ASSESSING THE FLOOD REDUCTION BENEFITS OF RELAY INTERCROPPING PRACTICES IN IOWA

Final Report
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Principal Investigator
Antonio Arenas
aarenas@iastate.edu
Assistant Professor
Civil, Construction and Environmental Engineering
Iowa State University

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TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGMENTS

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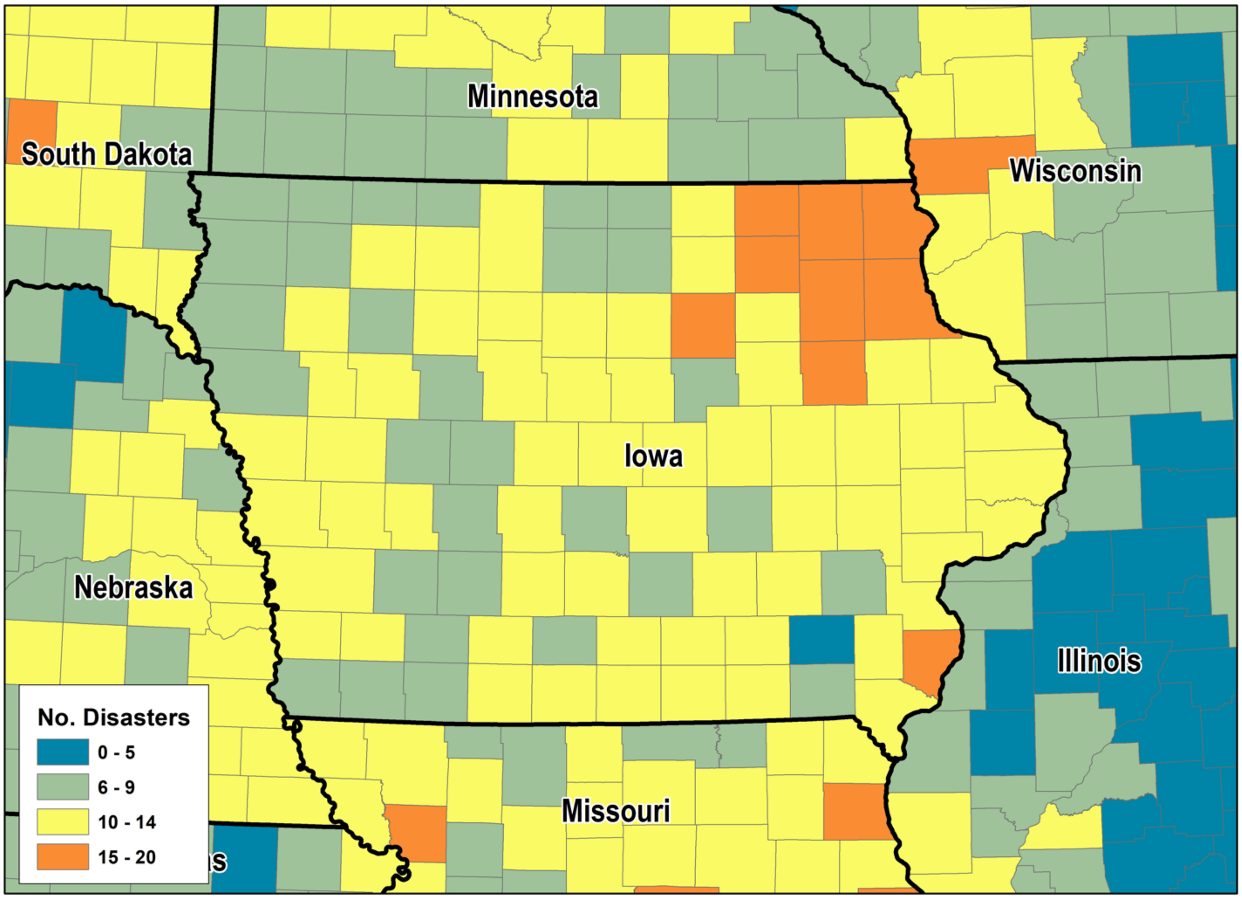
EXECUTIVE SUMMARY

In this project, we explored the potential of relay intercropping as a flood mitigation strategy. The analysis integrated soil moisture time series from relay intercropping fields, satellite-based evapotranspiration estimates, a literature review, hydrologic modeling, existing urban flood maps, and information on building locations. The study focused on the Cedar River Watershed upstream of Cedar Rapids, Iowa, covering the period between 2003 and 2018. This period includes the two largest peak flows recorded at Cedar Rapids in 2008 and 2016.

In-situ and remotely sensed data on relay intercropping were used to adjust the parameters of the existing GHOST model, as presented in Politano et al. (2023). These modifications considered a 30% increase in infiltration and reference evapotranspiration to reflect the benefits of implementing relay intercropping. Model simulations quantified reductions in annual peak flows, showing decreases ranging from 6% to 30%. The USA Structures dataset was used to estimate the number of structures that would have remained flood-free during the major floods of 2008 and 2016. Analyses indicate that approximately 500 structures in Cedar Rapids would have been protected if relay intercropping had been adopted in the Cedar River Watershed.

1. INTRODUCTION AND OBJECTIVES

Flooding represents one of the most significant challenges in Iowa. According to records from the Federal Emergency Management Agency (FEMA), approximately 80% of the roughly 1,300 federally declared disasters in Iowa counties between 1989 and 2022 were related to flooding (Figure 1).



Raw data from https://www.fema.gov/

Figure 1. Flood-related disaster declarations in Iowa counties (1989–2022)

According to the SHELDUS database (1988–2015), estimated losses in Iowa amount to $13.5 billion in direct property damages and $4.1 billion in direct crop losses. In 2019, the National Oceanic and Atmospheric Administration (NOAA) estimated that extreme weather events resulted in approximately $1.9 billion in losses in Iowa, primarily driven by flooding. More recently, in the summer of 2024, several communities in Northwest Iowa faced catastrophic flooding, which triggered disaster declarations as flood levels surpassed those of the Great Flood of 1993. Some estimates indicate that over 2,000 properties were affected by the rising waters.

The U.S. is one of the largest producers of corn and soybeans globally, with these crops primarily grown in the Midwest, and Iowa being a leading producer (McLellan et al., 2015). Iowa's agricultural success is largely due to the conversion of wet prairies into arable land, and the use of agricultural tile drainage and synthetic fertilizers (Kanwar et al., 1983; Swenson and Eathington 2013; Smith et al., 2015). Each year, about two-thirds of Iowa's land is planted with corn and soybeans, typically from late April (or mid-May) to late September (or mid-October). If no other crops, such as cover crops, are planted, Iowa's agricultural fields remain bare from October through early May.

There is ample scientific evidence that adding small grains to standard corn or soybean rotations has the potential to have a variety of agronomic and environmental benefits (Weisberger et al., 2021; Qi and Helmers, 2010). Cover crops grown in the off-season are one of the most widely documented approaches to adding small grains into corn or soybean production systems. Furthermore, several state and federal programs provide different cost-share levels to incentivize the implementation of cover crops. Despite all this, cover crops adoption remains low, with research pointing to structural changes needed (e.g., availability of markets) to boost cover crops implementation (Weisberger et al., 2021).

Relay-intercropping offers an alternative to cover crops grown in the off-season for adding small grains to corn or soybean rotations. Relay-intercropping is like a conservation crop rotation, where a fibrous-rooted, high-residue crop is grown in conjunction with a low residue crop such as soybeans. The difference between relay-intercropping and conservation crop rotation is that with relay-intercropping the farmer grows and harvests multiple crops in the same year from the same field (Figure 2). Relay-intercropping is not widely established in Iowa, but the practice is quickly gaining approval and adoption by farmers looking to diversify their production and enhance soil health. Initial relay-intercropping trials completed through Multi-Cropping Iowa (https://www.facebook.com/MultiIowa/) show that relay-intercropping has the potential to enhance production opportunities. In addition, soil testing showed that relay-intercropping is effective as a regenerative practice that helps build soil structure and improve soil health. Some of the trials resulted in a yield drag for both the cereal grain and soybean compared to monocrop systems. However, the land-use equivalency for productivity was similar to or greater than the monocrop system. Research on the flood-reduction benefits of relay intercropping has been limited and this report aims to fill that knowledge gap.


Figure 2. Rye-soybean relay cropping system

This study integrated in-situ measurements of volumetric water content in fields with relay intercropping, a literature review, analyses of satellite-based evapotranspiration patterns, and hydrologic modeling to explore the potential of relay intercropping as a flood mitigation strategy.

The specific objectives of this project were as follows:

1. Conduct a literature review and analyze time series data on volumetric water content to estimate the anticipated changes in infiltration rates resulting from relay intercropping.
2. Utilize satellite-based estimates of evapotranspiration to assess the increased water consumption of relay intercropping systems compared to conventional corn and soybean rotations.
3. Evaluate the watershed-scale flood reduction benefits of relay intercropping practices. The research team used the Generic Hydrologic Overland-Subsurface Toolkit (GHOST), as outlined in Politano et al. (2023), focusing on the Cedar River Watershed in Iowa. This watershed has a history of significant flooding events in recent years.

2. FIELD AND GEOSPATIAL DATA

2.1. Monitored Sites

Since 2021, the American Flood Coalition, in partnership with Northeast Iowa RC&D and the Iowa Flood Center, has been monitoring fields using relay intercropping practices in Iowa. The first monitoring site was established at FLOLO Farms in Northeast Iowa, where two hydrostations were installed to measure rainfall, soil volumetric water content, and soil temperature. A second monitoring site was established in 2023 near Guthrie Center, approximately 60 miles west of Des Moines. Figure 3 displays the locations of the two monitoring sites, along with other commercial and research farms in Iowa where relay intercropping is currently being practiced.

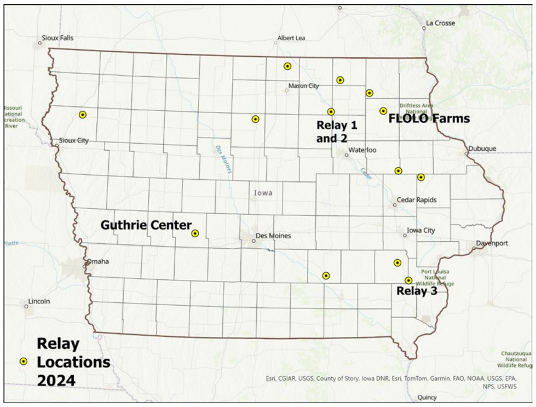


Figure 3. Relay intercropping sites in Iowa.

The volumetric water content time series show patterns that suggest that relay intercropping can be beneficial for reducing flood impacts. Fields with relay cropping typically show lower surficial water content than conventional corn-soybean fields (Figure 4). This is likely due to increased crop water consumption when two crops are grown simultaneously. This reduction in water content also promotes greater water infiltration into the soil, which helps mitigate the impact of heavy precipitation events. However, a potential drawback of relay intercropping systems could emerge during dry conditions, as two crops such as winter wheat/rye and soybean may compete for limited soil moisture.

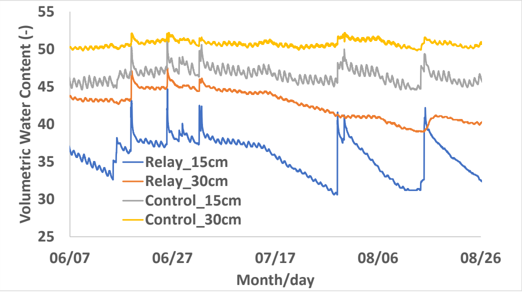


Figure 4. Volumetric water content measured in 2024 at the Guthrie Center site.

2.2. Infiltration

Agricultural practices that leave soils without vegetative cover reduce their capacity to infiltrate water, leading to excessive runoff from fields. Basche and DeLonge (2019) conducted a meta-analysis of 89 studies to evaluate the effects of alternative practices such as no-till, cover crops, crop rotation, and the introduction of perennials on infiltration. Relay intercropping was categorized under crop rotation, as described in the article: “we included two experiments where an additional crop was grown not in rotation but as an intercrop (i.e., two plant species grown simultaneously on the same field).” Basche and DeLonge (2019) reported inconsistent infiltration increases associated with crop rotation. However, they found an average infiltration rate increase of about 20%, with a maximum increase close to 50%, based on 39 studies.

2.3. Relay Intercropping in Iowa and Evapotranspiration Patterns

Precipitation is the most important component of the terrestrial hydrologic cycle, and it is relatively easy to measure and simple for the layperson to grasp, as it is a process we all have observed firsthand. In basic terms, precipitation involves water, in various forms, moving from the atmosphere to the earth. The reverse process, where water moves from the earth to the atmosphere, is called evapotranspiration (ET). ET is typically the second largest component of the hydrologic cycle and plays a crucial role in water resource management. Evapotranspiration includes both the evaporation of water from soil and water bodies, and transpiration, which occurs through plant leaves.

Until recently, ET was commonly estimated using lysimeters, weather stations, or water balance methods. However, in recent years, satellite-based estimates of ET have become an important tool as well (Volk et al., 2024). In this project, we utilized satellite-based estimates from the OpenET project (https://etdata.org/) to assess the increases in ET when switching from conventional corn and soybean rotations to relay cropping practices.

Our analysis focused on fields located at Iowa State University research farms, where rye was planted in mid-October (2023), soybean was planted in mid-May (2024), and rye was harvested in mid-July (2024). The location of these fields is shown in Figure 3, and the ET estimates are displayed in Figure 5. In Figure 5, periods where the blue line (relay intercropping) rises above the black line (control) indicate times when relay intercropping is consuming more water, effectively "making more room" in the soil to absorb heavy rains and thus reducing runoff. Between January 1st and June 30th, evapotranspiration in relay intercropping fields was, on average, 34% higher, representing an additional water consumption of 2.8 inches.

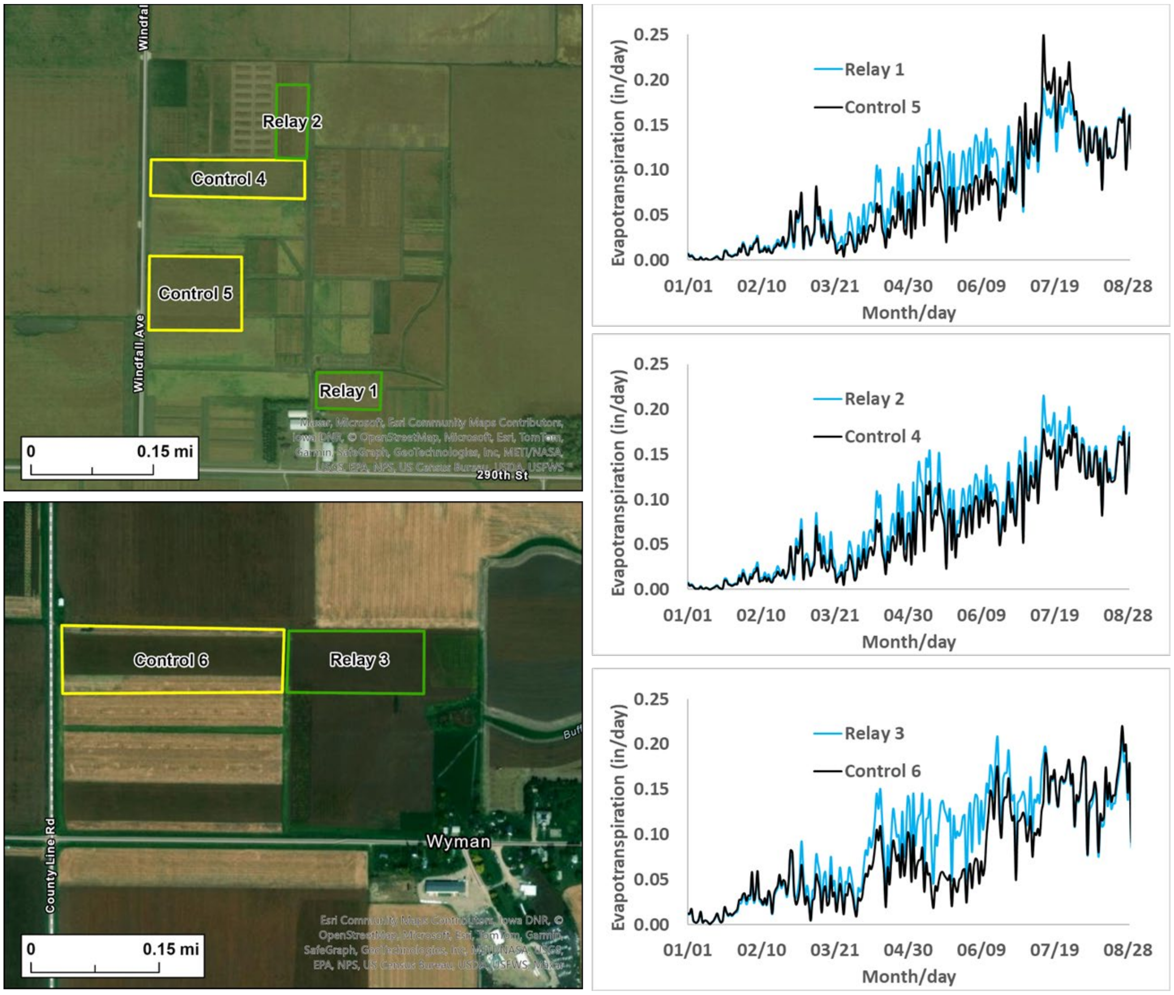


Figure 5. Daily evapotranspiration patterns in 2024. The location of the fields is shown in Figure 3.

3. HYDROLOGIC MODELING

The modeling component of this project builds upon the work presented in Politano et al. (2023), with some figures and text adapted from that journal article. For further details on the GHOST model formulation, computational mesh, and calibration and validation processes, the reader is referred to that article.

3.1. The Cedar River Watershed

The Cedar River Watershed (CRW) in Iowa spans an area of 17,500 km² and comprises five HUC8 watersheds. Over the past thirty years, the CRW has experienced significant flooding events in 1993, 2008, and 2016. The predominant soil textures in the CRW are loam (39%) and silty clay loam (36%). The watershed stretches from Minnesota, where the elevation reaches 440 meters above sea level, down to Cedar Rapids in southeastern Iowa, which sits at 245 meters above sea level. Approximately three-quarters of the watershed is dedicated to the cultivation of corn and soybeans.

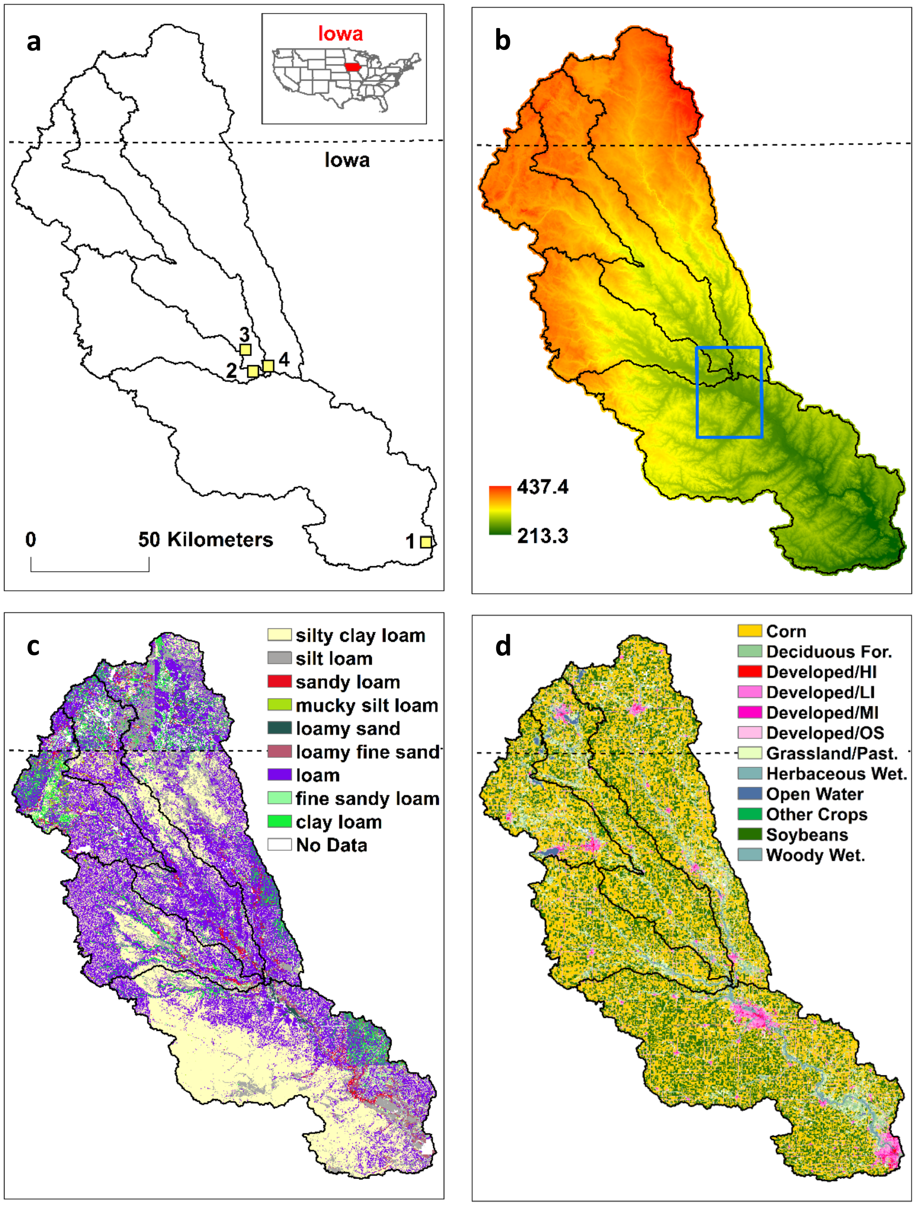


Figure 6. Cedar River Watershed, Iowa. a) Watershed location and streamflow monitoring stations: 1) Cedar River at Cedar Rapids, 2) West Fork Cedar River at Finchford, 3) Shell Rock River at Shell Rock, and 4) Cedar River at Janesville. b) Elevation data in meters above sea level. c) Soil texture, and d) Land use. Taken from Politano et al. (2023).

3.2. The Flood of 2008

In June 2008, many USGS stream gages in the CRW recorded flow rates near or even exceeding the 500-year flood event. On June 13, the river in Cedar Rapids peaked at 140,000 cubic feet per second. The flooding was driven by a series of heavy storms that started in late May. A significant storm impacted the upper CRW on June 8, followed by another major storm in the lower CRW on June 12. The timing and location of these storms caused runoff from the upper CRW to converge with additional runoff from the lower CRW, leading to historic flood conditions at Cedar Rapids on June 13. Figure 7 illustrates the accumulated precipitation in the CRW from May 30 to June 13, with maximum recorded values nearing 300 mm (approximately 12 inches). The City of Cedar Rapids' official website provides several key facts about the 2008 flood. Below is a selection of information drawn from their site:

- More than ten square miles (14%) of the City impacted by floodwaters.
- 10,000 estimated residents were displaced by flood.
- 1,300 estimated flood-damaged properties will be demolished.
- FEMA disaster declaration based on estimated financial public assistance. Floods & Tornadoes, IA, $848 million.

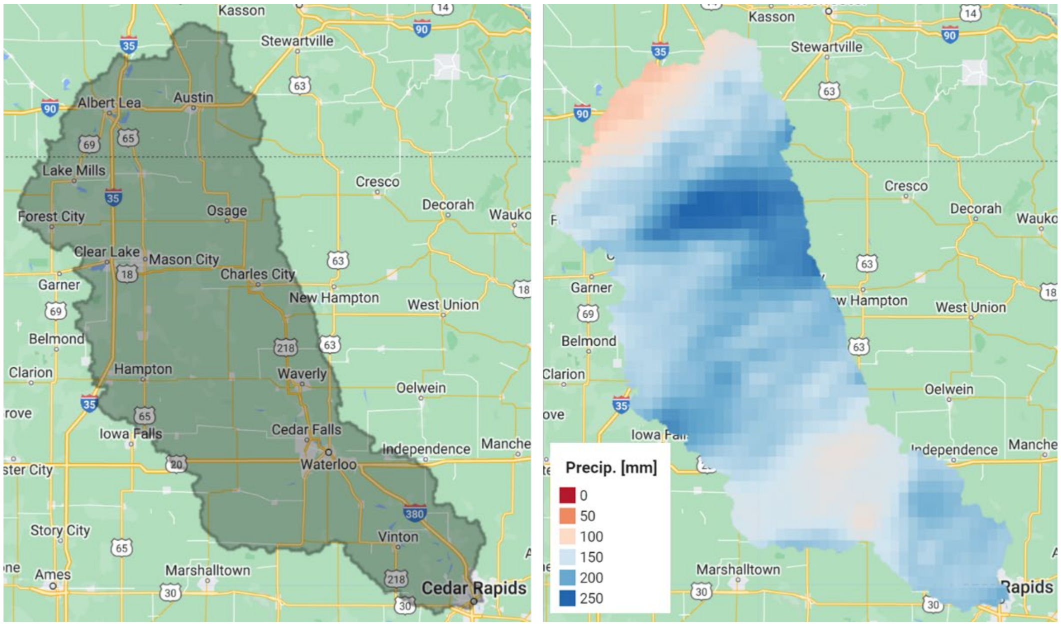


Figure 7. Accumulated precipitation in the CRW in 2008. May 30-June 13.

3.3. The Flood of 2016

In the last two weeks of September 2016, heavy rainfall, along with riverine and flash flooding, affected several watersheds in eastern Iowa. On September 27, the Cedar River in Cedar Rapids peaked at 81,600 cfs, nearing the 100-year flood event. This was the second-highest flow recorded at that location since the early 1900s, exceeded only by the 2008 flood. Figure 8 illustrates the accumulated precipitation in the CRW from September 13 to September 27, with maximum values approaching 320 mm (approximately 13 inches). Unlike the 2008 event, which was driven by widespread heavy rainfall across the CRW, the 2016 flood was caused by a more localized concentration of intense precipitation that primarily affected the central part of the watershed. FEMA records indicate that Iowa was granted a Major Disaster Declaration due to severe storms and flooding occurring from September 21 to October 3, 2016. Eighteen counties in Iowa qualified for Public Assistance, resulting in funding obligations of approximately $17 million.

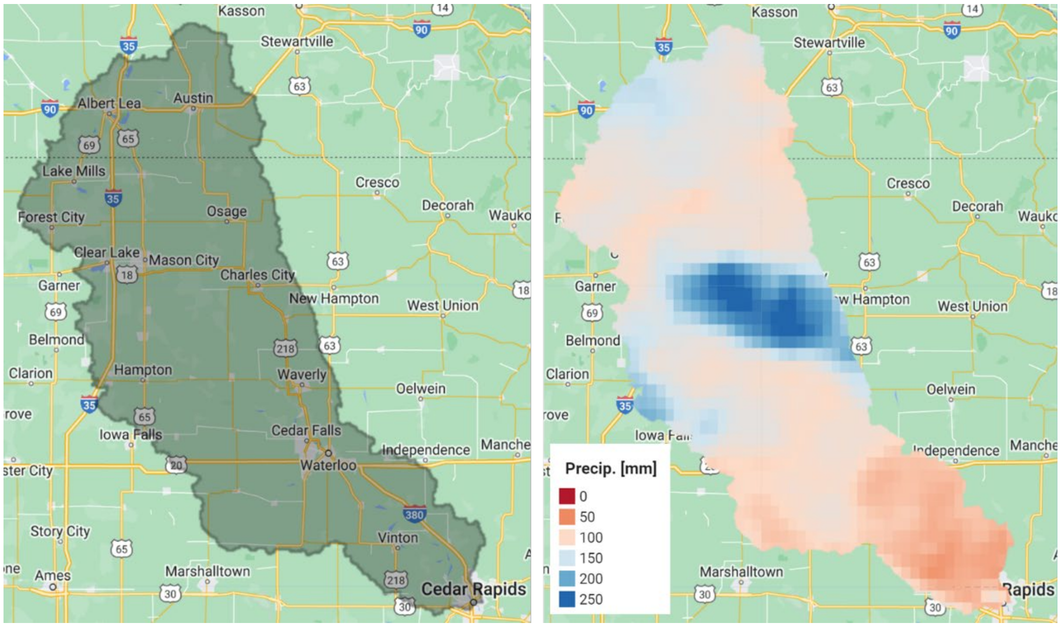


Figure 8. Accumulated precipitation in the CRW in 2016. Sep 13-Sep 27.

3.4. The GHOST Model

GHOST is a rainfall runoff model that has been thoroughly validated across various watersheds in Iowa. It supports both event-based and multi-year simulations for small catchments and large basins, utilizing finite volume techniques. The model simulates surface flows through a 2D diffusive wave approximation of the Saint Venant equations, while water depth in canals and streams is calculated using a 1D approach. GHOST also models unsaturated zone dynamics under the assumption of vertical dominant flow, with groundwater flow governed by Darcy's law. It incorporates processes such as infiltration, exfiltration, recharge, and lateral mass exchanges between surface and groundwater in its flux calculations (Politano et al., 2023). Figure 9 illustrates the key hydrologic processes included in the GHOST model.

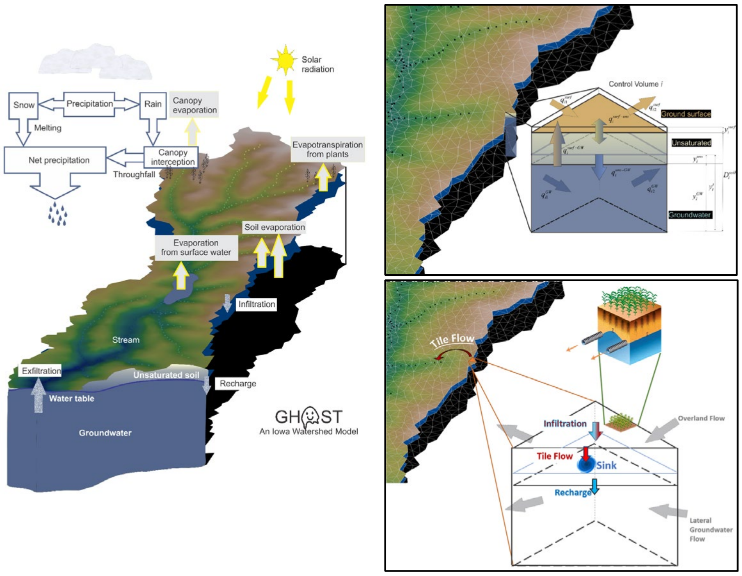


Figure 9. Hydrologic processes, domains, and fluxes modeled in GHOST. Taken from Politano et al. (2023).

Politano et al. (2023) discusses the application of the GHOST model to the CRW. The model successfully simulated the 2003-2018 window, showing excellent agreement between the numerical results and observations collected at four different USGS stream gage stations. Figure 10 presents the annual peaks (predicted and observed) for the four gaging stations displayed in Figure 6, panel a.

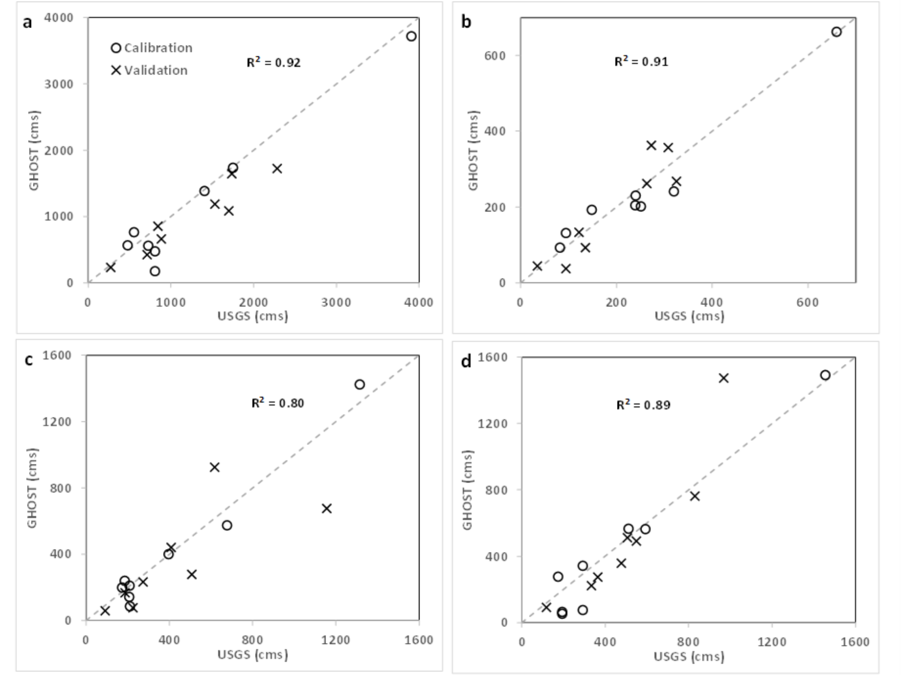


Figure 10. Streamflow annual peaks (2003-2018). a) Cedar River at Cedar Rapids, b) West Fork Cedar River at Finchford, c) Shell Rock River at Shell Rock, and d) Cedar River at Janesville. Taken from Politano et al. (2023).

3.5. Mitigating the Effects of High Runoff with Relay Intercropping in the Cedar River Basin

We combined in-situ data from relay intercropping fields with findings from a literature review and satellite-based estimates of evapotranspiration to modify the GHOST model parameters presented by Politano et al. (2023). This adjustment aimed to simulate the effects of adopting relay intercropping practices across all acres currently dedicated to row crop agriculture. Specifically, we increased two parameters: the soil infiltration rate and the reference evapotranspiration, following the results outlined in Section 2. The infiltration rate was raised by 30%, and the reference evapotranspiration was also increased by 30%, but only during the period from October of one year to June of the next. No other parameters were changed, enabling us to compare the baseline conditions (flows reported by Politano et al. (2023)) with the modified simulation to assess the potential flood-reduction benefits of widespread relay intercropping in the CRW.

3.5.1. Changes in peak flow values for different return periods

In the simulated period from 2003 to 2018, the model results indicate significant variability in peak flow reductions for flood levels below the 50-year flood, with reductions of up to 30% linked to the adoption of relay intercropping. This variability is affected by factors such as snowmelt's contribution to flooding and the temporal and spatial distribution of precipitation. Figure 11 illustrates the expected peak flow reductions resulting from the adoption of relay intercropping practices in the CRW. The estimated peak flow reductions for the floods of 2008 and 2016 are 6.5% and 7.1%, respectively.

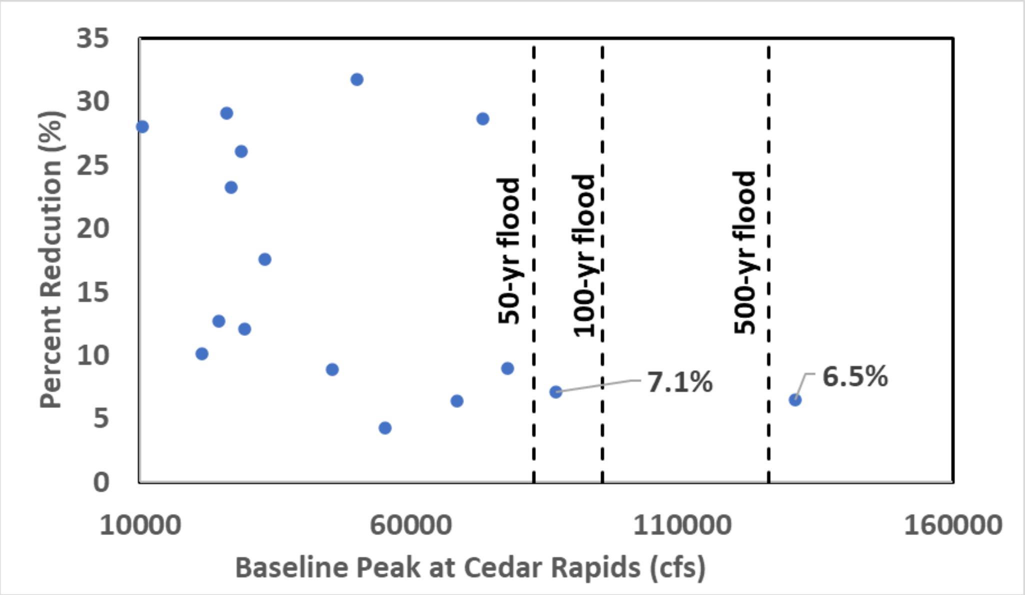


Figure 11. Simulated peak flow reductions at Cedar Rapids due to the adoption of relay intercropping practices in the CRW from 2003 to 2018.

3.5.2. Flood mapping

The Iowa Flood Center (IFC) has developed a library of urban inundation maps for various communities in Iowa using high-resolution hydraulic models. These simulations are based on river stage increments of 0.5 feet at the nearest USGS gage. The hydraulic models incorporate data from several sources, including high-resolution LiDAR, land use information, river stage-to-discharge relationships at stream gage locations, and the locations of levees, weirs, and bridges provided by municipalities and federal agencies, as well as data collected by the IFC and bathymetric mapping. Details on the map creation process can be found in Gilles et al. (2012). Additionally, these maps can be visualized on the Iowa Flood Information System (IFIS) at https://ifis.iowafloodcenter.org/ifis/en/app/. This report utilized the IFC maps and flows estimated with the GHOST model to assess changes in inundation extent at Cedar Rapids expected from the adoption of relay intercropping in the Cedar River Watershed.

3.5.3. Changes to the 2008 and 2016 flood impacts

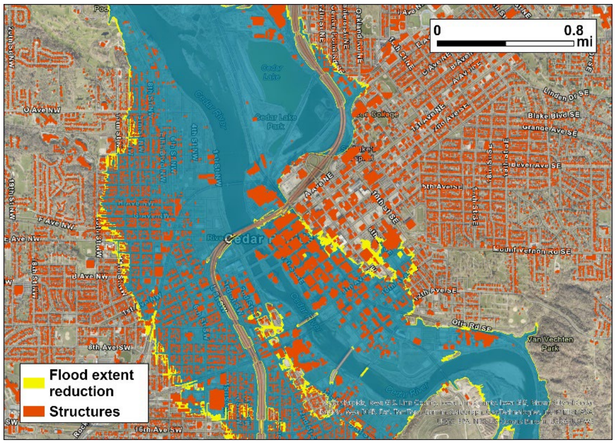


Figure 12. Reduction in inundation extent in 2008.

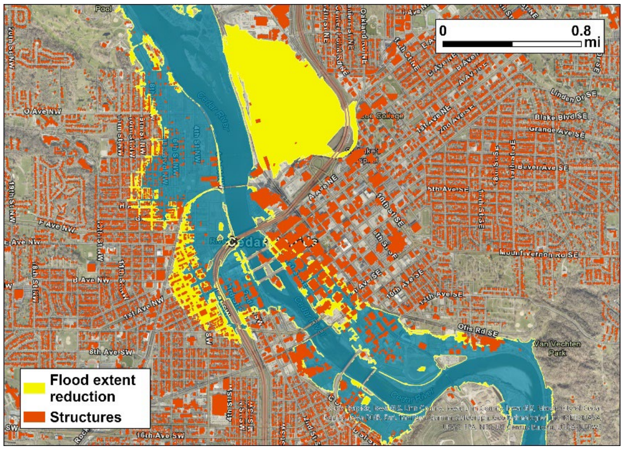


Figure 13. Reduction in inundation extent in 2016.

To expand the analysis beyond the peak flow reductions shown in Figure 11, we integrated the IFC's inundation maps with flow predictions from the GHOST model. Additionally, we utilized the USA Structures dataset to estimate how many structures would have remained flood-free if relay intercropping had been implemented in the CRW. The USA Structures dataset, developed through a collaboration between DHS, FIMA, FEMA's Response Geospatial Office, Oak Ridge National Laboratory, and the U.S. Geological Survey, provides a nationwide inventory of structures larger than 450 square feet.

The yellow areas in Figures 12 and 13 highlight the regions in Cedar Rapids that would have remained flood-free if relay intercropping had been implemented in the CRW during the 2008 and 2016 floods, respectively. The yellow area in Figure 12 covers 0.16 square miles, while in Figure 13, it spans 0.62 square miles. Relay intercropping would have reduced the inundated areas by 4% in 2008 and by 26% in 2016.

In contrast, more structures would have been protected by relay intercropping during the 2008 flood than in the 2016 flood. The yellow polygons in Figure 12 (2008) intersect with 550 structures, whereas the yellow polygons in Figure 13 (2016) intersect with 489 structures.

4. LAND AREA IN IOWA SUITABLE FOR IMPLEMENTING RELAY INTERCROPPING

To comprehensively assess the number of acres in Iowa suitable for adopting relay intercropping practices, several factors need to be considered. These include agronomic best practices (e.g., cereal rye varieties, seeding dates and rates, etc.), commodity prices and farm profitability, farmers' attitudes towards RI, and weather and climatic analyses, among others. Such a comprehensive assessment is beyond the scope of this report.

Given the potential challenges of relay intercropping systems in dry conditions, we examined precipitation and drought data to identify areas in Iowa that are becoming drier. This analysis helps identify regions where relay intercropping might compete with cash crops for relatively limited moisture. While installing irrigation systems can mitigate this moisture competition, irrigation remains an uncommon practice in the state.

The precipitation trends were analyzed using daily values from the PRISM dataset, aggregated annually for a 40-year time window (1984–2023). Annual precipitation totals were calculated by summing daily values for each year, resulting in a time series dataset. Linear regression was then applied to compute annual precipitation trend slopes over the 40 years. The drought analysis was based on the U.S. Drought Monitor dataset. For this analysis, data were analyzed over a 20-year time window (2004–2023) by calculating the annual means. The average drought conditions for the entire 20-year period ranges from 0.3 to 1, indicating varying levels of drought severity across the state.

Dry zones were identified by combining precipitation and drought analyses. Specifically, areas with negative precipitation trends and average drought categories above a threshold value of 0.7 were selected. To calculate the number of rowcrop acres cultivated in the dry areas, we used the 2023 Cropland Data Layer. Figure 14 presents the results of the precipitation and drought data analyses.

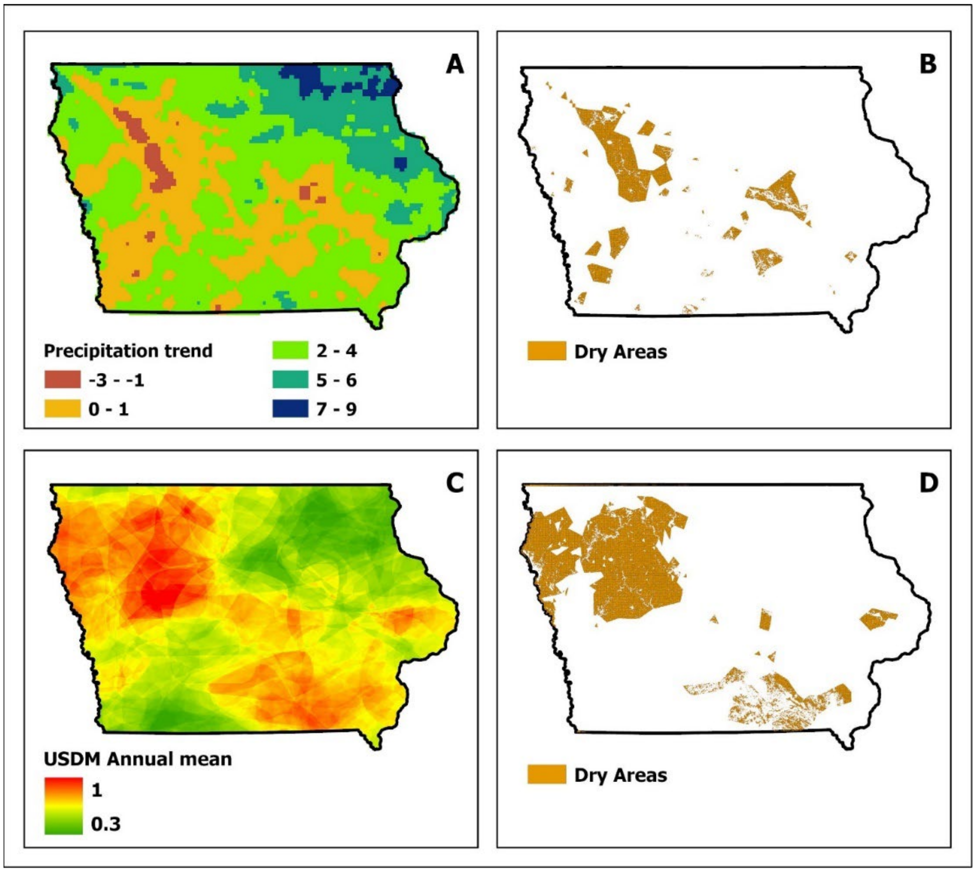


Figure 14. A. Annual precipitation trends (1984–2023). B. Rowcrop acres in areas with negative precipitation trends. C. Average drought category (2004–2023). D. Rowcrop acres in areas with average USDM above 0.7.

In Iowa, about 65% of the state is dedicated to growing corn and soybeans, covering approximately 35,296.8 square miles. This area remains relatively consistent year to year. Within this cultivated area, dry regions identified in Figure 6, panel B span 3,906.9 square miles (11%), while those in panel D cover 8,565.8 square miles (24%). Currently, corn and soybeans are grown on roughly 26,731 square miles (17.1 million acres) where precipitation trends are stable or increasing, and droughts occur relatively infrequently. These areas present promising opportunities for adopting relay intercropping under rainfed conditions without requiring irrigation. However, additional factors must be considered to fully assess the suitability of Iowa's cropland for relay intercropping.

5. CONCLUSIONS AND FUTURE WORK

The primary aim of this research was to investigate the flood-reduction benefits of relay intercropping in Iowa. The project integrated in-situ and remotely sensed data with hydrologic modeling, along with existing datasets on inundation extent and structure locations in the Cedar River Watershed. Peak flow reductions in the study area ranged from 6% to 30%. Detailed inundation maps for the 2008 and 2016 floods revealed that relay intercropping could have prevented flooding in at least 0.16 square miles of downtown Cedar Rapids and protected approximately 500 structures from being flooded.

Several additional analyses can build upon the findings and products of this research, including:

- **Longer Datasets for Stronger Conclusions.** The conclusions of this research would be more robust with longer datasets. Several fields in Iowa are currently implementing relay intercropping, and continued monitoring of these fields is recommended to gather long-term data.

- **Testing Relay Intercropping under Extreme Weather Scenarios.** The hydrologic modeling focused on the period between 2003 and 2018, which includes two historic flood events in the study area. However, we recommend testing relay intercropping as a flood mitigation strategy under various synthetic or downscaled extreme weather events. Stochastic storm transposition can be used to generate hypothetical but plausible storms for more comprehensive simulations. Additionally, downscaled climate forcing data can explore how relay intercropping performs under projected climate conditions.

- **Assessing Flood Mitigation for Upstream Communities.** This research focused on the flood-reduction benefits for Cedar Rapids, but many upstream communities and farm fields would likely also experience flood mitigation under the simulated scenarios. Studying these areas would provide a more complete picture of relay intercropping as a flood mitigation strategy.

- **Economic Analyses and Cost-Benefit Studies.** Once the flood-reduction benefits of relay intercropping are quantified, conducting loss-avoidance or benefit-cost analyses becomes essential. These analyses would provide valuable data for policymakers and decision-makers, enabling them to make informed decisions about the adoption of relay intercropping and its potential to enhance flood resilience.

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