TYPE Mini Review
PUBLISHED 09 December 2024
DOI 10.3389/frwa.2024.1506255

OPEN ACCESS

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RECEIVED 04 October 2024
ACCEPTED 25 November 2024
PUBLISHED 09 December 2024

CITATION
Spor Leal LB, Roy T, Uden DR and Schoengold K (2024) Hydrological impacts of the conservation reserve program—a mini review.
Front. Water 6:1506255.
doi: 10.3389/frwa.2024.1506255

Hydrological impacts of the conservation reserve program—a mini review

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The Conservation Reserve Program (CRP) is a voluntary land conservation initiative implemented by the U.S. Department of Agriculture (USDA). The program aims to improve the natural environment and enhance wildlife by incentivizing landowners to convert sensitive agricultural land into vegetative cover. This mini review synthesizes known peer-reviewed research on the effects of CRP on hydrological processes, highlighting the effects on water quality, groundwater levels, surface water yields, surface water runoff, and effects on the hydrological cycle. These studies show that the CRP appears to have a positive impact on water quality, decreasing the levels of nitrogen and suspended solids. Furthermore, the CRP denotes positive results when used to manage excess runoff on surrounding land. Regarding groundwater volume, the impact of CRP varied by location and showed limited changes in volume. Despite these findings, this review highlights the need for further and continued research on the effects of CRP on hydrology to improve monitoring strategies and increase its benefits on the environment.

KEYWORDS
hydrology, water resources, conservation practices, agricultural management, conservation reserve program

1 Introduction

Agricultural land has continuously been analyzed to assess the effect of agrarian practices on the environment (Girardin et al., 2000; Gomiero et al., 2011; Canter, 1986). Through these various reviews, it has been noted that intensive agriculture negatively affects various areas of environmental concern, such as ecology and the hydrology (Chamberlain and Fuller, 2000; Pfister et al., 2011). As such, various efforts across the globe encourage environmental conservation in agricultural landscapes (Knowler and Bradshaw, 2007). In the United States, one of the largest conservation programs is the Conservation Reserve Program (Stubbs, 2014). The CRP aims to re-establish previous land cover and enhance the environment by providing financial incentives for farmers to retire portions of land and plant native species instead (U.S. Department of Agriculture, 2024a). Various reviews have noted that the CRP has been successful in increasing sustainability and providing economic benefits (Dunn et al., 1993; Hansen, 2016). Such environmental benefits include improved soil health (Kasmerchak et al., 2024) and air quality betterment (Becker et al., 2022) to name a few. Despite these desirable outcomes, the implementation of the CRP continues to be reviewed as enrollment in the program varies, leading to uncertainty regarding the future conditions of the land (Bigelow et al., 2020).

While the CRP's effects on the environment have generally been considered positive, the specific effects on hydrology require further research. For example, only a handful of ongoing studies listed on the Farm Service Agency (FSA) website specifically focus on water (U.S. Department of Agriculture, 2024b). The FSA highlights that monitoring assessment and evaluation reports often require years of observation to complete. Due to the limitations of time and scarcity of active hydrological assessments, it is imperative to acknowledge the existing work before addressing the work that should be required in the future. As such, this review summarizes the existing peer-reviewed hydrology literature focused on the CRP for the benefit of guiding future work. By analyzing the current literature, the full range of findings on the effects of CRP on surface and groundwater quality and quantity can be compiled and compared to identify commonalities, differences, and information gaps. Furthermore, previous methodologies and study sites can inform future methodologies and geographies for addressing information gaps in the future. While the impacts of conservation practices on hydrology have been reviewed recently (Srivastava et al., 2023), this article focuses on peer-reviewed hydrologic research articles that explicitly analyzed the CRP program or conservation efforts that operate in the same manner. The search terms utilized for this research were: "Conservation Reserve Program," "Hydrology," "Groundwater," "Surface Water," "Runoff," and "Water Resources." As such, the studies reviewed must focus on at least one hydrological characteristic as its main focus and must have been published in a peer-reviewed journal. The geographical scope of the work is intentionally limited to the United States due to the nature of the CRP, as it is intended to focus on work most similar to its conditions. All pieces of research discussed in this article were thoroughly scouted for scope of work, main objective and conclusions, temporal scale and extent, and data sourcing and evaluation as seen on the Supplementary Table 1. The findings of this review were organized into three categories, summarizing the available published information on the effects of CRP or similar approaches on (1) Water Quality, (2) Water Yield and Groundwater Levels, and (3) Hydrological Cycle and Water Runoff. These three categories were developed based on the main objectives of the articles reviewed, grouping similar hydrological topics for accessibility of research.

2 Water quality

Environmental improvement is a goal of the CRP, and water quality is one of the characteristics most often used to analyze the effectiveness of the program. In the most recent General Signup Period, water quality improvements were worth up to 100 points (over 25% of the maximum possible score) in the CRP Environmental Benefits Index (EBI; U.S. Department of Agriculture, 2024c). The EBI is the mechanism used to rank CRP applications and determine program acceptance. Improving water quality in the US is imperative since, as of 2017, over 600,000 miles of rivers and streams have been identified as impaired (U.S. Environmental Protection Agency, 2017). The EPA highlights that the top causes of pollution in rivers and streams are often pathogens, sediment, and nutrients such as phosphorus and nitrogen. Most existing studies use the concentration of these pollutants to determine the impact of the CRP, focusing on one at a time or a combination of the aforementioned. These studies have highlighted positive outcomes, finding a decrease in nitrogen and suspended solids following CRP enrollment. A long-term review utilizing remote sensing found that the downstream total nitrogen was lowered in the CRP-enrolled areas (Yin et al., 2021). Remote sensing allows for evaluations over larger (i.e., broader) geographic extents, which is less feasible with field data. To procure the most accurate data, site studies often focus on a specific area to monitor, often for limited annual durations. These investigations have all led to similar conclusions as that of the regional scale, denoting positive outcomes for water quality. A study in Walnut Creek, Iowa, found that nitrate levels decreased with the application of conservation practices and increased rapidly when converted back to row crops (Schilling and Spooner, 2006). In 2014, the analysis of a site in North Carolina found that the groundwater concentrations of nitrogen were reduced by 76 to 92% due to the buffers created under CRP (Wiseman et al., 2014). These outcomes are not limited to nitrogen concentrations. A study in Beasley Lake, Mississippi, had a similar conclusion after CRP enrollment, noting a decrease in sediment concentrations and improved water clarity (Locke et al., 2008). These studies focused on monitoring hydrological data directly, but that is not the only method used to analyze water quality. Marton et al. (2014) analyzed the soil properties of various restored riparian buffers to evaluate the potential for carbon sequestration and nutrient accumulation, as these ecosystem services led to numerous benefits, including water quality improvement. Other studies have used water quality to analyze economic benefits. Ribaudo (1989) used the daily concentrations of nitrogen, phosphorus, and suspended solids correlated water quality improvements to economic damages to water users, noting the potential for economic benefits through water quality improvement. Overall, it is noted that the CRP provides benefits to water quality. This conclusion, however, can be a bit limited due to the spatial and time scale of the research conducted.

3 Water yield and groundwater levels

Water volume is one of the aspects often reviewed when analyzing conservation impacts on hydrology, as the amount of water available for use (e.g., irrigation) on the participating land and surrounding areas could change. Land conservation efforts such as riparian buffers, which are encouraged by the CRP, have been linked to an increase in water yield (Zheng et al., 2016). This is an aspect often reviewed in the CRP analysis, as climate change continues to impact water availability (Malek et al., 2018). A GIS study utilizing data from 1960 to 2000 found that there was a positive relation between groundwater level and CRP enrollment across Texas County and Oklahoma (Rao and Yang, 2010). Similar results were found in a study across the High Plains aquifer, where it was noted that playas embedded in CRP have a greater capacity for water storage (Daniel et al., 2014). While site sampling supports the conclusion of increases in groundwater quantity with CRP enrollment, not all modeling work agrees. Riley et al. (2019) studied the portions of the High Plains Aquifer in Kansas and Nebraska, and found that after adjusting for irrigation withdrawals, CRP land cover would decrease recharge when compared to the corn and soybean crops across Nebraska. However, no difference in recharge was found in the Kansas region. This conclusion leads to questions regarding the impacts of row crop farming, particularly in areas with predominantly rainfed agriculture. These studies show that the impact of CRP on available water may be dependent on regional characteristics or on specific geographical features such as playas. However, further comparison to other management practices highlights the possibility of better results in different areas across the United States.

4 Hydrological cycle and water runoff

CRP enrollment may have differential effects on various parts of the hydrological cycle. Specifically, climate change has been noted to impact evapotranspiration, atmospheric water-vapor content, and precipitation (Huntington, 2010). Due to this, studies investigating CRP effects have often focused on evapotranspiration, infiltration rates, or surface runoff. Surface runoff has been studied with rainfall simulations in different sites. Two studies (Gilley et al., 1996; Gilley et al., 1997) focused on the comparison between CRP and different agricultural conditions under the same rainfall simulations. The first study found an increase in runoff when land was used for grazing or haying over the CRP conditions, while the later study noted an increase in runoff on sites that were returned to crop production after enrolment in CRP. Both studies also noted no significant change in erosion rates, ultimately favoring CRP for management of excess runoff. Rainfall data has not only been simulated but observed in natural conditions over certain periods of time. A study conducted in the Texas High Plains analyzed rainwater infiltration through various rainfall events (Goebel et al., 2016). This study noted a slight increase in the depth of rainwater infiltration in land managed under CRP when compared to cotton fields but noted limitations in the amount of rainfall observed for that year. As in the aforementioned studies, site comparisons are often used to demonstrate the impact of CRP when measured against standard crop conditions. This approach is also followed when attempting to analyze evapotranspiration rates. A study conducted across seven sites in the US Midwest Corn Belt compared CRP conditions against agricultural crop land and former CRP land (Abraha et al., 2020). This study identified various seasonal patterns while noting that the evapotranspiration rate of the standard CRP reference was constantly higher. The methodology of these studies all relied on study sites where in-field data could be sourced. In contrast, Jobe et al. (2018) focused on flooding in the Nodaway River Basin and utilized a modeling approach to simulate various conditions, ultimately concluding that the inclusion of CRP coverage could increase flood zone areas but decrease flow velocities during such events. The variety of studies that focused on the hydrology cycle and water runoff mostly noted small benefits with the inclusion of CRP, decreasing runoff impacts under flooding conditions, and little to no significant change in erosion and infiltration rates.

5 Discussion

As reviewed in the previous sections, most individual research appears to denote a beneficial finding regarding water resources in the presence of the CRP. Water Quality studies highlight a decrease in the amount of nitrate, phosphorus, and sediments. However, by focusing on these elements, the research creates a gap in knowledge when it comes to focusing on other aspects of water quality. Hardness, alkalinity, and pH are other key water quality indexes that are often considered when analyzing water quality (Li et al., 2023). As such, the analysis of whether the CRP impacts these indexes should be considered. Furthermore, regarding the water yield and groundwater levels, most studies focus on the impacts on groundwater or specific geographic features such as playas. The effects of CRP could lead to potential changes to water levels of streams and rivers, especially when conservation efforts are located near surface water. Groundwater recharge appears to show little to no improvement when compared to other agricultural conservation practices outside of CRP across the Midwest area of the US. This result denotes a counterintuitive response to the CRP when compared to the increased runoff and infiltration rates of other studies. This could be attributed to the geographical differences of each study site and highlight the need for greater spatial scale studies, as these could help compare the impact of the changes in climate and geography when analyzing the same hydrological feature. Literature shows numerous benefits of CRP on hydrology, but the number of research studies on this topic, in general, is limited. Therefore, there is a need for comprehensive assessments on different dimensions of hydrological impacts within the context of CRP.

In order to address the current gaps of knowledge in the hydrology field and conservation practices, certain pathways could be taken to continue improving our knowledge. Regardless of the objective of the research, most methodologies reviewed followed a similar approach of onsite testing and observations over extended periods of time. Current research development has led to the increased availability of data and refined modeling procedures. Various government sources provide hydrological data that is up to date across the United States, such as the USGS Water Data for the Nation (U.S. Geological Survey, 2024). Similarly, hydrological modeling software continues to develop increasingly refined modeling tools to simulate hydrological characteristics. These tools allow for greater-scale applications, unlike the limitations of *in-situ* sampling. Implementing updated technology could help push research into more efficient methodologies, leading to faster assessments regarding the hydrological field and conservation practices. It should be noted, however, that data regarding the CRP is currently limited, and the FSA notes a constant decrease in enrolled acres in the last decade (U.S. Department of Agriculture, 2022). This decrease is accredited to a variety of reasons, such as a reduction in the maximum CRP enrollment under the US Farm Bill and the permitted termination of CRP contracts to address crop supply decreases. Furthermore, economic issues, such as insurance coverage, further affect the enrollment and cooperation of various farmers (Graven et al., 2021). These economic issues could continue to decrease the participation of various entities, leading to the need for further involvement from the government to help address them. Furthermore, the agencies involved should invest in rigorous assessment to identify these possible economic issues as they occur. Increased usage of technology could help improve the efficiency of hydrological assessments while addressing current gaps of knowledge, but there is a growing issue regarding the economic feasibility and security of the CRP enrollment that could jeopardize the program's future. The proposed pathways for improvement, coupled with the subjects of discussion in this section, are summarized in Figure 1.

6 Conclusion

The implementation of the CRP and its effects on hydrology are continually being studied, but the existing studies show a need for further research. The study sites reviewed showed positive improvement in water quality, yield, infiltration rates, and flooding

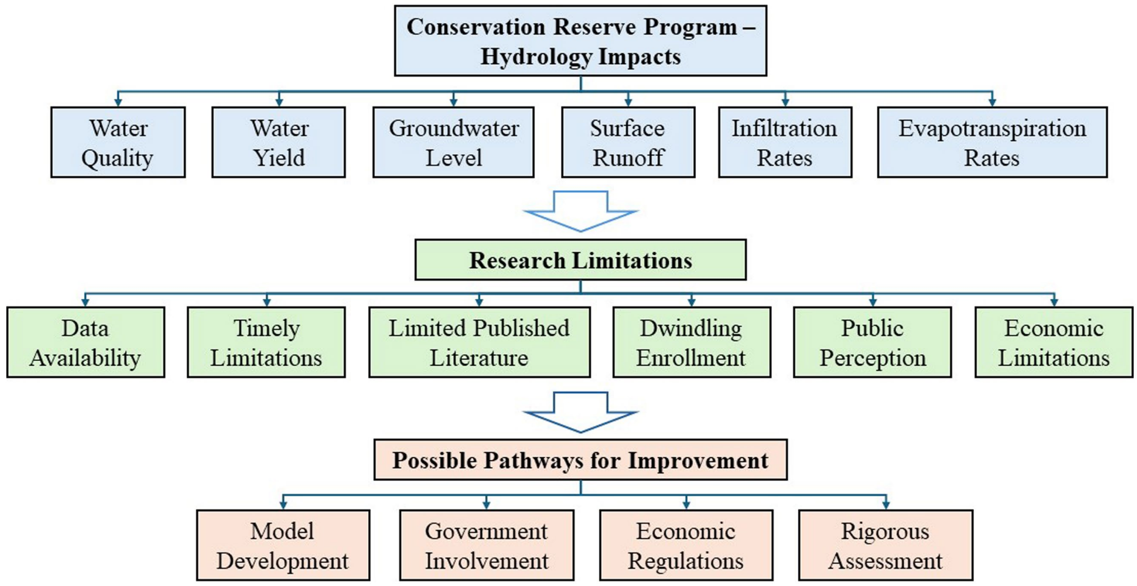

FIGURE 1
Diagram summary of the hydrological impacts, noted issues, and possible pathways for improvement for the CRP.

management but little to no improvement in groundwater recharge across the Midwest. These contradictory results highlight a large uncertainty due to the lack of studies conducted. Furthermore, the studies selected for this review only accounted for those specifically mentioning the CRP despite the existence of other conservation programs that could be similar. This was done to ensure that the conservation practices analyzed would not lead to outlying results that could not apply to the specific characteristics of the CRP. Considering the aforementioned limitations, the following aspects were highlighted:

- Water quality improves with the inclusion of CRP, as seen by the decrease in nitrogen and suspended solids in the US.
- Groundwater volume can increase or have minimal changes depending on the location of the CRP.
- CRP can be used to manage excess runoff since it can help decrease flow velocities while maintaining erosion rates.
- Comparative studies show negative impacts on the hydrological cycle when CRP is reversed and returned to agricultural use.
- Limitations with data availability hinder the extent of research that can be done when studying the CRP.

Author contributions

LS: Conceptualization, Investigation, Visualization, Writing – original draft, Writing – review & editing. TR: Conceptualization, Supervision, Writing – review & editing. DU: Writing – review & editing. KS: Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. Funding for this study came from the USDA FSA project titled “Hydrological Outcomes of the Conservation Reserve Program in Water-stressed High Plains Watersheds.” Award Number: #FSA23CPT0013586.

Conflict of interest

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frwa.2024.1506255/full#supplementary-material

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