Water, Earth and Biota in the Anthropocene
A Research Agenda for Systems in Transition

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Climate and the landscape combine to determine the hydrologic regime.
Co-evolution of structure and dynamics

**Coupling processes across scales**

**Fast dynamics:** e.g. soil moisture
\[ \frac{d}{dt} \Theta = f (\Theta, \text{Vegetation}, \text{Soils}, \ldots) \]

**Slow dynamics:** e.g. vegetation
\[ \frac{d}{dt} \text{Vegetation} = f (\Theta, \text{Vegetation}, \text{Soils}, \ldots) \]

**Very slow dynamics:** e.g. soil properties
\[ \frac{d}{dt} \text{Soils} = f (\Theta, \text{Vegetation}, \text{Soils}, \ldots) \]

Ciaran Harman
Richer view:

Landscape structures have a history. Structures that control hydrology have co-evolved within the context of the landscape.
Newtonian and Darwinian approaches: need a synthesis

“Newtonian”
- Study the individual mechanisms
- Search for universal laws
- Goal is prediction
- Initial and boundary conditions determine solution
- Focus on ideal systems

“Darwinian”
- Study the behavior that emerge from interactions
- Search for weak trends across populations
- Goal is insight/explanation
- System arises from historical contingent factors
- Focus on real systems

John Harte
Welcome to the Anthropocene
Humans have changed the way the world works. Now they have to change the way they think about it, too.

Figure 4. The “human footprint” in the northeastern United States.
Murrumbidgee within the Murray – Darling Basin

- 7.5% of the Murray Darling Basin, draining an area of 84,000Km².
- Murrumbidgee catchment is home to about 545,000 people.
- River supplies water to Riverina agricultural region, considered as South East Australia’s 'food-bowl'.
  - Agricultural production in the catchment is worth over AUD $1.9 billion per annum.

Swainson et al, 2011
CONCEPTUAL REPRESENTATION OF ENVIRONMENTAL FLOWS AND RELATED INDICATORS

- Environment flow as % of river flow
- ** man made Storage Capacity (as a %) comprising dams and weirs
- Population in Murrumbidgee Irrigation Area
42% of NSW grapes

50% of Australian rice

90% of NSW potatoes

80% of NSW carrots
A crystal ball

- Increased productivity is a given with more produced per drop ($ farm output /ML).
- New assets in the valley with primary purpose of efficiently supplying to environmental customer.
- Water trading becoming more efficient and sensitive to climate trends, better than stock traders in Wall Street.
- Less number of farmers, only most water efficient surviving with the rest selling out their water rights.
- Some communities/townships disappearing from the map.
Water Trading

Horticulturalists purchased allocations in low allocation seasons.

Rice growers sold annual allocations.

New private horticultural developments purchased entitlements, but public districts sold entitlement.

Urban purchases.

Dairy and mixed farming bought and sold water, with net entitlement sales to downstream users.

Source: National Water Commission
Socio-Hydrology Research Alliance to Investigate Future Assets Strategy for Murrumbidgee Basin

- Increase the understanding of where the water may move to in the catchment – identify location for new and redundant assets
- Understand the cost of delivery of water within the Basin
- Improved understanding of the value of water within the local communities
- Investigate the development of new assets to deliver water to the environmental customers
  - water efficiency measures
  - New water storages

Understand inter-dependence of hydrology to other elements in the watershed:

- River Morphology
- Ecology, Biodiversity
- Hydrology
- River Flows/ Groundwater
- Storage, Diversions, extractions
- Socio-economic values
- Hydro-meteorological processes, Climate Change
Predictions under Change

Natural systems don’t exist, they evolve

HUMANS AS DRIVERS OF GLOBAL WATER CYCLE CHANGE
END OF STATIONARITY END OF LINEARITY START OF COMPLEXITY
HYDROLOGY OF AN EVOLVING LANDSCAPE

Focus on understanding, predictability, sustainability
What must we do to face the new prediction challenges?

• Non-stationarity: Embrace the time arrow

Vörösmarty and Sahagian 2000 BioScience
What must we do to face the new prediction challenges?

- Non-stationarity: Embrace the time arrow
- Inter-connectedness: Hydrology is not just about water!

Many serious problems with a hydrologic component are also ecologic, geomorphic, economic, (etc, etc...), problems
What must we do to face the new prediction challenges?

- Non-stationarity: Embrace the time arrow
- Inter-connectedness: Hydrology is not just about water!
- Newtonian-Darwinian synthesis: Connect the individual to the population

Relate behavior of particular systems to other systems with similar history or conditions

Sivapalan et al 2011 WRR
What must we do to face the new prediction challenges?

- Non-stationarity: Embrace the time arrow
- Inter-connectedness: Hydrology is not just about water!
- Newtonian-Darwinian synthesis: Connect the individual to the population
- Socio-hydrology: a new science of people and water

Human activities are part of the landscape, and human choices are conditioned on environmental change

Foley et al 2005 Science
• Growth of understanding
• about the hydrology of landscapes

It is a conceptual model of the science, NOT of the system

Ciaran Harman
Drivers + Structure + Dynamics
Five types of science questions: PI Science along Hydrocomplexity Spiral

Ciaran Harman

from systems-thinking.org, Gene Bellinger
Water Cycle Projections over Decades to Centuries at River Basin to Regional Scales

Need for “Big/Team Science”
Water Cycle Projections over Decades to Centuries at River Basin to Regional Scales

Investment in “Big/Team Science”

Real Time

Co-Evolution

Time for Time

Function?

Regime

Space for Time

Space
Summary

• **PI Science along the Hydro-complexity Spiral**
  • (co-evolution modeling, socio-hydrology, discovery of organizing principles, predictability/ uncertainty)

• **Big/Team Science**
  • **Space for time**: comparative hydrology, analysis across a climatic or human impact gradient
  • **Time for time**: historical reconstruction
  • **Real-Time learning**: interactive modeling and observation in real places where real people live

Water Cycle Projections over Decades to Centuries at River Basin to Regional Scales