Continuous Nitrate Monitoring on the Galena River: A Basis for Change

A. Nutrient Issue

The League of Women Voters of Jo Daviess County in Illinois (LWV-JDC) has been actively seeking water quality data in order to increase our local knowledge. The ultimate goal is to achieve science-based stewardship of the water resources in our area. The Nutrient Sensor Action Challenge is a perfect addition to the League's efforts. Two sensors will be deployed, one each at the top and bottom of the Lower Galena River subwatershed to gather continuous data on nitrate levels in this portion of the Galena River. The League has been building relationships throughout the area for over six years and those relationships will provide valuable avenues for communicating the results of the data obtained through continuous nitrate monitoring.

Scientists from the Illinois State Geological and Water Surveys (ISGS and ISWS) at the Prairie Research Institute of the University of Illinois have been providing the expertise needed to achieve science-based stewardship. Team members Walton R. Kelly, Groundwater Science Section Head (ISWS), Samuel V. Panno, Senior Geochemist (ISGS), and Beth Baranski, Project Coordinator (LWV-JDC) have been collaborating for four years on efforts to obtain and analyze water quality data in Jo Daviess County and to bring this information to local governments and to the public at large to inform land use decisions.

The Nutrient Sensor Action Challenge is a well-timed opportunity to obtain valuable data that will clarify our understanding of the relationship between local land uses and water quality. These data will be used as a basis for shifting landowners to best management practices designed to reduce nutrient pollution. The work that has been done to date will serve as foundational support for the new data obtained through continuous nitrate monitoring.

In 2016, the LWV-JDC Project Coordinator participated in the U.S. Fish & Wildlife Service (USFWS) Fishers & Farmers Leadership Network workshops, and learned about farmer-led groups in other areas successfully tackling the nutrient loss problem. Using the Galena Watershed planning project, state EPA grant funds, along with financial contributions from the City of Galena, a local fertilizer plant, local not-for profits and private donors for match, a 2017 U.S. Fish & Wildlife Fishers & Farmers grant for $20,000 was obtained to support the formation of a farmer advisory group in the Galena Watershed. Workshops and field days organized by the farmers, river water sampling, and soil nitrate testing are being scheduled to engage the agricultural community in water resource management.

Using private donations and volunteer time as match, a 2016 U.S. Fish & Wildlife Service (USFWS) grant for $7,000 was obtained to conduct spring sampling with scientists from the Illinois State Geological and Water Surveys. This sampling was done to help establish baseline water chemistry in the area's shallow aquifer for future reference. The project also included the development of a model karst feature database to store information on springs, sinkholes and bedrock fractures to be used both locally and by the USFWS.

LWV-JDC members organized and facilitated the development of a countywide water resource management plan. A diverse set of stakeholders were brought to the table to learn together about the area's water resources, and to agree on a set of facts so that we could develop goals and objectives to maintain our resources effectively. We agreed to use evidence-based decision making to achieve science-based stewardship. We presented to and surveyed every local governing board (county, municipal, township, and resort community) at the start and at the finish of our planning effort. An Illinois EPA approved Quality Assurance Project Plan was completed for the survey effort. To date, the county, 9 municipalities, 5 townships and a resort community have approved this plan. This

project, a 100% volunteer effort, received the "Community Engagement Award" at the 2016 National League Convention.

One of the county plan action items was a focused sub-watershed plan to identify specific projects for water resource management. The Lower Galena River sub-watershed surrounding the City of Galena was selected, and - using private donations and volunteer time for match - a 2016 $38,000 Illinois EPA Grant was obtained to cover technical assistance, printing costs, and planning consultant expenses for this 2-year planning project.

The Lower Galena River sub-watershed (HUC 12, 070600050703) is located in Jo Daviess County in the far northwest corner of Illinois. Wisconsin shares the northern border of the county and the Mississippi River forms the western border. The lowest point of the sub-watershed is defined by the Galena River's entry into the Mississippi.

Jo Daviess County is located in the "Driftless Area." Bypassed by ice-age glaciers, the rugged landscape is characterized by erosional valleys that have been cut down through the Silurian Dolomite, Maquoketa shale and Galena/Platteville Dolomite.

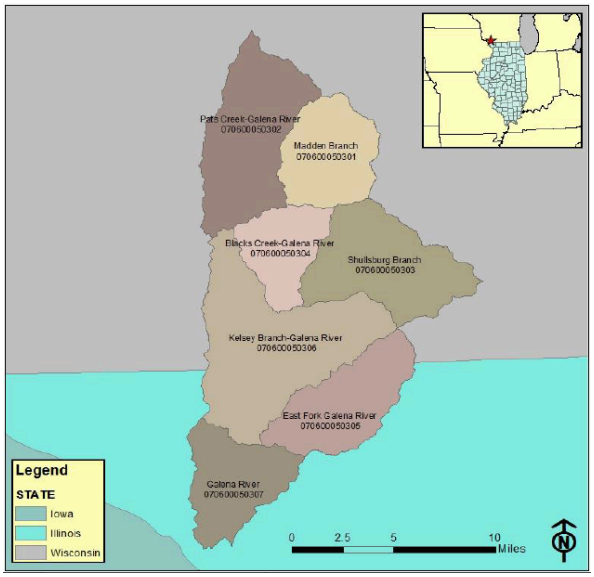

Figure 1. HUC 12s in the Galena River Watershed

The complex hydrogeology and steep slopes in the area make attempts to understand and address run-off and nutrient loss issues difficult. Jo Daviess County has a karst terrain, with karst defined as:

> "...a geologically and hydrologically integrated or interconnected and self-organizing network of landforms and sub-surface large-scale, secondary porosity created by a combination of fractured carbonate bedrock, the movement of water into and through the rock body as part of the hydrologic cycle, and physical and chemical weathering."
> (Panno et al, 2017a)

The topography here is not what you expect to see in Illinois; the average slope in the state is 1.2%, Jo Daviess County has the highest average slope of any county in the state at 11.4%, and this Galena sub-watershed has an average slope of 16.7%. These factors make the need for reliable data imperative.

Jo Daviess County's countryside, a blend of agricultural fields and woodlots, is dotted with small rural communities. The City of Galena is the county seat and the largest community with a population of less than 3,500. In the *Illinois Nutrient Loss Reduction Strategy*, agriculture is cited as the primary source of nutrients lost to the Mississippi River (82% of the Total N, 80% of the Nitrate-N, and 48% of the Total P are estimated to be from agricultural sources). The Strategy identified the Northern Mississippi Valley (which includes this sub-watershed) as having the highest Nitrate-N yield from non-tiled land in the state at 31.3 lb/acre/year, with a distant second being 11.8 lb/acre/year in the Central Mississippi Valley.

While agriculture offers a great opportunity to reduce nutrient loading, rural areas typically have low populations, tend to have the least amount of available data, and often lack the resources needed to obtain data. Small communities in rural areas, likely to be required to implement costly changes to their

sewage treatment plants to help meet the 45% nutrient reduction goals required in the state strategies, face the same daunting problems.

Designing an approach to a complex problem like nutrient pollution is challenging in and of itself. The LWV-JDC has taken on the task of facilitating discussions and obtaining resources. Local stakeholders worked together to better understand the various aspects of water resource management through shared learning, and to evaluate possible solutions to issues that have been identified. One of the goals identified in the *Jo Daviess County Water Resource Management Plan*, completed in 2016, is to "protect/maintain/improve" water quality," and the plan workbook asks: "How can we establish a consistent and sustainable water quality monitoring effort?" Continuous monitoring is the answer.

Reliable, continuous, low-cost nutrient monitoring is needed at the local level in rural areas to support meaningful conversations and the strategic focusing of resources to reduce nutrient loss. Efforts to improve water resource management in the sub-watershed have relied thus far on Illinois Environmental Protection Agency (IEPA) monitoring data, volunteer biological monitoring through the RiverWatch program in the state, and sampling efforts by the ISGS and ISWS as funding could be obtained. These data are very helpful for a broad understanding of water quality issues, but, because so many reasonable questions arise when the data referenced represents single and separate points in time, it cannot provide the clarity needed for sensitive discussions and sound decisions.

Watershed planning at the HUC 12 scale allows for focused conversations with a subset of landowners that can lead to projects that will improve water quality. Measuring the nitrate levels continuously will provide the data needed to make these conversations meaningful and constructive. The data and subsequent analysis will be incorporated into the Galena River Watershed-based Planning process, which is currently underway, and will be used to guide the implementation strategy and to determine incremental reductions in nitrate loss due to agricultural or landscape nutrient-reduction or runoff-reducing practices.

B. Team - The team members for this challenge are as follows:

Samuel V. Panno
Samuel V. Panno is a Senior Geochemist and has been with the Illinois State Geological Survey since 1988. Mr. Panno has B.S. degrees in Biology and Geology, a M.S. degrees in Geology, and post-graduate work in Hydrogeology and Groundwater Chemistry. Currently, Mr. Panno is leading research on the geology, hydrogeology and groundwater quality of karst regions of Illinois, the location, significance and origins of saline springs throughout the Illinois Basin, the origin and evolution of Illinois Basin brines, and the use of speleothems in identifying paleoearthquakes in the Midwestern US.

Walton R. Kelly
Walt Kelly is a groundwater geochemist who has been at ISWS since 1992. He is also currently the head of the Groundwater Science Section. He is an adjunct professor in the Department of Geology and Geography at Illinois State University. He has a master of arts in geological sciences from Case Western Reserve University and a PhD in environmental sciences from the University of Virginia. His research interests are primarily related to groundwater quality, and he is an author on more than eighty reports and peer-reviewed papers.

Beth Baranski

Beth Baranski has a B.S. degree in Architecture. She has used her architectural education, research, writing and facilitation skills to promote thoughtful development in northwest Illinois for over 25 years. Ms. Baranski has served as an elected official on the Jo Daviess County Board, currently serves on the Unit 1 University of Illinois Extension Advisory Board, is a Trustee for the Jo Daviess Conservation Foundation land trust, serves on the board of the Galena Foundation (focused on funding historic preservation efforts in the Galena area), is a founding member of the Jo Daviess County Horticultural Society, is a founding member of the Community Foundation of Jo Daviess County, and is leading a countywide water resource management effort under the auspices of the League of Women Voters.

1. **Lead:** Beth Baranski (LWV-JDC) will serve as the primary point of contact for the project. Her contact information is:

   Beth Baranski
   1101 South Bench Street
   Galena IL 61036
   Ph: 563/580-6192
   Email: beth@bhms-arch.com

2. **Water quality monitoring:** Walton R. Kelly (ISWS) and Samuel V. Panno (ISGS) will assist with deployment of the sensors and will train local field technicians to operate and maintain the sensors.

3. **Data Management/Information Technology:** Walton R. Kelly (ISWS) will oversee data management/information technology.

4. **Data Analytics:** Samuel V. Panno (ISGS) will analyze the data and provide reports summarizing the analysis.

5. **Communication:** Beth Baranski (LWV/JDC) will ensure that the data and data analysis are presented to, and made available to, local governments and the public at large. She will incorporate the information in the Galena River Watershed-based Planning process to provide a basis for identifying and implementing best management practices that will reduce nutrient loss into the Galena River.

6. **Continuous Nutrient Sensors:** Two Hydrolab Series 5 multi-parameter sondes (MiniSonde 5 or MS5) will be provided by OTT Hydromet. Sales Representative, Jennifer Davis, provided the quote (see below), and can be reached at 970/669-3050 ext. 6318 or jdavis@OTTHydromet.com

C. Current Monitoring

1. **IEPA -** The Illinois EPA regularly collects samples and records data on streams and lakes in Jo Daviess County to comply with the Federal Clean Water Act. Data on over 50 parameters is available for the Galena River. The data are maintained in the IEPA's STOrage and RETrieval and Water Quality Exchange databases, STORET and WQX.

2. **ISGS/ISWS -** Members of the ISGS and ISWS have been studying the geology, sampling wells (Panno et al. 2017a) and springs (Panno et al. 2017b) since 2014, and are currently collecting stream water in Jo Daviess County. Coupled with earlier geological and hydrogeochemical studies,

the identification and sampling of 28 springs during one of these investigations has provided data from which we were able to characterize the hydrogeology and groundwater chemistry of northwestern Illinois' Driftless Area. Based on these studies, the ISGS and ISWS found an abundance of karst terrain in Jo Daviess County that is reflected in the groundwater quality of the underlying karst aquifer.

The background concentrations (of sodium, chloride, nitrate, potassium, phosphate, sulfate and fluoride) for groundwater within Jo Daviess County were calculated from 46 spring and well samples using cumulative probability plots. These calculations revealed multiple thresholds that represented those of groundwater from deep aquifers, as well as pre-settlement and post-settlement background values. Given that groundwater is feeding surface waters, and the fact that springs were sampled during low flow conditions, the background ranges calculated should be the same as those for both groundwater and surface water within the watersheds of the county, and perhaps the entire Driftless Area. The presence of pre- and post-settlement background levels indicate the prevalence of surface-borne contaminants such as chloride and nitrate in shallow groundwater.

3. **RiverWatch** - Volunteer biological monitoring has been conducted in the Lower Galena River subwatershed for the past three years. The Illinois RiverWatch Network is a statewide, non-profit, volunteer stream monitoring program. Volunteers are trained and certified as "Citizen Scientists" to monitor local streams by examining indicators of water quality like stream habitat and the diversity and number of macroinvertebrates. Results are stored at the National Great River Research Center (http://www.ngrrec.org/RiverWatch/resources/).

D. Sensors and Monitoring

Two sensors will be deployed in the Galena River to gather continuous data on nitrate levels. The sensors will be secured in the riverbed in protective housings as shown below. Sensor A will be placed at the top of the subwatershed, and Sensor B at the bottom so that contributions from within the watershed can be ascertained both as a baseline, and to measure reductions over time as best management practices are employed.

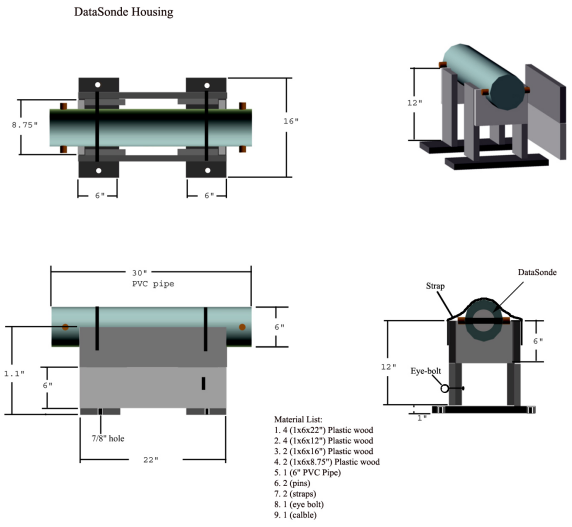

Figure 2. Design for Protective Housing

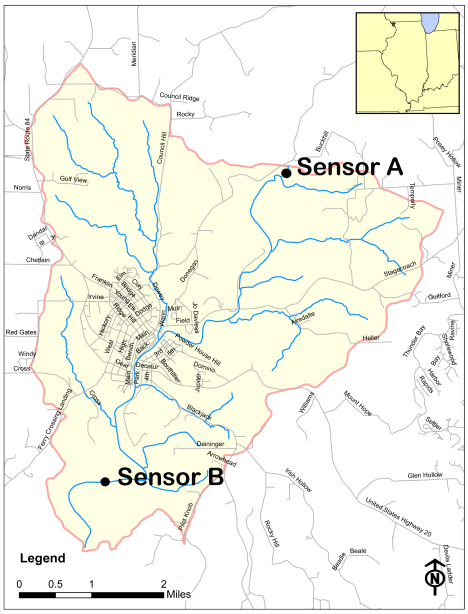

Figure 3. Sensor Locations

The Hydrolab MiniSonde 5 (MS5) bases will be used. Each Sonde will be configured with an internal battery pack, a Nitrate ISE sensor, pH sensor and conductivity sensor. The quoted price for each configured MS5 is $11,040.

MiniSonde 5 – MS5

- Four built-in expansion ports configured to fit your specific needs
- Measures up to 12 parameters simultaneously
- Compact and lightweight 44 mm (1.75") diameter housing fits into groundwater wells
- Used for attended or unattended monitoring

Figure 4. The Hydrolab MiniSonde 5 (MS5)

The nitrate sensor being used has a range of 0-100 mg/L-N, and an accuracy of the greater of +/- 5% of reading or +/- 2 mg/L-N. The resolution is 0.1 mg/L-N and the maximum depth is 15 meters.

OTT Hydromet — QUOTATION — HYDROLAB

Date	12 Sep 2017
Quotation Number	17-003227
Valid For	60 Days

Bill To:
Baranski Hammer Moretta & Sheehy
1101 S Bench St
Galena, Illinois 61036
beth@bhms-arch.com

Ship To:
Baranski Hammer Moretta & Sheehy
Beth Baranski

MS5 Sonde

No	Part #	Product Description	Qty	Unit Price (USD)	Ext. Price (USD)
1	MS5BASE	MS5 WITH THE FOLLOWING OPTIONS: Hydrolab MS5 sonde with temperature and other integrated sensors	2	3,250.00	6,500.00
2	MS5IBP	IBP OPTION Internal battery pack integrated to Hydrolab MS5 sonde	2	620.00	1,240.00
3	S5COND	CONDUCTIVITY ONLY PROBE Conductivity sensor integrated to Hydrolab Series 5 sonde	2	380.00	760.00
4	S5PHSREF	PH WITH STANDARD REF PROBE pH sensor integrated to Hydrolab Series 5 sonde with standard reference	2	480.00	960.00
5	S5NO3	NO3 PROBE OPTION Nitrate ISE sensor integrated to Hydrolab Series 5 sonde	2	790.00	1,580.00
			Group Subtotal Price		11,040.00

Figure 5. Price Quote for One Configured Sonde

The estimated battery life for this sensor configuration with a 15-minute sampling frequency suggests the batteries would need to be replaced roughly every 5-7 days. Alternatively, the instruments can be connected to data loggers with telemetry capabilities for autonomous data collection, allowing the sonde to be powered through the data logger's external power supply. Local technicians will be trained by ISWS personnel to maintain the sensors.

E. Data

1. Solution Architecture:

The overall configuration of the proposed data solution is shown conceptually in Figure 1, and will generally follow U.S. Geological Survey protocols. The field installation will include the sensor, datalogger, and telemetry unit. Data will be collected at 15-minute intervals and transferred to the database server via a digital cellular network. Provisional data will be immediately uploaded to the project website and labeled as such. Data will be periodically reviewed and undergo QA/QC checks; once data have passed through the review process, they will be uploaded to the project website and labeled as "Final." The project website will be available to the public via computer or mobile phone.

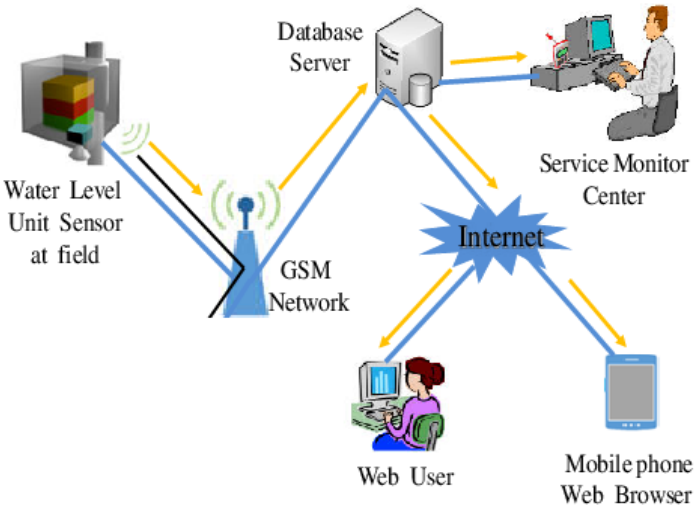

Figure 6. Conceptual model of proposed solution architecture.

The two monitoring sites will be registered in a database maintained at the ISWS. All data will be archived internally behind the existing firewall-protected SQL Server database, while the web services delivering data will be provided from the publically available ISWS data server. The ISWS will implement data transfer protocols through the deployment of XML web services and use open standard data services such as those based on the Open Geospatial Consortium (OGC) protocols. This will enable data to be more easily integrated and shared with the broader water data community.

2. QA/QC: Describe how quality assurance and data validation will be addressed

Field technicians will be trained by experienced ISWS field staff prior to installation of the sensors.
QA/QC procedures will generally follow published USGS methods (e.g., Bennett et al., 2014). Sites will be visited at least monthly, and maintenance and calibration will be performed. Sensors will be checked against known standards and recalibrated as necessary. A water sample will be collected and analyzed for nitrate to compare with the sensor reading at the same time. Sensor drift is expected, and sensor concentration data will be corrected based on the grab sample, assuming linear drift over the period since the previous calibration. For the nitrate sensors, there will be a 2-point calibration, following manufacturer's instructions. Acceptance criteria will follow Bennett et al. (2014): 0 point within ± 0.3 mg/L using inorganic blank water and (or) ± 5 percent of expected value of the standard value.
Pressure transducers used to monitor river stage will be assessed by QA/QC procedures as specified by the vendor. Methods and QA procedures for pressure transducers will follow USGS protocols (Cunningham and Schalk, 2011). An accuracy check will be performed on temperature sensors using

either a single- or multi-point accuracy check to verify that they meet the accuracy quoted by the manufacturer.

3. Data Sharing:
In addition to making the sensor data accessible for judging using web services following Open Geospatial Consortium data standards for communicating and sharing continuous monitoring data, we plan to make the data available on the ISWS website.

4. Metadata:
We anticipate following the National Water Quality Monitoring Council's recommendations for metadata, specifically their 2006 Water Quality Data Elements: A User's Guide, Technical Report No. 3. The two sampling sites will be given a unique location identifier based on the water body name and their latitude, longitude, and sensor depth. Data fields will include sample date, sample time, nitrate concentration, units (mg/L), and water level.

F. Analytics and Interpretation

The two locations selected will provide data for our analysis. The upriver site will serve as an indicator of what is flowing in from Wisconsin; the data from this site will be used to subtract the mass of what is found downriver and ultimately, what is discharging to the Mississippi River from Illinois.

The resulting data from this work will be analyzed in the following manner. All chemical and field-parameter data will be compared to data previously collected from spring, wells and the Galena River in the study area by the applicant and the ISGS and ISWS. Some of these data have been published in Panno et al. (2017a) and appear in a report to the USFWS (Panno et al. 2017b). In addition, data from water sampling and discharge measurements conducted on the nearby Apple River watershed as well as the more limited data from the Galena River by the USGS and IEPA will be used for comparison.

Background concentration ranges and thresholds for selected cations and anions will be determined using a graphical cumulative probability technique developed by Panno et al. (2006). These background ranges will allow us to determine the degree of contamination within the Galena River and its tributaries since settlement of the region, and develop a baseline with which we can compare our results.

Specific conductance data will be converted to sodium and chloride concentrations via least squared analysis based on data previously collected in the region, as well as data collected from streams from northern Illinois (e.g., Panno et al. 2006b; Kelly et al. 2010). This works well for these ions because they are easily derived and are representative of road salt and septic effluent. Nitrate vs chloride plots will be generated in order to examine the likely sources of these ions. Nitrate from nitrogen fertilizers tends to follow the nitrate axis whereas chloride from road salt follows the chloride axis. Nitrate and chloride from septic effluent and animal waste form a characteristic trend between these two extremes.

Time-series analysis of the chemical data will be conducted and compared to likely sources responsible for variations in the data. In addition, models will be fit to the data and used as predictive tools for estimating mass loading based on limited future data.

Discharge measurement based on pressure sensors will be used to calculate mass loading of nitrate and sodium chloride for the Galena River. Differences in chemistry as a function of location, season (January–March, April–June, July–September, October–December), and river discharge for both authors' data and the historical data sets will be evaluated using ANOVA tests at the 95% confidence level ($a = 0.05$). For the authors' data, the Galena River and its tributaries will be divided into sections to compare differences in nitrate concentrations among different reaches.

A two-way ANOVA using season and relative discharge rate as factors was performed to determine if discharge affected concentrations above and beyond seasonal effects for both the new sample data and available historical data sets. In addition to the data sets, river discharge values from our two gaging stations will be used to determine relative discharge rates during the monitoring period. Discharge values below the 25th percentile for the period of evaluation will be defined as being ‘‘low discharge,” values above the 75th percentile will be defined as ‘high discharge,” and values in between will be defined as ‘‘intermediate discharge.”

The presence of trends in river discharge and nitrate loads and concentrations will be determined using Kendall’s tau test at the 95% confidence level, and annual rates of change will be estimated by calculating slope coefficients (Helsel and Hirsch, 2002).

The data analysis will provide insight into the baseline data (both chemical and mass loading) for nitrate and calculated ions, and yield information as to the seasonal variability of those parameters both historically and in recent times. Estimates of the application of nitrogen to the field within the main watershed and subwatersheds will be used to determine the mass of nutrients lost to the surface streams during each season.

G. Communication and Use

The League of Women Voters' structure and approach allow members to play an instrumental role in efforts to address complex issues. Organized at the local, state, regional, and national levels, League efforts and resources can be scaled up and down as appropriate. With a formal process for studying issues important to voters and coming to consensus before taking action, the League has become widely respected for its non-partisan, fact-based, educational approach. The League of Women Voters of Jo Daviess County is creating a model that showcases how "The League Way" is working with residents in this rural area on the locally controversial, nationally important, and globally critical topic of water resource management.

In addition to the data from continuous nitrate monitoring being publically available on the ISWS website, the League of Women Voters of Jo Daviess County will proactively share the analysis reports based on these data with residents in the county through publication on the League's Water Protection Partnership website (https://sites.google.com/site/jodaviesscountywatershedplan/) and in local papers (the Galena Gazette, Dubuque Telegraph Herald, Warren Flash). The information will be incorporated into the *Galena River Watershed-based Plan*, incorporated into updates to the *Jo Daviess County Water Resource Management Plan*, and formally presented to local governments and the public at large.

Finally, the League of Women Voters of Jo Daviess County initiated the formation of the "Upper Mississippi River Region Inter-League Organization" (http://www.lwvumrr.org/) to work on water resource management at a larger scale. This entity was incorporated with 60 local League chapters participating from four states in October, 2016. The primary focus of the organization is to reduce nutrient pollution. The results of the continuous monitoring project will be shared as a model with other local leagues working on water quality projects through this organizational structure.

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