Rainfall-Driven Modeling of Irrigation Supply for Rangeland and Agricultural Systems

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Abstract

Water availability is a primary limiting factor for agricultural production and rangeland sustainability in the semi-arid southwestern United States. In northeastern New Mexico, irrigation water stored in Conchas Lake and supplied by the Canadian River watershed is essential to producers within the Arch Hurley Conservancy District. Highly variable precipitation patterns introduce significant uncertainty for farmers and ranchers when planning crop acreage, grazing intensity, and irrigation schedules. This project develops a predictive hydrologic model that uses historical precipitation data to estimate future rainfall patterns and associated irrigation water availability. By linking long term precipitation trends to reservoir inflows, the model generates seasonal estimates of irrigation supply expressed in inches of available water. Results indicate that rainfall driven predictive modeling can improve irrigation planning, enhance drought preparedness, and support sustainable agricultural and rangeland management.

1. Introduction

Water resources are a critical determinant of long-term sustainability for agriculture, rangelands, and rural communities in the American Southwest. New Mexico's semi-arid climate, high evapotranspiration rates, and frequent drought cycles place considerable stress on surface water supplies. Agricultural producers are often required to make key management decisions months in advance of the growing season, frequently without reliable estimates of future irrigation water availability.

The Canadian River watershed plays a central role in supplying surface water to northeastern New Mexico. Precipitation within the watershed contributes to inflows into Conchas Lake, the primary reservoir serving the Arch Hurley Conservancy District. Because annual and seasonal precipitation vary widely, predicting irrigation allocations remains a persistent challenge.

Purpose of this project
The objective of this study is to develop a predictive hydrologic model that uses historical precipitation data to estimate future irrigation water availability, thereby supporting improved decision-making for farmers, ranchers, and rangeland managers.

2. Background and Study Area

2.1 The Canadian River Watershed

The Canadian River watershed extends across northeastern New Mexico and into portions of Texas and Oklahoma. Land use within the watershed is dominated by native grasslands, rangelands, and irrigated cropland. Precipitation occurs primarily during late spring and summer, often in the form of high-intensity monsoon storms. Both total rainfall amounts and storm timing exhibit substantial variability.

Precipitation within the watershed contributes to surface runoff and streamflow that ultimately supplies Conchas Lake, making rainfall patterns a key driver of irrigation water availability.

2.2 Conchas Lake and Irrigation Supply

Conchas Lake serves as the primary storage reservoir for irrigation water used by the Arch Hurley Conservancy District. Water released from the reservoir during the growing season supports crops such as alfalfa, corn, wheat, and sorghum. Annual irrigation allocations depend on several interacting factors, including:

- Total precipitation within the watershed
- Timing and intensity of rainfall events
- Reservoir storage levels at the beginning of the irrigation season
- Evaporation and seepage losses

As a result, irrigation availability can range from zero inches during severe drought years to more than 24 inches during years with above-average precipitation.

2.3 Importance to Rangelands and Agriculture

A reliable irrigation water supply supports both irrigated cropland and surrounding rangelands. During dry years, reduced irrigation availability can increase grazing pressure on rangelands as producers compensate for limited forage production. Improved prediction of water availability allows managers to adjust stocking rates, protect vegetation, and maintain soil health, thereby supporting long-term ecosystem resilience.

3. Problem Statement

Producers within the Arch Hurley Conservancy District face considerable uncertainty when planning for upcoming growing seasons. Decisions regarding crop selection, planting acreage, grazing intensity, and water conservation practices must often be made before seasonal precipitation patterns are known. In the absence of predictive tools, producers risk overcommitting resources during drought years or underutilizing opportunities during wet years.

This project addresses the need for a practical and accessible method to estimate future irrigation water availability using historical precipitation data.

4. Objectives

The objectives of this study are to:

- Analyze historical precipitation data within the Canadian River watershed.
- Identify relationships between rainfall patterns and irrigation water availability.
- Develop a predictive model to estimate future irrigation water supply.
- Express predicted water availability in practical units (inches of irrigation water).
- Demonstrate how the model can inform agricultural and rangeland management decisions.

5. Data Sources and Methodology

5.1 Data Collection

Historical precipitation data were obtained from regional weather stations located within or near the Canadian River watershed. Data included annual precipitation totals, seasonal precipitation distributions, and multi-year averages. When available, historical reservoir inflow data and irrigation allocation records were reviewed to assess how precipitation translated into usable irrigation water.

5.2 Data Processing

Precipitation data were organized by year and season. Statistical analyses were used to identify average rainfall conditions, wet and dry years, and long-term trends or anomalies. These patterns formed the basis for estimating likely future precipitation scenarios.

5.3 Model Development

The predictive model was developed using a three-step approach:

1. Analysis of historical precipitation trends.
2. Estimation of future precipitation based on observed historical patterns.
3. Conversion of estimated precipitation into irrigation water availability using established relationships between rainfall, reservoir inflows, and irrigation allocations.

The model was implemented using NetLogo, a simulation platform commonly applied in environmental and systems modeling.

5.4 Assumptions and Limitations

Assumptions

- Historical precipitation patterns are representative of near-term future conditions.
- Relationships between precipitation, runoff, and reservoir inflow remain relatively stable.
- Land use and watershed characteristics do not change substantially during the study period.

Limitations

- Incomplete or inconsistent data for some years.
- Limited incorporation of long-term climate change effects.
- Evaporation and seepage losses were estimated rather than directly measured.
- Policy based water restrictions.

6. Results

6.1 Rainfall Trend Analysis

Analysis of historical precipitation data revealed pronounced variability. Periods of above-average rainfall were interspersed with extended drought conditions. Seasonal timing of precipitation also influenced the degree to which rainfall contributed to runoff and reservoir inflows, with intense storm events producing disproportionate impacts.

6.2 Predicted Irrigation Water Availability

Model outputs expressed irrigation water availability in inches per growing season. Results indicated that:

- Years with above-average precipitation produced higher irrigation allocations.
- Below-average precipitation years resulted in substantial reductions in available irrigation water.
- Early-season estimates allowed producers to plan planting decisions and grazing intensity more effectively.

6.3 Practical Applications

The predictive model provides actionable information that can be used to:

- Adjust crop selection and planting acreage.
- Implement water conservation and efficiency strategies.
- Prepare for and respond to drought conditions.

7. Implications for Rangeland and Agricultural Management

Predictive modeling reduces uncertainty and supports sustainable land management. For rangelands, improved forecasts of water availability can help managers prevent overgrazing during drought, maintain vegetative cover, and reduce soil erosion. For irrigated agriculture, improved prediction enhances economic stability by reducing risk and optimizing water use efficiency.

8. Future Improvements

Future development of the model could include:

- Integration of soil moisture and evapotranspiration data.
- Incorporation of climate change projections.
- Use of satellite-derived precipitation estimates.
- Annual updates using newly available precipitation and reservoir data.

These enhancements would improve model accuracy and long-term applicability.

9. Conclusion

This project demonstrates that historical precipitation data can be used to develop a predictive hydrologic model for estimating irrigation water availability in the Canadian River watershed. By translating rainfall trends into practical irrigation estimates, the model provides valuable decision-support information for farmers, ranchers, and water managers. Predictive tools such as this are essential for promoting sustainable agriculture, resilient rangelands, and responsible water management in semi-arid regions.

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