Advancements from Long-Term Research on Woody Plant Encroachment in the Western United States: the Hydrology Component of the SageSTEP Study

Sagebrush Steppe SageSTEP Treatment Evaluation Project

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Problem: Woodland Encroachment into Sagebrush Steppe

- Pinyon and juniper species have replaced millions of hectares of sagebrush steppe rangeland across western North America.
- Encroachment has negative ramifications on ecosystem structure and function.
- Restoration to sage-brush steppe vegetation is difficult, particularly on late-succession woodlands.

Problem: Woodland Encroachment into Sagebrush Steppe

Ladder fuel structure and dense woody fuel loading on woodlands promote high severity burns.

High severity burns on woodland sites result in barren landscapes and present restoration challenges.

Overarching Research Objectives

PINYON AND JUNIPER ENCROACHMENT (link: Pierson et al., 2010)

- **Determine thresholds for increased runoff and erosion** with declines in vegetation.
- **Improve our understanding of the hydrologic connectivity** between under tree canopy and intercanopy areas.

SHORT-TERM EFFECTS OF TREE REMOVAL PRACTICES (links: Pierson et al., 2014, 2015; Williams et al., 2014; Al-Hamdan et al., 2012, 2015)

- **Quantify the impact of tree removal** on infiltration, runoff, and soil erosion associated with vegetation recovery.
- **Develop hydrologic parameter data sets** to expand the applicability of the Rangeland Hydrology & Erosion Model (RHEM) to cover woodland management scenarios.

LONGER-TERM TREATMENT EFFECTS (links: Williams et al., 2019, 2020; Nouwakpo et al., 2020)

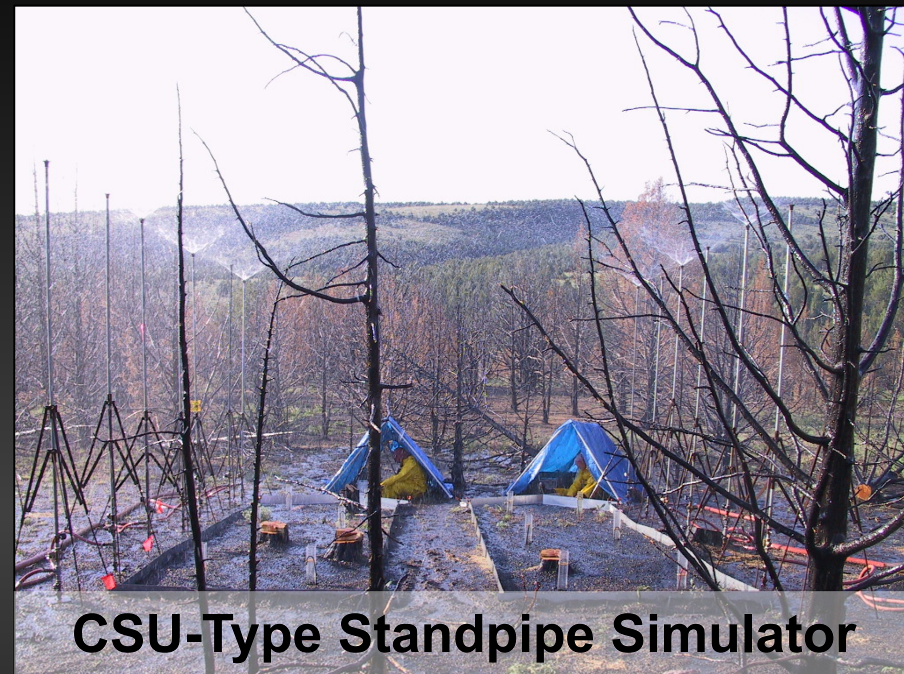
- **Evaluate whether site vulnerability to accelerated runoff and erosion** improves with understory recovery following tree removal?
- **Determine time period necessary to obtain maximum hydrologic site stability** following tree removal?

Methods: Rainfall Simulations

Small Plots (0.5 m^2)

Oscillating Arm Simulator

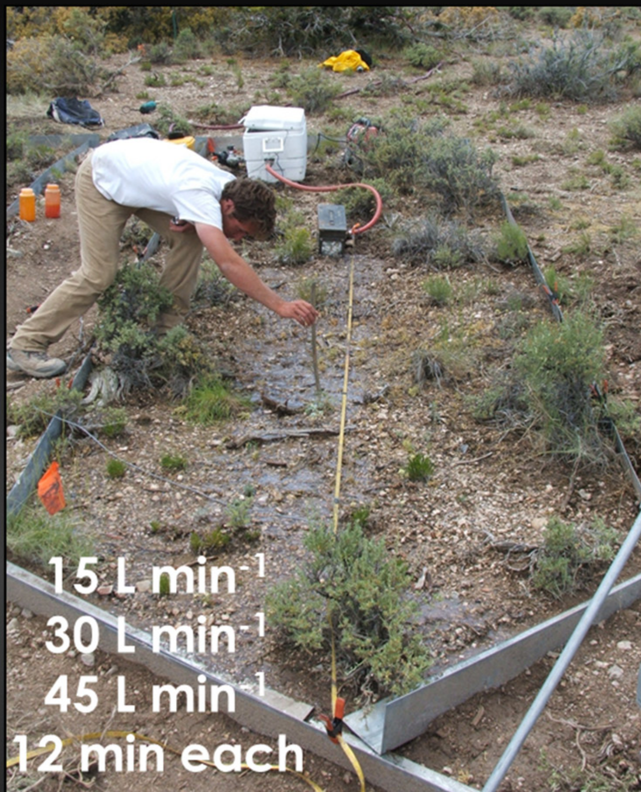
Large Plots (13 m^2)

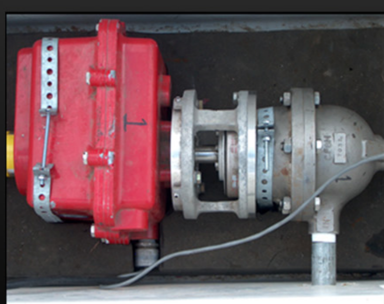


CSU-Type Standpipe Simulator

Walnut Gulch Simulator

Methods: Overland Flow Simulations





Methods: Vegetation, Ground Cover, Soils

Study Sites

Links: Pierson et al., 2019
Williams et al., 2020

Onaqui – Utah Juniper

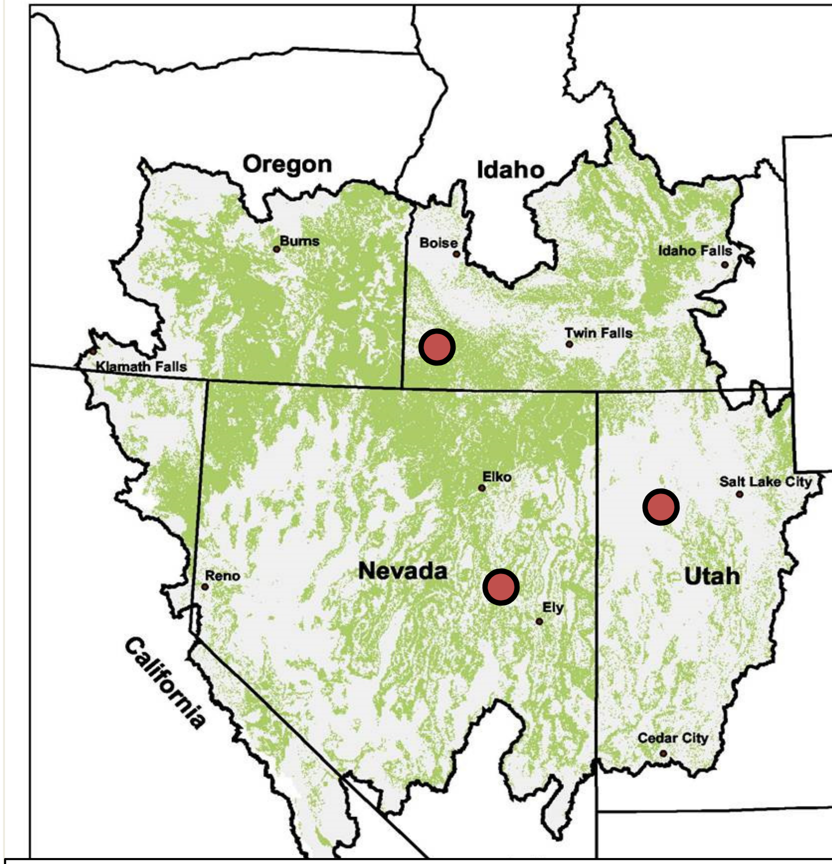
SageSTEP
3 – Woodlands

Marking Corral – Pinyon-Juniper

Tree cutting and mastication, prescribed fire, and wildifre

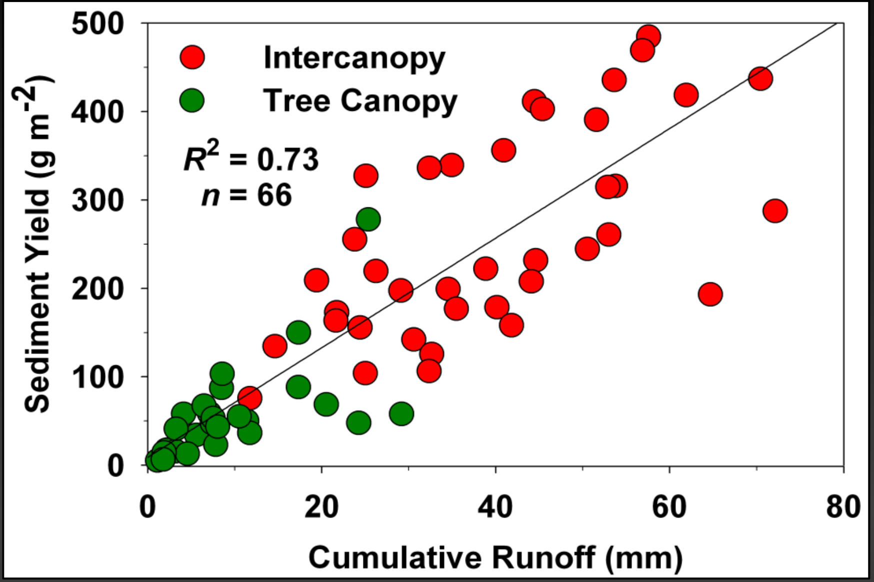
Castlehead – Western Juniper

Fine- to coarse-textured soils



Large Vegetation Plots (33m x30m)	57
Small-Plot Rainfall Simulations	1,034
Large-Plot Rainfall Simulations	364
Overland Flow Simulations	870
Total Hydrology Plot Runs	**2,268**

Encroachment: Biotic-Abiotic Thresholds: Connectivity



- Flow velocity is function of bare ground, discharge, and slope.
- Probability of overland flow to concentrate *f* (*slope, bare ground, and discharge*):

$$P = \frac{\exp(-6.397 + 8.335S + 3.252bare + 3440q)}{1 + \exp(-6.397 + 8.335S + 3.252bare + 3440q)}$$

$$(n = 756)$$

- Erosion linearly related to runoff.
- Runoff, erosion, and velocity increase exponentially where bare ground exceeds 50-60%.
- High erosion rates largely due to formation of concentrated flow within intercanopy.

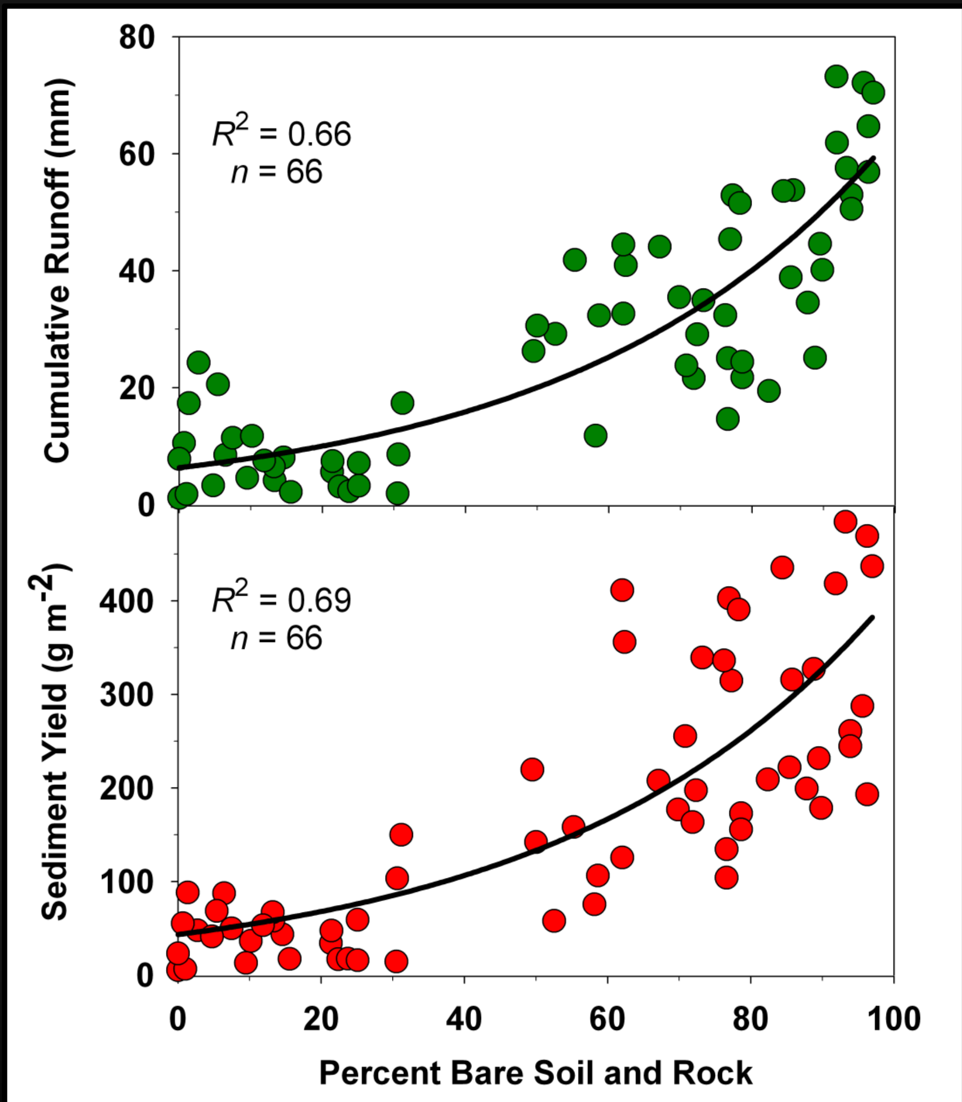
Pierson et al. 2010 – Rangeland Ecology and Management 63: 614-629.

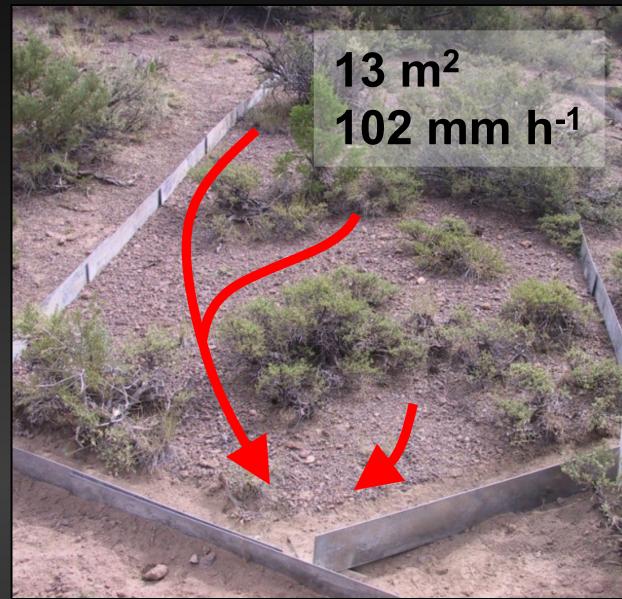
Pierson et al. 2013 – Rangeland Ecology and Management 66: 274-289.

Williams et al. 2014 – Ecohydrology 7: 453–477.

Al-Hamdan et al. 2013 – Transactions of ASABE 56: 539-548.

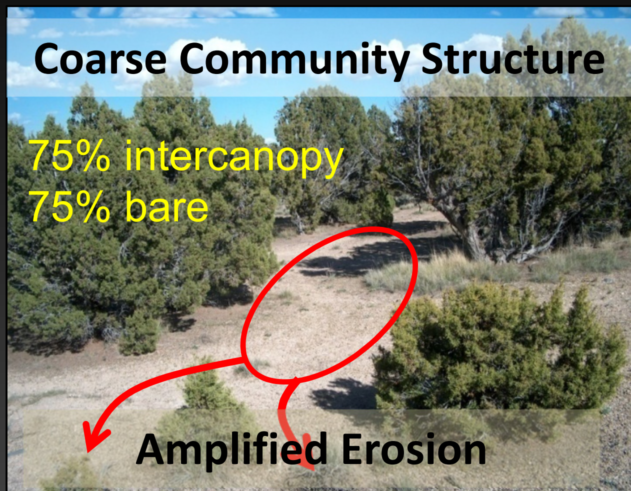
Encroachment: Bare Ground & Connectivity of Processes

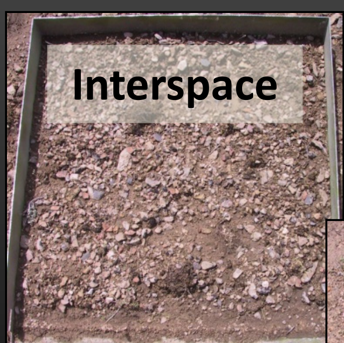




Pierson et al. 2010 – Rangeland Ecology and Management 63: 614-629.

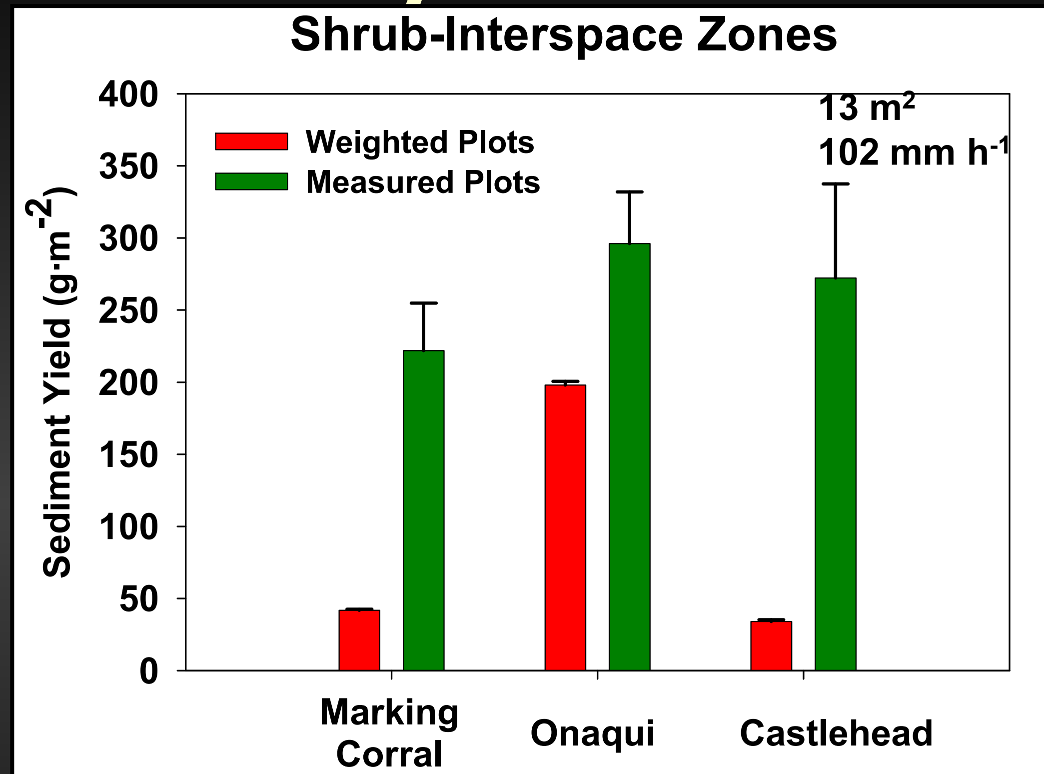
Encroachment:
Cross-Scale Connectivity of Processes





40 - 60 mm
40 - 210 g m^{-2}

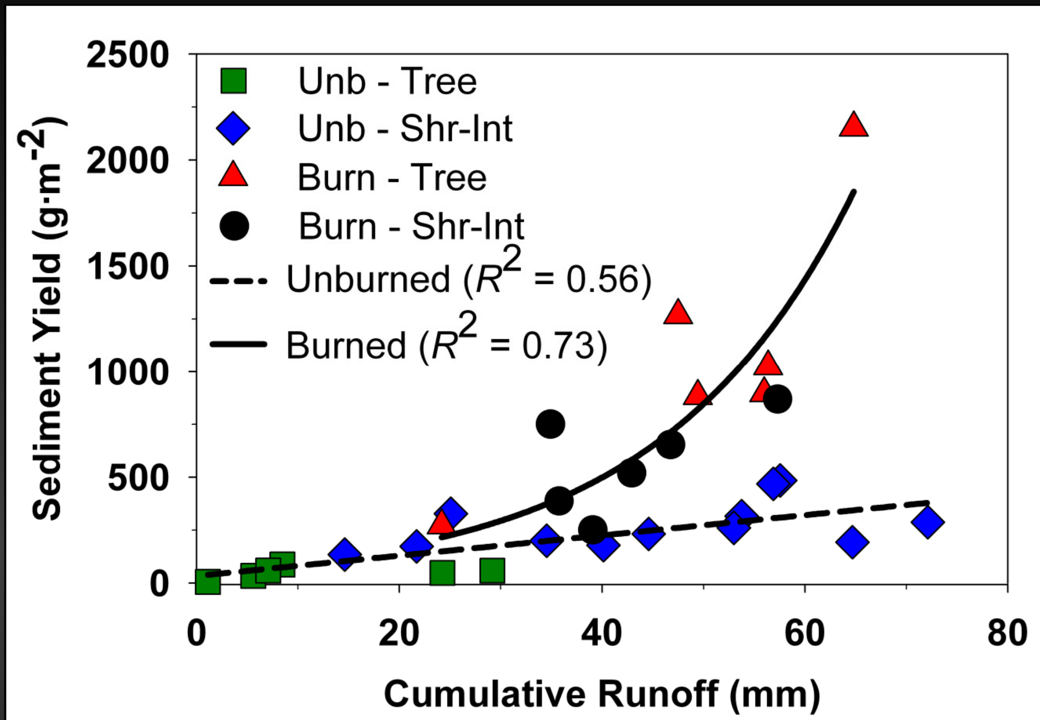
5 - 20 mm
5 - 40 g m^{-2}

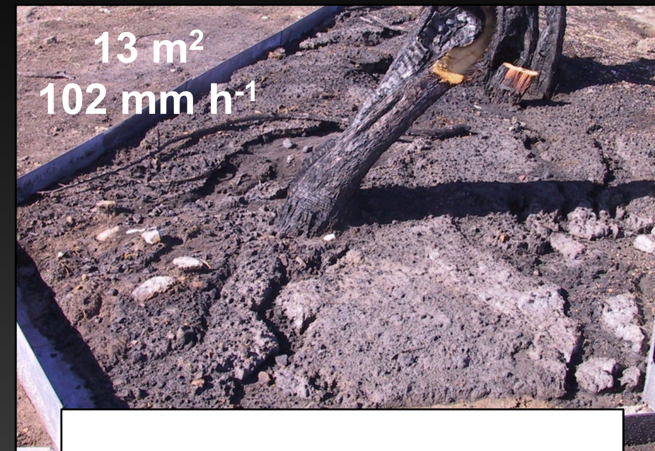


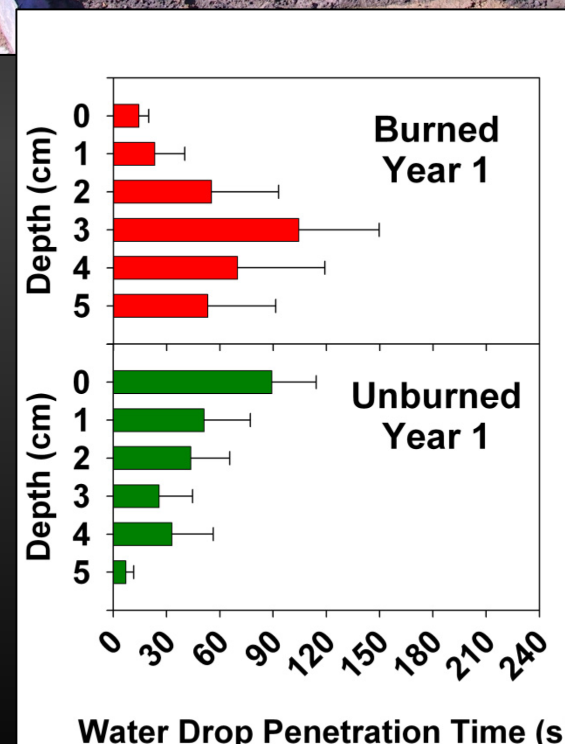
- Minor to no increase in runoff across spatial scales (≈ 40 mm at large plot scale).
- Increased erosion with increasing spatial scale due to connectivity of runoff sources.

Pierson et al. 2010 – Rangeland Ecology and Management 63: 614-629.
Williams et al. 2014 – Ecohydrology 7: 453–477.

Fire (Short-Term): Greater Connectivity of Processes

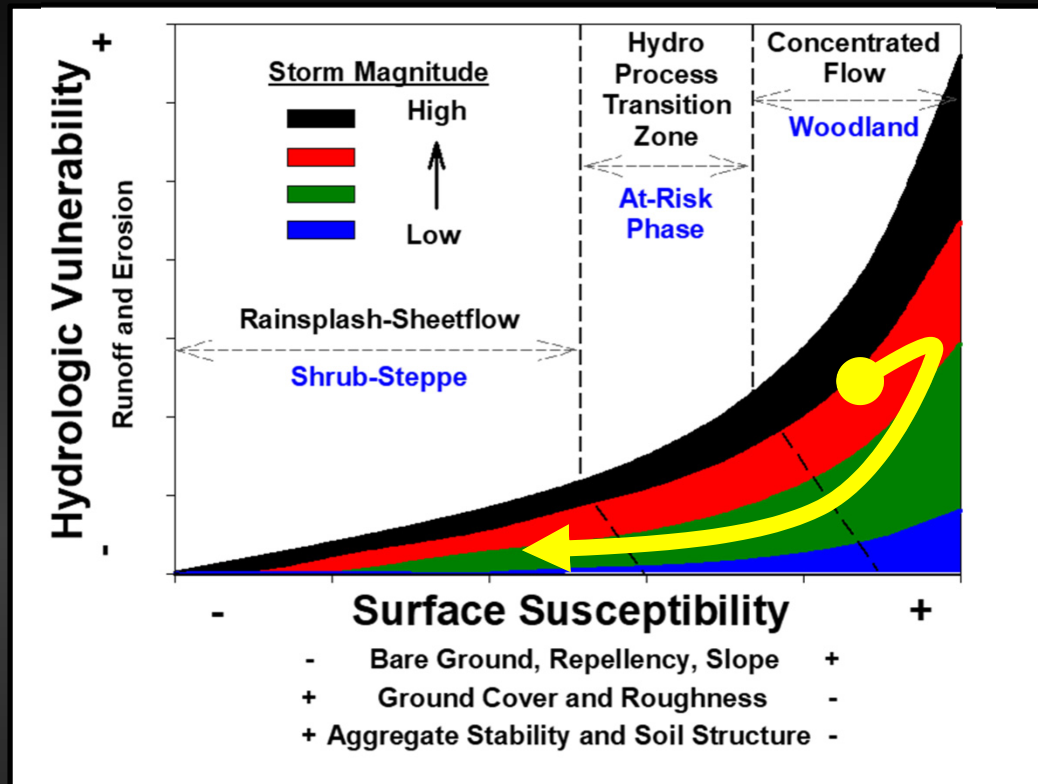






Williams et al. 2014 – Ecohydrology 7: 453–477.
Pierson et al. 2013 – Rangeland Ecology and Management 66: 274-289.

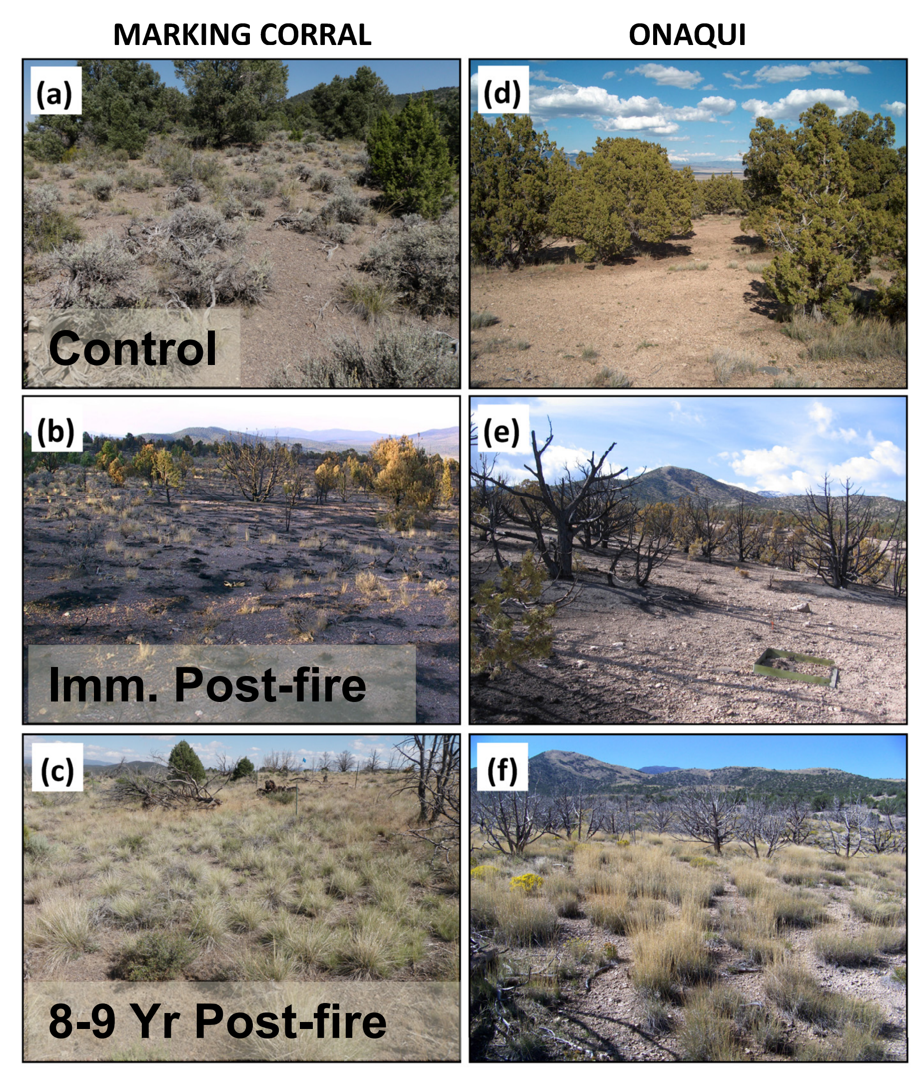
Fire (Long-Term): Ecohydrologic Threshold Reversal

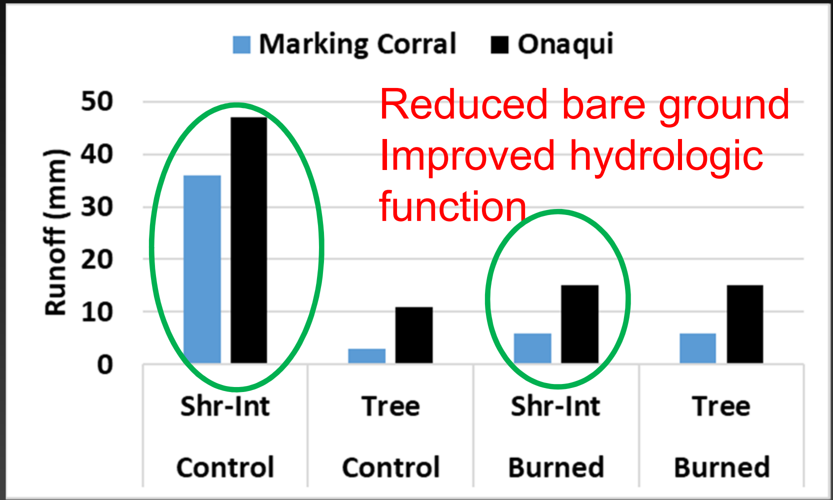


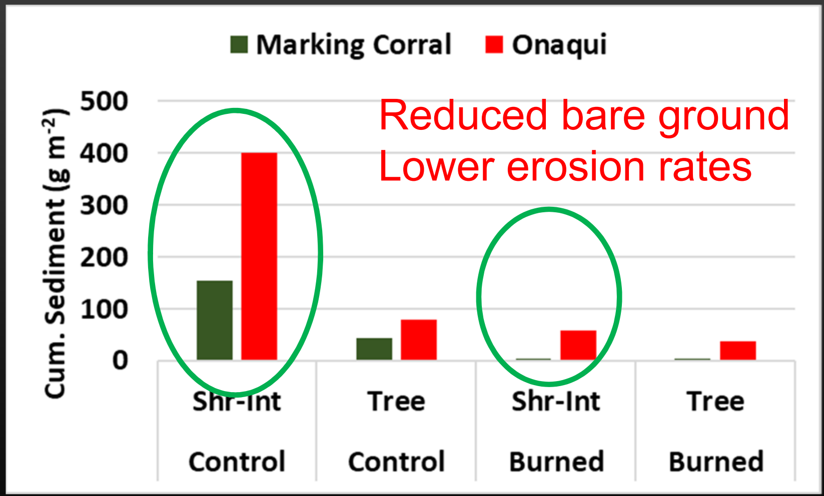
- Burning may reduce long-term erosion by reducing competition and promoting intercanopy vegetation.
- Increased cover reduces structural and functional connectivity and limits sediment availability.

Williams et al. 2014 – Ecohydrology 7: 453–477.
Williams et al., 2019 – Ecohydrology 12:e2086.

Fire (Long-Term): Ecohydrologic Threshold Reversal



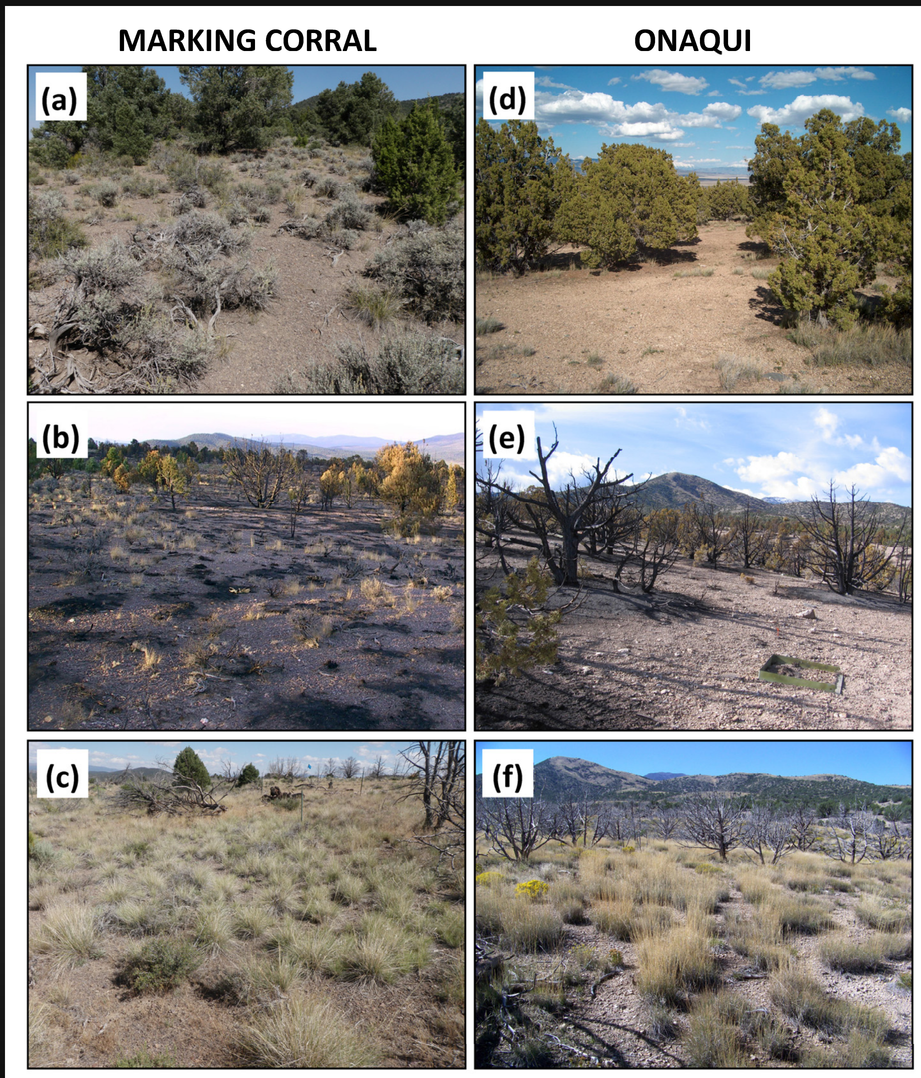




Williams et al. 2019 – Ecohydrology 12: e2086.
Williams et al. 2019 – Catena 185: 103477.

Nouwakpo et al. 2019 – Catena *185: 104301.*

Fire (Long-Term): Ecohydrologic Threshold Reversal



Although fire increased cover and reduced connectivity of runoff and erosion processes, burning also promoted increases in the fire-prone invasive annual cheatgrass (inside yellow circle below).

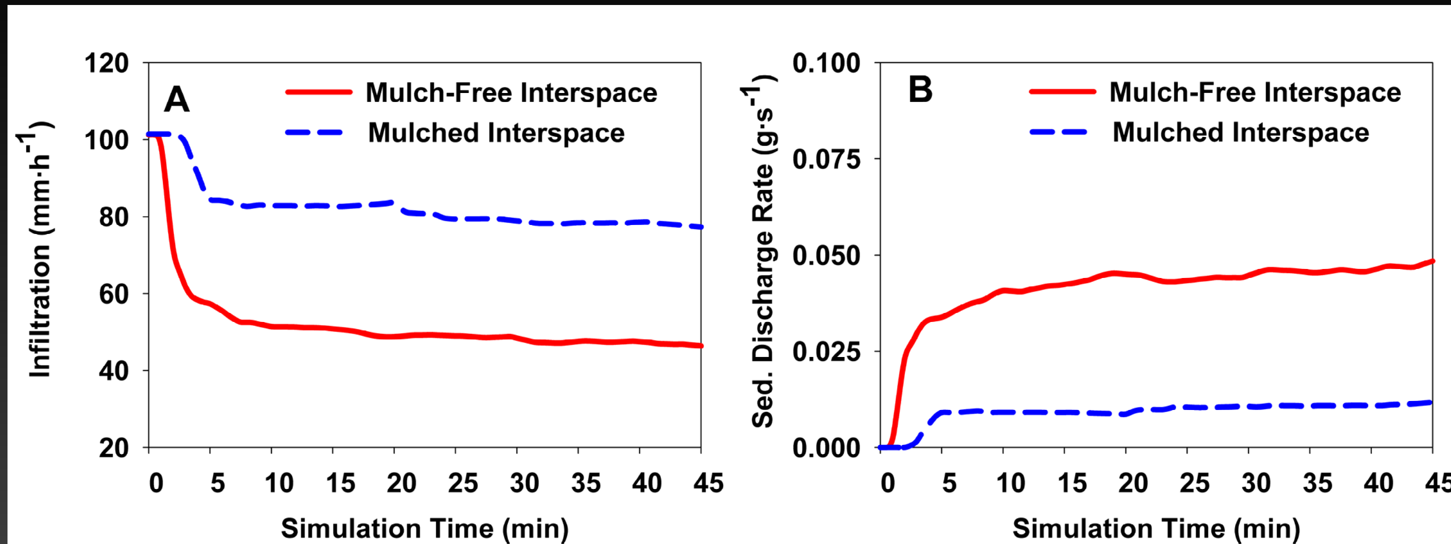
However, cheatgrass was primarily restricted to under trees representing 25% of total area at the sites.

Williams et al., 2019 – Ecohydrology 12:e2086.
Williams et al. 2019 – Catena 185: 103477.

Cut/Mastication: Ecohydrologic Reversal Mechanism?

Mast. (Short-Term): Decreased Connectivity

Small
Plot
Scale
- 0.5 m^2



Pierson et al. 2014 – Rangeland Ecology & Management 67: 522–538.

23 mm RO
133 g m^{-2} Sed

52 mm RO
313 g m^{-2} Sed

11 mm RO
39 g m^{-2} Sed

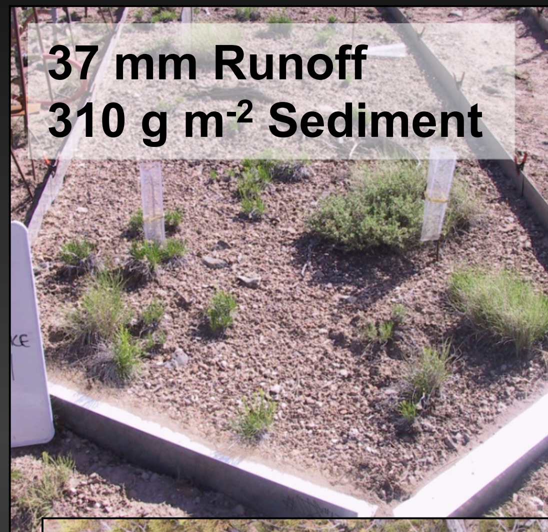
53 mm RO
403 g m^{-2} Sed

Cline et al. 2010 – Rangeland Ecology & Management 63: 467–477.

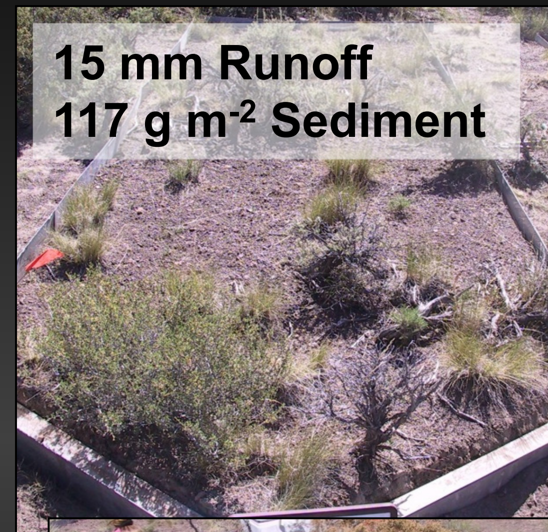
Cut (Short-Term): Decreased Connectivity?

Castlehead

Onaqui



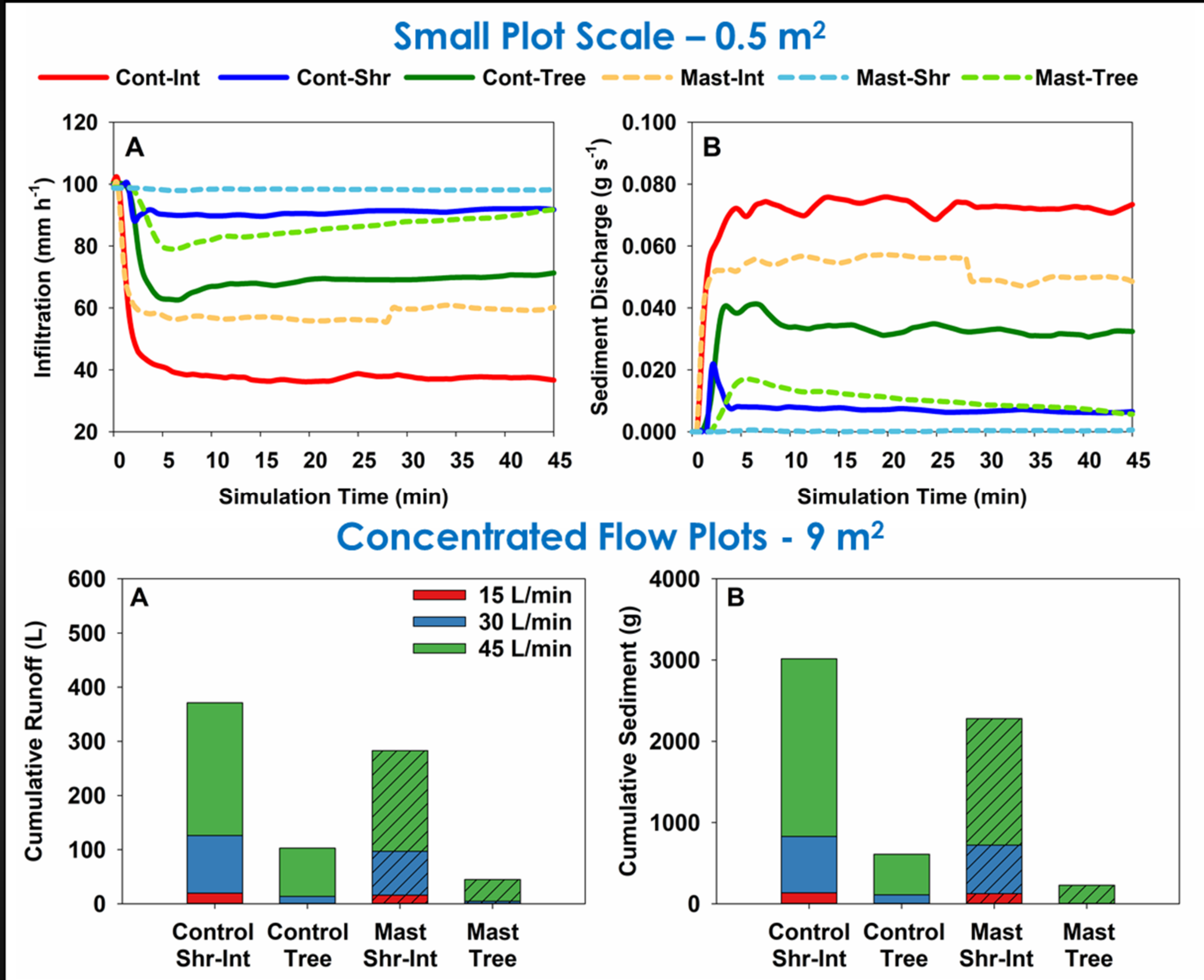
Marking Corral



Pierson et al. 2013 – Rangeland Ecology and Management 66:274-289.

No immediate impact?

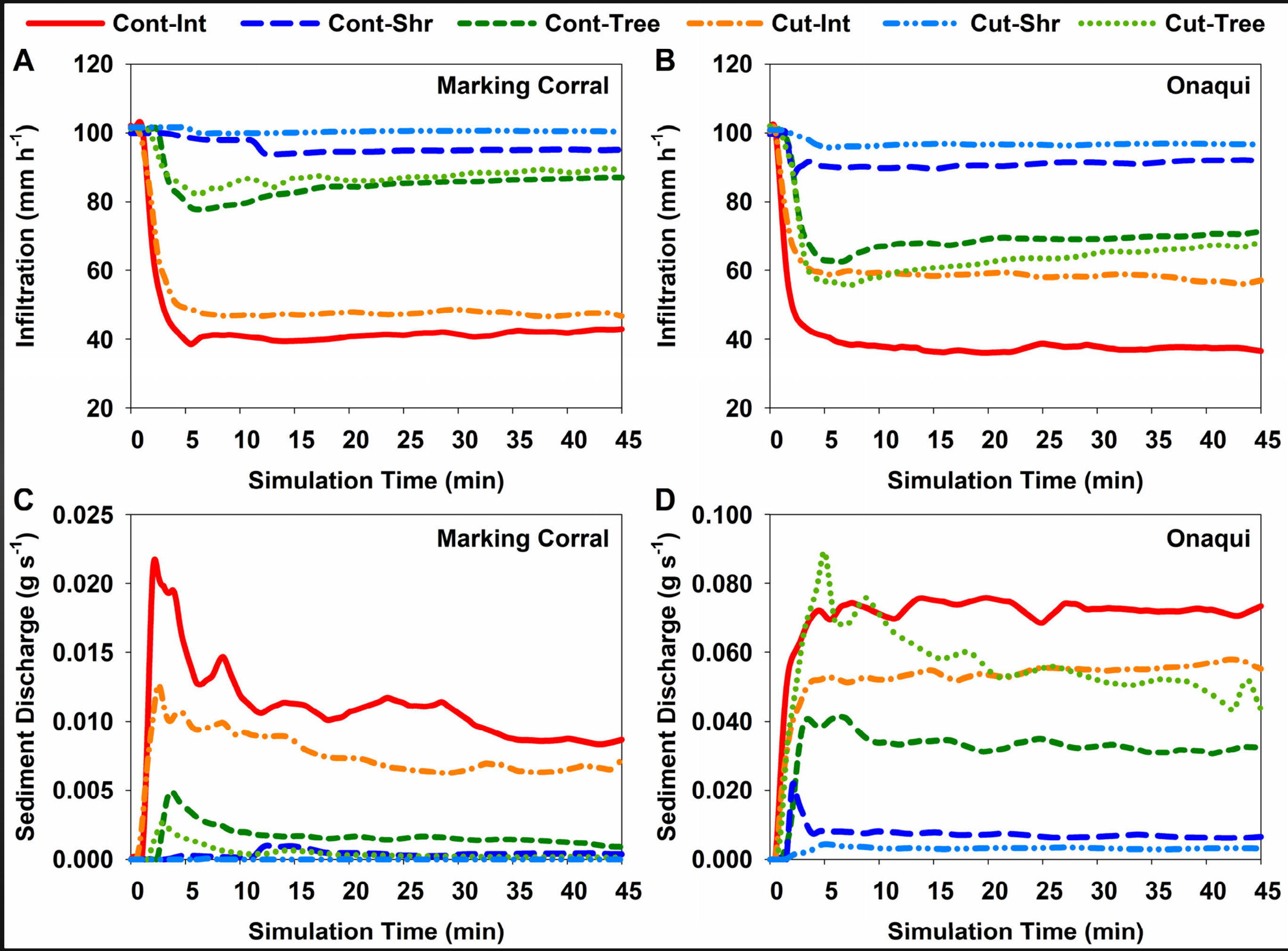
Mast. (Long-Term): Decreased Connectivity



Over the long-term, mastication treatment facilitating some gradual improvements in hydrologic function within interspaces (Cont-Int vs Mast-Int; Control Shr-Int vs Mast. Shr-Int).

Williams et al. 2019 – Rangeland Ecology & Management 72: 47-68.

Cut (Long-Term): Ecohydrologic Reversal Mechanism?



Over the long-term, cutting treatment is facilitating some gradual improvements in hydrologic function within interspaces (Cont-Int vs Cut-Int).

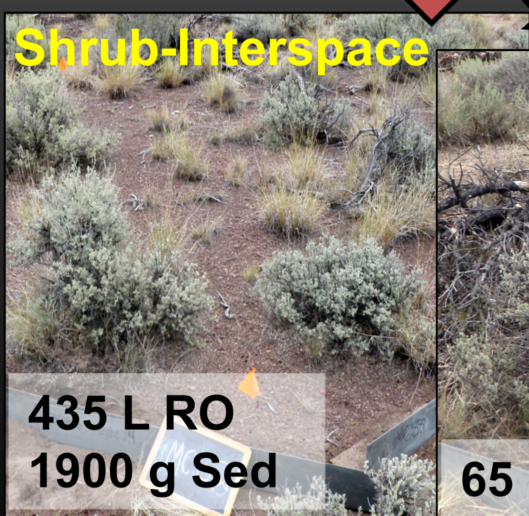
Williams et al. 2019 – Rangeland Ecology & Management 72: 47-68.

Cut (Long-Term) - Ecohydrologic Reversal Mech?

Marking Corral

Control

Downed trees captured runoff and sediment.



9 Yr Post-Cut

Onaqui

Control

And, thereby limited downslope transfers and improved hydrologic function.

9 Yr Post-Cut

Williams et al. 2019 – Rangeland Ecology & Management 72: 47-68.

RHEM: Model Enhancements

Rangeland Hydrology and Erosion Model Web Tool

SageSTEP contributions to model development:

Friction factor (f):

$$\log f = 0.298 + 1.156\,litter + 1.956\,basal + 1.383\,rock - 1490\,Q + 1.565\,S$$

$$\log f = 1.711 - 1.4151\,bare - 1594\,Q + 1.528\,S \quad (R^2=0.54)$$

Velocity (V):

$$\log V = -0.953 - 0.471\,litter - 0.685\,basal - 0.562\,rock + 957\,Q + 0.273\,S$$

$$\log V = -1.503 + 0.552\,bare + 979\,Q + 0.283\,S \quad (R^2=0.51)$$

Flow width (w):

$$\log w = -0.896 + 0.24\,litter + 0.235\,basal + 0.176\,rock + 716\,Q - 0.754\,S$$

$$\log w = -0.669 - 0.223\,bare + 703\,Q - 0.75\,S \quad (R^2=0.4)$$

litter, ***basal***, and ***rock:*** are the fractions of litter cover, basal plant and cryptogam cover, and rock cover to the total ground area respectively.

bare: is the bare soil fraction of the total ground area.

Q: is the rill discharge

S : is the average slope

Al-Hamdan et al. 2012a – Earth Surface Processes and Landforms 37:157-168.

Al-Hamdan et al. 2012b – Water Resources Research 48:W07504.

Al-Hamdan et al. 2013 – Transactions of ASABE 56: 539-548.

Al-Hamdan et al., 2015 – Hydrological Processes 29:445-457.

Al-Hamdan et al., 2017 – Transactions of the ASABE 60:85-94.

RHEM: Applications to Woodland Encroachment & Tree Removal

Williams et al. 2016 – Rangelands 38:379-388

RESULTS

SCENARIO INPUTS

Download results as PNG CSV

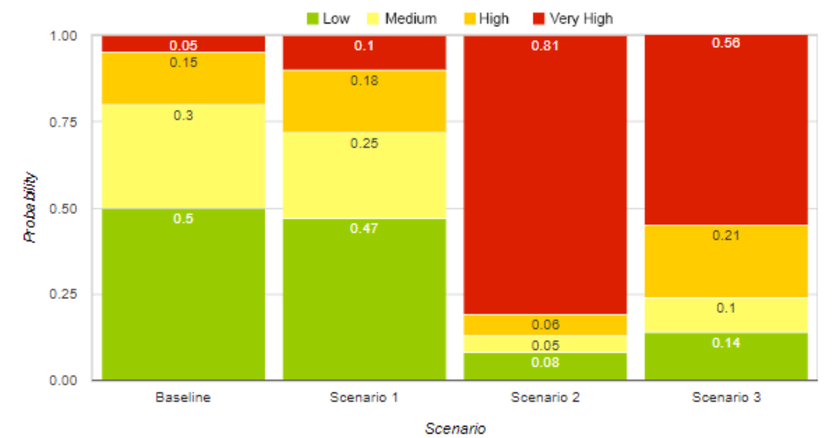
	SAGEBRUSH-STEPPE	WOODLAND_	WILDFIRE	BURNED	10YR_CUT
Version	2.3	2.3	2.3	2.3	2.3
State ID	OR	OR	OR	OR	OR
Climate Station	Sheaville	Sheaville	Sheaville	Sheaville	Sheaville
Soil Texture	Loam	Loam	Loam	Loam	Loam
Soil Water Saturation %	25	25	25	25	25
Slope Length (meters)	50	50	50	50	50
Slope Shape	Uniform	Uniform	Uniform	Uniform	Uniform
Slope Steepness %	35	35	35	35	35
Bunch Grass Foliar Cover %	14	6	0	0	15
Forbs and/or Annual Grasses Foliar Cover %	12	2	0	0	10
Shrubs Foliar Cover %	28	2	1	1	15
Sod Grass Foliar Cover %	0	0	0	0	0
TOTAL FOLIAR COVER %	54	10	1		
Basal Cover %	25	4	1		
Rock Cover %	3	14	5		
Litter Cover %	40	10	5		
Biological Crusts Cover %	2	0	0		
TOTAL GROUND COVER %	70	28	11		

ANNUAL AVERAGES

RHEM Web Tool — Rangeland Hydrology and Erosion Model Web Tool

PROBABILITY OF OCCURRENCE (yearly soil losses)

Click for help



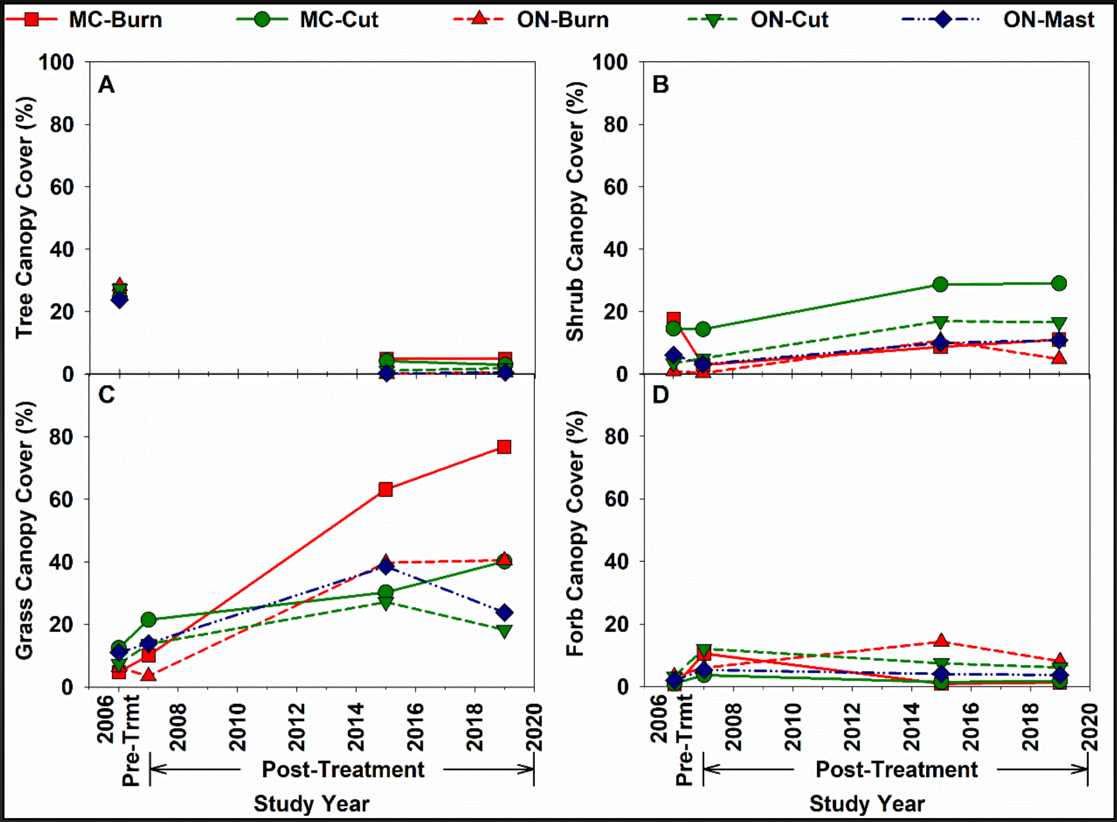
25 YEAR RETURN FREQUEN

	SAGEBRUSH-STEPPE	WOODLAND_	WILDFIRE	BURNED	10YR_CUT
Rain (mm)	42.500	42.500	42.500	42.500	42.500
Runoff (mm)	5.401	12.195	12.135	12.135	6.224
Sediment Yield (Mg/ha)	0.527	6.527	23.635	23.635	0.727
Soil Loss (Mg/ha)	0.533	6.560	23.829	23.829	0.738

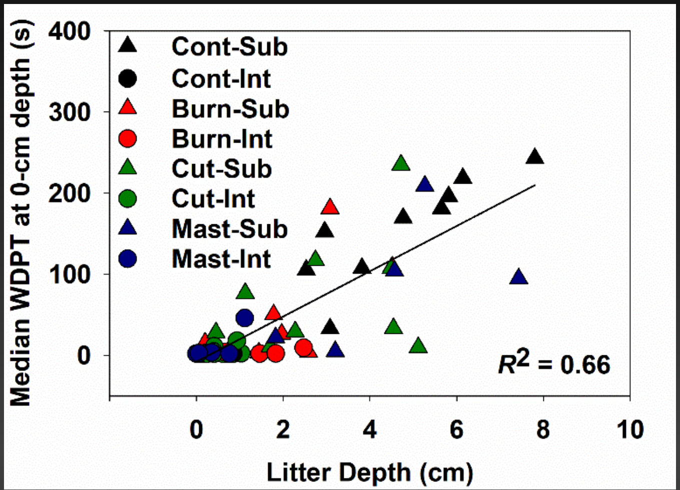
Model effective in forecasting treatment effects and guiding management.

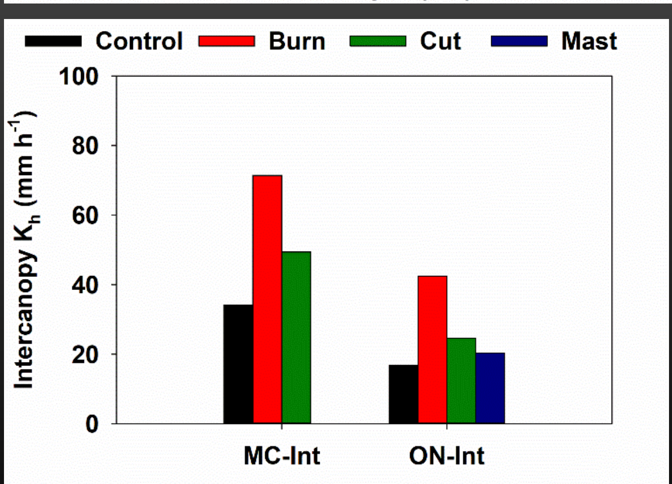
http://apps.tucson.ars.ag.gov/rhem/tool

Ongoing Research: 13 yr Post-Treatment



Williams et al. – *In Prep.* - Water





Vegetation and ground surface conditions continued to change across treatments at both sites at 13 yr post-treatment.

Increased herbaceous cover improved hydraulic conductivity in previously degraded intercanopies within burned areas, but more limited enhancement of vegetation in mechanical treatments resulted in lesser hydrologic improvement relative to burned areas.

Study Accomplishments

- Provided well-replicated data and increased understanding of woodland encroachment effects on hydrology and erosion.
- Quantified short- and long-term hydrologic and erosion impacts of tree-removal treatments and associated key ecohydrologic feedbacks.
- Compiled hydrology and erosion parameter datasets and delivered enhancements for RHEM prediction tool.
- Numerous peer-review publications on ecohydrologic impacts of woodland encroachment, tree removal, and wildfire and conceptual and quantitative ecohydrologic models (many available here and at www.sagestep.org).
- Contributions provide greater ecohydrologic process understanding and tool transfer to land managers.

Data Availability

- Much of the data collected from years 2006-2015 is now available from the USDA Ag Data Commons – National Agricultural Library (NAL), at:

Sagebrush Steppe
SageSTEP
Treatment Evaluation Project

USDA ARS

Vegetation, rainfall simulation, and overland flow experiments before and after tree removal in woodland-encroached sagebrush steppe: the SageSTEP hydrology study

USDA Ag Data Commons
U.S. DEPARTMENT OF AGRICULTURE

https://doi.org/10.15482/USDA.ADC/1504518

- The NAL dataset is described in our recent ESSD publication, available at:

Vegetation, rainfall simulation, and overland flow experiments before and after tree removal in woodland-encroached sagebrush steppe: The Sagebrush Steppe Treatment Evaluation (SageSTEP) study

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https://www.earth-syst-sci-data-discuss.net/essd-2019-182/

- The dataset will be updated as the project continues.

Recent Contributions & Other Publications

Catena 185 (2020) 103477

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Effectiveness of prescribed fire to re-establish sagebrush steppe vegetation and ecohydrologic function on woodland-encroached sagebrush rangelands, Great Basin, USA: Part I: Vegetation, hydrology, and erosion responses

C.J. Williams[a,*], Frederick B. Pierson[b], Sayjro K. Nouwakpo[c], Osama Z. Al-Hamdan[d], Patrick R. Kormos[e,f], Mark A. Weltz[g]

Catena 185 (2020) 104301

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Effectiveness of prescribed fire to re-establish sagebrush steppe vegetation and ecohydrologic function on woodland-encroached sagebrush rangelands, Great Basin, USA: Part II: Runoff and sediment transport at the patch scale

Sayjro K. Nouwakpo[a,b,*], C. Jason Williams[c], Frederick B. Pierson[d], Mark A. Weltz[e], Patrick R. Kormos[f,g], Awadis Arslan[b], Osama Z. Al-Hamdan[h]

Received: 25 September 2018 | Revised: 4 February 2019 | Accepted: 25 February 2019

DOI: 10.1002/eco.2086

RESEARCH ARTICLE

WILEY

Long-term evidence for fire as an ecohydrologic threshold-reversal mechanism on woodland-encroached sagebrush shrublands

C. Jason Williams[1] | Frederick B. Pierson[2] | Sayjro K. Nouwakpo[3] | Patrick R. Kormos[4] | Osama Z. Al-Hamdan[5] | Mark A. Weltz[6]

View abstracts and links to many of the papers on ResearchGate:

https://tinyurl.com/SageSTEP-Hydrology

Information on this study and the greater SageSTEP study is available at:

http://www.sagestep.org/

water

MDPI

Review

Spatial and Temporal Variability of the Impacts of Pinyon and Juniper Reduction on Hydrologic and Erosion Processes Across Climatic Gradients in the Western US: A Regional Synthesis

C. Jason Williams [1,*], Keirith A. Snyder [2] and Frederick B. Pierson [3]

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Sagebrush Steppe

SageSTEP

Treatment Evaluation Project

USDA

United States Department of Agriculture

The Ecology, History, Ecohydrology, and Management of Pinyon and Juniper Woodlands in the Great Basin and Northern Colorado Plateau of the Western United States

Richard F. Miller, Jeanne C. Chambers, Louisa Evers, C. Jason Williams, Keirith A. Snyder, Bruce A. Roundy, Fred B. Pierson


Sagebrush Steppe
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NATIONAL INTERAGENCY FIRE CENTER
BOISE, IDAHO
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