Water Resource Planning in a Changing World

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Amherst, MA
Outline of Talk

- Challenges Associated With Trend Detection, Attribution, Prediction and Response
- Are Flood (Damages) Increasing or Decreasing?
- Planning under Nonstationarity
- Hydromorphology – Dealing with a morphing hydrosphere
Trend Detection and Attribution: Grand River, Michigan

Drains intensively cultivated land and received increased inputs of nitrogen fertilizer throughout the 1970s.

Point-source nitrogen loads decreased during late 1970s as a result of improved municipal waste treatment.

Aberjona River, Massachusetts
24 sq. mi. urban catchment northwest of Boston
Like Clockwork, and Like Urbanization, Annual Maximum Flood Discharges are steadily increasing.
Note how 100-year flood on Aberjona River has steadily increased from one decade to the next.
It is not only floods on Aberjona River which are influenced by urbanization.

![Graph showing increased flows from 1940s-1950s to 1960s-1970s to 1980s-1990s]
Trend Detection is All about Data (or lack thereof)
“While trend magnitude can be determined with little ambiguity, the corresponding statistical significance, sometimes cited to bolster scientific and political argument, is less certain…”
Most trend studies in US have employed the USGS Hydro Climatologic Network (HCDN)


1474 Stations

Average Record Length = 48 years
The Problem of Statistical Significance

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Douglas et al (2000) findings, HCDN basins:

• Ignoring spatial and temporal correlation led to many significant trends

• Accounting for spatial and temporal correlation made those trends disappear!
Which Is It?

Increasing risk of great floods in a changing climate

P. C. D. Milly*, R. T. Wetherald†, K. A. Dunne* & T. L. Delworth†

No upward trends in the occurrence of extreme floods in central Europe

Manfred Mudelsee¹*, Michael Börngen¹, Gerd Tetzlaff¹
& Uwe Grünewald²
A short lesson in statistics

We only have control over probability of type I error, $\alpha$
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Type I Error Should Always be Worst Error

The Elevator Cable Problem

<table>
<thead>
<tr>
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<th>Cable too Weak</th>
<th>Cable too Strong</th>
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<tbody>
<tr>
<td>Don’t Use Cable</td>
<td>No Error</td>
<td>Type II Error (overdesign)</td>
</tr>
<tr>
<td>Use Cable</td>
<td>Type I Error (underdesign)</td>
<td>No Error</td>
</tr>
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</table>

Because we have control over probability of type I error
Traditional Approaches for Planning for Change

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<table>
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<th>Our Decision</th>
<th>Trend in Floods</th>
<th>No Trend in Floods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adapt</td>
<td>1 - α</td>
<td>β</td>
</tr>
<tr>
<td></td>
<td>Type II Error</td>
<td>Type II Error</td>
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<tr>
<td></td>
<td>(over-design)</td>
<td>(over-design)</td>
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<tr>
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<td>α</td>
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<td>Type I Error</td>
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<td></td>
<td>(under-design)</td>
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- Why have all previous trend studies assumed the null hypothesis is NO TREND?
- This implies we are only concerned about over-design!
- Shouldn’t we be more concerned about under-design?
Planning for change is a statistical decision problem.
Application of Statistical Decision Theory to Planning
Application of Statistical Decision Theory to Planning

The Sweet Spot

Probability of Detecting a Trend

Probability of Overdesign

Theory

1970

2011
Water Resource Planning in a Changing World

A noted hydrologist, Yogi Berra, claims that

"We're getting those 100-year floods more often than we used to"
Flood Trends: Attribution

Flood fatalities in Africa: From diagnosis to mitigation

Giuliano Di Baldassarre, Alberto Montanari, Harry Lins, Demetris Koutsoyiannis, Luigia Brandimarte, and Günter Blöschl


“We find that intensive and unplanned human settlements in flood-prone areas appears to be playing a major role in increasing flood risk.”
Flood fatalities in Africa: From diagnosis to mitigation

Giuliano Di Baldassarre,¹ Alberto Montanari,² Harry Lins,³ Demetris Koutsoyiannis,⁴ Luigia Brandimarte,⁵ and Günter Blöschl⁶

1950-2000 Fatalities in Africa caused by floods
Flood fatalities in Africa: From diagnosis to mitigation

Giuliano Di Baldassarre, Alberto Montanari, Harry Lins, Demetris Koutsoyiannis, Luigia Brandimarte, and Günter Blöschl


1950-2000 Total and Urban Population in Africa
Figure 4. Spatial distribution of population growth (number of inhabitants per cell; resolution 2.5') in Africa in the period 1960–2000; and location of floods (dots) and deadly floods (black circles) in the period 1985–2009.

Flood fatalities in Africa: From diagnosis to mitigation

Giuliano Di Baldassarre,¹ Alberto Montanari,² Harry Lins,³ Demetris Koutsoyiannis,⁴ Luigia Brandimarte,⁵ and Günter Blöschl⁶
“Based on the results of both continental and at-site analyses, we find that the magnitude of African floods has not significantly increased during the Twentieth Century and that climate has not been a consequential factor in the observed increase in flood damage.”
Define Flood Magnification Factor,

\[ M = \frac{T - \text{year flood in year } t + \Delta t}{T - \text{year flood in year } t} \]

Decadal Magnification Factors of Floods – Sites w/ no regulation
1,642 of 14,893 USGS Gage Sites

Legend
- Magnification Factor (p>0.9)
  - <1.25
  - 1.25-1.5
  - 1.5-2
  - 2-5
  - >5
- Stream Gage (>10 yrs record)

From Vogel et al. (2011) JAWRA, in press
Decadal Flood Magnification Factors
Sites With No Regulation

From Vogel et al., 2011, in press, JAWRA
Decadal Flood Magnification Factors - HCDN Sites

From Vogel et al. (2011) JAWRA, in press
Decadal Flood Magnification Factors

Summary

Magnitude of climate induced trends (HCDN) are minimal compared with other anthropogenic induced trends

From Vogel et al., (2011) in press, JAWRA
Water and Climate Change

Carbon Dioxide in the Atmosphere

Carbon Dioxide Levels Today are Higher than over the Past 650,000 Years

Industrial CO₂ Levels
Pre-industrial CO₂ Levels

New Antarctic ice core data extends the record back to 650,000 years before the present and shows that CO₂ levels were below 300 ppmv.
“Today the time for doubt has passed. The IPCC has unequivocally affirmed the warming of our climate system, and linked it directly to human activity.”

(UN Secretary General, November 2007)
Shrinking of Arctic Sea Ice
(from Epstein, 2008)

Extent of Ice Cover (millions of sq. mi)

1978  Year  2008
Figure 6. Field photograph of terminus region of Chhota Shigri glacier, Lahaul and Spiti district, of HP taken in 1988 and 2003. In 1988, glacial ice is exposed on the surface and small portion of the terminus is covered by debris. By year 2003, the entire terminus zone is covered by debris.

Glacial retreat in Himalaya using Indian Remote Sensing satellite data

Anil V. Kulkarni¹, I. M. Bahuguna¹, B. P. Rathore¹, S. K. Singh¹, S. S. Randhawa², R. K. Sood² and Sunil Dhar³
Increased Coastal Flooding under Climate Change

-More coastal erosion

Brandt Beach Long Beach Island, NJ
Coastal Flooding in Boston under Present and High Emission Sea Levels

Source: NECIA/UCS 2007
Boston: The Future 100-Year Flood under the Higher-Emissions Scenario

Source: NECIA/UCS, 2007 (see: www.climatechoices.org/ne/)
Taking on Water

ARE WE PREPARED IF LAST MAY’S DAMAGING FLOODS IN PEBODY AND SURROUNDING AREAS MAKE A REPEAT PERFORMANCE? BY JEREMY MILLER

The storms that dropped more than a foot of rain in 24 hours on northeastern Massachusetts last May are not likely to fade from memory, or the record books, any time soon. After the deluge, parts of Lawrence and Lowell were under five feet of water, and sections of downtown Peabody sat under more than twice that much. Tons of raw sewage sluiced from municipal sewer systems into regional waterways. More than 4,000 residents in 17 communities throughout Middlesex, Essex, and Suffolk counties fled the rising floodwaters. Just more than $70 million in state and federal aid poured in to finance the recovery and repair of nearly 11,000 damaged households and businesses.

These were the dreaded “100-year floods,” a designation applied to a defined area of land with a 1 in 100 chance of experiencing a flood of this magnitude in a single year. It serves as a key guideline for the design and maintenance of flood defenses, as well as zoning and home insurance premiums.

But many in the Boston engineering community say our 100-year flood boundaries are dangerously outdated. They point to Peabody and its perennial downtown floods.

Richard Carnevale, Peabody’s public services director, says his town has experienced five so-called 100-year events in the last 10 years. It doesn’t take an actuary to see something’s amiss here. The odds of five 100-year floods in the span of a decade, says Tufts environmental civil engineering professor Richard Vogel, is about one in 48 million. Serious, repeat floods aren’t unique to Peabody. In the last decade, Massachusetts saw six federal states of emergency related to flooding—all involving one or more of the state’s most populous, and built up, eastern counties.

Vogel says our flood designations don’t account for one critical variable: urban development. In natural settings, rainwater soaks into the earth, eventually percolating into aquifers deep underground. But in the concrete terrain of modern cities,
Tufts University

Of 377 records with n>20 yrs, 119 or about 25% probably have trends

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NOAA - NWS is Currently Updating Precipitation Frequency Maps for the US

Example of a NOAA - NWS Atlas 14 for Virginia
100 year 24-hour storm
Of 377 records with n>20 yrs, 119 or about 25% probably have trends.

Status of NOAA Atlas 14 Updates
Given the current emphasis on climate change by NOAA and other agencies:

- Given the plethora of NOAA - NCDC and other studies which document increases in precipitation frequencies and magnitudes

- Why is the NOAA – NWS office updating Atlas 14 WITHOUT including trends?
Part 1 - Summary

Nonstationarity poses a central challenge to our field.

We still do not have a systematic approach for water planning in a nonstationary world.

Statistical decision theory (statistics + decision theory) provides a rigorous approach to water resource planning under nonstationarity.
Water Resources Planning in a Changing World

A New Field of Engineering and Science is Needed to Address Planning Under Nonstationarity

Naming the problem is a first step …
What is HYDROMORPHOLOGY?
A new branch of hydrology

GEOMORPHOLOGY
is to
GEOLOGY
AS
HYDROMORPHOLOGY
is to
HYDROLOGY
GEOMORPHOLOGY
A branch of geology

Geomorphology deals with structure of the earth's surface and the evolution of processes controlling topography of the earth.
The evolution of earth's topography is due to both natural and anthropogenic processes.
HYDROMORPHOLOGY
A subdiscipline of hydrology

Hydromorphology deals with structure and evolution of hydrologic systems
due to complex coupling between human and natural systems
Hydromorphologic problems represent scientific, social and engineering challenges related to how humans reshape fresh-water systems through modifications to the landscape, water infrastructure, and climate, and how our reshaped water systems influence life on the planet.

- Article in progress by:

- A CUAHSI Hydrologic Synthesis Center Initiative
Why do we need a new field of HYDROMORPHOLOGY?

Human influences are now pervasive

Virgin watersheds no longer exist.
Virgin or Pristine Watersheds No Longer Exist – “Stationarity is Dead” (Milly et al., Science, 2008)
The Net Impact of Dams and Human Water Use

Colorado River Delta Runs Dry


Fig. 1. Colorado river flows below all major dams and diversions, 1905 to 2001. Data are flows of the Colorado River as measured at U.S. Geological Survey Gage 09-5222, 35 km downstream from Morelos Dam. As shown, flows reaching the Colorado River delta have dropped to near zero in most years.
It is no longer possible to ignore human impacts on hydrologic systems
Hydromorphology deals with the impacts of humans on hydrologic systems.
Tufts University

Hydromorphology also deals with the impacts of water on humans.

Water Pollution and Water Scarcity

Are the two biggest water challenges of the 21st Century.
Hydromorphology also deals with the impacts of water on humans.

Today, 1 out of 6 people, more than a billion

Suffer from inadequate access to safe freshwater
Hydromorphology also deals with the impacts of water on humans.
## Hydromorphology: A Field/Word Needing Definition

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<tr>
<td>Hydromorphology</td>
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Human Induced Hydromorphologic problems are in their infancy

Global Population Growth

Population in Billions

YEAR (AD)
What is needed to move forward?

• All existing water resource planning methods need revisions to account for human impacts and nonstationarity

• Problems cannot be solved piecemeal:
  • Stormwater problems are also water supply problems
  • Nonstationarity results from changes in climate, land use and water use
Systems Modeling Methods are Needed

Integrated Watershed Management Modeling: Generic Optimization Model Applied to the Ipswich River Basin

Viktoria I. Zoltay, A.M.ASCE; Richard M. Vogel, M.ASCE; Paul H. Kirshen, M.ASCE; and Kirk S. Westphal, M.ASCE

Tufts University
SW = surface water; GW = groundwater; WTP = water treatment plant; P use = potable water use; NP use = nonpotable water use; ASR = aquifer storage and recharge; and WWTP = wastewater treatment plant.
Beirut, Lebanon

- Integrated water supply optimization model
- Includes wastewater disposal, and reuse options
- Considers entire anthropogenic water cycle
- Considers both potable and nonpotable sources
A Systems Approach to Solving Flood Problems on Aberjona River

Optimal Location of Infiltration-Based Best Management Practices for Storm Water Management

Cristina Perez-Pedini, M.ASCE¹; James F. Limbrunner, M.ASCE²; and Richard M. Vogel, M.ASCE³
Aberjona river discharges are on the rise
Where Should We Site Best Management Practices on Aberjona River to Control Downstream Flooding?

Aberjona flood, Winchester Center 2001
Results

Potential BMP locations

BMPs
Factors Influencing BMP Placement

- High CN values
- Large and impervious contributing areas
- Flow arrival time resonance with other hydrologic response units
Summary

We can no longer ignore anthropogenic influences on the hydrologic cycle.

Hydrologic science and engineering methods must deal with a changing hydrosphere.

All the hydrology textbooks need to be rewritten to include humans and to deal with nonstationarity.
Summary

Hydromorphological Science

“understanding the role of land use, climate and infrastructure on the hydrologic cycle”

Hydromorphological Engineering:

“Hydrologic engineering in a changing hydrosphere”
University of Massachusetts at Amherst is Poised Because:

- **Systems** approaches are needed to address future hydromorphological challenges
- Univ. of Mass. Amherst is a **Systems** Powerhouse with:
  - Rick Palmer, Casey Brown & David Ahlfeld in Civil & Environ Engr
  - And their **Systems** colleagues in Industrial Engineering
Questions?

Thanks for Listening