NEBRASKA NATURAL RESOURCES COMMISSION

Water Sustainability Fund

Application for Funding

Section A.

ADMINISTRATIVE

PROJECT NAME: Quantifying the Effects of Eastern Redcedar Encroachment on Recharge in the Nebraska Sandhills

PRIMARY CONTACT INFORMATION

Entity Name: University of Nebraska-Lincoln

Contact Name: Aaron Mittelstet

Address: 245 L.W. Chase Hall, Lincoln, NE 68583

Phone: 402-472-1427

Email: amittelstet2@unl.edu

Partners / Co-sponsors, if any: Water for Food Institute

1. Dollar amounts requested: Grant

   Grant amount requested. $ 144,716

   Loan amount requested. $ 0

   If Loan, how many years repayment period? N/A

   If Loan, supply a complete year-by-year repayment schedule.
   N/A

2. Permits Needed - Attach copy for each obtained (N/A = not applicable)

Nebraska Game & Parks Commission (G&P) consultation on Threatened and Endangered Species and their Habitat	N/A☒	Obtained: YES☐ NO☐

Surface Water Right	N/A☒	Obtained: YES☐	NO☐
USACE (e.g., 404 Permit)	N/A☒	Obtained: YES☐	NO☐
Cultural Resources Evaluation	N/A☒	Obtained: YES☐	NO☐
Other (provide explanation below) Click here to enter text.	N/A☒	Obtained: YES☐	NO☐

3. Are you applying for funding for a combined sewer over-flow project?

   YES☐ NO☒

   If yes, do you have a Long Term Control Plan that is currently approved by the Nebraska Department of Environmental Quality?

   YES☐ NO☒

   If yes attach a copy to your application. Click here to enter text.

   If yes what is the population served by your project? Click here to enter text.

   If yes provide a demonstration of need. Click here to enter text.

   If yes and you were approved for funding in the most recent funding cycle, then resubmit the above information updated annually but you need not complete the remainder of the application.

4. If you are or are representing an NRD, do you have an Integrated Management Plan in place, or have you initiated one?

   N/A☒ YES☐ NO☐

5. Has this application previously been submitted for funding assistance from the Water Sustainability Fund and not been funded?

   YES☒ NO☐

   If yes, have any changes been made to the application in comparison to the previously submitted application? Yes

   If yes, describe the changes that have been made since the last application. Changes have only been made to Section C. Section B remains unchanged.

   No, I certify the application is a true and exact copy of the previously submitted and scored application. (Signature required) Click here to enter text.

6. Complete the following if your project has or will commence prior to next July 1st.

As of the date of submittal of this application, what is the Total Net Local Share of Expenses incurred for which you are asking cost share assistance from this fund? $ N/A

Attach all substantiating documentation such as invoices, cancelled checks etc. along with an itemized statement for these expenses. N/A

Estimate the Total Net Local Share of Expenses and a description of each you will incur between the date of submittal of this application and next July 1st for which you are asking cost share assistance from this fund.
$ N/A

Section B.

DNR DIRECTOR'S FINDINGS

Does your project include physical construction (defined as moving dirt, directing water, physically constructing something, or installing equipment)?

YES☐ NO☒

1(a). If yes (structural), submit a feasibility report (to comply with Title 261, CH 2) including engineering and technical data and the following information:

A discussion of the plan of development (004.01 A);
Click here to enter text.

A description of all field investigations made to substantiate the feasibility report (004.01 B); Click here to enter text.

Maps, drawings, charts, tables, etc., used as a basis for the feasibility report (004.01 C); Click here to enter text.

A description of any necessary water and land rights and pertinent water supply and water quality information, if appropriate (004.01 D);
Click here to enter text.

A discussion of each component of the final plan including, when applicable (004.01 E);

Required geologic investigation (004.01 E 1); Click here to enter text.

Required hydrologic data (004.01 E 2); Click here to enter text.

Design criteria for final design including, but not limited to, soil mechanics, hydraulic, hydrologic, structural, embankments and foundation criteria (004.01 E 3). Click here to enter text.

1(b). If no (non-structural), submit data necessary to establish technical feasibility including, but not limited to the following (004.02):

A discussion of the plan of development (004.02 A);

In the last 20 years, the Eastern Redcedar (redcedar) has spread throughout the Nebraska Sandhills region, which is a crucial area of recharge to the Ogallala Aquifer and discharge to four major rivers. Due to its effects on evapotranspiration (ET), the redcedar is a legitimate threat to recharge of the Ogallala Aquifer and base flow to the river systems the aquifer feeds. While the redcedar is native to Nebraska, conservation plantings and lack of wildfires have led the species to

expand. Due to its drought resistance, expansion of the redcedar may continue unhindered. In addition to its threats to water resources in the state and beyond, the redcedar threatens economically significant grassland where more than half a million cattle graze. Thus, there is a clear and critical need to quantify the cumulative hydrological effects of future encroachment of the redcedar on groundwater recharge and levels, streamflow, and the cattle industry. Several questions must be addressed, including:

- What is the location and magnitude of the current redcedar population in the Sandhills?
- How might the redcedar's coverage expand in the next 20 to 50 years?
- How will redcedar encroachment affect the recharge, groundwater levels, stream flow and cattle industry in the Sandhills?
- How will the future encroachment of the redcedar affect discharge to the Platte River?

We propose to use multi-temporal satellite and airborne imagery, to quantify the current location and magnitude of the redcedar in the Sandhills. Because this region is infeasibly large to study as a whole in the current scope of the project, we have chosen a smaller study area (Figure 1): current high-resolution imagery (Rapid Eye) of the Middle Loup River watershed will be used to quantify the current and future rate of encroachment supported with NAIP 1-meter resolution imagery provided through the State of Nebraska GIS Council. In addition, we will use historical NAIP and Landsat Thematic Mapper 30 meter image to monitor the progression of the invasion over a 35 year period. We will then create a hydrological model to simulate multiple scenarios of future redcedar encroachment and its impact on water resources. Prior to applying the model, it will be calibrated and validated using measured ET, soil moisture, streamflow and groundwater levels. These simulations will be used to quantify the effects on recharge, groundwater levels, streamflow, and the cattle industry in the Sandhills.

Predicting the future encroachment of the redcedar and its effects on the hydrologic cycle of the Sandhills will be essential to the development of water policy decisions in Nebraska. This information will be invaluable to state agencies, Natural Resources Districts, and ranchers in their efforts to understand the significance and impacts of the redcedar's threats to the sustainability of the Ogallala Aquifer and to the cattle industry.

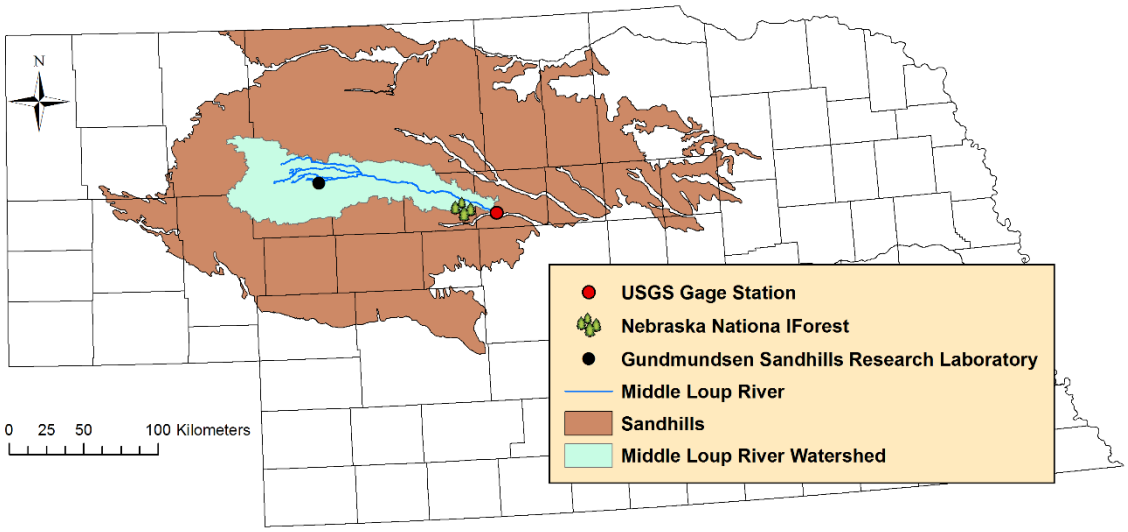

Figure 1. Proposed study area, including US Geological Gage gage station and research stations.

A description of field or research investigations utilized to substantiate the project conception (004.02 B);

The redcedar has expanded throughout the Midwest, including the Sandhills (Eggemeyer et al., 2006). While the redcedar is native to Nebraska, conservation plantings and lack of wildfires have led the species to expand. Due to the redcedar's drought resistance, there appears to be no limit to its expansion in the Sandhills and the rest of Nebraska. From 1995 to 2015, the population of the redcedar in Nebraska increased from fewer than 10 thousand trees to over 300 thousand (FIDO, 2016). The species now constitutes 22% of Nebraska's forest area and is the second largest tree seedling population, with nearly 275 million seedlings (FIDO, 2016). However, because the USDA Forest Service samples a limited number of plots annually, much uncertainty remains about the size of the redcedar population and the distribution across the state. There is thus a critical need to quantify the redcedar population throughout the Sandhills.

Zou et al. (2014) compared the hydrological responses between grassland- and redcedar-dominated watersheds in Oklahoma and found the redcedar reduced soil moisture and streamflow. They concluded that the transformation of grassland to redcedar has the potential to drastically reduce streamflow and groundwater recharge. Awada et al. (2013) arrived at the same conclusion for a similar study conducted at the Nebraska National Forest in the Sandhills, further finding that the reduction in soil water content can be attributed to the redcedar's longer growing season and amount of intercepted precipitation. During times of drought, the redcedar was able to uptake water from depths greater than 0.9 m and possibly down to 7 m (Eggemyer et al., 2009). Burns and Honkala (1990) reported redcedar roots penetrating up to 7.5 m. For

comparison, tree roots penetrating greater than 4 m would have limitless water access across 20% of the Sandhills. While the hydrological impact of the redcedar is unquestioned, its cumulative and critical effects on recharge, groundwater levels, and streamflow must be determined.

The reduction in forage production is also an issue with the spread of the redcedar. As the infestation increases, handling livestock becomes more challenging. When canopy coverage approaches 80%, forage production is essentially zero. Even if the trees are removed, native herbaceous plants do not recover quickly. This loss of forage production can potentially cost the cattle industry millions of dollars.

A description of the necessary water and/or land rights, if applicable (004.02 C); N/A

A discussion of the anticipated effects, if any, of the project upon the development and/or operation of existing or envisioned structural measures including a brief description of any such measure (004.02 D).

The Sandhills region is a major recharge area for the Ogallala Aquifer, which is vital for municipal, industrial, and agricultural development in Nebraska. Flow to four major rivers originates in the Sandhills, one of which (the Platte) is a critical source of water for the city of Lincoln as well as an important waterbody for countless birds, fish and other aquatic wildlife. During times of drought, 100% of the flow in the Platte River originates in the Sandhills. While the importance of the Sandhills region to the vitality of the state's water resources is unquestioned, the extent of redcedar encroachment and its effect on Sandhills hydrology is unknown. The myriad effects of this species' encroachment must be understood to enable proactive approaches to resource conservation in Nebraska. The proposed study will shed critical new light on the impacts of the redcedar on the Sandhills and the rest of the state.

2. Provide evidence that there are no known means of accomplishing the same purpose or purposes more economically, by describing the next best alternative.

The only method to understand the complexities of the hydrological cycle in the Sandhills is to use a hydrological model. Hydrological models are among the most useful tools to elucidate the interaction between surface and groundwater. We propose the application of the newly coupled SWAT-MODFLOW model to our study area. Two of the most commonly used hydrological models are the Soil and Water Assessment Tool (SWAT) and MODFLOW which have been extensively used to represent surface and groundwater processes, respectively (Arnold et al., 1998; Harbaugh, 2005). SWAT is used to simulate the effects of management practices, land use change, and climate change on streamflow, crop yield, and soil and nutrient loads and was successfully used to quantify the hydrological effects of redcedar encroachment in Oklahoma (Qiao et al.,

2015). MODFLOW is better used to illustrate surface and ground water interaction and predict groundwater conditions.

While these two models have been extensively applied worldwide to an array of water resource problems, their application in the Nebraska Sandhills is limited. MODFLOW was successfully applied to the Middle Loup watershed by Chen and Chen (2004) to simulate the effects of reduced precipitation on groundwater and streamflow; however, MODFLOW cannot simulate complex surface water processes such as vegetative growth and land use change. Also, while SWAT is an ideal model to simulate vegetative growth and land cover changes, it has limited or poor ability to model surface/groundwater interaction with accuracy (USGS, 2009). For reference, groundwater accounts for 95% of the total flow in the Middle Loup River and 98% of total flow in the Dismal River, also in the Sandhills (Chen and Chen, 2004). While these individual models have limited applicability for our proposed work, a recent, improved coupling of SWAT and MODFLOW has been completed at Colorado State University (Wible, 2016). This coupled model simulates streamflow, groundwater flow, sediment and nutrient loads, and crop yields at the watershed scale.

3. Document all sources and report all costs and benefit data using current data, (commodity prices, recreation benefit prices, and wildlife prices as prescribed by the Director) using both dollar values and other units of measurement when appropriate (environmental, social, cultural, data improvement, etc.). The period of analysis for economic feasibility studies shall be fifty (50) years or with prior approval of the Director, up to one hundred (100) years [T261 CH 2 (005)].

Describe any relevant cost information including, but not limited to the engineering and inspection costs, capital construction costs, annual operation and maintenance costs, and replacement costs. Cost information shall also include the estimated construction period as well as the estimated project life (005.01). Click here to enter text.

The total estimated cost for this project is $241,462. This three year project includes the cost for two PhD students. One will quantify the current and future encroachment of the redcedar in the Nebraska Sandhills and the other will quantify the redcedar impact on groundwater recharge and stream discharge. Other costs include travel to the study site and travel to conferences and publication costs to disseminate results.

Only primary tangible benefits may be counted in providing the monetary benefit information and shall be displayed by year for the project life. In a multi-purpose project, estimate benefits for each purpose, by year, for the life of the project. Describe any intangible or secondary benefits separately. In a case where there is no generally accepted method for calculation of primary tangible benefits describe how the project will increase water sustainability, such that the economic feasibility of the project can be approved by the Director and the Commission (005.02).

There are not any tangible direct benefit as a result of this project; however, an improved understanding of the magnitude of red cedar encroachment and its hydrological impact will improve decision making and enlighten policy makers and ranchers to the significance of the red cedar encroachment and its control. In the long-term, we hypothesize that water sustainability will increase on the Loup, Platte, Niobrara and Elkhorn Rivers if the redcedar is controlled.

All benefit and cost data shall be presented in a table form to indicate the annual cash flow for the life of the proposal, not to exceed 100 years (005.03).

No direct tangible benefit versus cost has been provided for this project.

In the case of projects for which there is no generally accepted method for calculation of primary tangible benefits and if the project will increase water sustainability, the economic feasibility of such proposal shall be demonstrated by such method as the Director and the Commission deem appropriate (005.04).

Although there is no method to quantify the tangible benefits of this project, the knowledge gained may encourage ranchers, state agencies and NRDs to be proactive. Controlling future encroachment into the Sandhills and the rest of Nebraska will help sustain the state's water resources and pasture.

4. Provide evidence that sufficient funds are available to complete the proposal.

Water for Food Institute has provided $96,746 as match for this project. See attachment for letter from Dr. Christopher Neale, Director of Research of the Water for Food Institute.

5. Provide evidence that sufficient annual revenue is available to repay the reimbursable costs and to cover OM&R (operate, maintain, and replace).

N/A

6. If a loan is involved, provide sufficient documentation to prove that the loan can be repaid during the repayment life of the proposal.

N/A

7. Describe how the plan of development minimizes impacts on the natural environment.

Field work will include driving around the Sandhills to ground truth the remote sensing imagery, using printed image maps and GPS navigation. We will also visit the

Gudmundsen Sandhills Research Laboratory and Nebraska National Forest. No damage will be done to the natural environment.

8. Explain how you are qualified, responsible and legally capable of carrying out the project for which you are seeking funds.

The faculty at the University of Nebraska have the expertise to carry out this project. Aaron Mittelstet, the primary investigator, is well established as a hydrological modeler. He has published multiple papers using the SWAT and MODFLOW models and recently completed a project in Oklahoma studying the hydrological impact of the redcedar on runoff. Other contributors to this project include the following:

Christopher Neale, Director of Research, Water for Food Institute, University of Nebraska-Lincoln, president of the International Commission on Remote Sensing of the International Association of Hydrological Sciences; expertise include remote sensing mapping of natural and agricultural systems, modeling of evapotranspiration from remote sensing.

Suat Irmak, Professor, Biological Systems Engineering, University of Nebraska-Lincoln; expertise include measurement and modeling of surface-energy fluxes, including evapotranspiration.

Craig Allen, Leader of the U.S. Geological Survey – Nebraska Cooperative Fish and Wildlife Unit; expertise include invasive species and ecosystems ecology

Dirac Twidwell, Assistant Professor and Rangeland Ecologist, University of Nebraska-Lincoln; expertise include redcedar management

9. Explain how your project considers plans and programs of the state and resources development plans of the political subdivisions of the state.

Data and results obtained from this project will be shared with faculty members in multiple departments at the University of Nebraska. State agencies such as DEQ and DNR will be able to incorporate the project findings such as modeling results and vegetation classification maps into best management plans. Results will be shared with the NRDs located in the Nebraska Sandhills and Lancaster County so they can incorporate the findings into future management plans.

10. Are land rights necessary to complete your project?

YES☐ NO☒

If yes, provide a complete listing of all lands involved in the project.

Click here to enter text.

If yes, attach proof of ownership for each easements, rights-of-way and fee title currently held.

Click here to enter text.

If yes, provide assurance that you can hold or can acquire title to all lands not currently held.

Click here to enter text.

11. Identify how you possess all necessary authority to undertake or participate in the project.

Data for our model will be obtained from online sources, the Gudmundsen Sandhills Research Laboratory and Nebraska National Forest. The Gudmunsen Sandhills Research Laboratory and Nebraska National Forest are located within our study area. Data from multiple studies at these two research sites are readily available as well as access to the study sites. Previous research at the Gudmundsen Sandhills Research Laboratory used Bowen Ratio Energy Balance Systems (BREBS) to determine daily estimates of grassland ET at a meadow, a valley, and an upland dune (Healey et al., 2011). Healey et al. found a strong correlation between the ET measured with the BREBS and Landsat images. Also, Awada et al. (2013) measured ET for the redcedar in the Nebraska National Forest. These collective ET data for various land covers in the Sandhills, coupled with Landsat imagery, provide us with strong ET estimates for our proposed study area.

12. Identify the probable environmental and ecological consequences that may result as the result of the project. Click here to enter text.

Understanding the hydrological impact of redcedar encroachment is imperative to the sustainability of recharge to the Ogallala Aquifer and discharge to the Loup, Platte, Niobrara and Elkhorn Rivers. Flow to these rivers originates in the Sandhills, one of which (the Platte) is a critical source of water for the city of Lincoln as well as an important waterbody for countless birds, fish and other aquatic wildlife. During times of drought, 100% of the flow in the Platte River originates in the Sandhills. While the importance of the Sandhills region to the vitality of the state's water resources is

unquestioned, the extent of redcedar encroachment and its effect on Sandhills hydrology is unknown. The myriad effects of this species' encroachment must be understood to enable proactive approaches to resource conservation in Nebraska. The proposed study will shed critical new light on the impacts of the redcedar on the Sandhills and the rest of the state.

Section C.

NRC SCORING

In the NRC's scoring process, points will be given to each project in ranking the projects, with the total number of points determining the final project ranking list.

The following 15 criteria constitute the items for which points will be assigned. Point assignments will be 0, 2, 4, or 6 for items 1 through 8; and 0, 1, 2, or 3 for items 9 through 15. Two additional points will be awarded to projects which address issues determined by the NRC to be the result of a federal mandate.

Notes:

- The responses to one criterion *will not* be considered in the scoring of other criteria. Repeat references as needed to support documentation in each criterion as appropriate. The 15 categories are specified by statute and will be used to create scoring matrixes which will ultimately determine which projects receive funding.

- There is a total of 69 possible points, plus two bonus points. The potential number of points awarded for each criteria are noted in parenthesis. Once points are assigned, they will be added to determine a final score. The scores will determine ranking.

- The Commission recommends providing the requested information and the requests are not intended to limit the information an applicant may provide. An applicant should include additional information that is believed will assist the Commission in understanding a proposal so that it can be awarded the points to which it is entitled.

Complete any of the following (15) criteria which apply to your project. Your response will be reviewed and scored by the NRC. Place an N/A (not applicable) in any that do not apply, an N/A will automatically be placed in any response fields left blank.

1. Remediates or mitigates threats to drinking water;

    - Describe the specific threats to drinking water the project will address.

The Eastern Redcedar (redcedar) has expanded throughout the Midwest, including within the Sandhills (Eggemeyer et al., 2006). The Kansas Forest Service estimates that from 1965 to 2005, the redcedar volume has increased by 23,000 percent in Kansas. While the redcedar is native to Nebraska, conservation plantings and a lack of wildfires have led the species to expand. Due to the redcedar's drought resistance, there appears to be no limit to its expansion in the Sandhills and the rest of Nebraska. From 1995 to 2015, the population of the redcedar in Nebraska increased from fewer than 10,000 trees to over 300,000 (FIDO, 2016). The species now constitutes 22% of

Nebraska's forest area and is the second-largest tree seedling population, with nearly 275 million seedlings (FIDO, 2016). However, because the USDA Forest Service samples a limited number of plots annually, much uncertainty remains about the size of the redcedar population and the distribution across the state; therefore, there is a need to quantify the redcedar population using more accurate methods.

Importantly, this landscape transformation from rangeland to redcedar has the potential to drastically reduce groundwater recharge and discharge to the stream system. Zou et al. (2014) compared the hydrological responses between grassland- and redcedar-dominated watersheds in Oklahoma and found the redcedar reduced soil moisture and streamflow. They concluded that the transformation of grassland to redcedar has the potential to drastically reduce streamflow and groundwater recharge. Awada et al. (2013) arrived at the same conclusion after a similar study was conducted at the Nebraska National Forest in the Sandhills, further finding that the reduction in soil water content can be attributed to the redcedar's longer growing season and amount of intercepted precipitation. During times of drought, the redcedar was able to uptake water from depths greater than 0.9 m and possibly down to 7 m (Eggemyer et al., 2009). Burns and Honkala (1990) reported redcedar roots penetrating up to 7.5 m. For comparison, tree roots penetrating greater than 4 m would have limitless water access across 20% of the Sandhills due to the shallow water table. In another study conducted in the Nebraska National Forest, recharge in the native grassland was measured at 27 mm yr^{-1} compared to 4 mm yr^{-1} in the redcedar forest, a reduction of 85% (Adane and Gates, 2015).

Recharge in the Sandhills is imperative since nearly 50% of the water in the Platte River originates in the Sandhills. Just upstream of the Loup River confluence, the average daily flow in the Platte River is 52 $m^3 s^{-1}$ with a standard deviation of 62 $m^3 s^{-1}$. The average daily flow in the Loup River that flows into the Platte River is 48 $m^3 s^{-1}$ with a standard deviation of only 22 $m^3 s^{-1}$. This means that the flow in the Loup River is more constant and reliable. During periods of drought, 100% of the water originates from the Loup River. From June 1 to September 30, 2012, the average flow in the Platte River upstream of the Loup River was only 3.6 $m^3 s^{-1}$ with 58 days having no flow. The average daily flow in the Loup was 22 $m^3 d^{-1}$ with zero days having no flow. Without water from the Sandhills, the Platte River near Omaha would be dry, thus effecting the source of water for both Lincoln and Omaha.

Flow reductions in the Loup River will also impact water quality. The average nitrate concentration in the Loup River watershed is 0.62 mg l^{-1}, compared to 2.56 mg l^{-1} in the Platte River watershed (Mittelstet et al., 2017). The median atrazine concentrations from 2001-2017 was 0.37 mg l^{-1} upstream of the Loup River confluence and only 0.22 mg l^{-1} downstream. The clean water from the Sandhills dilutes the polluted water in the Platte, thus reducing water treatment costs for the cities of Lincoln and Omaha. While the hydrological and water quality impacts of the redcedar is unquestioned, its cumulative and critical effects on recharge, groundwater levels, and streamflow need to be determined.

Click here to enter text.

- Identify whose drinking water, how many people are affected, how will project remediate or mitigate.

Overall, nearly 1 million people will be impacted by redcedar encroachment if current practices continue. The population of Omaha is approaching 500,000 people. The majority of their water comes from the Platte and Missouri Rivers. During times of drought, 100% of the flow in the Platte originates within the Sandhills. The reduction in flows in the Platte River due to the redcedar will impact both water quantity and quality. Omaha already has some of the most polluted drinking water in the U.S. (Going Green, 2011). Reducing flow in the Platte River will threaten one of their primary sources of water and further decrease the water quality, thus increasing water treatment costs. The City of Lincoln, with a population of 268,000, receives its water from the Platte River alluvial aquifer near Ashland. This project will quantify the reduction in water supply originating from the Loup River and increases in pollutants in the Platte River as a result of redcedar encroachment. This information will encourage state agencies and agricultural producers to be proactive in eliminating redcedar encroachment into the Nebraska Sandhills.

- Provide a history of issues and tried solutions.

This project will quantify the encroachment of the redcedar and its current and future hydrological effects on recharge to the Ogallala Aquifer and discharge and water quality in the Platte River. The redcedar is now a major issue in Texas and Oklahoma and is expected to become one in Nebraska in the near future. Currently very little is being done to monitor and control the spreading of the redcedar in Nebraska. To protect our future water resources, it is imperative to know the scope of the problem and its impact. That is precisely what this study will accomplish.

- Provide detail regarding long range impacts if issues are not resolved.

Without this study, we will not know the potential magnitude of redcedar encroachment and its hydrological, ecological and economic impact to the state. Redcedar encroachment will impact water quantity, quality, and water treatment costs. Recent and ongoing research in Nebraska demonstrates up to 80% collapse in grazing revenue, the loss of unique grassland species and biodiversity, heightened wildfire danger, and surprising economic losses to public school funding. The School Land Trust has increased spending from $175,000 to $400,000 annually to control redcedar encroachment in Nebraska. They own more than 950,000 acres of grassland, generating $573 million to public schools in Nebraska in the last ten years (http://newsroom.unl.edu/announce/beef/5577/31325). However, economic assessments have not been established for Nebraska. To provide an example of the kind of impacts that might be expected, Oklahoma State University estimated economic losses due to the redcedar would exceed $447 million by 2013

(https://www.ok.gov/conservation/documents/Eastern%20Redcedar%20Invading%20the%20Landscape%20publication.pdf). The costs were contributed to catastrophic wildfires ($107 million), cattle forage losses ($205 million), declines in lease hunting ($107 million) and recreation ($17 million) and water loss ($11 million).

Under the status quo, control methods will increase in cost as redcedar becomes more abundant in the state. Thus, maintaining desired water quality and quantity levels will become more costly if changes in management are not made. When redcedar is initially spreading into grasslands, control costs are minimal and often less than $5 – 7 per acre; once redcedar dominates a site, control costs have risen to $150 – 250 per acre in Nebraska and they are even higher in states with a longer history of redcedar encroachment (up to $2,000 per acre). Increasing control costs represents an additional long-range economic impact that has not been accounted for in the management of Nebraska's hydrological resources.

2. Meets the goals and objectives of an approved integrated management plan or ground water management plan;

    - Identify the specific plan that is being referenced including date, who issued it and whether it is an IMP or GW management plan.
    - Provide the history of work completed to achieve the goals of this plan.
    - List which goals and objectives of the management plan the project provides benefits for and how the project provides those benefits.

This project address the Lower Loup NRD and Upper Loup NRD Integrated Management Plan (IMP), both of which were approved in 2016.

This project addresses three of the four goals from the Lower Loup NRD's IMP:

- Goal 1: Promotes and supports a water supply by using the best available science and technology.
- Goal 2: Provides a basis for evaluating impacts of existing and future uses.
- Goal 3: Evaluate and understand impacts on streamflows resulting from uses outside of management control.

This project also addresses two of the three goals from the Upper Loup NRD's IMP:

- Goal 1: Maintain water supply and protect to the extent possible existing uses, the local economy, social and environmental health and safety, and recreational uses while allowing for growth and changes in use.
- Goal 2: To develop and implement information gathering and monitoring processes of hydrological and other related data to assess water resources and

uses within the Upper Loup NRD using the best available information, data and science.

This project directly benefits the IMPs of both the Lower and Upper Loup NRDs by using the latest technology to quantify the current and future impact of a growing problem in the watershed: redcedar encroachment. By understanding the extent of the problem, the IMPs can be improved and the groundwater and surface water quantity and quality in the Loup and Platte River watersheds can be better managed.

3. Contributes to water sustainability goals by increasing aquifer recharge, reducing aquifer depletion, or increasing streamflow;

   List the following information that is applicable:

   - The location, area and amount of recharge;
   - The location, area and amount that aquifer depletion will be reduced;
   - The reach, amount and timing of increased streamflow. Describe how the project will meet these objectives and what the source of the water is;
   - Provide a detailed listing of cross basin benefits, if any.

This study will quantify current recharge in the Middle Loup watershed and assess the impact of redcedar encroachment on recharge and streamflow in the Nebraska Sandhills, a region encompassing 50,000 km^2, and Platte River. Zou et al. (2014) compared the hydrological responses between grassland- and redcedar-dominated watersheds in Oklahoma and found the redcedar reduced soil moisture and streamflow. They concluded that the transformation of grassland to redcedar has the potential to drastically reduce streamflow and groundwater recharge. During times of drought, the redcedar was able to uptake water from depths greater than 0.9 m and possibly down to 7 m (Eggemyer et al., 2009). Burns and Honkala (1990) reported redcedar roots penetrating up to 7.5 m. For comparison, tree roots penetrating greater than 4 m would have limitless water access across 20% of the Sandhills. In another study conducted in the Nebraska National Forest, recharge in the native grassland was measured at 27 mm yr^{-1} compared to 4 mm yr^{-1} in the redcedar forest, a reduction of 85% (Adane and Gates, 2015).

To determine the impact of redcedar encroachment over such a large area with recharge, water table elevation, soil characteristics and aquifer properties varying spatially, a complex hydrological model will be required. The model will be created using measured evapotranspiration, groundwater levels, streamflow, and soil moisture. This model will simulate the current and future effects of redcedar on streamflow in the Loup and Platte Rivers. Results from this study will be critical for future management plans in the Lower Loup Basin. The hydrological model and methods used can be readily transferred to other watersheds throughout Nebraska. Since redcedar encroachment is an issue statewide, the transfer of this project's methods is imperative.

4. Contributes to multiple water supply goals, including, but not limited to, flood control, agricultural use, municipal and industrial uses, recreational benefits, wildlife habitat, conservation of water resources, and preservation of water resources;

    - List the goals the project provides benefits.
    - Describe how the project will provide these benefits
    - Provide a long range forecast of the expected benefits this project could have versus continuing on current path.

Goals: The goals of this project are to quantify current and future redcedar encroachment in the Nebraska Sandhills and determine the effects it will have on recharge to the Ogallala Aquifer and discharge to the Loup and Platte Rivers. Accomplishing this goal will lead to a number of economic and environmental benefits (see "expected benefits" below).

Approach: Our objectives are to:

- Quantify the current extent of the redcedar in the Sandhills;
- Quantify the historical and predicted distribution of the redcedar in the proposed study area;
- Create a hydrological model for the proposed study area;
- Quantify the effects of redcedar encroachment on recharge, groundwater flow, and streamflow in the Sandhills and Platte River

To accomplish these objectives and attain our goal, we will use remote sensing with high-resolution images so we can accurately quantify the current redcedar encroachment. We will then use the powerful SWAT-MODFLOW model to simulate the surface and ground water in the Middle Loup River watershed (**Figure 2**). The modeling results will quantify the redcedar's effects on recharge to the Ogallala Aquifer and discharge to the Loup, Platte, Elkhorn, and Niobrara Rivers.

Expected Benefits: If the issue of redcedar encroachment is not addressed, much of the Sandhills region may become encroached with redcedar. This study will help us understand the impact the encroachment will have on water quantity and quality in the Loup and Platte Rivers, while leveraging findings from other university research led by collaborating investigators on this project that quantifies impacts to agricultural producers, wildlife habitat and recreation benefits. We will identify potential management practices that can be implemented.

Recharge in the Sandhills is imperative since nearly 50% of the water in the Platte River originates in the Sandhills. During periods of drought, 100% of the water originates from the Loup River. From June 1 to September 30, 2012, the average flow in the Platte River upstream of the Loup River was only 3.6 $m^3 s^{-1}$ with 58 days having no flow. The

average daily flow in the Loup was 22 $m^3 d^{-1}$ with zero days having no flow. Without water from the Sandhills, the Platte River near Omaha would be dry, thus effecting the quantity and quality of water for both Lincoln and Omaha. With a reduction in flow from the Sandhills, water quality will decline in the Platte River, thus increase water treatment costs for the cities of Omaha and Lincoln.

Reduction in forage production is also an issue with the spread of the redcedar. As the infestation increases, handling livestock becomes more challenging. When canopy coverage approaches 80%, forage production is essentially zero. Even if the trees are removed, native herbaceous plants do not recover quickly. If we continue at the current rate, 530,000 cattle residing in the Sandhill will be impacted. This loss of forage production can potentially cost the cattle industry millions of dollars.

The redcedar encroachment will impact the habitat for many plants and animals, including the prairie chicken, sharp-tailed grouse and sturgeon. The prairie chicken and grouse need wide open grassland, which the Sandhills currently provides. As encroachment continues, their populations will decline as well as the funds generated by hunting. A study from Kansas State University and the USGS (http://lpcinitiative.org/redcedar-removal-restores-lesser-prairie-chicken-habitat/) found that the prairie chicken did not nest in grasslands with more than one tree per acre and stopped using grasslands altogether when the tree density reached three trees per acre.

Reductions in flow from the Sandhills will impact both the Elkhorn and Lower Platte Rivers, home to the endangered pallid sturgeon. Hamel et al. (2014) found that most of the pallid sturgeon in Nebraska were found in the lower-most 52 km, all below the Loup River confluence. Tributaries such as the Platte are important as they may provide habitat for fish spawning and reproduction.

This project will help us determine the current and projected extent of the Redcedar problem in the Nebraska Sandhills and its impact on our water resources and the associated costs.

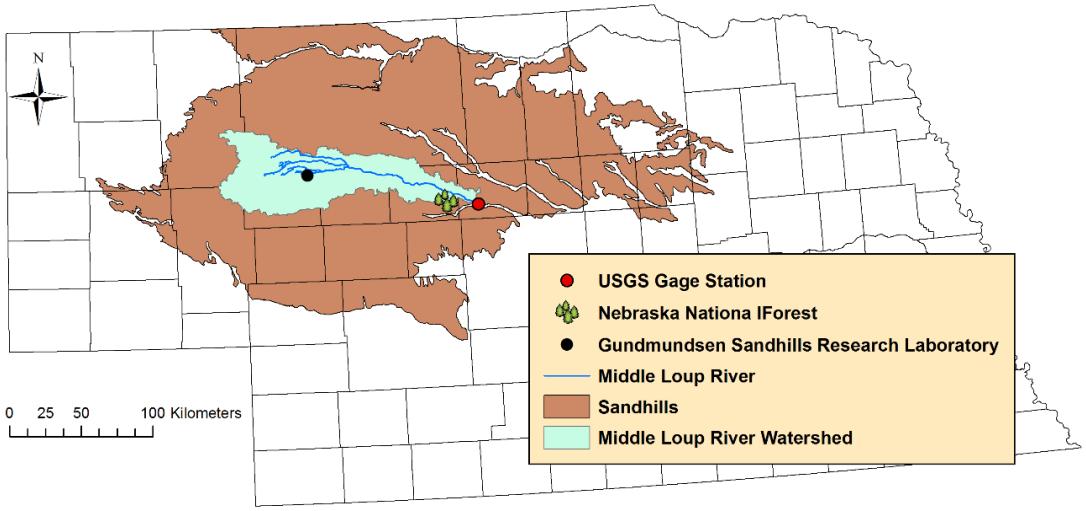

Figure 2. Proposed study area, including US Geological Gage gage station and research stations.

5. Maximizes the beneficial use of Nebraska's water resources for the benefit of the state's residents;

    - Describe how the project will maximize the increased beneficial use of Nebraska's water resources.
    - Describe the beneficial uses that will be reduced, if any.
    - Describe how the project provides a beneficial impact to the state's residents.

The Sandhills region is a major recharge area for the Ogallala Aquifer, which is a vital source of municipal, industrial, and agricultural development in Nebraska. Flow to four major rivers originates in the Sandhills, one of which (the Platte) is a critical source of water for the cities of Lincoln and Omaha as well as an important waterbody for countless birds, fish, and other aquatic wildlife. During times of drought, 100% of the flow in the Platte River originates in the Sandhills. While the importance of the Sandhills region to the vitality of the state's water resources is unquestioned, the extent of redcedar encroachment and its effect on Sandhills hydrology is unknown. The myriad effects of this species' encroachment must be understood to enable proactive approaches to resource conservation in Nebraska. The proposed study will shed critical new light on the impacts of the redcedar on the Sandhills and the rest of the state.

Under the status quo, control methods will increase in cost as redcedar becomes more abundant in the state. Thus, maintaining desired water quality and quantity levels will become more costly if changes in management are not made. When redcedar is initially spreading into grasslands, control costs are minimal and often less than $5 – 7 per acre; once redcedar dominates a site, control costs have risen to $150 – 250 per acre in Nebraska and they are even higher in states with a longer history of redcedar

encroachment (up to $2,000 per acre). Increasing control costs represents an additional long-range economic impact that has not been accounted for in the management of Nebraska's hydrological resources.

Without this study, we will not know the potential magnitude of redcedar encroachment and its hydrological, ecological and economic impact to the state. Redcedar encroachment will impact water quantity, quality, and water treatment costs. Recent and ongoing research in Nebraska demonstrates up to 80% collapse in grazing revenue, the loss of unique grassland species and biodiversity, heightened wildfire danger, and surprising economic losses to public school funding. The School Land Trust has increased spending from $175,000 to $400,000 annually to control redcedar encroachment in Nebraska. They own more than 950,000 acres of grassland, generating $573 million to public schools in Nebraska in the last ten years (http://newsroom.unl.edu/announce/beef/5577/31325).

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6. Is cost-effective;

- List the estimated construction costs, O/M costs, land and water acquisition costs, alternative options, value of benefits gained.
- Compare these costs to other methods of achieving the same benefits.
- List the costs of the project.
- Describe how it is a cost effective project or alternative.

Without this study, we will not know the magnitude of the redcedar encroachment and its hydrological, ecological and economic impact. Redcedar encroachment will impact water quantity and quality, water treatment costs and loss of ecological diversity and irreplaceable grassland. As one example, the School Land Trust has increased spending from $175,000 to $400,000 annually to control redcedar encroachment in Nebraska. They own more than 950,000 acres of grassland, generating $573 million to public schools in Nebraska in the last ten years (http://newsroom.unl.edu/announce/beef/5577/31325). The redcedar threatens both the grassland and funding for the Nebraska public schools. Oklahoma State University estimated economic losses due to the redcedar would exceed $447 million by 2013 (https://www.ok.gov/conservation/documents/Eastern%20Redcedar%20Invading%20the%20Landscape%20publication.pdf). The costs were due to catastrophic wildfires ($107 million), cattle forage ($205 million), lease hunting ($107 million), recreation ($17 million) and water loss ($11 million). If management practices don't change, the same can be expected in Nebraska as well.

Reactive management strategies such as mechanical removal and prescribed burning cost $53.81 per acre whereas proactive control methods such as haying and prescribed

burning have minimal cost (Simonsen et al., 2015). In Nebraska, we now have the opportunity to control the encroachment before the problem gets out of hand. The proposed study is a cost-effective way to determine the hydrological impact the redcedar will have on the state of Nebraska. The most significant cost to this project will be funding for two high-quality doctoral students.

Using a hydrological model is the only means of understanding the interaction between the surface water and groundwater. Due to its large size, creating a hydrological model for the entire Sandhills region is not feasible. We chose the Middle Loup River watershed (Figure 1) as our study area for multiple reasons. First, the entire study area (nearly 10,000 km^2) is located within the Sandhills and thus represents the Sandhills. Second, a USGS gage station at the outlet provides measured streamflow data since 1948. Finally, the Gudmundsen Sandhills Research Laboratory and Nebraska National Forest are located within the study area, and data from multiple studies at these two research sites are readily available. Researchers from these previous studies understand the significance of this proposed study and will thus be collaborators.

Selecting a study site that is 6,000 km^2 instead of 50,000 km^2 will also save significant money on high-resolution satellite images. To quantify and project the redcedar encroachment, we will need to use high-resolution imagery. While Landsat images can be freely downloaded, the multispectral spatial resolution is only 30 m; this makes the images useful for identifying clusters of redcedars and for historical observations, but not individual trees. Therefore, high-resolution images will be used to quantify the current and historical encroachment within the Middle Loup River watershed. Rapid Eye 5-m resolution multispectral images will be ordered for 2012 and 2017 to quantify the current rate of encroachment. This information will be supported by available NAIP 1-meter imagery for the state of Nebraska through the State of Nebraska GIS Council/NITC acquired in 2012, 2014, and 2016. While high-resolution satellite images may be costly, they are necessary to accurately quantify the extent and progression of the encroachment. To understand the predicted encroachment of the redcedar, we must understand the historical population thoroughly and will use a combination of NAIP 1-m and Landsat 30 m to go back in time. Using this information, we will be able to make informed predictions of the redcedar's future spatial and temporal encroachment.

7. Helps the state meet its obligations under interstate compacts, decrees, or other state contracts or agreements or federal law;

    - Identify the interstate compact, decree, state contract or agreement or federal law.
    - Describe how the project will help the state meet its obligations under compacts, decrees, state contracts or agreements or federal law.
    - Describe current deficiencies and document how the project will reduce deficiencies.

The results of this project will help the Central Platte NRD and the state of Nebraska meet the Platte River Program obligations for groundwater depletions; sustain flow for countless birds, fish, and other aquatic species; and assist the NRDs with regulation of their water resources. The information obtained from this study will prevent significant water quantity and quality issues in the Platte River. Reductions in flow from the Sandhills will impact both the Elkhorn and Lower Platte Rivers, home to the endangered pallid sturgeon. Hamel et al. (2014) found that most of the pallid sturgeon in Nebraska were found in the lower-most 52 km, all below the Loup River confluence. Tributaries such as the Platte are important as they may provide habitat for fish spawning and reproduction.

The methodology and results from this study will be easily transferrable to other watersheds within Nebraska. This information will assist Nebraska in meeting interstate contracts and federal laws such as the Republican River compact, an area already infested with redcedar.

8. Reduces threats to property damage or protects critical infrastructure that consists of the physical assets, systems, and networks vital to the state or the Untied States such that their incapacitation would have a debilitating effect on public security or public health and safety;

    - Identify the property that the project is intended to reduce threats to.
    - Describe and quantify reductions in threats to critical infrastructure provided by the project and how the infrastructure is vital to Nebraska or the United States.
    - Identify the potential value of cost savings resulting from completion of the project.
    - Describe the benefits for public security, public health and safety.

While natural fires and prescribed burns by Native Americans originally kept the redcedar from spreading, this is no longer the case. The reduction in fires enabled redcedar to encroach and makes fires that do occur more intense. This results in hotter, larger fires that can cause millions of dollars in damages. A fire in 2016 in Kanas was much worse than a similar fire in 1996 due to the increase in redcedar (http://www.kansas.com/news/local/article72238842.html). The 2016 fire was the worst in Kansas history, burning 400,000 acres in southern Kansas and northern Oklahoma. For the first time ever, the Forest Service spent more than half ($1.3 billion) of their budget on fire suppression. There are already signals that wildfire is on an increasing trajectory in the Great Plains (Donovan et al. 2017), and due to climate change and redcedar encroachment, wildfires in Nebraska will only intensify in the future, threatening millions of dollars in property across the state.

9. Improves water quality;

    - Describe what quality issue(s) is/are to be improved.
    - Describe and quantify how the project improves water quality, what is the target area, what is the population or acreage receiving benefits, what is the usage of the water: residential, industrial, agriculture or recreational.
    - Describe other possible solutions to remedy this issue.
    - Describe the history of the water quality issue including previous attempts to remedy the problem and the results obtained.

Recharge in the Sandhills is imperative since nearly 50% of the water in the Platte River is from the Loup River, the large watershed that drains most of the Sandhills. Just upstream of the Loup River confluence, the average daily flow in the Platte River is 52 $m^3 s^{-1}$ with a standard deviation of 62 $m^3 s^{-1}$. The average daily flow in the Loup River that flows into the Platte River is 48 $m^3 s^{-1}$ with a standard deviation of only 22 $m^3 s^{-1}$. This means that the flow in the Loup River is more constant and reliable. During periods of drought, 100% of the water originates from the Loup River. From June 1 to September 30, 2012, the average flow in the Platte River upstream of the Loup River was only 3.6 $m^3 s^{-1}$ with 58 days having no flow. The average daily flow in the Loup was 22 $m^3 d^{-1}$ with zero days having no flow. Without water from the Sandhills, the Platte River near Omaha would be dry, thus effecting the source of water for both Lincoln and Omaha.

Flow reductions in the Loup River will also impact water quality. The average nitrate concentration in the Loup River watershed is 0.62 mg l^{-1}, compared to 2.56 in the Platte River watershed (Mittelstet et al., 2017). The clean water from the Sandhills dilutes the polluted water in the Platte, thus reducing water treatment costs for the cities of Lincoln and Omaha. While the hydrological and water quality impacts of the redcedar is unquestioned, its cumulative and critical effects on recharge, groundwater levels, and streamflow need to be determined.

Water quality in the Sandhills can also be improved through modeling. The development of a complex hydrological model will help us understand the strong interaction between surface water and groundwater in the Sandhills. This will be invaluable information in understanding the movement of nitrates and other pollutants from the surface water to groundwater and vice versa. Once the model is created, future projects can utilize the model to simulate best management practices to reduce groundwater contamination. Future water quality projects will be much less expensive, since the most time-consuming aspect of modeling is obtaining and incorporating measured data so the model represents the physical processes involved.

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10. Has utilized all available funding resources of the local jurisdiction to support the program, project, or activity;

- Identify the local jurisdiction that supports the project.
- List current property tax levy, valuations, or other sources of revenue for the sponsoring entity.
- List other funding sources for the project.

Financial support has been guaranteed from the Robert B. Daugherty Water for Food Global Institute at the University of Nebraska ("Water for Food Institute"; please refer to attached supporting letter). This money was obtained from a private donor. The total cost of the project is $241,462, of which $96,746 (40%) will be provided by the Water for Food Institute to support a graduate student.

Though financial support has not been obtained from NRDs or other agencies, multiple agencies support the project. Some include the Lower Loup RC&D, Twin Platte NRD, USGS, Nebraska Department of Environmental Quality, and The Nature Conservancy. The investigators are currently conducting research associated with redcedar encroachment, focusing on its impacts and potential solutions, through funding partnerships with the NRCS, NGPC, NE DEQ, TNC, among other local groups. In addition, the investigators serve on multiple interagency working groups (e.g. the Eastern Redcedar Task Force, Invasive Species Advisory Council) that include producers (e.g. Loess Canyon Rangeland Alliance, Sandhills Task Force), agribusiness groups (e.g. Nebraska Cattlemen, Farm Bureau) and natural resource agencies.

11. Has a local jurisdiction with plans in place that support sustainable water use;

- List the local jurisdiction and identify specific plans being referenced that are in place to support sustainable water use.
- Provide the history of work completed to achieve the goals of these plans.
- List which goals and objectives this project will provide benefits for and how this project supports or contributes to those plans.
- Describe and quantify how the project supports sustainable water use, what is the target area, what is the population or acreage receiving benefits, what is the usage of the water: residential, industrial, agriculture or recreational.
- List all stakeholders involved in project.
- Identify who benefits from this project.

The Sandhills RC&D received nearly $85,000 in 2014 from the Nebraska Environmental Trust to control Eastern Redcedar encroachment and the Lower Loup NRD indicates redcedar control as one of their needs and concerns. This project will help these organizations as well as Natural Resource Districts, Loup Basin RC&D, Cedar Task Force, Nebraska Conservation Commission, agricultural producers and the cities of Omaha and Lincoln identify the current and future redcedar encroachment and where they should focus their control efforts. Information derived from this project will have

long-lasting benefits for a variety of stakeholders across the state. For example, although the Twin Platte NRD is outside this projects area of study, Ken Miller from the Twin Platte NRD provided a letter of support since the information obtained from this project can be transferred to his or any other NRD. Beneficiaries of the project include ranchers, irrigators, producers, cities, and surface water and groundwater users in the Loup, Platte, Elkhorn, and Niobrara watersheds. Through water sustainability, improvements in water quality for the cities of Omaha and Lincoln and improved management of grasslands across the state, this project will benefit many stakeholders in Nebraska.

12. Addresses a statewide problem or issue;

- List the issues or problems addressed by the project and why they should be considered statewide.
- Describe how the project will address each issue and/or problem.
- Describe the total number of people and/or total number of acres that would receive benefits.
- Identify the benefit, to the state, this project would provide.

The encroachment of the redcedar is a statewide problem. On July 5, 2015, the *Lincoln Journal Star* published an article by Craig Allen (Co-PI of this proposal) of the Nebraska Cooperative Fish and Wildlife Research Unit. The article discusses the encroachment of the redcedar into Nebraska and that during the past decade, an average of 38,000 acres of Nebraska's range lands and forests have been converted to redcedar forest each year. Allen states that cattle production declines as much as 75% after redcedar encroachment and that the redcedar may change stream flows. With shallow groundwater within much of the Sandhills, there is nothing to limit redcedar spreading throughout the area. Currently, we do not know the effect the redcedar will have on Nebraska's water supply, especially in the Sandhills.

This project will model the surface and groundwater system in the Middle Loup River watershed and simulate the current and future encroachment of the redcedar. Our goal is to quantify the current and future effects of redcedar encroachment on recharge and groundwater levels in the Ogallala Aquifer and streamflow in areas influenced by the Sandhills. To meet this goal, we will:

- Quantify the current extent of the redcedar in the Sandhills;
- Quantify the historical and predicted distribution of the redcedar in the proposed study area;
- Create a hydrological model for the proposed study area;
- Quantify the effects of redcedar encroachment on recharge, groundwater flow, and streamflow.

This study will benefit the entire Sandhills, a region encompassing 50,000 km^2. People throughout the Sandhills and along the Platte River, as well as the citizens of Lincoln and Omaha, will benefit from this project. Understanding the impact of redcedar

encroachment will enlighten ranchers and policy makers to the importance of acting now before the redcedar population gets out of control.

To achieve these goals and objectives, we will create a hydrological model using the recently coupled SWAT-MODFLOW. Hydrological models are among the most useful tools to elucidate the interaction between surface and groundwater. Two of the most commonly used hydrological models are the Soil and Water Assessment Tool (SWAT) and MODFLOW, which have been extensively used to represent surface and groundwater processes, respectively (Arnold et al., 1998; Harbaugh, 2005). SWAT is used to simulate the effects of management practice; land use change; and climate change on streamflow, crop yield, and soil and nutrient loads and was successfully used to quantify the hydrological effects of redcedar encroachment in Oklahoma (Qiao et al., 2015). MODFLOW is better used to illustrate surface and ground water interaction and predict groundwater conditions.

While these two models have been extensively applied worldwide to an array of water resource problems, their application in the Nebraska Sandhills is limited. MODFLOW was successfully applied to the Middle Loup watershed by Chen and Chen (2004) to simulate the effects of reduced precipitation on groundwater and streamflow; however, MODFLOW cannot simulate complex surface water processes such as vegetative growth and land use change. Also, while SWAT is an ideal model to simulate vegetative growth and land cover changes, it has limited or poor ability to model surface/groundwater interaction with accuracy (USGS, 2009). For reference, groundwater accounts for 95% of the total flow in the Middle Loup River and 98% of total flow in the Dismal River, which is also in the Sandihlls (Chen and Chen, 2004). While these individual models have limited applicability for our proposed work, a recent, improved coupling of SWAT and MODFLOW has been completed at Colorado State University (Wible, 2016). This coupled model simulates streamflow, groundwater flow, sediment and nutrient loads, and crop yields at the watershed scale and is thus ideal for use in the proposed study.

13. Contributes to the state's ability to leverage state dollars with local or federal government partners or other partners to maximize the use of its resources;

    - List other funding sources or other partners, and the amount each will contribute, in a funding matrix.
    - Describe how each source of funding is made available if the project is funded.
    - Provide a copy or evidence of each commitment, for each separate source, of match dollars and funding partners.
    - Describe how you will proceed if other funding sources do not come through.

Financial support has been guaranteed from the Robert B. Daugherty Water for Food Global Institute at the University of Nebraska ("Water for Food Institute"). This money was obtained from a private donor. The total cost of the project is $241,462, of which

$96,746 (40.9%) has been provided by the Water for Food Institute (see attached letter).

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14. Contributes to watershed health and function;

    - Describe how the project will contribute to watershed health and function in detail and list all of the watersheds affected.

The proposed project will contribute to heath and function to the Loup, Niobrara, Elkhorn, and Platte River watersheds by quantifying the current and future redcedar encroachment and the effects it has on recharge and discharge to the Loup River. To quantify and project the redcedar encroachment, we will use high-resolution imagery. While Landsat images can be freely downloaded, the multispectral resolution is only 30 m; this makes the images useful for identifying clusters of redcedars, but not individual trees. Therefore, high-resolution images will be used to quantify the current and historical encroachment within the Middle Loup River watershed (Figure 2). Rapid Eye 5-m resolution multispectral images will be ordered for 2012 and 2017 to quantify the current rate of encroachment. While high-resolution images may be costly, they are necessary to accurately quantify the extent of the encroachment. To understand the predicted encroachment of the redcedar, we must understand the historical population thoroughly. Using this information, we will be able to make informed predictions of the redcedar's future spatial and temporal encroachment.

Hydrological models are among the most useful tools to elucidate the interaction between surface and groundwater. Two of the most commonly used hydrological models are the Soil and Water Assessment Tool (SWAT) and MODFLOW, which have been extensively used to represent surface and groundwater processes, respectively (Arnold et al., 1998; Harbaugh, 2005). SWAT is used to simulate the effects of management practices; land use change; and climate change on streamflow, crop yield, and soil and nutrient loads and was successfully used to quantify the hydrological effects of redcedar encroachment in Oklahoma (Qiao et al., 2015). MODFLOW is better used to illustrate surface and ground water interaction and predict groundwater conditions. To quantify the hydrological effects of redcedar encroachment on the Nebraska Sandhills, we will apply the newly coupled SWAT-MODFLOW model to our study area.

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15. Uses objectives described in the annual report and plan of work for the state water planning and review process issued by the department.

    - Identify the date of the Annual Report utilized.

- List any and all objectives of the Annual Report intended to be met by the project
- Explain how the project meets each objective.

The Annual Report published by the Nebraska Department of Natural Resources (dated September 2015) states that for the effective management and conservation of Nebraska's water resources the State of Nebraska must develop and maintain data and information regarding water supplies across the state. This project will give the State of Nebraska the information on redcedar encroachment and impact that they will have on water quality, water quantity, ecological diversity and fire management across Nebraska if we continue status que. This study will provide information on how to best manage redcedar in the future. Study results will be transferrable to other watersheds around the State.

During this project, we will work with multiple state agencies, NRDs, and RC&Ds. By quantifying the hydrological impact the redcedar has and will have on the Loup, Niobrara, Elkhorn, and Platte Rivers, IMPs can be improved and actions can be taken to protect our water resources.

Click here to enter text.

16. Federal Mandate Bonus. If you believe that your project is designed to meet the requirements of a federal mandate which furthers the goals of the WSF, then:

    - Describe the federal mandate.
    - Provide documentary evidence of the federal mandate.
    - Describe how the project meets the requirements of the federal mandate.
    - Describe the relationship between the federal mandate and how the project furthers the goals of water sustainability.

The main objective of this project is to quantify the impact that redcedar encroachment will have on groundwater and streamflow in the Loup River watershed. During times of drought, 100% of the flow in the Platte River originates in the Sandhills via the Loup River. This project will help Nebraska meet the requirements of the federal mandate to protect endangered species such as the whooping crane, piping plover, least tern, and pallid sturgeon, all of which depend on this area. Although the Platte River Basin Endangered Species Recovery Implementation Program helps conserve species upstream of the Loup River, reductions in streamflow in the Loup River will affect flow in the upper Platte River. If flow is significantly reduced in the Loup River, surface and ground water management plans throughout the Platte Basin will have to be modified and improved. Since redcedar encroachment is a statewide problem, it may be directly impacting streamflow throughout the Platte River Basin. Knowledge gained in this project can be directly applied to other basins in Nebraska, including the Platte. This information can be incorporated into the Cooperative Hydrology Study (COHYST). This will improve the recharge and discharge calculations of the model and aid in determining the significance of the issue in the Platte River Basin.

Section D.

PROJECT DESCRIPTION

1. Overview

   In 1,000 characters *or less*, provide a brief description of your project including the nature and purpose of the project and objectives of the project.

In the last 20 years, the Eastern Redcedar (redcedar) has spread throughout the Nebraska Sandhills region, which is a crucial area of recharge to the Ogallala Aquifer and discharge to four major rivers. Due to its effects on evapotranspiration, the redcedar is a legitimate threat to recharge of the Ogallala Aquifer and baseflow to the river systems the aquifer feeds. While the redcedar is native to Nebraska, conservation plantings and lack of wildfires have led the species to expand. Due to its drought resistance, expansion of the redcedar may continue unhindered. In addition to its threats to water resources in the state and beyond, the redcedar threatens economically significant grassland where more than half a million cattle graze. The goals of this project include the following:

- Quantify current and future encroachment of the redcedar?
- Quantify the effects of redcedar encroachment on streamflow and groundwater in the Nebraska Sandhills?

These goals will be accomplished through the use of remote sensing and hydrological modeling. Tools used include high-resolution satellite imagery, processed with ERDAS Imagine and ArcGIS 10.2, and the powerful SWAT-MODFLOW hydrological groundwater/surface water model.

Click here to enter text.

2. Project Tasks and Timeline

   Identify what activities will be conducted by the project. For multiyear projects please list what activities are to be completed each year.

Task 1: Quantify Current Extent of the Redcedar in the Sandhills. Gathering information over a large area such as the Sandhills requires the use of remote sensing. For example, the USDA Natural Resources Conservation Service used Landsat images to quantify the redcedar canopy for multiple counties in Oklahoma (USDA, 2009). We will use the latest Landsat and NAIP images to quantify the redcedar encroachment across the Sandhills region. The NAIP 1-m images will be ground truthed over different areas of the Sandhills region, using printed maps and GPS navigation. Due to the extensive

drought in Nebraska during 2012, a combination of that year's NAIP 1-meter color imagery and the new 2016 NAIP imagery being collected this year will be initially analyzed along with the 2012 and 2017 RapidEye multispectral imagery through supervised classification techniques using the ERDAS Imagine software. A subset of the ground truthed imagery will be separated and used for classification accuracy assessment.

Task 2: Quantify Historical and Predicted Distribution of Redcedar in the Study Area. While Landsat images can be freely downloaded, the multispectral spatial resolution is only 30 m; this makes the images useful for identifying clusters of redcedars, and for historical observations but not individual trees. Therefore, high-resolution images will be used to quantify the current and historical encroachment within the Middle Loup River watershed. Rapid Eye 5-m resolution multispectral images will be ordered for 2012 and 2017 to quantify the current rate of encroachment. This information will be supported by available NAIP 1-meter imagery for the state of Nebraska through the State of Nebraska GIS Council/NITC acquired in 2012, 2014 and 2016. While high-resolution satellite images may be costly, they are necessary to accurately quantify the extent and progression of the encroachment. To understand the predicted encroachment of the redcedar, we must understand the historical population thoroughly and will a combination of NAIP 1-m (back to 1999) and Landsat 30 m (back to 1984) to go back in time and understand the early progression of the invasion. Using this information, we will be able to make informed predictions of the redcedar's future spatial and temporal encroachment in different regions of the Sandhills.

Task 3: Create Hydrological Model for the Study Area. Hydrological models are among the most useful tools to elucidate the interaction between surface and groundwater. Two of the most commonly used hydrological models are the Soil and Water Assessment Tool (SWAT) and MODFLOW which have been extensively used to represent surface and groundwater processes, respectively (Arnold et al., 1998; Harbaugh, 2005). SWAT is used to simulate the effects of management practices, land use change, and climate change on streamflow, crop yield, and soil and nutrient loads and was successfully used to quantify the hydrological effects of redcedar encroachment in Oklahoma (Qiao et al., 2015). MODFLOW is better used to illustrate surface and ground water interaction and predict groundwater conditions.

While these two models have been extensively applied worldwide to an array of water resource problems, their application in the Nebraska Sandhills is limited. MODFLOW was successfully applied to the Middle Loup watershed by Chen and Chen (2004) to simulate the effects of reduced precipitation on groundwater and streamflow; however, MODFLOW cannot simulate complex surface water processes such as vegetative growth and land use change. Also, while SWAT is an ideal model to simulate vegetative growth and land cover changes, it has limited or poor ability to model surface/groundwater interaction with accuracy (USGS, 2009). For reference, groundwater accounts for 95% of the total flow in the Middle Loup River and 98% of total flow in the Dismal River, also in the Sandihlls (Chen and Chen, 2004). While these individual models have limited applicability for our proposed work, a recent, improved

coupling of SWAT and MODFLOW has been completed at Colorado State University (Wible, 2016). This coupled model simulates streamflow, groundwater flow, sediment and nutrient loads, and crop yields at the watershed scale.

We propose to apply the newly coupled SWAT-MODFLOW model to our study area. We will calibrate the model with data from 2007 to 2016 and validate results with data from 1997 to 2006, comparing the simulated streamflow, ET, and groundwater levels to observed values.

Task 4: Quantify the Effects of Redcedar Encroachment on Recharge, Groundwater Flow, and Streamflow. Based on the results of current and predicted redcedar encroachment from Tasks 1 and 2, we will simulate various scenarios with the calibrated SWAT-MODFLOW model to assess the effects of encroachment on recharge, groundwater flow, and streamflow, including a worst-case scenario (100% redcedar encroachment).

Table 1. Project timeline.

Task	Year of Project		
	1	2	3
Task 1			
Task 2			
Task 3			
Task 4			
Publish Results			

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3. Partnerships

Identify the roles and responsibilities of agencies and groups involved in the proposed project regardless of whether each is an additional funding source. List any other sources of funding that have been approached for project support and that have officially turned you down. Attach the rejection letter.

This project will be completed by the University of Nebraska and Water for Food Institute.

Though financial support has not been attained from NRDs or other agencies, multiple agencies support the project. Some include the Lower Loup RC&D, Twin Platte NRD and Nature Conservancy.

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4. Other Sources of Funding

Identify the costs of the entire project, what costs each other source of funding will be applied to, and whether each of these other sources of funding is confirmed. If not, please identify those entities and list the date when confirmation is expected. Explain how you will implement the project if these sources are not obtained.

Financial support has been guaranteed from the Water for Food Institute. This money was obtained from a private donor. The total cost of the project is $241,462, of which $96,746 (40%) has been provided by the Water for Food Institute. A copy of the letter from the Water for Food Institute is attached.

Funding Source	WSF	Water for Food	Total
Year 1	$54,498	$31,174	$82,552
Year 2	$45,166	$32,234	$76,350
Year 3	$45,052	$33,338	$77,340
Total	$144,716	$96,746	$241,462

Below is the budget classification for the WSF and Water for Food.

WSF Budget Justification

Personnel
GRA: A PhD graduate student will be responsible for all modeling efforts. (effort = 3 years)
Undergraduate students will assist the graduate students with whatever they need. Two will be needed the first year and one the second year. The hourly rate will be $10 per hour and each student will work 288 hours per year.
A 3% cost of living increase has been applied to all salaries in years 2 and 3.

Benefits

GRA benefits include tuition remission estimated at 40% of salary and health benefits estimated at $1,774 in year 1; $1,952 in year 2; and $2,147 in year 3. The actual cost of benefits for each person will be charged to the project.

Travel

Study Site: Two graduate students and I will spend five days at the study site each year. The following costs will apply.
Ground Transportation (400 miles X 0.575) = $230
Hotels (3 people X $125 per night X 4 nights) = $1,500
Conferences*:* The PI and two PhD students will travel to two national conferences.
Cost per conference = $2,000
Total cost = ($2,000 X 6) = $12,000

Airfare:	$700
Hotel (4 nights)	$750
Meal allowance	$350
Ground transportation	$200

Supplies
RapidEye Satellite images cost $1.28 per square km. Our study area is approximately 6,000 square km and we will need to purchase images for 2012 and 2017. The total cost will be $15,360
Publications
Cost of $2,000 in year 2 and $4,000 in year 3 is budgeted to cover the cost of publishing project results = $6,000

Water for Food Budget Justification

Personnel
GRA: A PhD graduate student will be responsible for all modeling efforts. (effort = 3 years)
A 3% cost of living increase has been applied to all salaries in years 2 and 3.
Benefits
GRA benefits include tuition remission estimated at 40% of salary and health benefits estimated at $1,774 in year 1; $1,952 in year 2; and $2,147 in year 3. The actual cost of benefits for each person will be charged to the project.

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5. Support/Opposition

Discuss both support and opposition to the project, including the group or interest each represents.

Multiple agencies support this project including the USGS, DEQ, Lower Loup RC&D, Twin Platte NRD and Nature Conservancy. There has not been any opposition to the study.

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