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The Right Answer for the Right Reason

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(Kirchner, 2006)

50 Years of Watershed Modeling
24 – 26 September 2012
Boulder, CO

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Photo credit: Lynn Starnes
What is Watershed Runoff?

ROGER P. BETSON
Tennessee Valley Authority, Knoxville

Betson, Bales, and Pratt, 1980

Roger and Margaret, 2002
Photo credit: Lynn Starnes
Are We Doing Better Than in 1986?

Betson, Bales, and Deane, 1981
Yes...

**Understanding**
- Hyporheic zone and GW-SW coupling
- Transit times of water
- Heterogeneity and “hot spots”
- Terrestrial – Atmospheric feedbacks
- Co-evolution of physical and ecological systems
- Instrumentation
- Data accessibility

**Modeling**
- Agri-ecosystems (DRAINMOD, SWAT)
- Hyporheic zone (OTIS)
- Coupled GW – SW modeling (GSFlow)
- Loose coupling to climate models
- Uncertainty
- Large modeling systems
Watershed Modeling for . . .

- Scientific Understanding
Watershed Modeling for . . .

- Scientific Understanding
- Engineering Design
Watershed Modeling for . . .

- Scientific Understanding
- Engineering Design
- Hazards

Battle Creek at Hermosa, SD
(Driscoll et al., 2011)
Watershed Modeling for . . .

- Scientific Understanding
- Engineering Design
- Hazards

July 2012

July 1934
Watershed Modeling for . . .

- Scientific Understanding
- Engineering Design
- Hazards
- Water-Resources Planning and Management

- Human supply
- Agriculture
- Energy
- Ecosystem needs

A changing climate
Irrigated Agriculture

2008 Farm and Ranch Irrigation Survey,
National Agricultural Statistics Service, 2010
Change in Cropland 2002 – 2007

2008 Farm and Ranch Irrigation Survey,
National Agricultural Statistics Service, 2010
Temporal Redistribution of Streamflow

April – July flow as a fraction of annual flow for 9 western Sierra Nevada rivers. Blue line is 9-yr moving average.

As much as 75% of western water supplies are derived from snowmelt runoff.

Trends in center mass of yearly streamflow, 1945 – 2000 (Dettinger, 2005.)
Redistribution of Floods?

Trend in annual flood peaks for stations having 85 – 127 years of record.

Hirsch, JAWRA, 2011.
Understanding “Redistribution”: Value of Long Record

1925 – 2009: Monotonic Trend
Understanding “Redistribution”: Value of Long Record

1925 – 2009: Monotonic Trend

1882 – 2009: Two-State System

Hirsch, JAWRA, 2011.
Understanding Variability vs. Change

Pacific Decadal Oscillation

Atlantic Multidecadal Oscillation
Temporal Variability in GW Discharge

Cable 1 Temp 2009/03/29 @ 02:43:24

Cable 1 Temp 2009/03/31 @ 09:07:23
GSFlow for Modeling Coupled GW-SW

PRMS hydrologic response units (colored basins) intersected with ModFlow finite-difference cells.

Enhanced soil-zone dynamics (capillary, gravity-flow, and preferential-flow reservoirs).

Vertical unsaturated-zone flow below soils, streams, and lakes using approx. to Richards’ equation.

Model-calculated recharge to water table.

Markstrom, et al., 2008
Model Performance

Simulated (red) and observed (black) annual mean discharges (Alkama et al., 2011, J. Climate, 24)
Model Performance

• Overall, the modelling of past abrupt events does not give us confidence in the ability of complex models to simulate critical threshold behaviour that we know has occurred in the past. (Valdes, Nature Geoscience, July 2011)

• In all examined cases, GCMs generally reproduce the broad climatic behaviours. . . However, where tested, replacement of the modelled time series with a series of monthly averages (same for all years) resulted in higher efficiency. . . At the annual and the climatic (30-year) scales, GCM interpolated series are irrelevant to reality. GCMs do not reproduce natural over-year fluctuations. (Koutsoyiannis, et al., 2008, Hyd. Sci. J.)

• This implies little skill in precipitation calculated at individual grid points, and thus applications involving downscaling of grid point precipitation to yet even finer-scale resolution has little foundation and relevance to the real Earth system (Stephens et al., 2010, JGR, 115)
Attribution of Change

- Non-climatic
  - Water management
    - Reservoirs
    - Consumptive use
    - GW declines
  - Land management
    - Tile drains
    - Changing land use

- Natural variability

- New measurement techniques

- Greenhouse-driven climate disruption.
Watershed Modeling for . . .

- Scientific Understanding
- Engineering Design
- Hazards
- Water-Resources Planning and Management
  - Human supply
  - Agriculture
  - Energy
  - Ecosystem needs
- Prediction of Contaminant Transport
Nitrogen

Nitrate concentration, in milligrams per liter as N

U.S. population

Nitrogen fertilizer input

1993–2003 period of record used in trend analysis of streams

Nitrogen fertilizer input, in millions of tons

U.S. population, in millions of people

Blackstone River at Millville, Massachusetts
San Joaquin River near Vernalis, California

Dubrovsky, et al., 2010
Prediction of Reactive Solute Transit

Measured nitrate concentration in shallow groundwater and deep aquifers by (A) date of sample collection and (B) estimated date when the groundwater was recharged

Dubrovsky, et al., 2010
Water-Cycle Research—
Getting the right answer to the **relevant questions** for the right reason

- **Observing**: Data and data interpretation
- **Understanding**: Physical processes
- **Modeling**: Add value to understanding
- **Communicating**: Ultimate goal

“There is a lot of practical value in learning how natural systems work.”

Thank you

Photo credit: Steve Norbeck, April 21, 1997, Red River of the North at Grand Forks, ND

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Kirchner, J.W., 2006, Getting the right answers for the right reasons: Linking measurements, analyses, and models to advance the science of hydrology, Water Resources Research, DOI 10.1029/2005WR004362.


