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Development of a novel framework for modeling field-scale conservation effects of depressional wetlands in agricultural landscapes

O.P. McKenna, J.M. Osorio, K.D. Behrman, L. Doro, and D.M. Mushet

Abstract: The intermixed cropland, grassland, and wetland ecosystems of the upper midwestern United States combine to provide a suite of valuable ecological services. Grassland and wetland losses in the upper midwestern United States have been extensive, but government-funded conservation programs have protected and restored hundreds of thousands of acres of wetland and grassland habitat in the region. The value of restored wetlands in agricultural fields is complex, and the USDA Natural Resource Conservation Service, Conservation Effects Assessment Project (CEAP) has been lacking the methodology to include these conservation practices in their analyses. Our aim is to develop a reproducible methodology for simulating wetlands within the CEAP cropland modeling framework used to evaluate other agricultural conservation practices. Furthermore, we evaluate the effect of using upland conservation practices on the functioning of restored wetlands. By simulating the addition of a depressional wetland that effectively removes 6% of the field from crop production, we obtained a 15% reduction in annual runoff and a 29% and 28% reduction in mean annual nitrogen (N) and phosphorus (P) losses, respectively. The presence of the depressional wetland in the field is estimated to also reduce edge-of-field losses of sediments by 20% and sediment-bound N and P by 19% and 23%, respectively. Additionally, adding a grass filter strip around the wetland greatly decreased sediment inputs to the wetland, increasing the effective life of the wetland, in terms of its ability to perform valued services, by decades to centuries. Our method for modeling depressional wetlands embedded in cropped fields provides a means to quantify the effects of wetland conservation practices on field-level losses for regional assessments, such as the CEAP.

Key words: APEX model—Conservation Effects Assessment Project—depressional wetland—ecosystem services—edge-of-field loss management—Prairie Pothole Region

Agricultural production in the United States has led to intensification of soil erosion and nutrient losses that reduce water quality and threaten the long-term viability of croplands. In response to these concerns, the USDA has administered a number of voluntary, incentives-based conservation programs funded by seven farm bills since 1985 (Sweikert and Gigliotti 2019). Subsequently, the Conservation Effects Assessment Project (CEAP) was established to develop a scientific understanding and methodology for estimating the environmental benefits and effects of conservation practices on agricultural landscapes at national, regional, and watershed scales (Maresch et al. 2008). The CEAP assessment of croplands includes a statistical survey of land use and natural resource conditions and trends on US nonfederal croplands that are used to parameterize field-scale and watershed-scale process-based simulation models that estimate reductions of soil erosion and nutrient inputs from croplands to aquatic systems (Duriancik et al. 2008).

One region of interest is the Upper Mississippi River Basin (UMRB), where a high percentage of the landscape is under agricultural production and there is a corresponding potential for enhanced soil, water, and nutrient conservation. The highest concentrations of cropland in the UMRB are in northeastern and central Iowa and southern Minnesota, where cropland makes up more than 80% of the land in some counties (USDA NRCS 2012). Conservation practices in the UMRB in place from 2003 to 2006 have led to an estimated 61% reduction in waterborne sediment losses, and a 45% reduction of both nitrogen (N) and phosphorus (P) losses (USDA NRCS 2012). Despite significant progress in reducing sediment and nutrient losses from agricultural systems into local waterways, there is still a need for the development of additional conservation efforts as agricultural inputs are still estimated to be the largest source of in-stream sediment (81%), N (68%), and P (60%) in the UMRB (Robertson and Saad 2019).

In parts of Iowa, Minnesota, and South Dakota, the UMRB overlaps another area of regional importance, the North American Prairie Pothole Region (PPR). The US region of the PPR contains more than 2.6 million depressional wetlands called prairie-pothole wetlands, of which an estimated 71% are located within or adjacent to agricultural lands (Dahl 2014). Prairie-pothole wetlands have extremely high nutrient, sediment, and stormwater retention potential (Gleason et al. 2008). Under moderately high streamflow, wetlands in a subwatershed of the UMRB were found to be five times more efficient per unit area at reducing riverine nitrate (NO_3^-) concentration than the most effective land-based N mitigation strategies, which include cover crops and land retirement (Hansen et al. 2018). Wetland

Owen P. McKenna is a research ecologist at US Geological Survey, Northern Prairie Wildlife Research Center, Jamestown, North Dakota. **Javier M. Osorio** is a research scientist at Texas A&M AgriLife Research and Extension Center, Temple, Texas. **Katherine D. Behrman** is a research ecologist at Grassland, Soil, and Water Research Laboratory, USDA Agricultural Research Service, Temple, Texas. **Luca Doro** is a research scientist at Texas A&M AgriLife Research and Extension Center, Temple, Texas. **David M. Mushet** is a research wildlife biologist at US Geological Survey, Northern Prairie Wildlife Research Center, Jamestown, North Dakota.

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conservation practices provide many benefits, but to date the benefits of the conservation practices remain difficult to assess, particularly for restored or constructed wetlands that receive surface water runoff and drainage water from farm fields prior to discharge to streams and rivers (USDA NRCS 2012).

Despite their multifaceted importance, wetlands have been impacted by different anthropogenic stressors. Approximately 90% of prairie-pothole wetlands that historically occurred in high intensity agricultural areas (e.g., the Des Moines Lobe of Iowa) have been drained (Skopec and Evelsizer 2018; Van Meter and Basu 2015). Understanding the conservation potential for existing and restored wetlands in the prairie-pothole region embedded within the agricultural matrix of the UMRB is critical for evaluating current and developing future US farm bill programs that fund wetland conservation and restoration. De Steven and Mushet (2018) outlined a conceptual framework for incorporating different classes of wetlands and wetland practice into the CEAP Cropland modeling framework. Due to the susceptibility of depressional wetlands to processes such as sedimentation (Gleason et al. 2008), the effectiveness of wetland restoration and conservation also depends on upland management and conservation practices to maximize long-term sustainability of a multitude of ecosystem services (De Steven and Mushet 2018).

The goal of this study is to build upon the theoretical framework of incorporating wetlands into the CEAP Cropland Assessment proposed by De Steven and Mushet (2018). Our first objective is to develop and demonstrate an added capability for simulating the conservation potential of prairie-pothole wetlands using novel modifications to the process-based model and the modeling framework employed by the CEAP cropland assessment for structural and cultural conservation practices. Our second objective is to assess the impact of different structural conservation practices on the functioning of agricultural wetlands in the PPR. The novelty of this research lies in a combination of modifications to the process-based model used by CEAP, using empirical data for wetland bathymetry and drainage in ways that represent this type of wetland, and implementing a valid field configuration for simulating prairie-pothole wetlands.

Materials and Methods

To address our first objective, we developed methodology for including a depressional wetland within the existing CEAP Cropland Assessment that utilizes the Agricultural Policy/Environmental eXtender (APEX) model and an empirical understanding of prairie-pothole wetland geomorphology. In the CEAP Cropland Assessment, the APEX model is used along with farmer surveys to estimate field-level effects of conservation practices. The APEX model (Williams and Izaurralde 2006) simulates field-scale plant growth; crop management; wind and water erosion; loss or gain of soil organic carbon (C); and field-level losses of soil, nutrients, and pesticides on a daily time step (Duriancik et al. 2008).

For the CEAP cropland survey conducted in 2003 to 2006, the sampling frame of National Resources Inventory (NRI) points was restricted to cultivated cropland (Johnson et al. 2015). A standardized 16 ha field configuration was developed to represent the cultivated cropland and associated infield structural conservation practices (Potter et al. 2009). Since wetlands are not currently sampled in the CEAP survey, it was assumed that cultivated cropland on a drained hydric soil is a previously drained and currently cultivated wetland. This fully cultivated condition of a previously drained wetland is referred to as the "no-wetland" condition because it is comparable to what was reported in the 2003 to 2006 CEAP survey (figure 1a). Next, we developed a basic restored wetland using a standardized agricultural field that drains into wetland drainage area (figure 2a). To address our second objective, we developed two "enhanced wetland management" conservation scenarios to determine how upland conservation management of the wetland watershed can impact water, sediment, and nutrient delivery from the drainage area to the wetland (figures 2b and 2c). The percentage difference between the no wetland condition and the three wetland scenarios were compared to quantify the water, sediment, and nutrient conservation potential of wetland restoration.

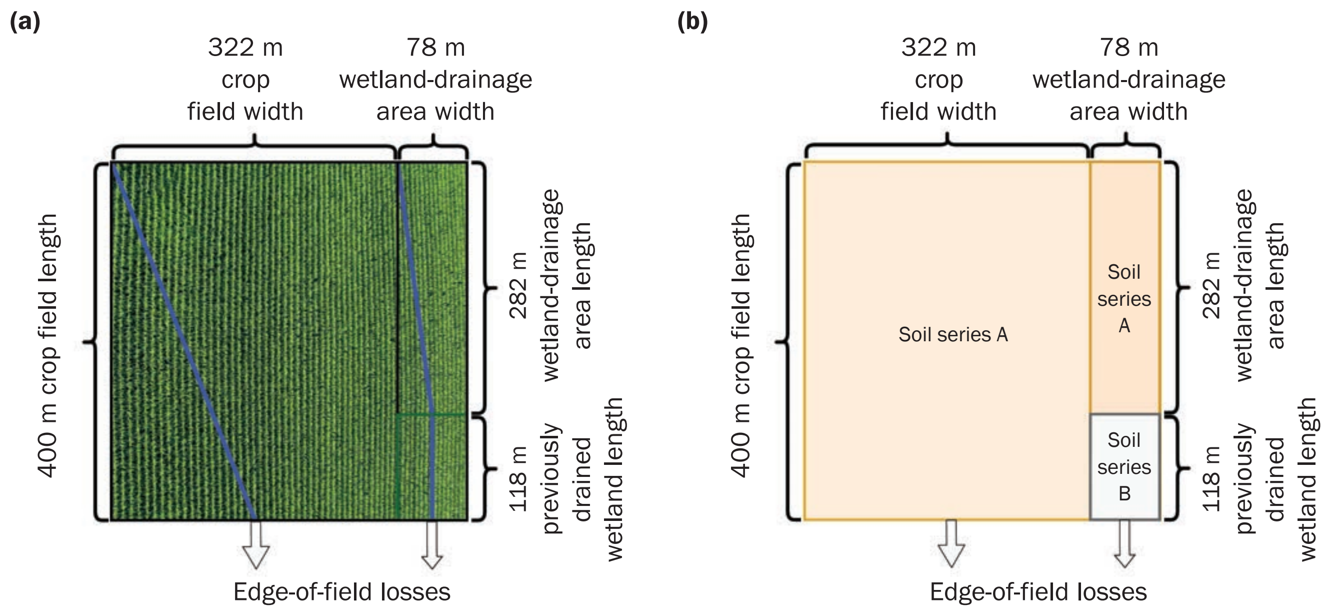
Of the two enhanced wetland management scenarios developed for this exercise, the first scenario is where a standard grass filter strip is planted upstream of the wetland occupying some of the cultivated cropland in the existing wetland-drainage area. In the second scenario, all the cultivated cropland in wetland-drainage area is converted to grassland. Next, the amount of water, sediment, and nutrients that flow into the restored wetland under three wetland scenarios (no wetland scenario, grass filter strip scenario, and full-drainage-area grassland restoration scenario) were compared. The approach and methodology designed here need to be validated more rigorously in the future to incorporate depressional wetlands into the full national CEAP Croplands Assessment.

Study Site. We developed our novel methodology using model inputs from agricultural field data in the Des Moines Lobe region of Iowa due to its location in both the UMRB and the PPR and because of the high potential for wetland restoration in the area. For this study, we used generalized soil (Andrews 1981) and crop management (Sanford and Selnick 2013) data from Boone County, Iowa. Soil series A is an agricultural soil commonly farmed, and soil series B is a hydric wetland soil. Soil series A (figure 1b) was represented by a moderately drained Webster series silty clay loam, which makes up ~30% of the soils in Boone County, Iowa. Soil series B (figure 1b) is a slowly permeable, fine-loamy hydric Williams series, which is found throughout the PPR. The simulated crop field had an average slope of 2%, which is also consistent for Boone County, Iowa (Andrews 1981). Cropland management was a corn (*Zea mays* L.)–soybean (*Glycine max* [L.] Merr.) annual rotation with conventional tillage operations. Daily maximum temperature, minimum temperature, and precipitation data were obtained from a National Oceanic and Atmospheric Administration National Climatic Data Center weather station in Boone, Iowa (latitude: 42.00, longitude: –94.02). In Boone, Iowa, the 30-year (1986 to 2015) mean annual precipitation was 922 mm; mean daily maximum and minimum temperatures were 15ºC and 3.4ºC, respectively.

We used empirical data from the Gleason and Tangen (2008) survey of ~600 wetlands in the PPR to estimate geometric characteristics of our restored wetland. The restored wetland area of 0.92 ha, volume of 2,211 m^3, and an upland drainage area of 2.19 ha were derived from the mean values (n = 288) for the Glaciated Plains physiographic region of the PPR (Gleason and Tangen 2008). This subregion was shaped by glacial processes that created a gently rolling landscape and simi-

Figure 1

Agricultural Policy/Environmental eXtender (APEX) field configuration for modeling the no-wetland condition and restored wetland practices. Both (a) and (b) represent a crop field that drains from top to bottom with a hydric soil in the bottom right corner. For the no-wetland condition, all areas are cultivated cropland with a corn–soybean rotation. There is a previously drained depressional and currently cultivated wetland in the bottom right corner of the field. (a) The direction of flow and the cropping regime. (b) The underlying soils for all subareas.



larly sized depressional wetland basins and upland grassland drainage areas (Visher 1966).

"No-Wetland" Field Configuration in APEX Model. We followed the field-scale modeling framework for the CEAP Cropland Assessment by assessing conservation practices on a representative 16 ha square field (400 m × 400 m). Figure 1 illustrates the cropping practices and underlying soils of the study field. For this study, we divided the 16 ha field into subareas for modeling wetland catchments and wetlands. Each subarea in the APEX model had homogeneous soil, land use, management, and weather. The APEX model routed water, nutrients and sediment between subareas and channel systems within the field. For each scenario, the APEX model was run daily for a 35-year period from 1981 to 2015. The first 5 years of model, runs were discarded as model spin up, and results presented are from 1985 to 2015.

For the no-wetland scenario, there were three subareas in our APEX model design. The first subarea was a 12.88 ha field with a corn–soybean crop rotation grown on soil series A (figure 1). The second subarea represented a 2.19 ha upland catchment area draining into the wetland on soil series A with a corn–soybean crop rotation. The third subarea was 0.92 ha on soil series B, representing a previously drained depressional wetland with a corn–soybean crop rotation. The wetland received drainage only from the second subarea.

We calibrated the corn and soybean yields in subareas 1 and 2 to match the average yield reported by the National Agricultural Statistics Service of the USDA for the period 1996 to 2015 in Boone County. First, considering the planting and harvest dates, we estimated the potential heat units required by the crops to reach the physiological maturity. This allows the model to simulate plant development over time. Then, specific parameters (table S1 in the supplemental material) were adjusted to correctly simulate the evapotranspiration estimated for the study area (Sanford and Selnick 2013) and properly simulate the effect of water stress on the harvest index. Finally, model parameters related to soil biological process were fine-tuned in order to better simulate nutrients dynamics and their availability (table S1). We used fertilization rates for soybeans of 25 kg ha^{-1} mineral P and 15 kg ha^{-1} mineral N. Fertilization rates for corn were 25 kg ha^{-1} mineral P and 162 kg ha^{-1} mineral N. These fertilization rates were the most frequent values for mineral fertilizer applied in Iowa from a 2003 to 2006 CEAP survey.

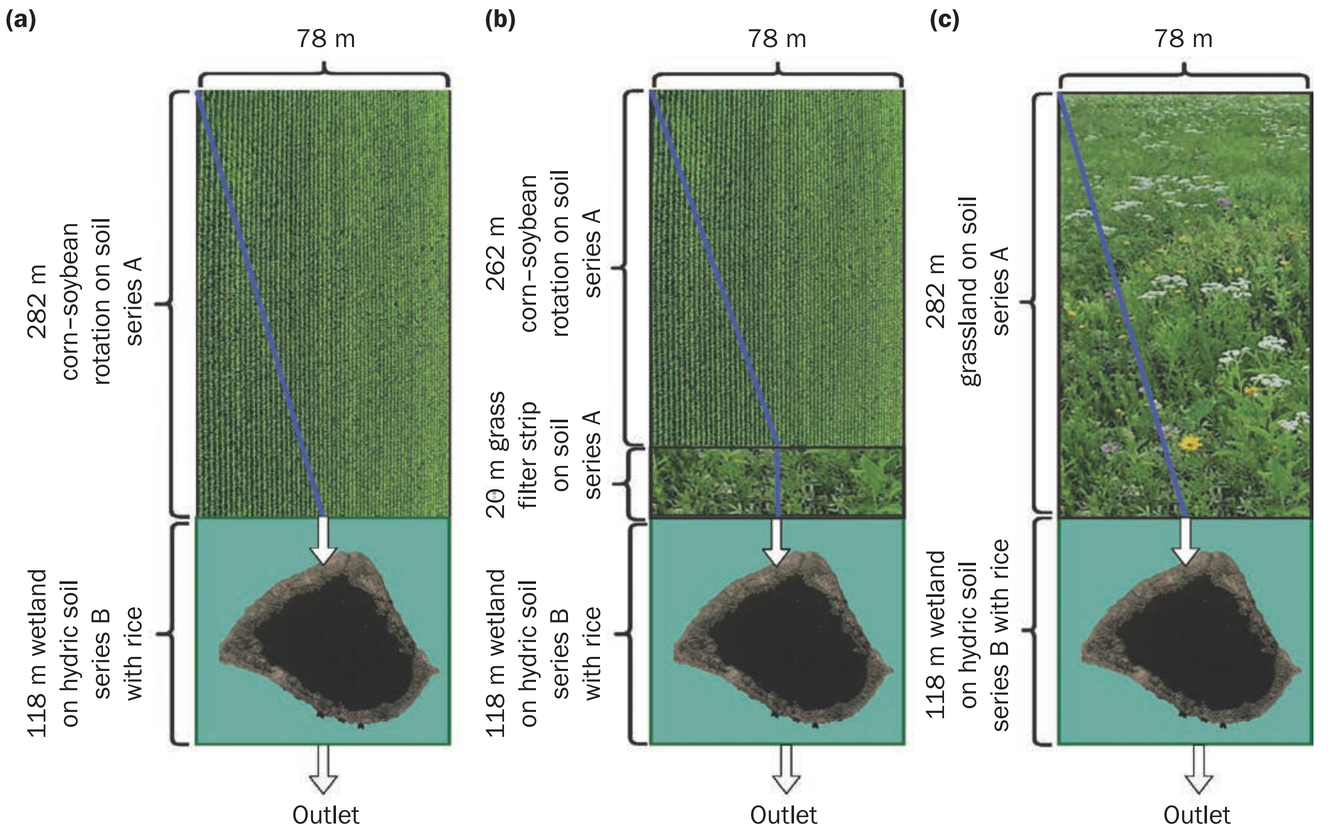
Simulating a Restored Depressional Prairie-Pothole Wetland in APEX. This capability was added to the APEX model to simulate restored depressional wetland using an existing "reservoir" feature to more accurately simulate the dynamics observed in a wetland (De Steven and Mushet 2008). This new APEX routine has not previously been applied to wetland modeling. We further built upon these added capabilities with added parameters specific to prairie-pothole wetlands. These additions allow the surface area and volume of the reservoir to change in size each day as a result of the calculated water balance. At a daily time-step, runoff is routed from the adjacent and all upstream subareas into the depressional wetland. In addition, precipitation that falls onto the ponded water immediately contributes to the wetland volume. At the same time, water is lost by evaporation, plant transpiration, seepage out of the bottom of the wetland, and by spill over to adjacent land areas if the wetland is full. As a result of these calculations, the surface area occupied by water within the reservoir and the volume of water within the reservoir increases and decreases.

The reservoir feature in APEX has two parameters that define how much water the reservoir can hold and when water will flow outside the reservoir. These parameters are

Journal of Soil and Water Conservation 75(6):695-703 www.swcs.org

Figure 2

Agricultural Policy/Environmental eXtender (APEX) model visualization for three wetland restoration configurations: (a) the basic restored wetland configuration where a cultivated crop field drains directly into a restored wetland, (b) an enhanced wetland management scenario where a cultivated crop field drains through a grass filter strip and into a restored wetland, and (c) an enhanced wetland management scenario where a cultivated crop field was converted to a grassland and drains into a restored wetland. In all scenarios water flows from the wetland to the edge-of-field at the outlet point when the wetland is full of ponded water.



the surface area at the emergency and principal spillway (in hectares), and the storage volume at emergency and principal spillway (in millimeters). These parameters define the main characteristics of the reservoir. With the modifications made to the reservoir feature, it is now possible to allow the surface area of the wetland to expand and fill one subarea. To simulate a wetland using the APEX new feature, we set first the surface area of principal and emergency spillways to 0.92 ha, the same size as the most downstream subarea. The reservoir storage volume is calculated using the bathymetric relationship derived from the regional average for wetlands in the Glaciated Plains observed from 288 wetlands by Gleason and Tangen (2008) and is

$$Volume = 0.25 \times \mathrm{Area}^{1.4742} \,. \tag{1}$$

Plants that grow in the wetland play a critical role in the functionality of any type of wetland. To simulate the impacts of plants growing in the wetland and for simplicity, a generic wetland plant was created based on plant parameters that describe growth and behavior from wild/native rice (*Zizania* sp.). Important crop parameters modified to simulate a general wetland plant were the plant base and optimal temperatures that were reduced to allow the plant to grow in colder environments compared to the ones where rice is cultivated. Also, parameters related to the leaf area development were adjusted to achieve a higher leaf area index in the early growing stage compared to rice. To make this generic wetland plant capable of growing when the field is saturated, and water is ponded, as well as under dry conditions, the crop Critical Aeration Factor (CAF) was set to one. CAF defines the fraction of soil porosity saturated by water that starts reducing plant growth. At CAF equal to one, the plant will continue to grow even when the soil is completely saturated by water. Also, we assumed that the evapotranspirative and nutrient dynamics of the wild rice are similar to that of native plants in prairie pothole wetlands. Transpiration of the generic wetland plant contributes to the total evapotranspiration of the subarea. The plant uptakes nutrients and interacts with the soil as part of the cycle of nutrients. The generic wetland plant is planted in the reservoir subarea every year, stays on the ground for five months, and is not harvested. Leaf litter contributes to the nutrients in the reservoir and contributes to reduced soil loss.

The maximum storage volume of a reservoir is a fixed value; however, the water-storage capacity can decrease through time as sediment accumulates in the bottom, thus reducing the water-storage capacity (Steglich et al. 2016). When the entire reservoir volume fills with water, any additional water added spills out of the outlet. The volume of water and associated nutrients leaving the wetland were compiled from the APEX daily reservoir output file (.DRS). To compare all restored wetland losses to the no-wetland condition losses, all simulations had to represent a constant 16 ha area. For the wetland scenarios, the total edge-of-field losses were calculated by adding the edge-of-field losses from the 12.88 ha field to the spill losses from the depressional wetland. The mean annual concentrations of dissolved N and P were multiplied by the volumetric spill losses from the depressional wetland to estimate that amount of dissolved nutrients lost in spill events.

Upland Conservation Practices for Enhanced Wetland Management. To address our second objective, we explored two scenarios, one where a standard grass filter strip was planted upstream of the wetland and the second where the whole subarea that drained into the wetland was converted from cropland to grassland. We followed the Steglich et al. (2016) conservation practices manual to develop our upland scenarios that are illustrated in figure 2.

In the first scenario, the upland subarea was divided into two unique subareas to accommodate the addition of a grass filter strip. The 0.15 ha grass filter strip subarea was placed directly upstream of the depressional wetland, leaving the 2.04 ha of cultivated cropland in the upland catchment (figure 2b). The grass filter strip was planted with big bluestem (*Andropogon gerardii*) on March 5 of each year, and grass was baled on September 1 of each year. Other modifications to the filter strip subarea were made in accordance with the APEX conservation parameterization manual (Steglich et al. 2016).

In the second scenario, the upland drainage area remained one unique subarea, and the cropland management was converted to grassland management (figure 2c). The 2.19 ha catchment was planted with big bluestem and modified according to the APEX conservation parameterization manual for a grass filter strip (figure 2c). In both scenarios the remainder of the field was left as 12.88 ha of cultivated cropland, and that did not drain into the depressional wetland.

Results and Discussion

Here, our results are organized by unique model runs corresponding to different objectives. First, model simulation output from one no-wetland model configuration is described in figure 1, and then we show the differences between the no-wetland configuration (figure 1) and the three wetland restoration scenarios (figure 2). We also show the additional field-scale and wetland-specific value of adding different conservation practices in the contributing upland of the restored wetland (figures 2b and 2c).

"No-Wetland" Outputs. The no-wetland scenario estimated the 30-year average annual total water runoff, dissolved N, dissolved P, and total sediment loss, sediment bound N, and sediment bound P from the 16 ha cultivated corn–soybean field (figure 1). Mean annual surface water runoff was equivalent to 22% of mean annual precipitation. Dissolved N and P losses were two orders of magnitude smaller than sediment-bound nutrient losses (figure 3).

Addition of Depressional Prairie-Pothole Wetland: Effects on Edge-of-Field Losses. Adding a depressional wetland embedded within the cultivated crop field reduced some edge-of-field losses disproportionately to the percentage of the field taken out of production (6%) (figure 4). The depressional wetland captured 100% of the sediment and sediment-bound nutrients that were deposited from the upland drainage area, which resulted in a 20% total reduction of sediment, a 23% total reduction in sediment-bound N, and 19% total reduction in sediment-bound P. The addition of a basic restored wetland reduced runoff by 8% relative to the no-wetland scenario (figure 4). Dissolved N (29%) and P (28%) decreased the most with wetland restoration. There were slightly higher reductions in surface water runoff (9%) and dissolved nutrient losses when a grass filter strip was used in combination with the depressional wetland (figure 4). Converting the whole upland contributing area to grassland had the largest impact on reducing surface water runoff (18%).

Upland Conservation Practices: Effects on Inputs to Restored Wetland. Not surprisingly, we found that converting the upland catchment to grassland reduced sediment and surface water runoff going into the modeled depressional wetland (figure 5). The addition of a 0.15 ha grass filter strip reduced surface water inputs to the wetland by 5%, sediment inputs by 70%, dissolved N and P runoff inputs by 54% and 54%, and sediment N and P by 53% and 55% (figure 5). Converting the whole 2.19 ha upland contributing area from cropland to grassland created the largest reductions in the nutrient, sediment, and

Figure 3

Mean annual edge-of-field losses from a 16 ha cultivated crop field or no-wetland scenario for a 30-year simulation. (a) Mean annual surface water runoff volume (Water, ha m), dissolved nitrogen mass (DN, kg), and dissolved phosphorus mass (DP, kg). (b) Mean annual total sediment mass (Total, Mg) losses, sediment-bound nitrogen (N, kg), and sediment-bound phosphorus (P, kg). Black error bars represent yearly variance as standard error.

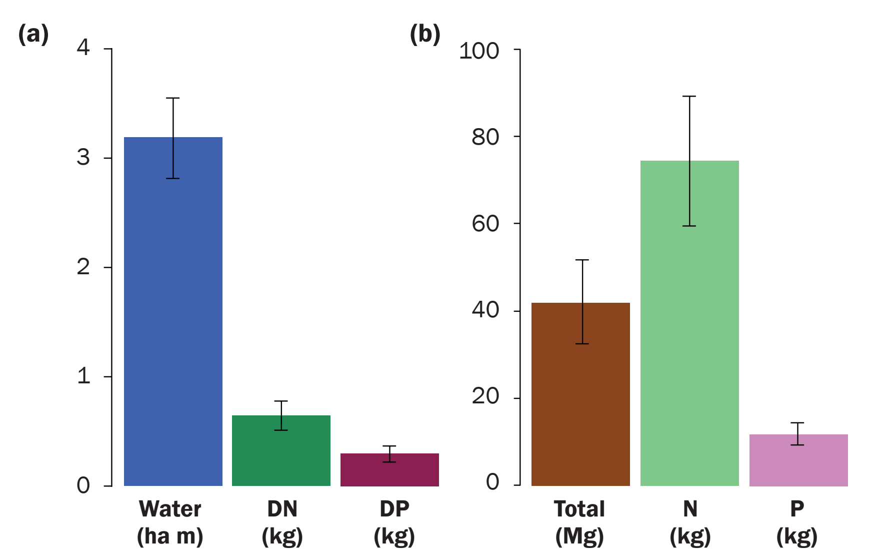


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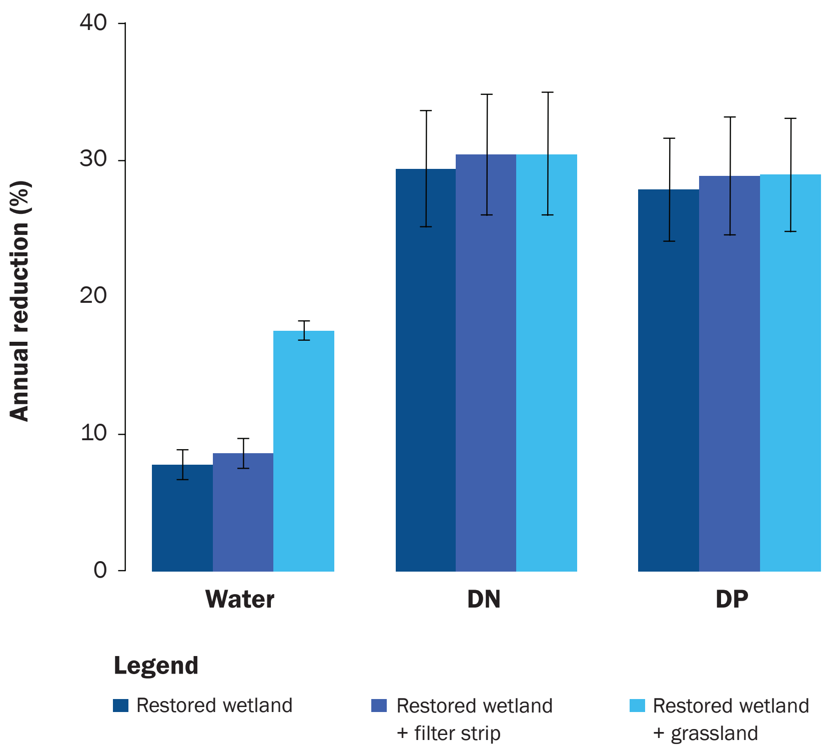
Figure 4

Percentage annual reductions of surface water, dissolved nitrogen (DN) in runoff, and dissolved phosphorus (DP) in runoff loss of three restored wetland scenarios relative to the no-wetland scenario for a 30-year simulation. The dark blue bars represent mean percentage annual reductions when 0.92 of the field was restored as a functioning wetland. The medium blue bars represent mean percentage annual reductions when 0.92 ha of the field was restored as a functioning wetland and 0.15 ha of the field was converted to a grass filter strip surrounding the wetland. The light blue bars represent mean percentage annual reductions when the entire 2.19 ha cultivated cropland is replaced by grassland. Black error bars represent yearly variance as standard error.



surface water moving into the depressional wetland. Grassland conversion reduced surface water inputs to the wetland by 54%, sediment inputs by 99%, dissolved N and P runoff inputs by 97% and 99%, respectively, and sediment N and P by 97% and 98% respectively (figure 5). The greatest difference on input reduction between the filter strip and a whole-field grassland conversion was a net 51% reduction in surface water (figure 5).

Precipitation in the first half of the 30-year simulation period (mean = 880 mm y^{-1}) was higher than the second half (mean = 944 mm y^{-1}). This increase in precipitation corresponds to an increase in wetland volumes (figure 6a) and spill events (figure 6c), which occurred anytime the water volume of a wetland (figure 6a) exceeds the wetland basin volume (figure 6b). The impact on sedimentation in the restored wetland is visualized in the figure 5b. Figure 6b show how the wetland basin volume changes over time due to sediments. The second scenario, which contained only the cultivated crop field and depressional wetland, resulted in a 10% decrease in wetland basin volume due to sedimentation at the end of the 30 years. The addition of a grass filter strip reduced basin volume loss due to sedimentation from 10% to 2%. The conversion of the whole 2.19 ha wetland catchment from a cultivated crop field to grassland eliminated wetland volume loss due to sedimentation (figure 6b).

Discussion. Overall, we demonstrated a new method for simulating depressional wetlands that can be readily included in the CEAP Cropland modeling framework using APEX. Furthermore, this approach for adding natural or restored depressional wetlands to the APEX model is easily reproducible across the UMRB for a wide range of upland cropping systems, management schedules, and environmental conditions.

Results from our APEX modeling simulations suggest that restoring an average-sized depressional wetland within a cultivated crop field in Iowa may significantly reduce edge-of-field losses. Even though the depressional wetland reduced average annual edge-of-field losses, it is interesting to note that in 2010 the water and dissolved nutrient losses from wetland spill were greater than the surface water losses from the upland. This precipitation-driven spill occurred because the antecedent water levels were very high from large runoff events in 2009, and precipitation in 2010 caused spill from the wetland. On the landscape scale, other research suggests that restoring all depressional wetlands might not be enough to store floodwater as Iowa continues to experience an increase in extreme precipitation years (Green et al. 2019). Although depressional wetland restoration might not store all floodwater, Green et al. (2019) also found that restoring wetlands could minimize flood severity and greatly reduce nutrient loads in the Mississippi River Basin. Location of wetland restorations has also been found to be important for peak streamflow water. Restored wetlands closer to the main stream network played a disproportionately important role in attenuating peak flow (Ameli and Creed 2019).

Our results for the no-wetland condition losses from a cultivated crop field were found to be comparable to other modeling and field studies. The estimated annual runoff (3.2 ha m, or 199 mm) was comparable to another field-scale runoff study in Iowa croplands (192 mm) (Hernandez-Santana et al. 2013). Other modeling studies have estimated that conservation practices have reduced the N loads by 28% and P loads by 45% from cultivated croplands in the Mississippi River Basin to the Gulf of Mexico (White et al. 2014). Our simulated estimates of mean annual dissolved N (0.11 mg L^{-1}) and P (0.05 mg L^{-1}) exports were lower when compared to median annual dissolved inorganic N (1.1 mg L^{-1}) and dissolved orthophosphate (0.62 mg L^{-1}) concentrations estimated by Skopec and Evelsizer (2018) for drained wetlands in Iowa croplands. The simulated estimates of mean annual sediment (5.9 Mg ha^{-1}), sediment-bound N (0.01 Mg ha^{-1}), and sediment-bound P (0.002 Mg ha^{-1}) erosion yields were similar to mean annual sediment (11.9 Mg ha^{-1}), sediment-bound N (0.035 Mg ha^{-1}), and sediment-bound P (0.005 Mg ha^{-1}) estimates by Tangen and Gleason (2008) for croplands in Iowa.

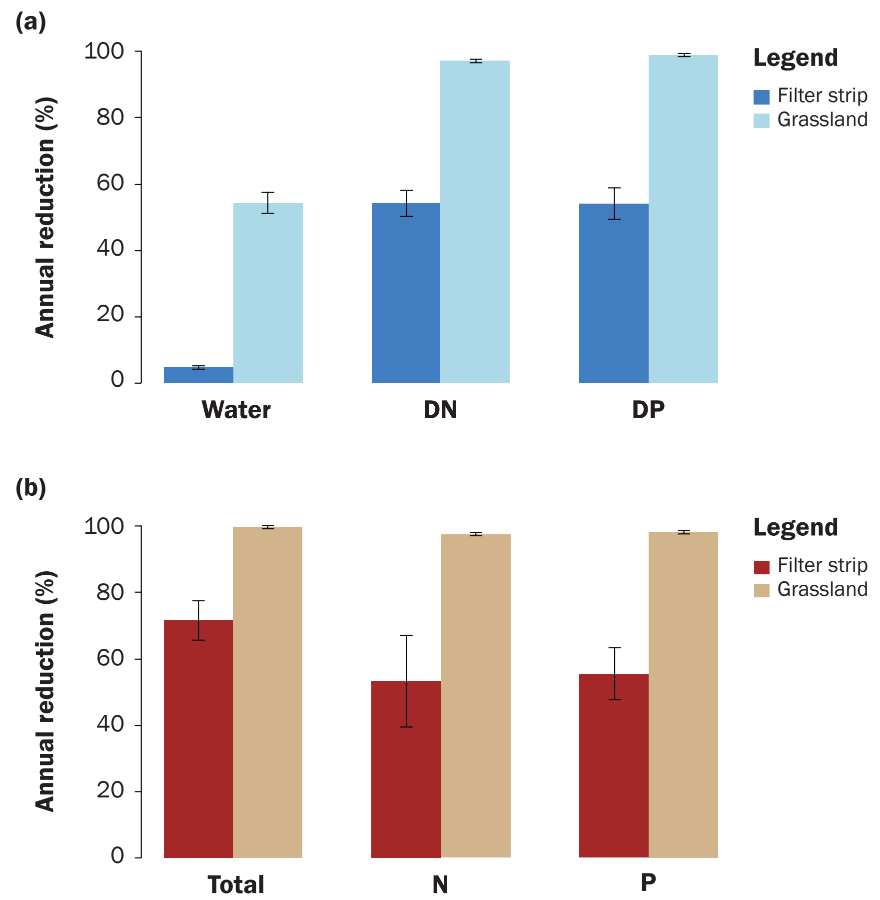
Management of upland sediment inputs is critical for depressional-wetland sustainability (Tangen and Gleason 2008). The addition of a 0.15 ha filter strip above a wetland reduced sediment and nutrients loads coming into the depressional wetland with a much smaller decrease in surface water inputs. This conservation practice provides the least disturbance to the hydroperiod of the depressional wetland while still reducing edge-of-field losses from the upland agricultural field. Adding a grass filter strip around a depressional wetland would delay filling the wetland basin via sedimentation by ~1,100 years (figure 5b).

Converting the whole depressional wetland catchment from cropland to grassland could provide a suite of ecosystem services in addition to the soil, nutrient, and water conservation benefits. These ecosystem services provide a benefit to society, and grasslands provide critical habitat for a large number of species (Mushet et al. 2014). Presence of grassland habitat is important for successful grassland bird populations (Shaffer et al. 2019), migratory waterfowl (Niemuth et al. 2014) and amphibians (Mushet et al. 2014). Cropland-to-grassland conversion would also ensure almost no sedimentation into the depressional wetland basin (figure 5b). Along with the positive reductions in sedimentation that cropland-to-grassland conversion provides, surface water inputs are also reduced by ~60% (figure 6). Such a large reduction in surface water inputs would sharply alter the hydroperiod of the depressional wetland, which would have impacts on the overall functioning of the wetland and the biotic communities it could support.

Application of this new modeling technique, along with more extensive field validation, provides opportunities for integration of depressional wetlands in CEAP Cropland assessments. Including the conservation impact of depressional wetlands in CEAP reports may help to better fulfill the CEAP program's Congressional mandate of quantifying the value of current conservation practices (Johnson et al. 2015). A significant application of this method would be to better estimate the value of the wetlands currently restored and protected under the Agricultural Conservation Easement Program (ACEP), which is a voluntary program implemented by the USDA Natural Resources Conservation Service. ACEP has already been identified as critically important for the success of a variety of bird populations (King et al. 2006). This method for integrating depressional wetlands into the APEX modeling efforts also has potential for modeling outside of the UMRB in other areas of the PPR and in regions such as the Southern High Plain where work has already been conducted to quantify a variety of ecosystem services provided by depressional, playa wetlands (Smith et al. 2011). This method has been used in restored wetlands in the Chesapeake Bay watershed (Sharifi et al. 2019).

Figure 5

Percentage annual reductions of field-to-wetland (a) surface water, dissolved nitrogen (DN), and dissolved phosphorus (DP) runoff and (b) sediment total, N, and P inputs from a 2.19 ha during a 30-year simulation. Bars represent mean percentage annual reduction in surface water and sediment-derived field-to-wetland inputs. The dark blue and red bars represent mean percentage annual field-to-wetland reductions when a 0.15 ha grass filter strip surrounds the simulated depressional wetland. The light blue and tan bars represent mean percentage annual field-to-wetland reductions when the whole 2.19 ha catchment is converted from a cultivated crop field to a grassland. Black error bars represent yearly variance as standard error.



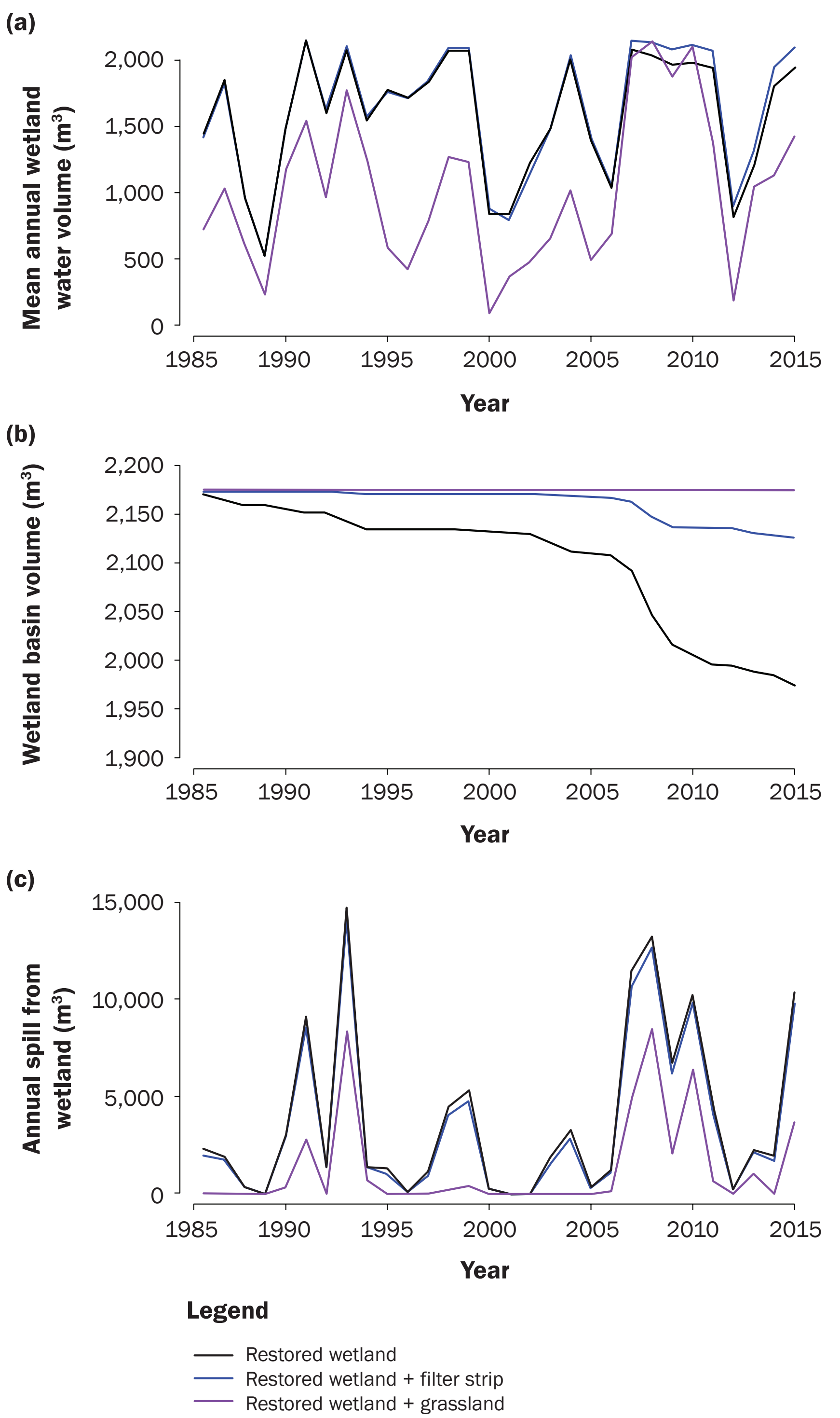
Summary and Conclusions

In conclusion, we found three major conservation implications of our research to be the following:

1. We demonstrated that the modified routines enabled APEX for modeling and quantifying the impacts of prairie-pothole wetlands as agricultural conservation practices.
2. By adding a depressional wetland that effectively removed 6% of the field from crop production, we obtained a 15% reduction in mean annual runoff and a 43% and 79% reduction in mean annual N and P, respectively. Additionally, the presence of the depressional wetland in the field also reduced edge-of-field losses of sediments by 38% and sediment-bound N and P by 42%.
3. Applying upland conservation strategies in-tandem with wetland restoration

Figure 6

Mean annual water volume, daily wetland volume, and mean annual spill volume for three different wetland management treatments for a 30-year simulation. The black line represents the wetland water volume for a depressional wetland with a completely agricultural 2.19 ha upland. The blue line represents the wetland water volume for a depressional wetland with a 0.15 ha grass filter strip and a 2.04 ha agricultural catchment above the filter strip. The purple line represents the wetland water volume for a depressional wetland with a completely grassland 2.19 ha upland.



can provide habitat for wildlife and potentially reduce the rate at which the restored wetland fills with sediments by as much as a millennium.

Supplemental Material

The supplementary table for this article is available in the online journal at https://doi.org/10.2489/jswc.2020.00096.

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