WyCEHG: Linking surface hydrology and groundwater through near-surface geophysics

Scott Miller and Steve Holbrook
University of Wyoming

CUAHSI Cyberseminar
April 12, 2013
Talk Outline

• What is WyCEHG? (“Y-Keg”)
• Goals of WyCEHG
• New Infrastructure: Human and physical
• Science Plans
• Preliminary Results
What is WyCEHG?

A center of excellence in environmental hydrology and hydrogeophysics that serves water science and watershed management in Wyoming by providing cutting-edge tools to managers, scientists and educators in the public and private sectors.

- Funded by a 5-year, $20 M grant from NSF-EPSCoR (plus $4 M match from UW).
- EPSCoR Track-1 Research Infrastructure Improvement grant
- Collaboration among: 8 UWyo departments in 4 colleges, 3 Wyoming community colleges, 26 faculty (so far)
- Two major facilities:
  - The Facility for Imaging the Near- and Sub-surface Environment (FINSE): Geophysical Equipment
  - The Surface and Subsurface Hydrology Lab (SSHL): Hydrological Equipment
- Private sector involvement: internships and long-term geophysical facility support
- Planned science in Focus Sites around Wyoming
- Long-term: Transition to a self-supporting, national facility for hydrogeophysics
  - a CUAHSI Hydrogeophysics Facility?

Find us at: www.uwyo.edu/WyCEHG
Science Goals

1. How do hydrological systems respond to change?
   - oil and gas development
   - bark beetle infestations
   - fires, floods, climate change

2. How do snow processes, particularly moisture content (SWE) and the timing of snowmelt, affect the downstream system?
   - Linkages across space and time. Teleconnections with impacts to water resource management

3. What information and approaches are needed to upscale from the point scale to the watershed scale in hydrological modeling?
Addressing Key Hydrologic Questions

• Closing the gap in the water budget
  • Fate and transport of water in a mountainous environments
    • Fracture flow
    • Partitioning of water into surface / soil / groundwater
  • Better information for water resource management
    • We live in uncertain times with changing runoff response – how will systems and people respond?
• Surface observation is not enough
  • Need to couple disciplines, build better models
  • Look into the subsurface and better describe the total system
New Infrastructure

National EPSCoR Goals: “Provide strategic programs and opportunities for EPSCoR participants that stimulate sustainable improvements in their R&D capacity and competitiveness”

- Human Infrastructure: New Hires (permanent)
- Physical Infrastructure: Geophysics and hydrology equipment
- Cyberinfrastructure: Databases and HPC
Human Infrastructure

Facility Managers

Elizabeth Traver, SSHL

Brad Carr, FINSE

New Faculty Hires

1. Snow Hydrologist: Noriaki Ohara
2. Hydrogeophysicist (search underway)
3. Integrated Modeler
4. Petrophysicist
Human Infrastructure

**Graduate Students**
Ten supported each year

**Postdocs**
Mehrez Elwaseif (geophysics)
*Search open for 3 more: contact us!*

**Undergraduate Research Fellowships**
25 each semester

**Distinguished Visiting Sabbatical Fellows**
Three fellowships ($33 K) available for 2013 or 2014: contact us!
WyCEHG Teams (and Team Leaders)

**Integrated Modeling** (Ye Zhang)
- Surface/subsurface hydrology connections through new high-performance computing models

**Component Modeling** (Thijs Kelleners)
- Quantify spatial and temporal distribution of water balance components in a target watershed

**Critical Zone Processes** (Cliff Riebe)
- Quantify processes and properties of surface and near subsurface, i.e., the “Critical Zone”

**Geophysical Modeling** (Po Chen)
- Develop new methods for inverting geophysical data to determine subsurface properties

**Hydrogeophysics** (Steve Holbrook)
- Acquire, analyze, and integrate near-surface geophysical data in focus sites

**Mountain Lakes and Climate** (Bryan Shuman)
- Quantify Holocene water-level history through stratigraphic, isotopic, and geophysical studies of mountain lakes

**Disturbances and Fluxes** (Scott Miller and Ginger Paige)
- Predict impacts of climate and development on water distribution to improve water management and planning

**Geochemical Tracers** (Bob Hall and Dave Williams)
- Develop tracer methods to elucidate pathways, residence times, and geochemical transport of water movement

**Snowmelt Partitioning** (Nori Ohara)
- Understand snow redistribution and snowmelt partitioning between subsurface flow and streamflow

**Bark Beetle Impacts** (Brent Ewers)
- Understand hydrological and ecological impacts of bark beetle kills at the watershed scale
What is Hydrogeophysics?

The application of geophysics to hydrological problems.

http://czo.colorado.edu/inter/index.shtml
Hydrogeophysics: Pros and Cons

**Advantages**
- Images of subsurface structure and physical properties over large areas
- Identification of potential flow pathways, aquifers and aquitards
- Inferences (or, with NMR, measurements) of subsurface water distribution

**Disadvantages**
- We generally measure physical properties (e.g., seismic velocity, dielectric constant, electrical resistivity), not hydrological parameters (saturation, porosity, hydraulic conductivity)
- Thus we need transfer functions via petrophysical relationships => **uncertainty**

Minsley et al., 2012, GRL
New Infrastructure: Hydrology

Surface, subsurface & eco-hydrologic observations.

**Nested watershed design:** stream gaging, shallow and deep GW, climate observations, flux towers (4), snow sensors (ultrasonic, pillows, Gamma-ray SWE), StreamPro ADCP; soil moisture....

**Hydroecological observations:** isotope and other tracer studies; SUNA UV Nitrate; stream oxygen; rhodamine; new membrane inlet mass spec; real-time field isotope sampling on towers and rivers; plant hydraulics...

**Technology:** high performance computing (NWSC, CI-WATER); ground-based and airborne LiDAR; remote sensing; field and lab-based science
Wyoming Center for Environmental Hydrology and Geophysics
Wyoming Center for Environmental Hydrology and Geophysics

GPR

Microgravity

Sub-bottom Profiler

Seismic Refraction

DC Resistivity

Magnetic Resonance Sounding

NUMIS Plus Magnetic Resonance system
Wyoming Center for Environmental Hydrology and Geophysics

Capacitively Coupled Resistivity

Complex Resistivity

Seismic Reflection

Magnetics

Electromagnetic Induction

Downhole Logging

Temperature Sensor

Wettax Array (Fluid Res.)

Centralizers (Optional)
2013 Summer Field Course in Ecohydrology and Hydrogeophysics

**Partnership with Jackson State**
- Exchange of students and faculty
- Alternate years in Wyoming & Mississippi; exposure to different landscapes
- This year: Snowy and Laramie Ranges, SE Wyoming in June
- 2-credit course

**Multiple Disciplines**
- Geophysics
- Hydrology
- Tracers and isotopes
- Eco-hydrology
- Field and lab based
- Techniques, data, analyses
10 Research Groups – but not Independent Actors

- Goal: all field research should incorporate teams from tracers, ecohydrology, hydrology & geophysics
- Field data feed all project teams and the modeling groups, who provide insight to the field campaign
- Open data access policies and rigorous commitment to QA/QC, storage & outcome-based effort
- Lift the entire community of scholars
Year 1: Build Local Platforms

Why build local watersheds?
1. Interesting research questions
2. Need to have a local test bed for equipment
3. Summer field course, UW coursework field components
4. Test out ideas, equipment and then launch into the State
Snowy Range Field Sites

- North Platte Drainage
- Nested sample design
- High mountain to valley
- Snow-driven
- Fracture flows
- Managed water
- Beetle-kill pervasive
- Local field site
- Summer field course

- Nash Fork = 21 km²
- Pine beetle kill
- Outwash plain
- Glacial lakes
- Private land
- Little Laramie R. = 410 km²
Snowy Range: Fate of Water in a Changing System

- Goal is to monitor and interpret changes in flow and partitioning of snowmelt, rainfall in Wyoming streams
  - Response to GCC, beetle kill, management
- Look for changes in surface & subsurface fluxes
  - Fracture control
  - Geophysics, tracers
- Nested watershed design
- Target critical hydrologic & ecologic locations
  - Synoptics runs
- Partner with USFS, share data with FS, WY G&F
- Private landowners as cooperators for site locations
- Outreach to agencies, citizens through hydrologic extension
Laramie Range: Subsurface Flows

- South Platte Drainage
- Nested sample design
- Snow-dominated high hills valley
- Snow-driven
- Fracture flows
- Managed water
- Beetle-kill pervasive
- Local field site
- Summer field course
Laramie Range: Plot → Watershed → Basin

- 4 sites
  - Each has (4) 2x6 m plots
- Tipping bucket rain gages
- Soil Moisture Probes
- Surface and subsurface flow experiments
  - Tracers
  - Geophysics
Laramie Range: Plot ➔ Watershed ➔ Basin

- 2 Large (67 and 23 km$^2$) watersheds
- 5 additional smaller sub-watersheds nested within the 2 larger watersheds
- Automated depth measurements
- Stream discharge measurements
Laramie Range: Why Hydrology & Geophysics?

High degree of variability in soils, topography, micro climate, and vegetation within the study area.
Laramie Range: Why Hydrology & Geophysics?

More variability; from very xeric sites to broad riparian habitats. Capturing this variability becomes key to modeling the Crow Creek watershed.

Upscaling is major challenge to closing the water balance. Scant overland flow and long lags challenge assumptions of watershed behavior. Need to inform models.
Laramie Range: Why Hydrology & Geophysics?

July storm event
2.7 in. storm
High rainfall intensity (>4 in/hr)
Laramie Range: Why Hydrology & Geophysics?

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**Time to Peak**: 11 hours

**Stormflow duration**: 34.5 hours

**Overland flow duration**: 5 hours

**Time to start of overland flow**: 10 minutes

**Base flow**: 0.2 cfs

**Peak flow**: 1.1 cfs
Laramie Range: Why Hydrology & Geophysics?

- Time to Peak: 13.5 hours
- Stormflow duration: 40.5 hours
- Overland flow duration: 3 hours
- Time to start of overland flow: 10 minutes
Laramie Range: Why Hydrology & Geophysics?

• Even high intensity / volume rainfall events do not penetrate to 40 cm depth in our plots
• Little overland flow observed over several years of observation
• Hydrographs show a subsurface dominated system
  • > 95% lateral / soil / saprolite flow
  • Uncertain transport pathways
Preliminary Results: Geophysics

- Southern Sierra CZO, California: Subsurface porosity (and weathering?) distribution
- Laramie Range, Wyoming: Fracture flow pathways
Southern Sierra CZO
Seismic velocity in the near surface is strongly controlled by porosity (~degree of weathering in hard rocks). By using a rock physics model, we can predict subsurface porosity over large areas from seismic velocities.
GPR Images of Fractures in (Weathered) Granite

What would a GPR image of fractures like this look like?

Vedauwoo, Wyoming
GPR Images of Fractures in (Weathered) Granite

James St. Clair, WyCEHG
Laramie Range Field Site
Laramie Range Field Site
GPR Image: Line 30

What causes strong reflections?

Pit (1 m)
Soil Pit along GPR line: clay layer (filled fracture?) in saprolite
Soil Pit along GPR line: clay layer (filled fracture?) in saprolite
GPR Image: Line 30

The clay layer (0.8 m depth) corresponds to the strong reflection

Pit (1 m)
Resistivity Model

Dipole–Dipole and Wenner Array

Brad Carr, WyCEHG
Resistivity Model with GPR reflectors

Flow pathways?
Seismic velocity may say more about weathering than about fracturing.
Seismic Attenuation Tomography

Note that seismic attenuation shows much more structure than seismic velocity: What is attenuation telling us?
Seismic attenuation may be a more sensitive indicator of fracturing (and water saturation?). (Note this is very preliminary.)
Summary and Outlook

Through WyCEHG we seek to establish:

• Nationally significant facilities in near surface geophysics and hydrology
• Interdisciplinary, cross-institutional teams focused on transforming water research in Wyoming
• A comprehensive external engagement program that includes stakeholders and new tools for decision-makers in water management
• A workforce development program that will train students and connect them to industry internships
• An open-access, national facility for hydrogeophysics that will include state-of-the-art instrumentation and will be sustained by an industry endowment
• Cutting-edge computational research that makes use of the new NCAR-Wyoming Supercomputing Center
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**University of Wyoming**

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