Impact of Weather and Climate Scenarios on Conservation Assessment Outcomes

Primary Focus

* Climate variable:  
  - Precipitation intensity & frequency

* Climate scenario:  
  - Increase in P intensity & frequency

* Time scale:  One to two decades

* Conservation outcomes:  
  - Hillside runoff and soil erosion  
  - Watershed runoff and sediment yield
Selected Case Studies

- Sensitivity to climate change
- Soil erosion in Arizona
- Flow responses in Mississippi
- Climate variations in Oklahoma
- Bank erosion in Iowa
- Runoff regime in Missouri
- Curve Number in Ohio
A Simple Thought Experiment: Sensitivity of Watershed Response to Climate Change
Hillside Runoff

Rainfall rate: $p$

Infiltration rate: $f$

Peak flow: $q_p = fct(p,f)$

Climate change: $p + \Delta p$

$$\frac{\Delta p}{p} \Rightarrow \frac{\Delta q_p}{q_p}$$
Sensitivity of Hillside Runoff

\[
\frac{\Delta q_p}{q_p} = \left(1 + \frac{\Delta p}{p} \frac{p}{p - f}\right)^a - 1 \quad a = 1.5 - 1.7
\]

Peak runoff change

P change

Exponential amplification of climate change signal

> 1
Hillside Runoff and Erosion

Flow
\[
\frac{\Delta q_p}{q_p} = \left(1 + \frac{\Delta p}{p} \frac{p}{p - f}\right)^a - 1 \quad a = 1.5 - 1.7
\]

Soil erosion
USLE
\[
\frac{\Delta q_{se}}{q_{se}} = \left(1 + \frac{\Delta P_d}{P_d}\right)^b - 1 \quad b = \sim 2.0
\]

Sediment transport
\[
\frac{\Delta q_s}{q_s} = \left(1 + \frac{\Delta p}{p} \frac{p}{p - f}\right)^{ac} - 1 \quad ac = 2.1 - 2.4
\]
Linearity and superposition apply

Peak flow: \( Q_p = \sum (c \times q_p \times l) \)
Channel Flow and Sediment Transport

Peak discharge

\[
\frac{\Delta Q_p}{Q_p} = \left(1 + \frac{\Delta p}{p} \frac{p}{p - f}\right)^a - 1
\]

a = 1.5 - 1.7

Sed. transport

\[
\frac{\Delta Q_s}{Q_s} = \left(1 + \frac{\Delta p}{p} \frac{p}{p - f}\right)^z - 1
\]

z = 2.0 - 2.7
Findings

- A relative change in precipitation rate ($\Delta p/p$) led to an exponentially amplified runoff and sediment yield response at the hillside and watershed outlet.

- Sediment transport and yield displayed the highest signal-response amplification.

- Climate scenarios that call for an increase in precipitation intensity have the greatest impact on conservation outcomes.
Climate Change Effects on Runoff and Soil Erosion in Southeastern Arizona Rangelands

Computer Simulation Study

Rangeland Hydrology and Erosion Model: RHEM
Green house gas emission scenarios:
high, medium, low emissions

Baseline : 1970-1999
Projection: 2030-2059
Findings

=> 80% to 90% increase in runoff

=> 130% to 150% increase in soil loss

=> No significant change in annual precipitation!
Climate change was a seasonal shift in precipitation and a change in frequency and intensity of extreme events.
Climate Change Implications

=> Based on computer models and for typical Arizona rangelands, the projected precipitation will lead to substantial increases in runoff and soil loss.

=> Increasing runoff and soil erosion may accelerate the transition of grassland to shrubland.

=> Conservation should focus on grasslands in danger of crossing the threshold to a degraded state dominated by shrubs.
Complex Flow Responses in Northern Mississippi
Pervasive channel instability in northern Mississippi

- Watershed sediment yield ~twice the national average
- 60-80% of sediments derived from channel boundary, not watershed
Demonstration Erosion Control Project

Seven larger watersheds (>100 km$^2$)

- Grade control structures (105)
- Bank protection (123 km)
- Riser pipes (449)

Costs of channel erosion controls approached cost of land protected.

1984
Discharge and sediment yield monitored for 11-17 years
Findings

In spite of large-scale channel bank stabilization and erosion control measures, trends in suspended sediment concentration, corrected for temporal variations in discharge, could not be detected over a 5 to 15 year period at the outlet of 6 of the 7 watersheds.
Climate Change Implications

Even large expenditures on channel erosion controls may not be adequate to reduce watershed sediment yield if channel peak discharges and channel energy slopes are not reduced.

By implication, increases in peak discharge and frequency due to climate change may overshadow effects of erosion controls on sediment yield.
Effects of Climate Variations and Soil Conservation on Sedimentation of an Oklahoma Watershed
Unique Opportunity

* Suspended sediment measurements in 1943 - 1950
* Fort Cobb Reservoir built in 1959
* Extensive soil and water conservation implemented between 1950s - present
* Fort Cobb Reservoir surveyed in 1993
* Suspended sediment measurements in 2004 - 2008
Intermediate Results

Estimated watershed sediment yield:

Pre-conservation
1940-1964  221,700 m³/year

Post-conservation
1984-2008  215,300 m³/year
Persistent Annual Precipitation Variations
Central Oklahoma Climate Division; 1940-2008

Annual precipitation

- 5-yr weighted average
- Below average
- Above average

Drought time period
Pluvial time period

Preliminary data, subject to revision
Findings

Estimated watershed sediment yield after correction for the shift in climate:

- **Pre-conservation (1940-1964)**: 221,700 m$^3$/year
- **Post-conservation (1984-2008)**: 75,400 m$^3$/year

Reduction: 65%
Climate Change Implications

- Without a shift in climate, soil conservation practices on the Fort Cobb watershed would reduce sediment yield by 65%.

- Increased erosion and sediment yield as a result of climate change can offset the benefits of soil conservation practices.
Bank Erosion from an Extreme Flood on the South Fork Iowa River

Extreme flood of June 2008: an example of what to expect under increased severe storms
Pasture CRP

Tipton Cr. (after 2008 flood)

Minimal bank erosion

Substantial bank erosion

Tipton Cr. (after 2008 flood)

Pasture

Legend:
- Green: accretion
- Red: erosion
- Grey: channel

Map scale:
- 0, 50, 100, 200 Meters
Findings

Channels that were straightened in the past are susceptible to widening and bank erosion during extreme flood events.

However, CRP land and buffer strips minimized channel bank erosion in both straightened and meandering channels (investigation ongoing).
Climate Change Implications

Conservation practices that successfully protected channel banks during past flood events will remain effective under climate change conditions.
Changes in Watershed Runoff/Sediment due to Weather and Climate

Goodwater Creek Watershed, Missouri
A significant trend (1972-2011) was detected in annual flow, annual peak flow, and number of out-of-bank flow events in the Goodwater Creek watershed.

Is this related to climate change?
Findings

- A corresponding trend could not be detected in annual precipitation or annual peak daily precipitation.

- Observed trend in the flow record was in part the result of land use changes and urbanization of the watershed.
Climate Change Implications

Anthropogenic activities in a watershed can modifying the runoff/sediment yield regime of a watershed and make it difficult to discern whether trends are due to climate change or other causes, especially over a short time period of a few decades.
Variation in Curve Number over Time on a Coshocton, Ohio, Watershed
The NRCS “Curve Number” (CN) is widely used for estimating watershed runoff, and often mandated for soil and water conservation design.

Does the CN change with climate change?

Sixty-eight years (1939-2006) of weather and runoff data for a small catchment in the Coshocton, Ohio, watershed were used to test whether CN changes in time due to climate change.
Findings

- A trend in annual or monthly precipitation could not be identified, but a trend in annual air temperature was found.

- There was no apparent trend in the CN over a period of 72 years.

- The trend in air temperature suggests that runoff-event antecedent soil-water storage may be increasing. (This investigation is ongoing).
U.S. Climate Regions

Percent change in amount of heavy precipitation

Southwest: 16%
Northwest: 9%
Central: 15%
Midwest: 31%
Southeast: 20%
Northeast: 67%
Conclusions

Climate change scenarios that call for increased precipitation intensity lead to an **exponentially amplified increase** in soil erosion and watershed sediment yield.

Increase in soil erosion and sediment yield due to climate change can **offset beneficial effects of currently implemented conservation practices**.
Conclusions

A change in conservation outcome in terms of watershed sediment yield will primarily result from upstream conservation practices that reduce channel peak discharge or channel slope.

Anthropogenic activities, legacy channel instabilities, and the integrated nature of the watershed response make it difficult to attribute changes in observed sediment yield to upstream conservation outcomes and climate change.