107N	R38W	19	NE 1/4	14-NOV-03 10:33	1439	884	Webster Delft CL
56T	44.05407515	95.44627720	COTTONWOOD	WESTBROOK	T107N	R38W	19	SE 1/4	19-NOV-03 14:01	1440	114, 241	Glencoe CL, Letri CL
57E	44.06771963	95.28740016	COTTONWOOD	STORDEN	T107N	R37W	16	SE 1/4	19-NOV-03 15:55	1383	1833	Coland CL, Occ Flooded
58E	44.06727556	95.29427248	COTTONWOOD	STORDEN	T107N	R37W	16	SW 1/4	19-NOV-03 16:25	1388	595C, 884	Swanlake L 6-12, Webster Delft CL
58 YARD	44.06706518	95.29483139	COTTONWOOD	STORDEN	T107N	R37W	16	SW 1/4	20-NOV-03 11:02	1386	595C, 884	Swanlake L 6-12, Webster Delft CL
60E	44.06841651	95.29067966	COTTONWOOD	STORDEN	T107N	R37W	16	SE 1/4	20-NOV-03 11:20	1372	884	Webster Delft CL
61E	44.06863980	95.29007223	COTTONWOOD	STORDEN	T107N	R37W	16	SE 1/4	20-NOV-03 11:28	1380	1833, 884	Coland CL Occ Flood, Webster Delft CL
62T	44.05491695	95.44280056	COTTONWOOD	WESTBROOK	T107N	R38W	19	SE 1/4	14-NOV-03 10:12	1443	886, 241	Nicollet Crippin CL, Letri CL
63T	44.06148216	95.42488558	COTTONWOOD	WESTBROOK	T107N	R38W	20	NE 1/4	14-NOV-03 10:47	1419	241	Letri CL
64T	44.05746672	95.42430564	COTTONWOOD	WESTBROOK	T107N	R38W	20	NE 1/4	19-NOV-03 14:45	1428	241, 345	Letri CL, Wilmonton CL
65T	44.05785858	95.42295397	COTTONWOOD	WESTBROOK	T107N	R38W	20	NE 1/4	19-NOV-03 14:31	1429	241	Letri CL
66T	44.06486861	95.41402356	COTTONWOOD	WESTBROOK	T107N	R38W	21	NW 1/4	14-NOV-03 11:03	1424	345, 241	Wilmonton CL, Letri CL
67TI	44.09282369	95.32681162	COTTONWOOD	STORDEN	T107N	R37W	7	NE 1/4	20-NOV-03 12:12	1345	114, 241	Glencoe CL, Letri CL
68T	44.09264507	95.32373738	COTTONWOOD	STORDEN	T107N	R37W	7	NE 1/4	20-NOV-03 12:26	1331	241	Letri CL
69 OLDT	44.14013400	95.29808734	COTTONWOOD	HIGHWATER	T108N	R37W	21	SW 1/4	20-NOV-03 13:08	1223	241	Letri CL
80T	44.18765612	95.40640307	COTTONWOOD	ANN	T108N	R38W	4	SE 1/4	20-NOV-03 15:36	1234	241	Letri CL
81T	44.18345377	95.40785062	COTTONWOOD	ANN	T108N	R38W	4	SE 1/4	20-NOV-03 15:23	1249	241	Letri CL
82T	44.18155066	95.40688318	COTTONWOOD	ANN	T108N	R38W	4	SE 1/4	20-NOV-03 15:11	1235	94B, 313	Terril L 2-6, Spillville L Occ Flood
83T	44.18705145	95.43362975	COTTONWOOD	ANN	T108N	R38W	5	SW 1/4	20-NOV-03 16:51	1252	589	Romnell CL
84T	44.18527164	-95.43679493	COTTONWOOD	ANN	T108N	R38W	5	SW 1/4	20-NOV-03 16:40	1267	589	Romnell CL
85T	44.18369710	-95.43727538	COTTONWOOD	ANN	T108N	R38W	5	SW 1/4	20-NOV-03 16:10	1245	589	Romnell CL
86T	44.18270124	-95.43502182	COTTONWOOD	ANN	T108N	R38W	5	SW 1/4	20-NOV-03 16:03	1253	241	Letri CL

* = #T: True ATI Location; #E: Estimated ATI Location; #EP: Estimated ATI Location; #TI: True Tile Intake (flush pipe or traditional) Location; #YARD: ATI True Location in Farmstead Building Site; #OLDT: True Location of tile fragments, estimated ATI Location

Note: “True” means visual confirmation of ATI feature, “Estimated” means best-guess location of ATI based on maps and contours

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We welcome your questions or comments! Please contact Jim Doering or Kelly Oliver at (507) 637-2142 ext. 4 or email Jim.Doering@mn.nacdnet.net.