Technical Guide to the Minnesota Agricultural Water Quality Certification Program Assessment Tool

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DEPARTMENT OF AGRICULTURE

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The Minnesota Agricultural Water Quality Certification assessment tool and this technical guide were adapted by the Minnesota Department of Agriculture[1] from the USDA/NRCS "Water Quality Index for Runoff Water from Agricultural Fields" written by Harbans Lal[2] and Shaun McKinney[2]

[1]Adaptions developed by the Minnesota Department of Agriculture Agricultural Water Quality Certification Program Staff in conjunction with RESPEC Consulting and Services, Kieser and Associates and Sense AI.

[2]Respectively Environmental Engineer and Team Leader of National Water Quality and Quantity Team of the Natural Resources Conservation Service of the US Department of Agriculture (NRCS/USDA) located at the West National Technology Support Center (WNTSC), Portland, OR

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1 Introduction

Water quality index (WQI) combines multiple water quality factors into a single dimensionless number by normalizing their values to subjective rating curves (Miller 1986). It is a simple, convenient way to express risk to water quality in easy to understand terms.

Several authors have worked on the WQI concept and presented examples with case scenarios (Bolton et al. 1978; Bhargave, 1983; House 1989; Mitchell and Stapp, 1996; Pesce and Winderlin, 2000; Cude, 2001; Liou et al. 2004; Said et al. 2004; Nasiri et al., 2007, NSF, 2007). Lal (2011) reviewed these works; and summarized and compared different WQI models using an example dataset. The paper also recognized and recommended the need for a WQI model for qualifying the quality of surface water runoff from agricultural fields.

The USDA/NRCS provides technical assistance (TA) and financial assistance (FA) that encourage agricultural producers to be good stewards of the Nation's soil, water, and related natural resources on private and tribal lands. One of the key goals of implementing conservation practices is to safeguard and improve water quality of the watershed. The USDA/NRCS is always looking for approaches and techniques to evaluate the effects of its programs on the environment. For example, the CEAP Program (USDA/NRCS, 2011) is one such program that uses the APEX model for this purpose. The WQI may serve as a simple tool in the effort to evaluate the effects of the conservation practices on improving and/or sustaining the water quality in the watershed. However, the structure and components of conventional WQI models discussed by Lal, 2011 would need to be modified for it to be more appropriate for evaluating water quality from agricultural landscapes.

This technical note describes such a model (referred to as WQIag) developed to evaluate the quality of runoff water from agricultural fields. Besides different components and how they are integrated into a single dimensionless number (WQIag), the paper also presents an example of using the index on a hypothetical farm in Martin County, Minnesota.

In 2014, an analysis of the WQI was completed by a private-public consortium made up of the Stearns County Soil and Water Conservation District, Minnesota Department of Agriculture, Kieser and Associates and Sense AI. At the time of analysis the Assessment Tool had been field tested and data was available from over 600 assessments throughout Minnesota. With that data, a sensitivity analysis was performed to help guide tool authors in correctly scoring, weighting and aggregating parameters. Additionally, a literature review and comparison against actual edge of field monitoring results was completed. This analysis helped inform Technical Committee members in making updates to the assessment tool, which this update covers. The complete report can be found at : http://www.mda.state.mn.us/en/protecting/waterprotection/awqcprogram.aspx or by contacting the Minnesota Agricultural Water Quality Certification Program at the MDA.

2 Components and Composition of WQIag

The factors influencing the runoff water quality from agricultural fields and captured within WQIag framework could be divided into following seven (7) broad categories:

1) Field characteristics and soil physical/erosion factors,
2) Nitrogen management factors
3) Phosphorus management
4) Tillage management factors,
5) Pest management factors,
6) Irrigation and tile drainage management, and
7) Conservation practices

The precipitation (magnitude and its duration) falling on a field becomes a source of runoff and leaching. The field sensitivity/physical factors such as slope, soil texture, etc., control the rate and quantity of runoff. It carries sediments and other pollutants both dissolved constituents as well as entraining particles. This portion of the index addresses the inherent characteristics of the field which do not change significantly over time.

The management practices such as tillage, nutrient and pesticide management, and irrigation and tile drain system also affect the runoff water quality flowing out of a field. The primary objective of nutrient and pest management is to balance the application of nutrients (organic and/or inorganic fertilizers) and pesticides for obtaining sustainable crop yields while minimizing their off-site transport. Nutrient management is composed of four variables: the rate, timing, form, and method of fertilizer application. The Minnesota AgBMP Handbook Agricultural BMPs Nutrient Management (590) and Pest Management (595) respectively describe these practices in much greater details (Minnesota Department of Agriculture September 2012).

Just like WQIag, the revised Minnesota Agricultural Water Quality Certification Assessment Tool provides an index ranked from 1-10 where the value of 10 is assigned to the highest and ranking of 1 to the lowest water quality. It is attune with the conventional water quality index where highest water quality is assigned WQI of 100.

2.1 Field Characteristics and Soil Physical / Erosion Factors (WQI-fs)

Field characteristics, especially the field slope, play an important role in runoff generation and transport. The higher the slope, the more susceptible it is to generate runoff and soil erosion. In addition the field slope interacts with the rainfall and soil physical and erosion factors such as hydrologic soil group (HSG) and the K-factor in generating runoff and need to be accounted for the runoff water quality index.

Soils within a hydrologic group have similar runoff potential under similar storm and cover conditions. Soil map unit components are assigned a hydrologic group in the NASIS soil survey database (USDA/NRCS. 2009). Most soils are placed in hydrologic groups A, B, C, or D. Soils assigned to hydrologic group "A" have the lowest runoff potential followed by group "B","C" and "D." The soils in hydrologic group "D" have the highest runoff potential. Given a field with a 5 percent slope, if the dominant hydrologic group is "D", there would be a significantly higher runoff potential than if the dominant hydrologic group is "A". Soils with seasonal high water tables at depths less than 60 cm may be assigned to dual hydrologic groups A/D, B/D, or C/D. The first letter in the dual groups indicates a "drained" condition; the second letter indicates an "undrained" condition. The assessment tool map calculator default for dual designation is D. Users that are assessing a field with a dual designation and subsurface tile drainage should update the autopopulated value to the first letter of hydrologic group.

On the other hand, K-factor defines the susceptibility of a soil to sheet and rill erosion. It is one of the six factors used in the Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) that predict the average annual rate of soil loss (USDA/NRCS, undated). The K factor ranges from 0.02 to 0.69 and is based primarily on percentage of silt, sand and organic matter, the soil structure and the saturated hydraulic conductivity. Other factors being equal, the higher the K value, the more susceptible the soil is to sheet and rill erosion, thus leading to a decrease in the quality of runoff water. USDA/NRCS. 2004 defines two types of K factors: Kf and Kw. Kf is referred to as a rock free K-factor and Kw as the whole soil factor. For the WQIag, we use Kw as it accounts for the effect of surface rock fragments in reducing erodibility.

Organic matter is the plant and animal residue in the soil at various stages of decomposition. It is expressed as a percentage, by weight, of the soil material that is less than 2 millimeters in diameter. It has a positive effect on available water capacity, water infiltration, and soil organism activity.

The MAWQCP Assessment Tool interface is designed with the menu items such as " very low" to "very high" for soil erodibility for different Kw ranges; and soils with "low" to "high" runoff potential for different hydrologic groups (A, B, C, D, etc.) which are easy to understand by the user.

2.1.1 Hydrologic Soil Group (WQI-fhg)

The field slope can range from a relatively flat land (no slope) to significantly high slope up to 40%. However, for the sake of simplicity for the WQIag calculation we grouped field slope gradients into five broad categories: less than 2%, 2-5%, 5-10%, 10-15% and more than 15%. **Table 1** presents the ranking of WQI-fhg for different soil groups under different slope ranges. For example, the relatively flat lands (slope < 2%) and the Hydrologic Soil group A of low runoff potential gets the highest WQI-fhg value of 10. It is mainly because this condition will generate much less amount of runoff compared to a field with the slope of more than 15% and Hydrologic soil group D with high runoff potential which is assigned the WQI-fhg of 1.

<u>**Table 1**</u>: WQI-fhg values for different hydrologic soil groups under different field slopes (**Hydrologic Soil Group (HSG) - Slope Interaction)**

Hydrologic Soil Group	**Slope Gradients**				
	< 2%	**2-5%**	**5-10%**	**10-15%**	**>15%**
A:Low runoff potential	10	9	7	5	4
B: Moderately low runoff potential	10	8	6	4	3
C :moderately high runoff potential	9	7	5	3	2
D, high runoff potential	8	6	4	2	1

2.1.2 K-Factor (WQI-fkw)

The soil K-factor referred to as soil erodibility factor also interact with the slope. **Table 2** gives the values of WQI-fkw for different combinations of the Kw and field slope ranges. The low gradient field (< 2%) and the very low erodibility (Kw <= 0.10) gets the highest WQI-fkw as it would produce much less amount of soil erosion compared to soils with very high erodibility (Kw between 0.44 to 0.64) on steeper fields with slope more than 15% which is assigned the WQI-fkw of 1.

<u>**Table 2**</u>: WQI-fkw values for different Kw ranges under different field slopes (**Kw Factor - Slope Interaction)**

Kw factor - surface mineral layer	**Slope Gradients**				
	< 2%	**2 - 5%**	**5 - 10%**	**10 - 15%**	**>15%**
<=0.10 very low erodibility	10	10	10	9	7
0.11 - 0.20 low erodibility	10	10	9	7	5
0.21 - 0.32 moderate erodibility	9	8	7	5	4
0.33 - 0.43 high erodibility	8	7	5	3	2
0.44 - 0.64 very high erodibility	8	6	4	2	1

2.1.3 Organic Matter (OM) content (WQI-fom)

Organic matter content of the soil can significantly influence the quality of water running off from a field. Soil organic matter can hold 10 to 1000 times more water and nutrients than the same amount of soil. The presence of OM in soils reduces sediment and nutrient load in the runoff and improves the water quality. Thus, **Table 3** assigns the highest WQI-fom value of 10 to the soil with the OM content of more than 4 percent and then is reduced correspondingly for the soils with smaller percentages of OM content.

Table 3: Percentage Organic Matter (OM) and associated WQI-fom

% OM Range	WQI-om
>4%	10
3-4%	8
2-3%	6
0.5-2%	4
<0.5%	2

2.1.4 Rainfall/ Vegetation Factor (WQI-fvr)

Rain falling on a field is the catalyst for runoff and soil erosion. However, vegetative cover (live and/or dead) present on the soil surface during the rainfall can significantly reduce runoff generation. Thus, this section evaluates the combined effect of these two factors on the water quality index.

Vegetative cover (crop, cover crop or residue) and rainfall are classified into three categories (low, medium and high). The following categories are used to reflect vegetative cover:

Less than or equal to 30% vegetative cover = Low Vegetation (Vl)
31 to 80% vegetative cover = Medium Vegetation (Vm)
More than 80% vegetative cover = High Vegetation (Vh)

To account for the field slope interaction with the rainfall potential to generate runoff, we categorized the monthly rainfall into three categories (low, medium and high). The precipitation data is from the thirty-year (1984-2014) monthly averages compiled by the Minnesota State Climatology Office network of trained weather observers. Isometric maps were created to determine estimates of precipitation at locations between weather stations. A weighted average calculation is used in situations where field boundaries cross isolines. **Table 4** presents these ranges for different slope intervals. At higher slopes (> 15%) even a small amount of rainfall can produce runoff while on the flatter lands it would require significantly higher amount to produce similar magnitude of runoff. Thus, for a flatter land with slope less than 2% a monthly rainfall of 7.0 inch or more is classified a high rainfall. On the other hand, on the steeper land with the slope more than 15% this amount reduced to 3.0 inch.

With three levels of vegetative covers: low (Vl), medium (Vm), and High (Vh); and the three levels of rainfall categories: low (Rl), medium (Rm), and high (Rh), a 3 by 3 matrix was developed to generate WQI-fvr as depicted in **Table 5a and 5b**. In this matrix, the combination of high vegetation (Vh) and low rainfall (Rl) gets the highest WQI-fvr rating of 9 as it would generate minimum amount of runoff. On the other extreme the combination of the low vegetation (Vl) and high rainfall (Rh) gets the lowest WQI-fvr rating of 1 as it would generate high runoff and erosion.

Multiple year and location information from the Discovery Farms shows that, on average, runoff starts in March with snowmelt and continues until frozen ground conditions in November. To coincide with these findings, the Rainfall/Vegetation scores takes into consideration March-November scores only. However, to aid in planning and education purposes the entire year is presented.

Table 4: Categorization of average monthly rainfall (low, medium and high) for different field slope ranges (**Rainfall - Slope Interaction)**

Rainfall Category	Slope Gradients				
	< 2%	2-5%	5-10%	10-15%	>15 %
Low	< 2.50 in	< 2.00 in	< 1.75 in	< 1.50 in	< 1.00 in
Medium	2.51 to 7.0 in	2.01 to 6.0 in	1.76 to 5.0 in	1.51 to 4.0 in	2.0 to 3.0 in
High	> 7.0 in	> 6.0 in	> 5.0 in	> 4.0 in	> 3.0 in

Table 5a: Decision Matrix for Rainfall/Vegetative (Includes crop, residue, cover crop) cover

	Rainfall		
Vegetative cover	Vh*Rl (9)	Vh*Rm (8)	Vh*Rh (7)
	Vm*Rl (6)	Vm*Rm (5)	Vm*Rh (4)
	Vl*Rl (3)	Vl*Rm (2)	Vl*Rh (1)

Vegetative Cover Range: low (Vl), medium (Vm), high (Vh)
Rainfall Range: low (Rl), medium (Rm), high (Rh)

Table 5b: Combination of rainfall and vegetative and associated WQI-fvr

VegCover*Rainfall	WQI-fvr
Vl*Rh	1
Vl*Rm	2
Vl*Rl	3
Vm*Rh	4
Vm*Rm	5
Vm*Rl	6
Vh*Rh	7
Vh*Rm	8
Vh*Rl	9

Table 5c presents an example for estimating the WQI-fvr for a field in Martin County, Minnesota. It shows the average monthly precipitation ranging from 0.71 inch in January to 4.06 inches in August. A rainfall ranking factor is assigned for each month using the following characterization system based for field slope between 2-5%.

Rainfall less than or equal to 2 in = Low Rainfall (Rl)
Rainfall between 2.0 to 6.0 in = Medium Rainfall (Rm)
Rainfall more than > = 6.0 in = High Rainfall (Rh)

The table 5c also shows monthly vegetation ranking for the test case scenario. The months of July to September, primarily the growing season in Minnesota, are assigned high (Vh) vegetative cover followed by October getting the medium vegetative cover (Vm), and December to April getting the low vegetative cover (Vl) with May and June again having medium cover (Vm). This assignment is arbitrarily taking into account the cropping season of the region. It could vary in real condition based upon the land use and land cover type.

Based upon the rainfall and vegetation ranking, a value of WQI-fvr is assigned for each month from the decision matrix tables 5a and 5b. The months of July to September get the highest ranking of 8 because of high vegetative cover (Vh) and medium rainfall combinations. **Table 5c** provides WQI-fvr value for each month and the overall mean for the entire year. The WQI-fvr values could be aggregated for a season such as the corn growing season or winter wheat growing season to calculate WQIag for that period. We could also use them individually for estimating WQIag for each month.

Table 5c: An Example of estimating WQI-fvr based upon the monthly rainfall and expected vegetative cover for a field in Martin County, Minnesota

	Rain (in)	Rain Factor	Veg. Factor	Veg* Rain	Veg*Rain Ranking
Jan	0.71	Rl	Vl	Vl*Rl	
Feb	0.78	Rl	Vl	Vl*Rl	
Mar	1.84	Rl	Vl	Vl*Rl	3
Apr	2.96	Rm	Vl	Vl*Rm	2
May	3.5	Rm	Vm	Vm*Rm	5
June	4.0	Rm	Vm	Vm*Rm	5
July	4.02	Rm	Vh	Vh*Rm	8
Aug	4.06	Rm	Vh	Vh*Rm	8
Sept	3.08	Rm	Vh	Vh*Rm	8
Oct	2.25	Rm	Vm	Vm*Rm	5
Nov	1.51	Rl	Vl	Vl*Rl	3
Dec	1.08	Rl	Vl	Vl*Rl	
Mean					**5.22**

2.1.5 Integrating Field Characteristics and Soil Physical / Erosion Factors into a single value (WQI-fs)

The rankings of field characteristics and soil physical / erosion factors (K-factor, Hydrologic Soil group, organic matter content, and rainfall/vegetation factor) are combined into a single WQI-fs value for the entire year using a simple arithmetic mean with a weighing factor assigned to each value. This technique permits adjusting the contribution of each component in the overall WQI-fs based upon the local preferences as demonstrated in **Table 6**. This table presents an example scenario for the Martin County, Minnesota with slope range of 2 to 5%.

Table 6: Integrating Soil Sensitivity/Physical factors into a single WQI-fs value for a slope of 2-5%

Soil Sensitivity Component	Soil Sensitivity Option	WQI Ranking (WR)	Weighing Factor (WF)[1]	WR *WF
Hydrologic Soil Group	**Group B** moderately low runoff potential	8	0.1	0.8
K-Factor	**0.30** 0.21-0.32 moderate erodibility	8	0.1	0.8
OM Content	**5%** 4-6% range	7	0.4	2.8
Rainfall/ Vegetation	Annual Mean Average for the example case	5.22	0.4	2.09
Mean WQI-fs (Total of all four rows)			**1.00**	**6.49**

[1]The sum total of rows should equal 1

2.2 Nitrogen Management (WQI-nm)

2.2.1 Nitrogen Application Rate Performance Level (WQI-nar)

Nutrient management components that affect runoff water quality from a field include: rate, form, timing and method of application of organic and inorganic nitrogen fertilizer. Higher fertilizer application rates may increase the risk to water quality if a runoff or leaching event occurs. It is therefore critical that producers are employing a nitrogen rate that maximizes crop uptake and minimizes loss to the environment.

Three performance levels for nitrogen rate are identified: Below Standard, Standard and Advanced. The Standard category for rate requires producers to adhere to crop- and region- specific University of Minnesota rates or develop their own through rigorous field trials employing the same principles. Producers not employing Standard practices are scored Below Standard. The specific Standard language is as follows:

- Account for previous crop N credits, manure N credits, starter, weed and feed program and contributions from phosphorus fertilizers, such as MAP and DAP
- Use a soil nitrate test when appropriate to a depth of 24 inches. Collect fall soil samples after soil temperatures at 6 inches stabilizes below 50 degrees F.
- If field-average soil samples are collected, the sample represents less than 20 acres.
- Select an appropriate N fertilizer rate within the University of Minnesota recommendations, including supplemental N worksheet OR On-farm trial

The University of Minnesota (UMN) provides separate recommendations for nitrogen application rates to optimize the balance between agronomic and environmental concerns. The UMN provides guidance for when additional N is appropriate based on climatic and agronomic conditions. This is highlighted in the supplemental N worksheet. All nitrogen sources should be considered when calculating a nitrogen rate. This may include crop N credits from previous crops, manure N credits, and carrier and supplemental N from phosphate applications, starter and/or weed and feed programs.

Advances in precision agriculture, such as GPS guided yield monitoring, as-applied fertilizer mapping and data management, have made it easier for producers to conduct in-field nitrogen trials. Sound experimental design may produce recommendations that are available at a finer resolution then UMN experimental sites. Producers who have this data and adhere to the same principles used in the UMN design are eligible for developing and using their own on-farm rate recommendations. Sound experimental design includes the following elements:

- Except for the management variable being tested, all other management practices should remain constant
- Fertile soils are preferred (P levels >16ppm Bray/>12ppm Olsen; K levels >121 ppm)
- Select plot locations based on uniform soil type and landscape position
- Replications and multiple learning blocks recommended. Plot size width of equipment variable and length adequate to maintain plot uniformity
- Maintain at least 30lbs difference in nitrogen application for rate trials. Starter, AMS, MAP and DAP blends are not recommended
- Include a zero rate check strip or block
- Include at least 3 years of data collection

Advanced performance levels for N rate may be achieved by employing management practices that increase crop uptake and reduce the risk that N is lost to the environment. These practices are highlighted below. Note that some practices are pathways to achieving the same result. For example, N modeling tools and in-season nitrate tests are two different methods measuring the same thing and therefore not practical or necessary to complete both. In these cases, prudent users would judiciously use 'not applicable' for a practice that is unavailable for that crop, not practical or achieve by a duplicative method.

The Advance performance level for nitrogen rate is defined as:

- Accounting for within-field variability using concepts and tools such as zone or landscape position management, and N sensors
- Use variable rate N technologies
- Multi-year yield maps
- Conduct replicated on-farm N rate studies and include a zero N rate. Use these studies to perform delta yield analysis.
- N rate is adjusted for in-season yield potential, utilizing N modeling tools, nitrate soil tests, supplemental N worksheet and/or leaf tissue results
- Multi-year basal stalk nitrate test
- Goal of nitrogen use efficiency of less than 1.0 pound / bu of corn or NEU of 0.6-0.8
- Lab analysis of representative manure samples are completed before a rate is established
- Fertilizer and manure applicators are calibrated based on equipment manufacturer's recommended frequency and methods
- Manure is applied in combination with commercial fertilizers to obtain balanced nutrients

Thus as depicted in **Table 7** producers are categorized into Below Standard, Standard and Advanced based on the number of N rate risk management practices employed.

Table 7: Performance level for Nitrogen application rate and associated WQI-nar

Application Rate Performance level	WQI-nar
Below Standard	1
Standard	8.5
Advanced	10

2.2.2 Nitrogen Timing, Source and Placement Performance level (WQI-nst)

The timing, source and placement of fertilizer application play an important role in the fate of nutrients because of the physiological effectiveness of the plant to uptake the applied nutrients. If applied at the optimum time and place, a large percentage of nutrients are taken up by the plants, thus minimizing negative impact on the water quality. In addition plants need nutrients at different growth stages.

The University of Minnesota publishes and update best management practices for nitrogen based on five agronomic regions: Southcentral, Southeast, Northwest, Southwestern/Westcentral and Coarse Textured Soils. Management practices are further divided into 'recommended' practices, 'acceptable with risk' and 'not recommended' categories. To score in the Standard performance level producers must adhere to strategies in the 'recommended' or 'acceptable with risk' and specifically avoid the 'not recommended' practices. A Below Standard performance level is scored if a 'not recommended' practice is employed.

There are several practices and technologies that allow producers to further refine their nitrogen management program. Agronomic practices that coincide with the ability to reduce negative water quality impacts should be promoted. The following practices are considered Advanced performance level for nitrogen, source and timing are defined below:

- Use ESN (poly-coated urea) in a urea blend or other slow release N fertilizers
- Urease inhibitor with surface applications of UAN/urea
- Utilize nitrogen inhibitors in manure application to maximize N credit from manure
- Lab analysis of any manure application and calibrated spreader
- Use in-season sensors or remote sensing tools to guide variable rate side-dress applications of N
- Apply nitrogen inhibitor on susceptible soils in the spring and all fall applications, if allowed in region
- If manure is utilized, spring preplant with incorporation or fall injection when soil temps stabilize below 50F
- Account for within-field variability using concepts and tools such as management zones, or landscape position
- Soil texture, elevation, distance to water and drainage is factored into placement decision
- Growers participation in a Certified Crop Advisor-approved nutrient management meeting
- All dry and liquid fertilizer sources that are surface applied are followed with tillage incorporation, rainfall in 3-4 days or applied with irrigation watering
- All manure applications are incorporated with tillage or subsurface placement tools within one day of applications
- N timing is applied with a minimum of two applications or more

Table 8: Performance level for Source, Timing and Placement WQI-ntt

Source, Timing and Placement	WQI-ntt
Below Standard	1
Standard	8.5
Advanced	10

Table 9: Nitrogen rate and Nitrogen source, timing and placement factors weight in overall Nitrogen management score

Parameter	weight
Nitrogen rate	0.3
Nitrogen source, timing and placement	0.7

2.3 Phosphorus Management (WQI-pm)

2.3.1 Phosphorus application rate performance level (WQI-pr)

Phosphorus is an essential element for plant life. Too much phosphorus in surface, however, can reduce dissolved oxygen in water caused by an increase in mineral and organic nutrients.

University of Minnesota studies show that there is little crop response to additional P application once soil test phosphorus (STP) levels reach certain levels. For example in corn, STP levels >21 ppm Bray P1 do not result in a crop response in controlled studies . Therefore, no additional P is recommended once STP reaches this level. This is the crop sufficiency phosphorus management strategy, where the STP levels are periodically tested and phosphorus application rates are based on these levels. Once adequate levels are reached, no further P application is completed until soil testing demonstrates that levels have dipped below these critical levels. For a water quality risk management standpoint, this method is encouraged.

Other P management strategies do exist. The build-maintenance program is another common strategy. This management strategy applies P based on the crop P removal rate across a single year or rotation. This ensures that soil fertility levels are at least maintained and STP levels not depleted from repeated crop removals. From a water quality standpoint, this strategy may increase risk as, given an erosion event, P concentrations in the soil may be greater than a field managed using the crop sufficiency method. It is therefore incumbent on the producer to ensure erosion reduction strategies are employed.

To accurately measure the risk of P loss, over 40 states, including Minnesota, have adopted the Phosphorus Index concept. This concept examines the risk of soluble and insoluble P to water quality as it relates to a host of parameters, including slope, runoff timing and buffers. The index concept also takes into consideration existing STP levels.

The concepts in the index approach have also been incorporated into the regulatory Minnesota Pollution Control Agency (MPCA) 70.20 rules and the non-regulatory Natural Resource Conservation Service (NRCS) 590 Nutrient Management standards.

The parameters are condensed and summarized in below. When practiced, a Standard performance level is achieved. When these basic practices are not employed, the appropriate risk management category is Below Standard.

Standard Performance level for phosphorus rate:

- Within the University of Minnesota recommendations based on crop sufficiency. If build-maintenance program is used a target soil test phosphorus level should be established not to exceed the upper end of the University of Minnesota recommendations of the most phosphorus-limiting crop in the rotation.
- If the build-maintenance program is used, utilize the Minnesota P Index.

- Soil sample every 3 to 4 years for field average nutrient levels
- Total P applied includes P205 use in starter, dual banding, broadcast and manure application.
- When manure is utilized, do not exceed 150 ppm Bray/120 ppm Olsen.
- When manure is utilized, ensure crop removal of P exceeds manure inputs of P once target soil test phosphorus level is reached (see first bullet on establishing a target soil test phosphorus level).
- If field-average soil samples are collected, the sample represents less than 20 acres.

Advanced performance level for phosphorus rate is defined as follows:

- Soil samples by grid or 5 management zones.
- P application rates are variably rate applied based on soil test levels, slope, texture and distance to surface waters.
- Quality yield maps for 5 years.
- When manure is utilized, the area within 300ft of sensitive features should not receive any manure when STP exceed 75ppm Bray/60 ppm Olsen.
- Conduct on-farm-research on P rates.
- Adjust N, P, K for balance of fertility and nutrient interaction affects.
- When manure is utilized, calibrate application equipment and complete manure testing.
- Manure is applied in combination with commercial fertilizers to obtain balanced nutrients.

Table 10: Performance level for phosphorus rate (WQI-pr)

Performance level	Score
Below Standard	1
Standard	8.5
Advanced	10

2.3.2 Phosphorus source, timing and placement performance level (WQI-ptt)

Phosphorous source, timing and placement Standard performance level:

- Incorporate commercial P and manure within 300ft of sensitive features. Incorporate within 24 hours or before a rainfall.
- For no-till P application, use Minnesota P index.
- Do no apply P in concentrated flow area, grassed waterways or road ditches.
- No frozen soil application of P.
- Do not apply P where gully erosion exists.
- P application times can be adjusted for a two-year application to facilitate incorporation or reduce soil compaction.
- Do not apply on soils with less than 24 inches of separation from high water table.
- Soil sampling based on field uniformity, with one sample per 20 acres maximum in diverse soil types.

Phosphorous source, timing and placement Advanced performance level

- Incorporate commercial P and manure within 24 hours or before a rainfall on all land that drains to a sensitive feature (i.e., even land greater than 300ft).

- Utilize starter P (note: new planters have various methods to place starters or bands).
- Lime to reduce P fixation from acid soils.
- Maximize available N in manure to prevent ancillary P application when applying manure based on N demand
- Use grain types and additives that reduce P in manure.
- P applications made annually vs 2 year periods.
- On soils subject to erosion, delay P application to reduce the window of potential erosion losses.
- Use a cover crop if crop rotation allows.
- Install buffer strips on all sensitive features.
- Use GPS auto steer to prevent overlaps from fertilizer application.
- Grower participation in CCA approved nutrient management meeting.
- On slopes of more than 6%, incorporate within 24 hours or before a rainfall.

Table 11: Performance level for phosphorus source timing and placement (WQI-ptt)

Performance level	Score
Below Standard	1
Standard	8.5
Advanced	10

Table 12: Phosphorus rate and Phosphorus source, timing and placement factors weight in overall Phosphorus management score

	weight
Phosphorus rate	0.3
Phosphorus source, timing and placement	0.7

2.4 Tillage Management (WQI-tm)

The effect of soil tillage on soil erosion is well established. The more the soil is tilled, the more susceptible it becomes to erosion. Thus, it is an important factor in evaluating the quality of runoff water from a field. Soil Tillage Intensity Rating (STIR) is a tool that has been widely used for evaluating the soil disturbance as well as the severity of the disturbance caused by tillage operations (Al-Kaisi, 2007 and Boetger, undated). Specific components of STIR value include: Operational speed of tillage operation, tillage type, depth of tillage operation and percentage of soil surface area disturbed.

The STIR value can range between 0-200. Low STIR value reduces likelihood of sheet rill erosion.

Table 13 presents different tillage systems with their possible STIR ranges and associated WQI-tm values. These designations and associated STIR ranges generally follow NRCS recommendations. One can use the table by identifying the tillage system most representative of existing conditions or use the RUSLE2 database to obtain the STIR value for the tillage system; and then selecting the corresponding WQI-tm value.

Table 13: Tillage description / STIR ranges and associated WQI-tm

Tillage Description	STIR Value	WQI-tm
No Till	</=10	10
Zone/Strip Till	>10-30	9
mulch/reduced till; >30% spring/fall residue	>30-80	8
mulch/reduced till; <30% spring/fall residue	>30-80	5
Conventional Till	>80	2

2.5 Pest Management (WQI-pm)

Pests (weeds, insects, and diseases) are expected elements of a farming system. Considerable amount of effort and resources are devoted on controlling and/or managing them. Modern pest management approach uses combination of practices generally referred to as Integrated Pest Management (IPM). Pests (weeds, insects, and diseases) are expected elements of a farming system. Considerable amount of efforts and resources are devoted on controlling and/or managing them. Modern pest management approach uses combination of practices generally referred to as Integrated Pest Management (IPM). They incorporate crop rotations, cultural practices, scouting, crop selections, and other field practices to prevent pest problems from occurring. When pest infestations do occur at damaging levels they are controlled using chemicals in the most effective way with minimum risk to environmental including water quality. **Table 14** employs this criterion and presents the WQI-pm rating for different levels of pest management options. Highest rating of 10 to WQI-pm is assigned to a system where Advanced IPM is followed which primarily involves employing all lower-rated IPM practices as well as cultural practices that minimize pests, and the lowest rating of 2 is awarded to a system that uses Basic Pest Control that suppresses pests with label mitigation (i.e. setbacks). Suppression of pests within the context of these ratings means the use of synthetic or organic chemical pesticides in farming systems. Because suppression does not necessarily lead to water quality impacts (or impacts of regulatory concern), and because a production system without suppression is technically not the goal of certification and is not the goal of IPM, the descriptions in Table 12a and related assessment factors in Table 12b do not preclude the use of pesticides nor award higher ratings for not using such chemicals. Instead, higher ratings are given to the adoption by farming operations of a number of IPM strategies. Each additional strategy beyond "Basic Pest Control" generally requires an increased level of effort on the part of the farmer. And while not all suggested MDA BMPs are appropriate for every farm, an effort has been made to simplify the detail provided in the original BMPs (http://www.mda.state.mn.us/protecting/bmps/voluntarybmps.aspx) by utilizing core concepts and pesticide-specific practices adoptable on any farm, as well as organizing them by ease of implementation. In this way, adoption of multiple strategies should reflect critical MDA WQ Pesticide BMPs designed to minimize the long-term potential for unreasonable adverse effects to water resources from the use of pesticides.

Of particular interest to MDA are the herbicides acetochlor and atrazine, and the insecticide chlorpyrifos. These pesticides have been identified by MDA as "surface water pesticides of concern," a non-regulatory designation based on frequency of detection and monitoring concentrations relative to state water quality standards. Although the designation is non-regulatory, the Minnesota Pollution Control Agency (MPCA) has declared surface water impairments for acetochlor and chlorpyrifos in select watersheds, resulting in contaminant reduction efforts within the context of the MPCA's Total Maximum Daily Load (TMDL) program.

While core MDA WQ Pesticide BMPs are designed to minimize loss of all pesticides, certain BMPs specifically address the use of acetochlor, atrazine and chlorpyrifos. Support material (Table 12b) provides guidance to the certification technician on how to apportion WQI-pm ratings based on a more refined assessment than afforded by use of Table 12a.

Table 14: Pest management practices, MDA pesticide BMPs and associated WQI-pm

Description of Practice	WQI-pm
Advanced IPM: low risk IPM plus cultural practices that minimize pests	10
Low Risk IPM: basic IPM plus uses alternatives with lower risk for runoff and/or rotates pesticides	7.5
Basic IPM: low risk control plus uses threshold-based suppression	5.0
Low Risk Pest Control: basic control plus uses < maximum label rates and any pesticide-specific additional vegetative buffers or application setbacks	4
Basic Pest Control: suppression with only label-required mitigation (e.g., veg. buffers or application setbacks)	2

Table 14 is shown below and can be used to further assess IPM activities as they relate to both core and pesticide-specific MDA WQ Pesticide BMPs.

To obtain the assigned rating for a given practice (Column 1 of Tables 12a and 12b), the certification technician must assess additional factors used by the farmer for any pesticide(s), as well as those used if acetochlor, atrazine and chlorpyrifos are applied to fields.

A WQI-pm rating will be easiest to assign if there is no use of acetochlor, atrazine or chlorpyrifos and only core BMP factors are assessed by the certification technician; however, if one or more of those pesticides are used, assigning the WQI-pm rating will require that the certification technician also assess pesticide-specific factors that accompany related core BMP factors as indicated in Table 12b.

Table 15: MDA WQ Pesticide BMPs – Additional Factors for WQI-pm ratings

<table>
<tr><th>IPM Practice Level
(from Table 12-A)</th><th colspan="2">Pesticide BMP factors</th></tr>
<tr><td>Advanced IPM: low risk IPM <u>plus</u> uses cultural practices that minimize pests</td><td colspan="2">Adjusts planting rates, timing, crop rotations, irrigation schedules or field machinery cleaning to disrupt or otherwise minimize annual carryover of pests or field conditions for pest outbreaks.</td></tr>
<tr><td>Low Risk IPM: basic IPM <u>plus</u> uses alternatives with lower risk for runoff and/or rotates pesticides</td><td colspan="2">Works with professionals to select pesticides with low loss ratings for soil runoff and/or rotates among those with different modes of action.</td></tr>
<tr><td>Basic IPM: low risk control <u>plus</u> uses threshold-based suppression</td><td colspan="2">Scouts fields for pests, maps infestations each year. Determines if control results in crop yield benefits or longer term pest suppression.</td></tr>
<tr><td></td><th>Core BMP factors for farmer using any synthetic or organic pesticide</th><th>Pesticide-specific BMP factors for farmer using acetochlor, atrazine or chlorpyrifos</th></tr>
<tr><td>Low Risk Pest Control: basic control <u>plus</u> uses < maximum label rates and any pesticide-specific additional vegetative buffers or application setbacks</td><td>Reduces application rates based on a label “rate range” and/or precision application methods; scouts for weed escapes or pest outbreaks, with subsequent applications only when necessary.</td><td>Atrazine:
• Uses ≤ 0.8 lbs a.i./yr in SE MN except on medium and fine textured soils where up to 1.0 lbs a.i./yr can be used.
• Employs application setbacks or buffers around tile inlets.
Acetochlor:
• Uses lower, early-season post-emerge weed control in herbicide tolerant crop production.
• Installs a 30-ft. or wider vegetative filter strip (66 ft. if in a watershed with acetochlor impairments) at points of field runoff.</td></tr>
<tr><td>Basic Pest Control: suppression with only label-required mitigation (e.g., vegetative buffers or application setbacks)</td><td>Reads labels and abides by legally required water quality protection restrictions.</td><td>Atrazine: Does not apply within 200 feet of lakes and reservoirs, and 66 feet from points where runoff enters streams and rivers.
Acetochlor: If applied with atrazine, application setbacks for atrazine are followed.
Chlorpyrifos: For soil- or foliar-applied liquid products, does not apply:
• within 25 ft. of water bodies for ground applications;
• within 150 ft. of water bodies for aerial applications.
For soil applied granular products, does not apply:
• within 150 ft. of water bodies for aerial applications.</td></tr>
</table>

3. Combining sub-indices into a single index score

Table 16 presents a hypothetical scenario for WQIag calculation by aggregating values of different WQI sub-indices such as WQI-fs, WQI-nm, WQI-phm, WQI-tm, and WQI-pm; and then adjusted for irrigation and tile-drain management systems and/or additional conservation practices if applicable (discussed later). The WQI-fs is arrived at by combining four field sensitivity/physical components namely K-factor (WQI-fkf), Hydrologic Soil group (WQI-fhg), OM factor (WQI-fom), and Rainfall/Vegetation interaction (WQI-fvr) as illustrated **Table 6**. The overall WQIag is then arrived at by combining the WQI-fs, WQI-nm, WQI-phm, WQI-tm, and WQI-pm (**Table 16**). The weighting of these sub-indices is 0.20, 0.25, 0.25, 0.175 and 0.125 for WQI-fs, WQI-nm, WQI-tm and WQI-pm, respectively.

For the hypothetical scenario (**Table 16**), the overall WQIag is arrived at 8.84 in the scale of 1-10. This number is not reduced since there is no irrigation and no tile drains. In these models, the WQI ranking of 60 is classified as poor water quality which is expected for the runoff water from the agricultural fields, though in this example it has already been exceeded. When one or more additional conservation practice(s) are applied, WQIag improves based upon the cumulative impact of their effectiveness. For the current scenario, a single conservation practice namely the grade stabilization structure increases the WQIag to 9.23. This increase is based upon the WQIag adjust factor of 35% using the model discussed later in the “**Integrating Conservation Practices in WQIag**” section.

Table 16: Integrating field sensitive/physical and management (nitrogen, phosphorus, tillage and pest) factors into a single WQIag

Factors	Description	Ranking		
		WQI Ranking (WR)	**WQI Ranking (WR)**	**WQI Ranking (WR)**
	Field Sensitivity Factors (WQI-fs) **(For field slope range between 2-5%)**			
Hydrologic Soil Group	B- moderately low runoff potential	8	.1	0.8
K-Factor	0.30 (0.21- 0.32 moderate erodibility)	8	.1	0.8
OM Content	5% (4-6% range)	7	.4	2.8
Rainfall/Vegetation	Annual mean average for the example case	5.22	.4	2.09
WQI-fs (Aggregated value of slope, K-factor, OM Content, and Rainfall /vegetation rankings**)**			**1.00**	**6.49**
Nitrogen Management (WQI-nm)				
N rate performance level	Standard	8.5	0.3	2.55
N source, timing, placement level	Advanced	10	0.7	7
WQI-nm			**1.0**	**9.55**
P rate performance level	Advanced	10	0.3	3
P source, timing, placement level	Advanced	10	0.7	7
WQI-phm			**1.0**	**10**
Tillage Management (WQI-tm)	Reduced till with a STIR value of >30-80; >30% residue			**8.0**
Pest Management (WQI-pm)	Advanced IPM: Low risk IPM plus cultural practices that minimize pests			**10.0**

	WQI-fs	WQI-nm	WQI -phm	WQI-tm	WQI -pm
WQI Ranking (WR)	6.49	9.55	10.0	8.0	10.0
Weight Factor (WF)	0.2	0.25	0.25	0.175	0.125
Weighted Value (WR*WF)	1.30	2.39	2.5	1.4	1.25

WQIag (Weighted mean value of WQI-fs, WQI-nm, WQI-tm, & WQI-pm)		**8.84**
Irrigation Method and Adjustment	No Irrigation (0%)	**8.84**
Tile Drain System	No tile drain (0%)	**8.84**
Additional Conservation Practice(s) and their adjustment	Grade Stab Structure (+35%)	**9.23**

4. Adjusting WQIag for Irrigation and Tile Drainage Systems

Irrigation is used to supplement rainfall for successful crop production. The negative effects of irrigation on the overall quality of water from an agricultural field have been documented (Trout, undated and URC, 2006). In addition, irrigation methods influence water quality based upon field slope and its soil physical properties such as organic matter (OM) content, hydrologic soil group and Kw factor. For example, if the producer decides to irrigate and saturate a field at the tail end of a dry spell; it would generate much higher runoff from a rainfall event than an adjacent field that did not get any irrigation -- thus leading to lower WQIag value. The impact of irrigation, however, depends upon a number of factors including well capacity to field size, droplet size and field slope.

There are some other considerations that certifiers should consider when scoring the irrigation section. Firstly, droplet size is a factor to consider especially before canopy closure. Soil impact and sealing can occur on fine textured soils when sprinkler guns, such as those found on center pivots or traveling guns, are employed.

Secondly, consider the size of the field in relation to the capacity of the irrigation system. A high field size to irrigation capacity ratio makes in more difficult to use all aspects of irrigation water management. For example, a producer may be more likely to leave an irrigation system delivering water if they are uncertain about an upcoming rainfall event if they have a lower capacity irrigation system serving a large field. If the predicted rain does not occur, there could be soil water deficit and their irrigation system unable to quickly respond on large field. Based on Soil and Water Conservation District's irrigation experts, wells greater the 200 gpm on outsized fields move significant amounts of water to increase the risk of runoff events on certain soil types.

Irrigation induced runoff is also a factor of slope. While the assessment tool takes into consideration slope, it may be helpful in determining between irrigation scoring options to consider the Mid Elevation Spray Application (MESA) standard. The NRCS uses this standard for some conservation practices. MESA states that the slope shall not exceed 3% over 50% of the acres with fine textured soils, and 5% slope on coarse textured soils. If a producer is irrigating on steeper slopes, this could also be taken into consideration in your scoring consideration.

If an irrigation water management system is employed, such as Conservation Practice 449 or similar, the field is eligible for the lower score adjustment of -1.5%. **Table 17** gives the percentage used for adjusting the WQIag value for different irrigation methods.

Table 17: Percentage reduction in WQIag for different irrigation methods

Irrigation Method	% WQIag Adjustment
No Irrigation	0%
Higher impact irrigation	-10%
Irrigation Scheduling (CP 449 or similar)	-1.5%
Trickle / Drip	0%
Lower impact irrigation	-5%

Contrary to irrigation needs in the drier regions, the lands in the humid regions need drainage for successful agricultural production. Although drainage allows production on wet soils, drainage water carries nutrients, sediment, pesticides and other pollutants to surface waters. Inlet type can influence the amount and sources of pollutants.

Systems 'without Open inlets', as the name implies include systems that are engineered without open inlets or those that contain rock inlets, French drains, water quality inlets or sufficient vegetative filters around inlets.

Fields that achieve a 9 or greater in the nitrogen management and tillage management sub-indices AND have closed inlets are eligible for a 0% adjustment on the tile drainage system. The logic behind this is that, under certain conditions, subsurface drainage may reduce the risk of surface runoff because saturated soil conditions are reduced. However, in turn, subsurface drainage may increase the risk to water quality by way of a different pathway: nitrate-nitrogen pollutants via the soluble pathway. However, a producer that is following the BMPs and building soil health through reduced tillage, is lowering the potential risk of nitrogen loss in the subsurface tile, and therefore negating the impact of tile on water quality risk.

Surface water quality problems caused by pollutants from the drained agricultural lands have been well documented. However, it has also been shown that a proper management of drained water prior to it entering a waterbody can nullify some of the negative effects of the drainage system. These systems could include controlled drainage, wetlands, bio-rectors, vegetative filters, etc. **Table 18** presents the percentage adjustment, negative or positive, for different type of tile drain systems with or without drainage water management system.

Table 18: Percentage adjustment in WQIag for different tile drains with and without drainage water treatment

Tile drain system	% WQIag Adjustment
No Tile Drain	0%
Tile Drainage with Open Inlets	-20.0%
Tile Drainage without Open Inlets	-15.0%
Tile Drainage with drainage water management	10%
Tile Drainage , treated intakes, advanced N and P management, min tillage	0%

5. Integrating Conservation Practices into WQIag

The quality of runoff water from an agricultural field can be improved considerably by implementing conservation practices also known as agricultural best management practices (BMPs). These practices can be field level practices which impact the entire field, such as contour strip-cropping; or site specific practices such as grassed waterways which address a specific gully issue on just a portion of the field. The effectiveness of these practices in controlling pollutants can vary significantly from one location to another. Furthermore how these effectiveness values should influence the WQIag is anybody's guess. Thus, for the present model we used effectiveness values reported by various studies with slight adjustment based upon authors' and other professional experiences. The practices receive adjustments of 35% or 45% to the Adjusted WQI score **Table 19** presents the list of conservation practices currently implemented in the WQIag model. More information on conservation practices is available from the Minnesota Department of Agriculture "The Agricultural BMP Handbook for Minnesota", September 2012.

<u>Table 19</u>: Conservation Practices and their effectiveness modeled in WQIag system

Conservation Practice		WQIag Adjust Factor %
Name	**Type**	
Contour Strip-cropping 1	Field	45%
Contour Buffer Strip 2	Field	45%
Cover crop 1	Field	45%
Sediment Basins 3	External	35%
Crop rotation with 2+ years perennial	Field	35%
Field Borders 2	Field	45%
Riparian Forest Buffer 4	External	45%
Filter Strip 2	External	45%
Grass Waterway 5	External	35%
Conservation Cover 7	Field	45%
Water & Sediment Control Basin 6	External	35%
Grade Stabilization Structure 7	External	35%

1. *Merriman et al. 2009; Gitau et al. 2005*
2. *Arora et al., 1996*
3. *MPCA, 2005*
4. *Miller, T. P., 2012*
5. *Fiener P, Auerswald K.2003*
6. *Mielke (1985)*
7. *Wilson et al. (2008)*

Table 20 is implemented into the WQIag using the following model:

Assuming:
Water Quality Index prior to conservation practice = "WQIag "
Conservation Practice Adjust Factor = "Eff"

WQIag <= 5.5 *mid-point range of the WQIag between 1 to 10*
= WQIag(1+Eff/100)

WQIag > 5.5
= (WQIag + ((10-WQIag)*Eff/100))

The above model improves the WQIag ranking directly proportional to the WQIag adjust factor (Eff) for low ranges of WQIag -- less than or equal to 5.5. For WQIag values higher than 5.5, the effect of conservation practice on the WQIag is reduced considerably. This model captures two fundamental behaviors of conservation practices in real world condition. When dirty water with low WQIag value passes through a conservation practice, there is high concentration of contaminants to capture thus it comes out much cleaner at the other end. On the other hand, when cleaner water passes through a conservation practice, it does not contain as many pollutants thus it would not impact the water quality as much related to initial WQIag. Furthermore the model would not allow the WQIag to ever exceed more than 10 as shown in **Table 20.** This table presents an example of changes in WQIag values with application of up to three conservation practices with starting WQIag value from 2 to 9 and their ability to improve water quality of the agricultural runoff

Table 21: Effect of multiple practices on WQIag

Conservation Practice	**Average Effectiveness**
Con 1	35%
Con 2	45%
Con 3	35%

WQIag	**WQI (Con1)**	**WQI (Con1+2))**	**WQI (con1+2+3)**
2	2.7	3.9	5.3
3	4.1	5.9	7.3
4	5.4	7.8	8.6
5	6.8	8.2	8.8
6	7.4	8.6	9.1
7	8.1	8.9	9.3
8	8.7	9.3	9.5
9	9.4	9.6	9.8

6. MAWQCP Assessment Tool

To track the fields being reviewed for the Minnesota Water Quality Certification Tool, we developed a simple and user-friendly website (https://mnwatercertify.mda.state.mn.us/wqcpapp/). The website allows users to enter information into the assessment tool and then save it to their computer. No credentials or log-in is required. The online tool also has a mapping feature which allows users to draw in their field and then query and auto populate many variables such as slope, weather data, location information and soil attributes.

7. Concluding Remarks

The Water Quality Index (WQI) used for the Minnesota Water Quality Certification Program takes complex information and data regarding water quality risk and combines them into single value that represents an overall snapshot of the risk to water quality a particular time and location. Traditionally WQI has been developed and used for evaluating water quality of water resources such as streams, rivers and lakes (Lal, 2011).

This technical note is the first attempt to define a WQI model, referred to as WQIag, for evaluating the risk to water from agricultural fields. WQIag incorporates subjective judgment on ranking different factors that influence runoff water from agricultural fields. In addition, the concept of weighting factors has been introduced to incorporate site-specific local preferences for different subcomponents to the overall WQIag.

WQIag is not a form of water quality monitoring. The index is designed not only to track the aggregate score but also factors that contribute to this change in order to provide information back to the producer for adaptive management in farm operations. Although the WQIag is not an instrument of water quality monitoring it could in fact be correlated to data-driven monitoring at different spatial scales (reach, watershed or basin). A WQIag score or trend may have a relationship to nutrient load monitoring in stream studies conducted by other agencies or entities. Most information required to calculate a WQIag score could be available in NRCS planning files. Thus this index could be constructed retrospectively as well as with new or planned activities. As discussed above, the WQIag could represent an important gauge of water quality for the nation's agricultural sector. In absence of quantitative monitoring, the WQIaq could play an important role in assessing water quality at the field level and across the landscape in a cost effective way.

The WQIag could also serve as a tool for evaluating the success of conservation practices for improving water quality. It could provide answers to commonly asked questions: how effective a conservation practice, cost-shared by NRCS, has been in improving the water quality. The simplicity of WQIag in expressing the water quality lends itself well to communicating the complex interrelationships involved with measuring water quality.

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