Earth Intelligence:

The Fourth Industrial Revolution, The National Water Model, and the Future of Water Prediction

Dr. Donald W. Cline

USGS Associate Director for Water Resources

A Brief History of Industrial Revolutions (IR)

- **First IR (Began late 18th Century)**
  - Production mechanized through water and steam power
- **Second IR (Began early 20th Century)**
  - Mass production created through electric power
- **Third IR (Began 1950s to 1970s)**
  - Rapid growth in computing and communication enabled by shift from mechanical and analog electronic technology to digital electronics
- **Fourth IR (Now)**
  - Unknown consequences from technological fusion that is blurring the lines between physical, digital, and biological spheres

Fourth Industrial Revolution

- **What distinguishes the fourth IR?**
  - Speed of current breakthroughs has no historical precedent – evolving at an exponential rather than linear rate
  - Disrupting almost every industry in every country
  - Breadth and depth of these changes herald transformation of entire systems of production, management, and governance

Fourth IR Technology Clusters Relevant to Environmental Applications

- 3D Printing
- Advanced Materials
- Artificial Intelligence
- Robotics
- Drones and Autonomous Vehicles
- Biotechnologies
- Energy Capture, Storage and Transmission
- Geo-engineering
- Internet of Things
- New Computing Technologies
- Advanced Sensor Platforms
- Virtual, augmented and mixed reality

3D Printing-Based Integrated Water Quality Sensing System

Muinul Banna [1], Kaustav Bera [2], Ryan Sochol [3], Liwei Lin [4], Homayoun Najjaran [1], Rehan Sadiq [1] and Mina Hoorfar [1,*]

Why Build the NWM?

Address Societal Need by Leveraging the 4th IR

Water and the Global Economy

WORLD ECONOMIC FORUM

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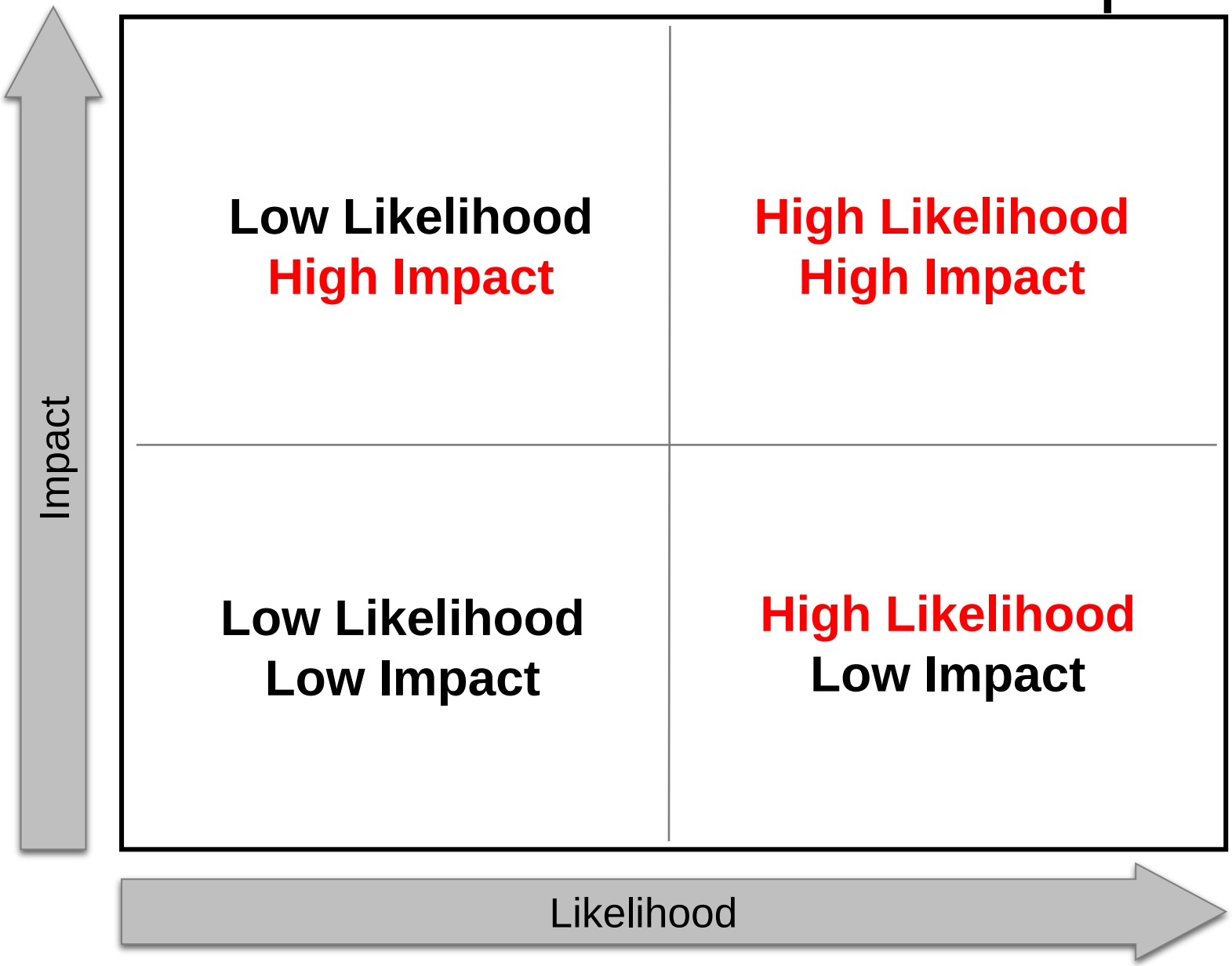
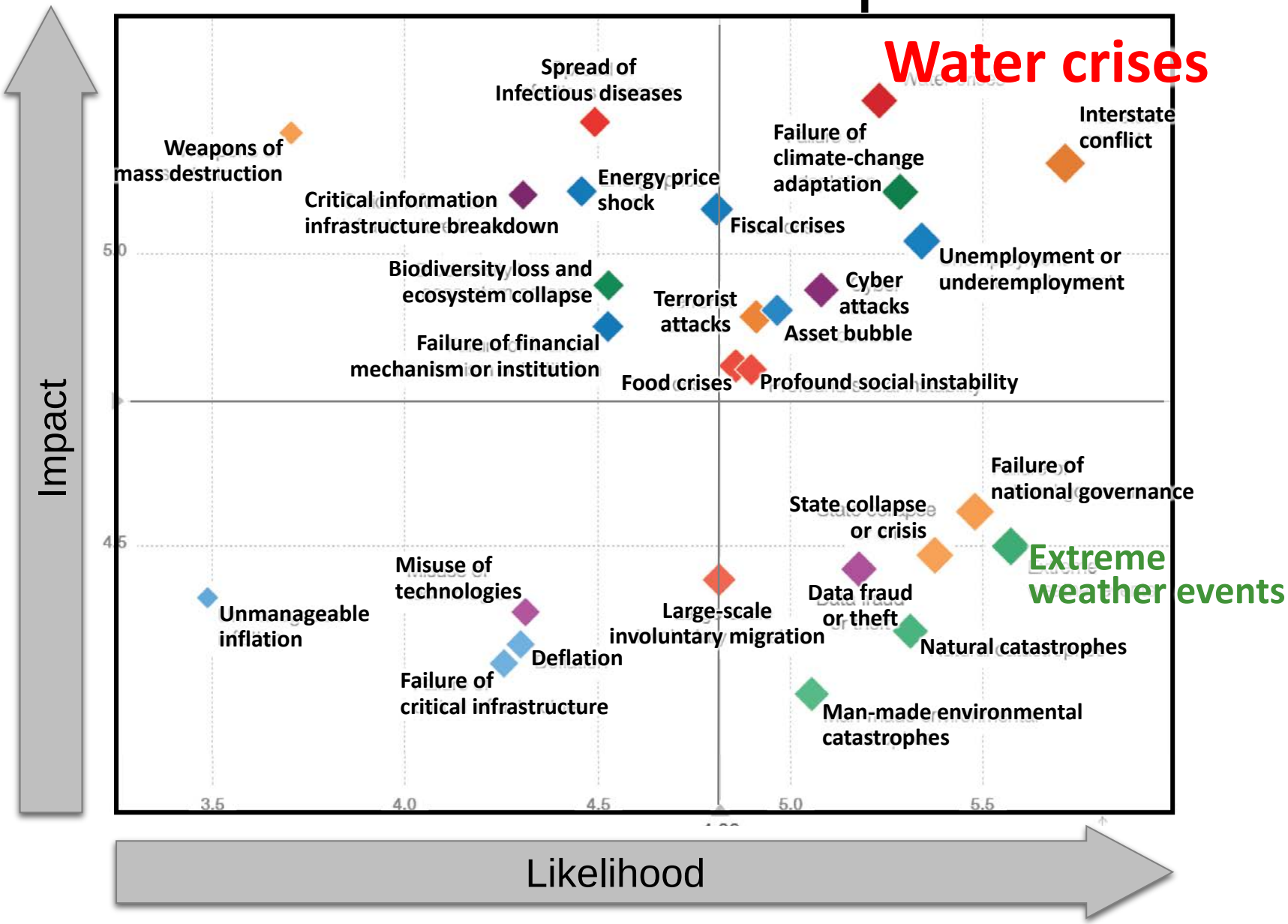
WEF Global Risks Landscape



Annual Survey; Typically 600-1000 respondents

Global Risks Landscape 2015



Insight Report: Global Risks 2015, 10th Edition, World Economic Forum, Geneva.

Water Stakeholders have Integrated Priorities

Flooding

Water Quality

Water Availability

Drought

Climate Change

Need integrated understanding of near- and long-term outlook and risks

Actionable Water Intelligence

Integrated Water Analyses, Predictions and Data

Hydrologic Economic Demographic Environmental Political

NATIONAL WATER MODEL

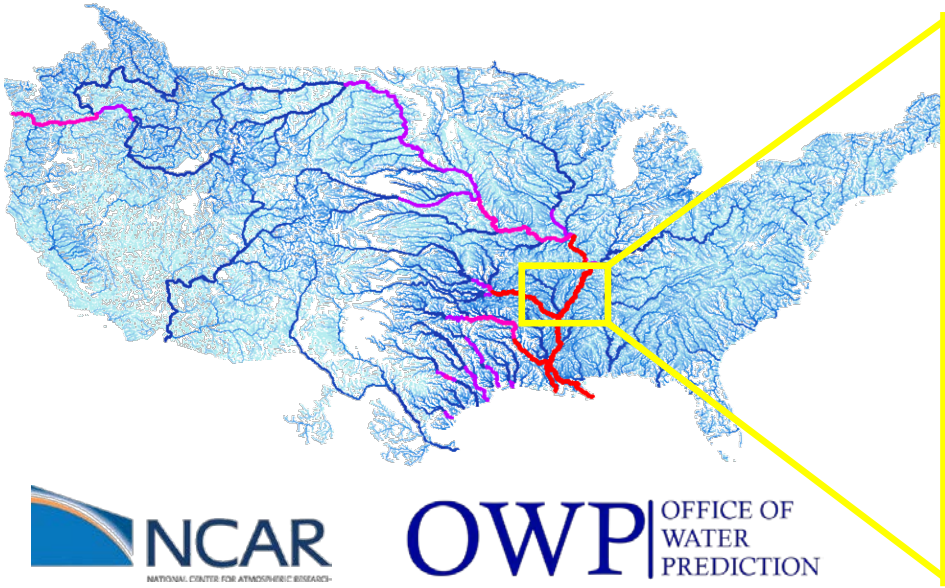
Movie (slide show to view)

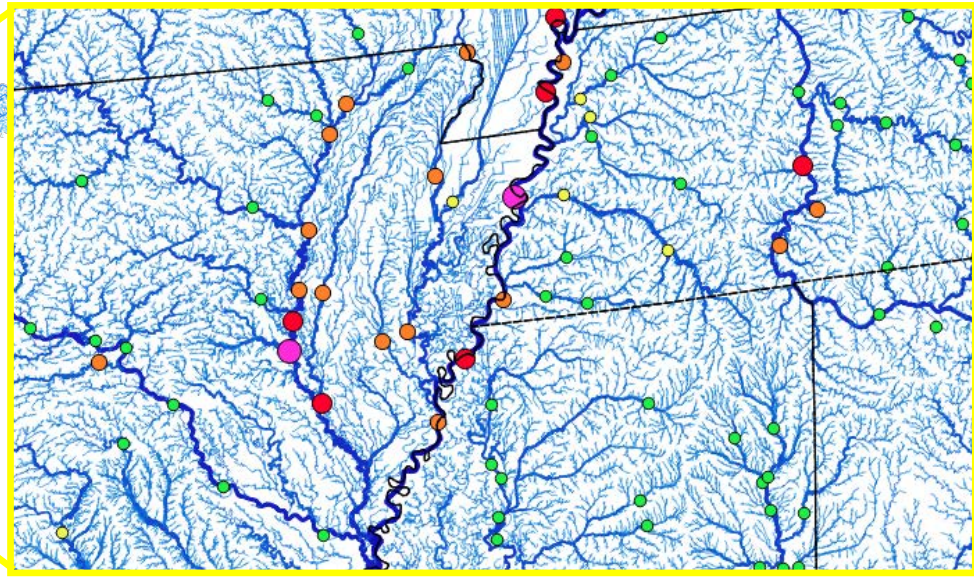
National Water Model

Initial Operating Capability – v1.0 implemented August 16, 2016

- **Spatially continuous estimates of major water cycle components** (e.g., snowpack, soil moisture, channel flow, major reservoir inflows, flood inundation)
- Operational forecast **streamflow guidance for currently underserved locations**: 3,600 forecast points → 2.7 million NHDPlus river reaches (700 fold increase in spatial density)
- Employs an **Earth system modeling architecture** that permits rapid model evolution of new data, science and technology (i.e. **WRF-Hydro**)

Current NWS River Forecast Points overlaid with NWM Stream Reaches

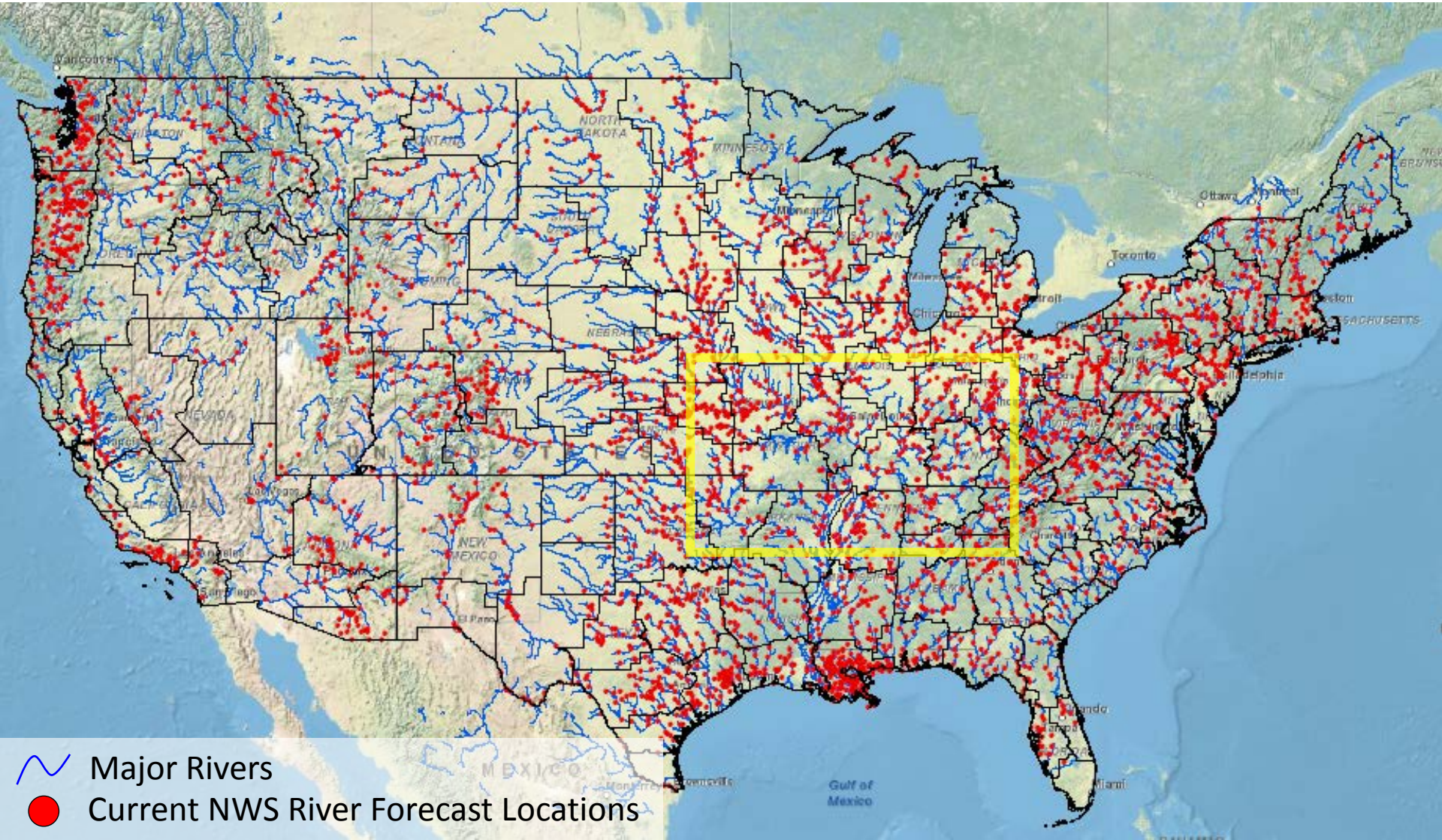




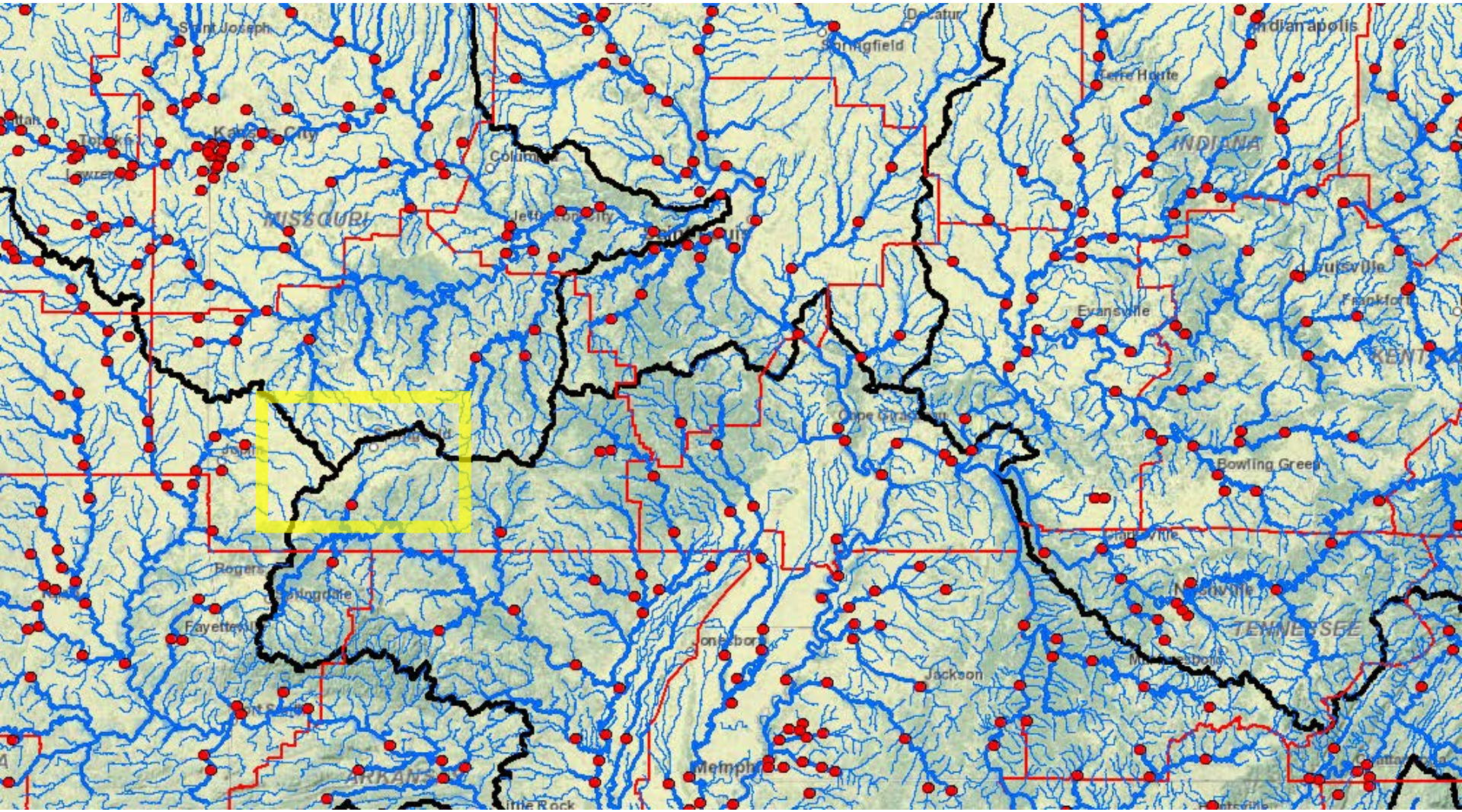
NCAR

OWP OFFICE OF WATER PREDICTION

Major Rivers and Traditional NWS Hydrologic Forecast Points
(~4000 USGS Streamgages)



Major Rivers and Traditional NWS Hydrologic Forecast Points



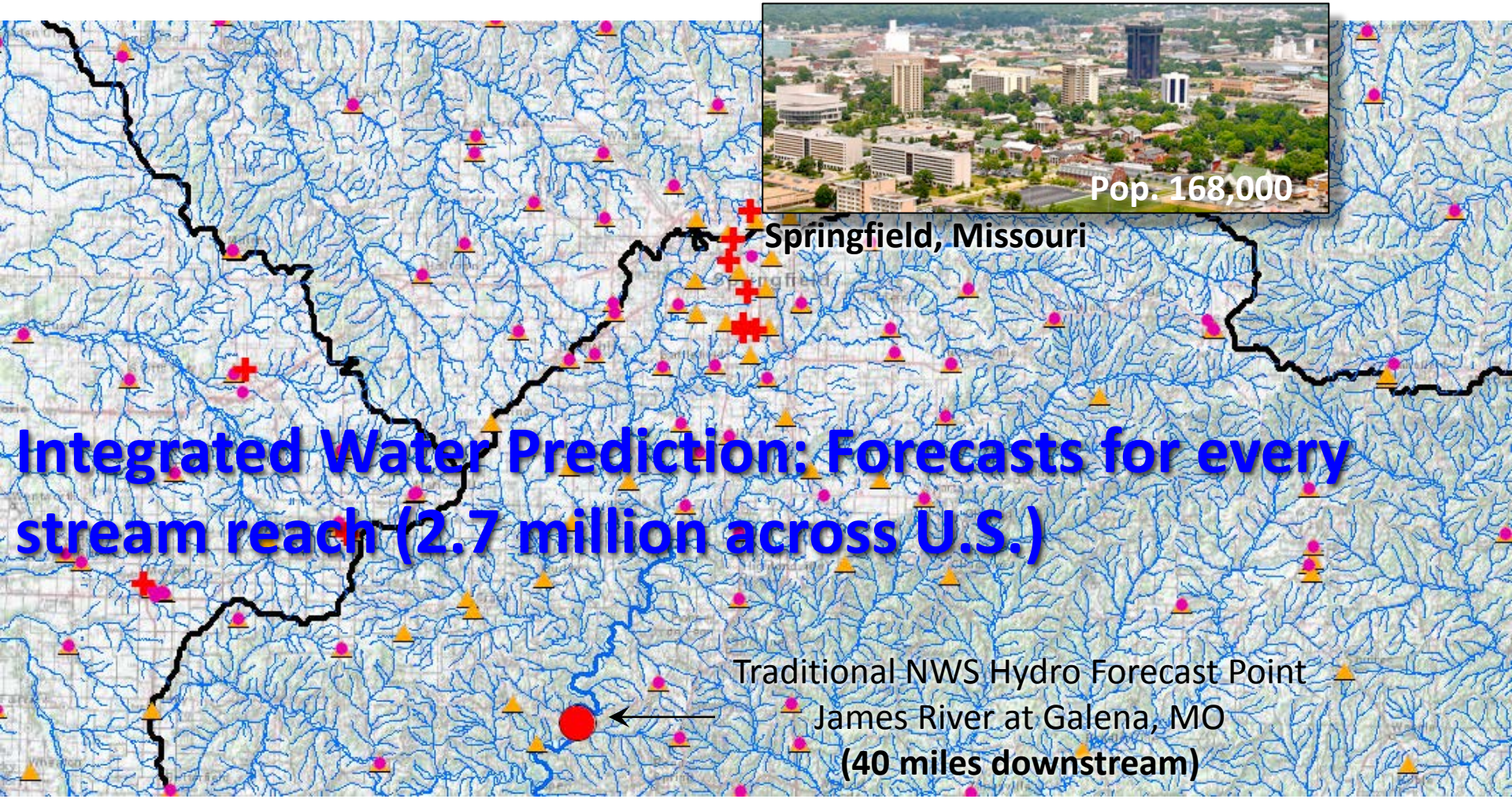
1000 km

Current NWS River Forecast Locations

WATER PREDICTION + NATIONAL INFRASTRUCTURE

Hospitals, EMS & Fire Stations

Full Resolution National Hydrography Dataset NHD+

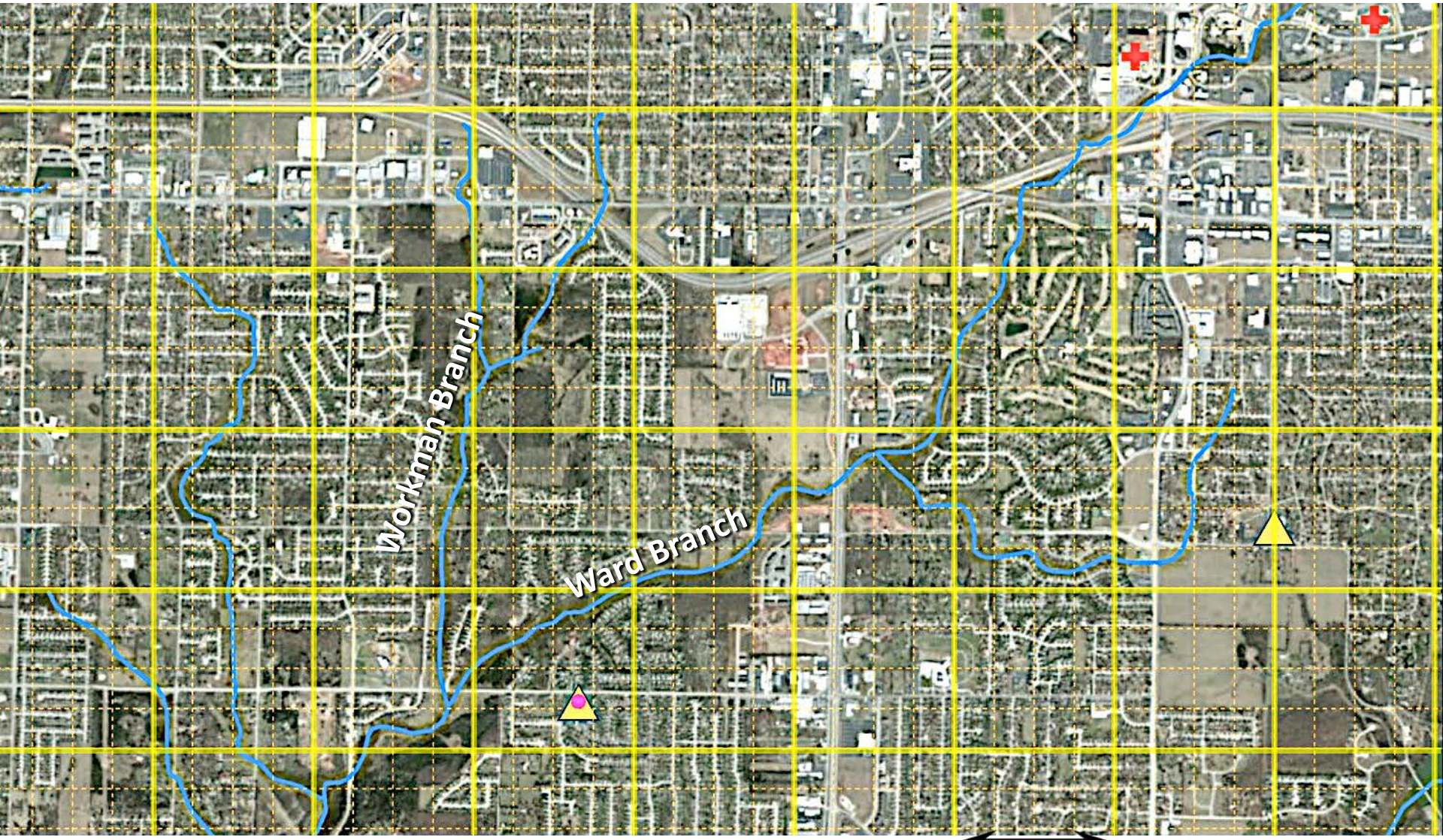


Hospitals EMS Fire

Infrastructure Data from National Geospatial Intelligence Agency

Hospitals, EMS & Fire Stations

Full Resolution National Hydrography Dataset NHD+



Hospitals EMS Fire

NWM Streamflow Forecast for Hurricane Harvey

10 Day Forecast (left) and corresponding Analysis (right): 12Z Aug 22 – 12Z Sep 1

Overall extreme streamflow pattern forecast several days in advance by NWM

What’s Next?

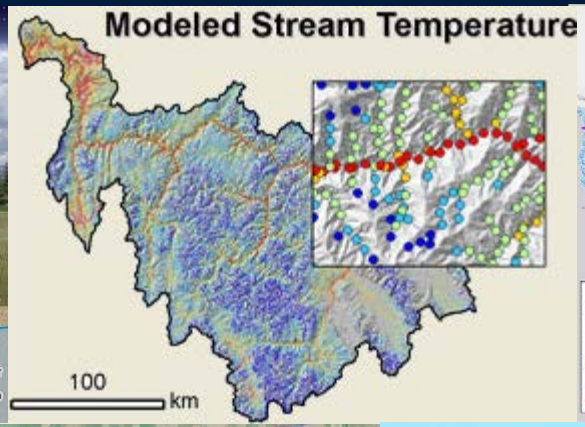
National Water Model 2.0 and Beyond…

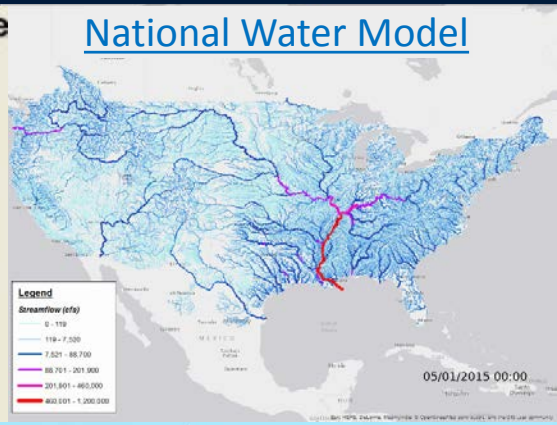
Water Prediction Work Program (2WP)

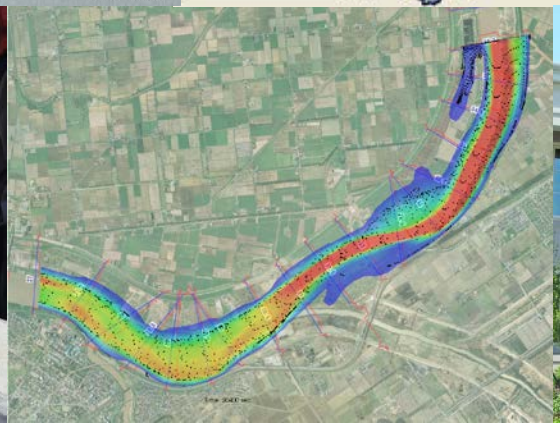
National Water Model 2.0

Don Cline

USGS Associate Director, Water Resources







2WP Development
Major Prediction Components

Add three new capabilities to the National Water Model:

- **Water Temperature**
  - National analysis (i.e. ”nowcast”) and prediction of thermal characteristics of every stream reach in NHD+ hydrography (N = 2.7 million)
- **Surficial Processes: Erosion and Sediment/Constituent Entrainment**
  - National analysis and prediction of sources, characteristics, and movement of materials that end up in NHD+ stream channels
- **In-Channel Constituent Transport**
  - National analysis and prediction of materials being transported in NHD+ stream channels, including physical and chemical fate

Environment and the Economy

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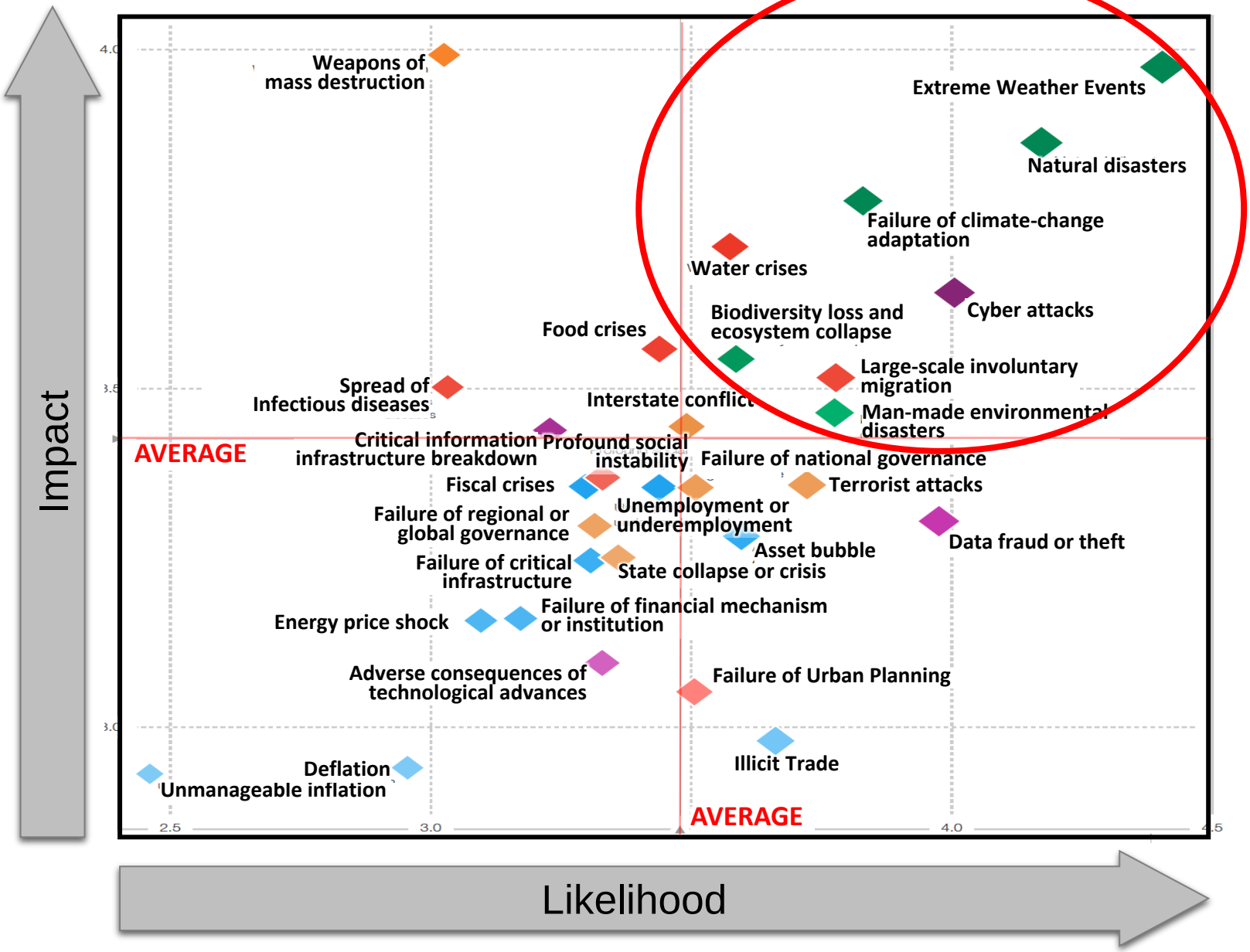
Global Risks Landscape 2018



Insight Report: Global Risks 2018, 13th Edition, World Economic Forum, Geneva.

WEF Vision: A Real-Time Digital Dashboard of the Earth

- A real-time, open API digital geospatial dashboard for the planet would enable the monitoring, modeling and management of environmental systems at a scale and speed never before possible.
- We have the AI methods to do this, but we need more information, more frequently received and at greater resolution than present.
- Challenge is to build something truly transformational, easy to use in real-time, open-access and data dense.

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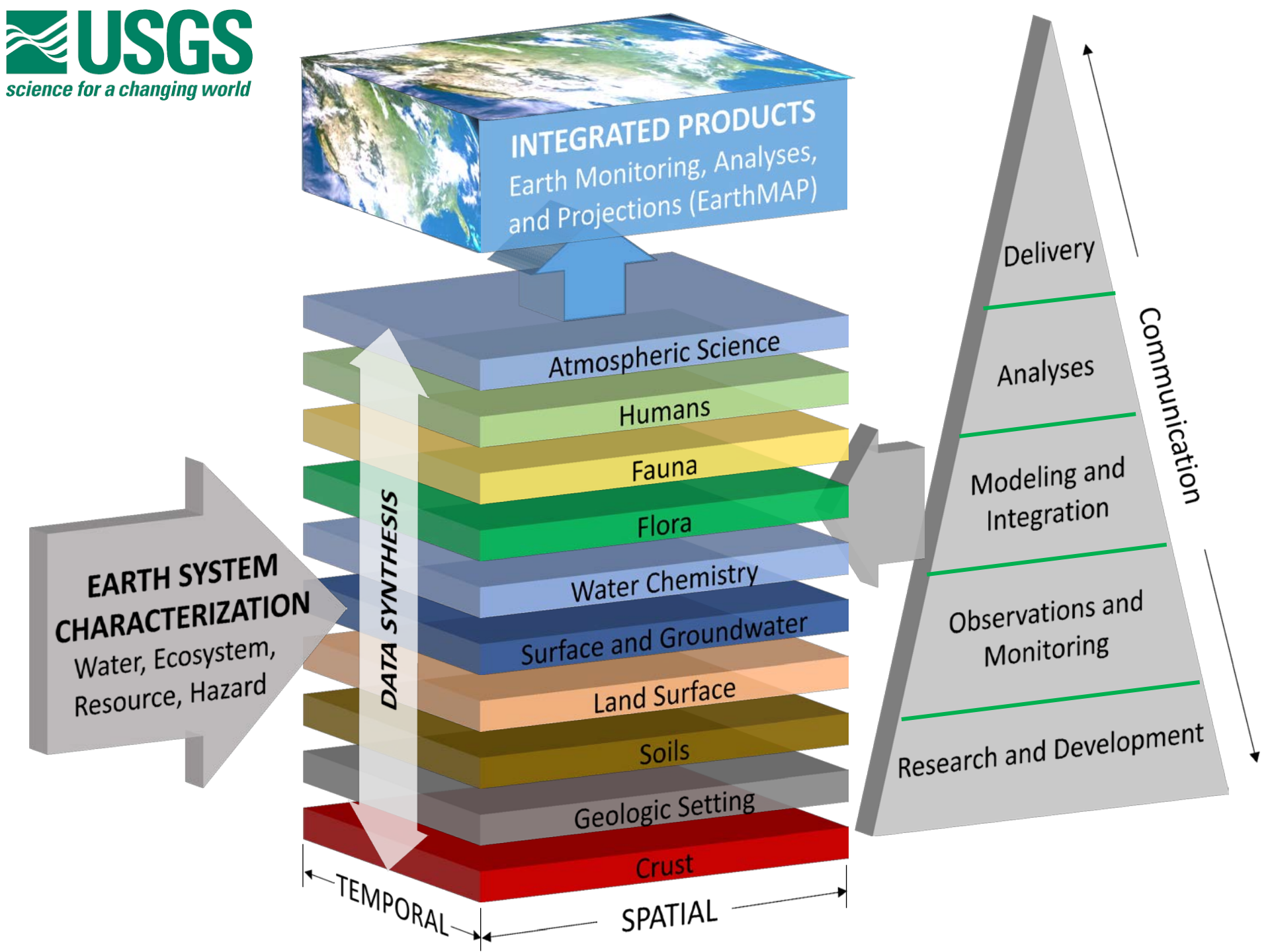
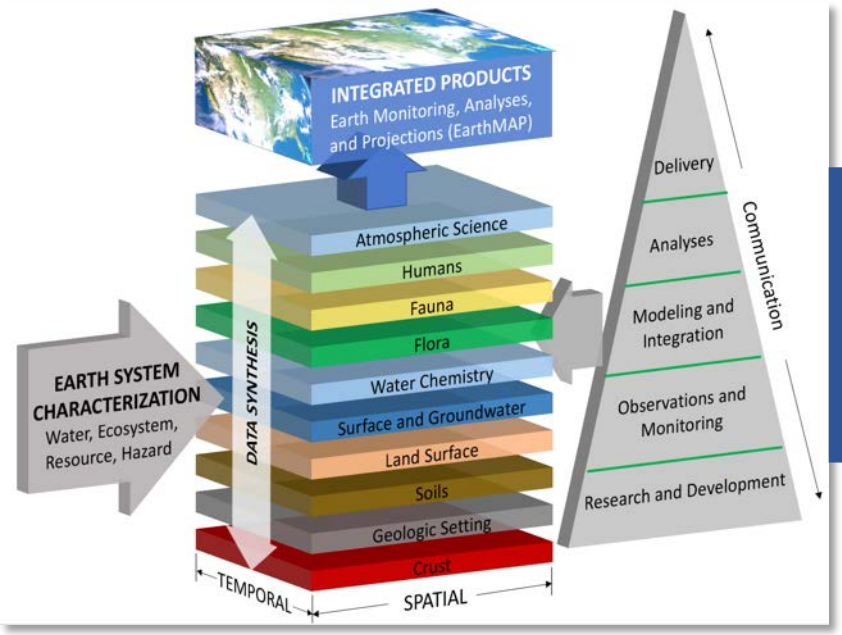
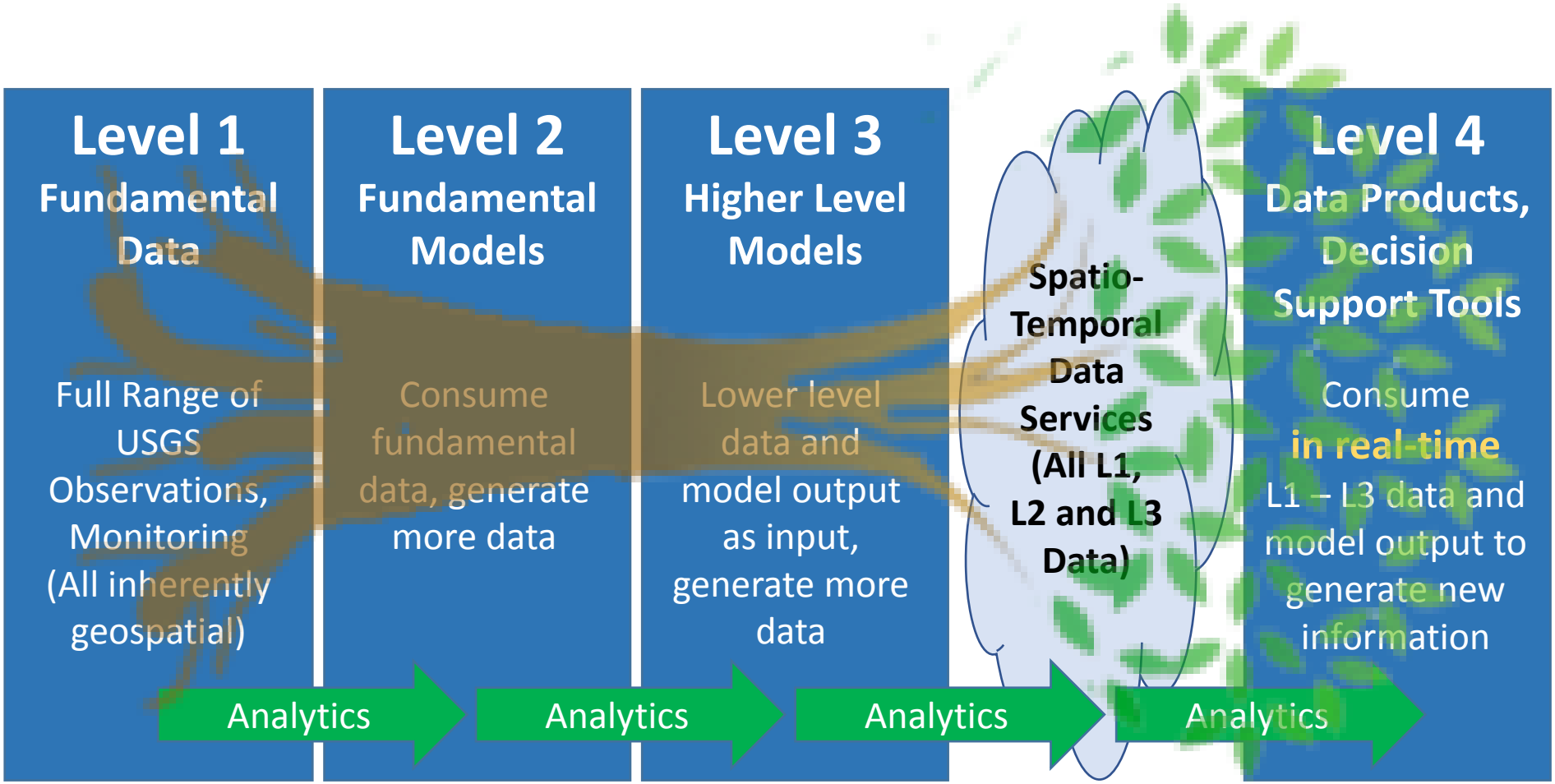

USGS
science for a changing world
INTEGRATED PRODUCTS
Earth Monitoring, Analyses, and Projections (EarthMAP)
EARTH SYSTEM CHARACTERIZATION
Water, Ecosystem, Resource, Hazard
DATA SYNTHESIS
Atmospheric Science
Humans
Fauna
Flora
Water Chemistry
Surface and Groundwater
Land Surface
Soils
Geologic Setting
Crust
TEMPORAL
SPATIAL
Delivery
Analyses
Modeling and Integration
Observations and Monitoring
Research and Development
Communication

USGS Integrative Predictive Science Capacity

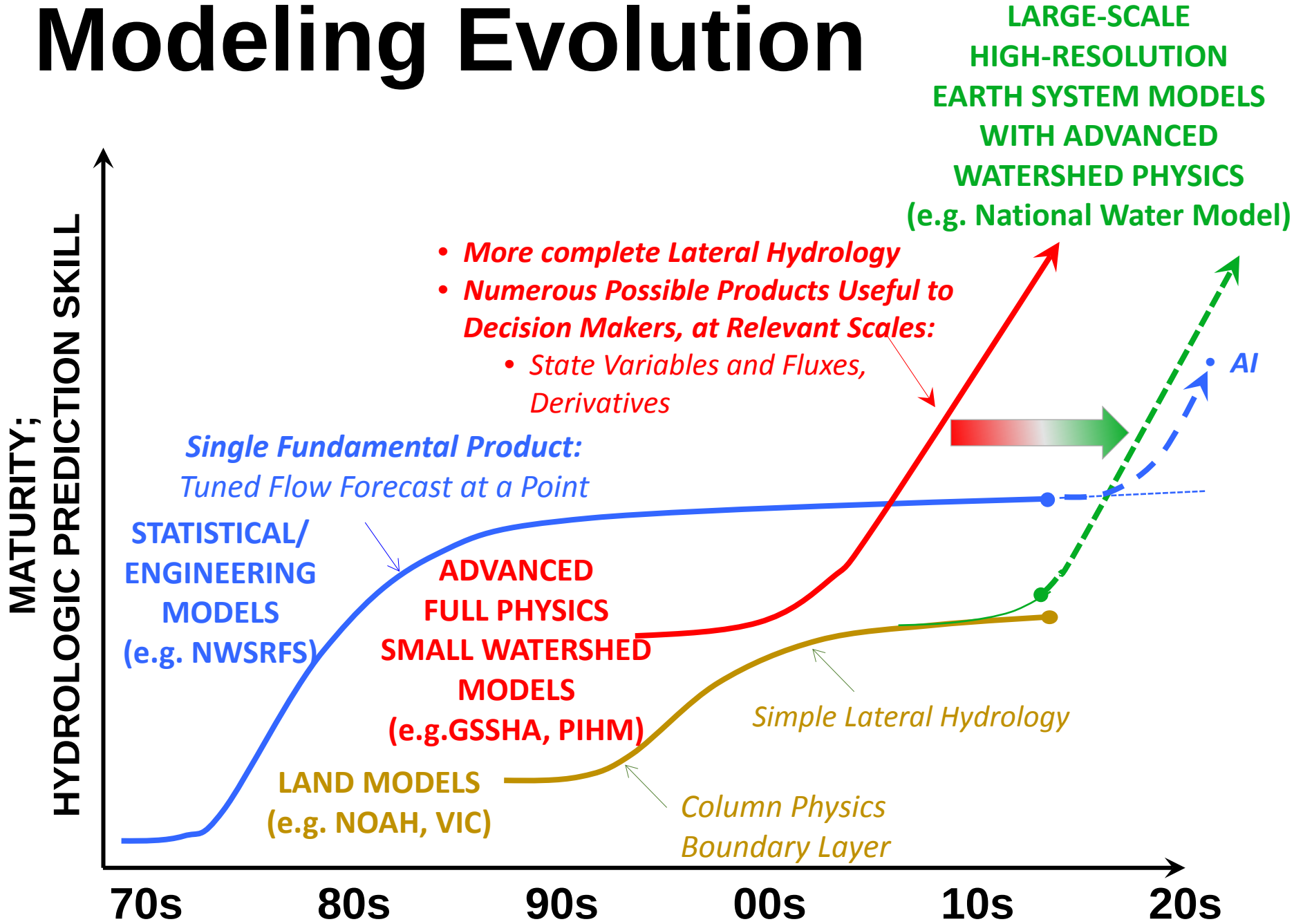
We are beginning to transform very high level concepts into feasible integrated plans that build upon the National Water Model.



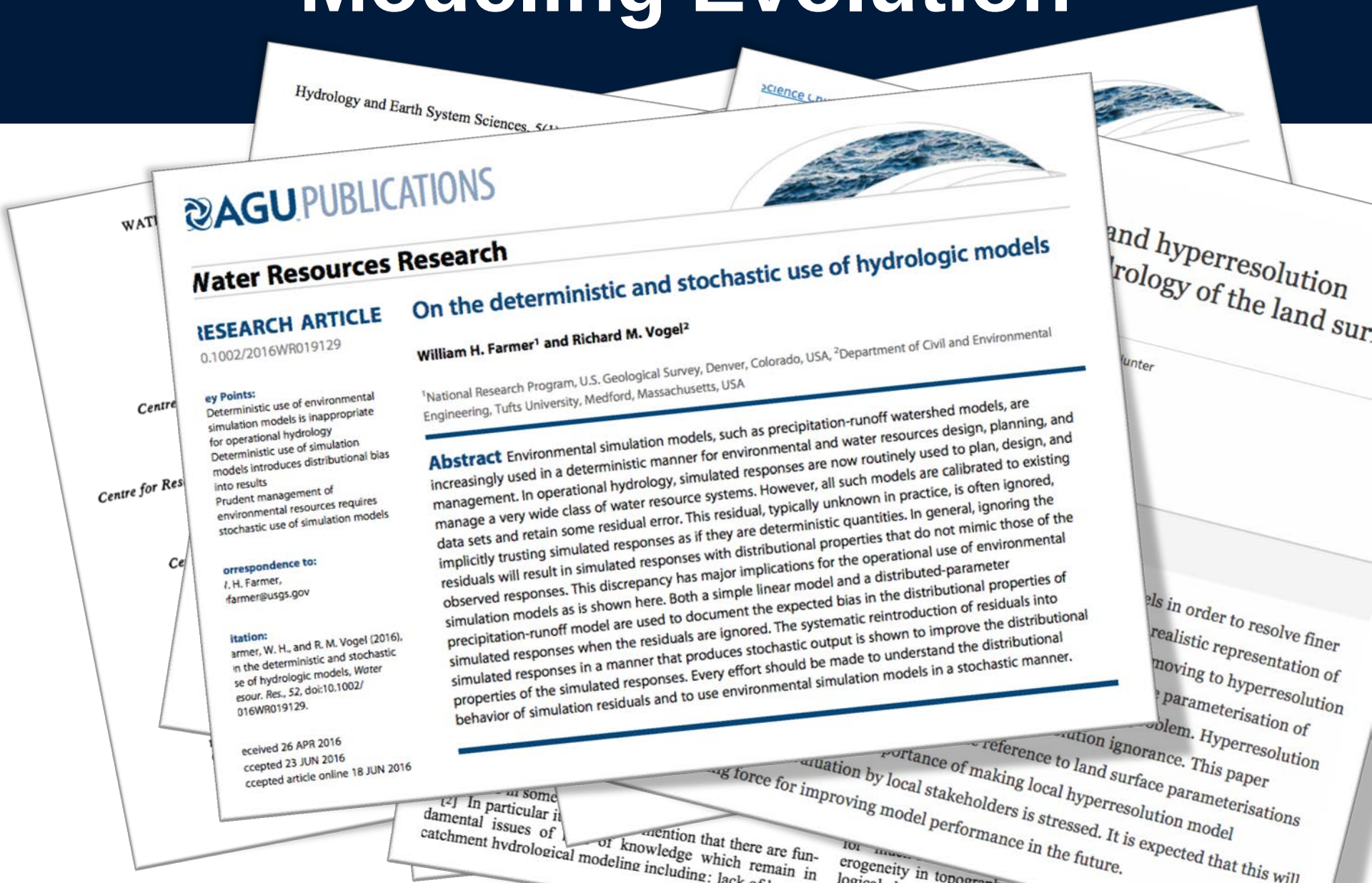
Emerging Systems Concept



Modeling Evolution



Modeling Evolution



AGU PUBLICATIONS

Water Resources Research

RESEARCH ARTICLE

0.1002/2016WR019129

ey Points:
Deterministic use of environmental simulation models is inappropriate for operational hydrology
Deterministic use of simulation models introduces distributional bias into results
Prudent management of environmental resources requires stochastic use of simulation models

orrespondence to:
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On the deterministic and stochastic use of hydrologic models

William H. Farmer[1] and Richard M. Vogel[2]

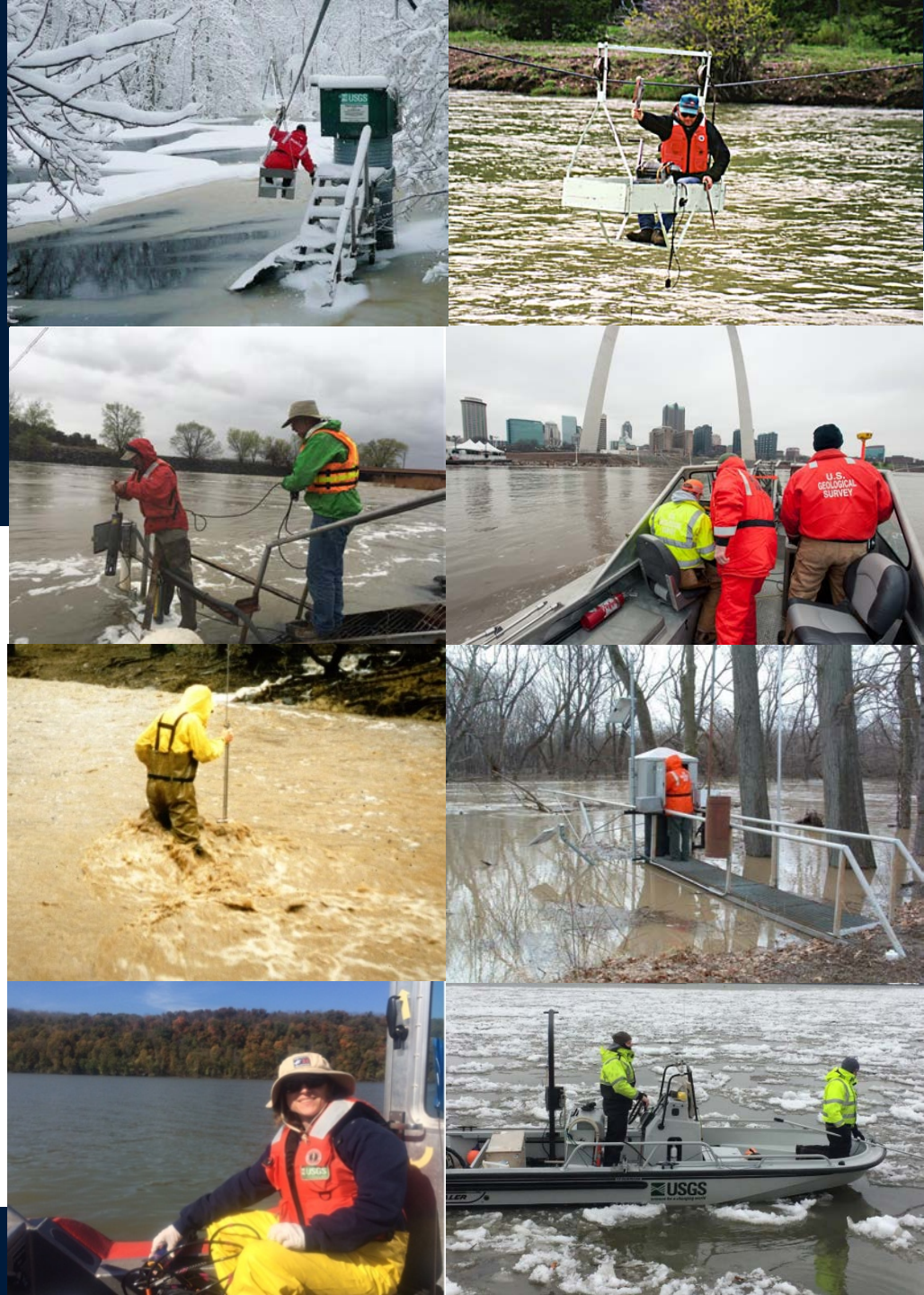
[1]National Research Program, U.S. Geological Survey, Denver, Colorado, USA, [2]Department of Civil and Environmental Engineering, Tufts University, Medford, Massachusetts, USA

Abstract Environmental simulation models, such as precipitation-runoff watershed models, are increasingly used in a deterministic manner for environmental and water resources design, planning, and management. In operational hydrology, simulated responses are now routinely used to plan, design, and manage a very wide class of water resource systems. However, all such models are calibrated to existing data sets and retain some residual error. This residual, typically unknown in practice, is often ignored, implicitly trusting simulated responses as if they are deterministic quantities. In general, ignoring the residuals will result in simulated responses with distributional properties that do not mimic those of the observed responses. This discrepancy has major implications for the operational use of environmental simulation models as is shown here. Both a simple linear model and a distributed-parameter precipitation-runoff model are used to document the expected bias in the distributional properties of simulated responses when the residuals are ignored. The systematic reintroduction of residuals into simulated responses in a manner that produces stochastic output is shown to improve the distributional properties of the simulated responses. Every effort should be made to understand the distributional behavior of simulation residuals and to use environmental simulation models in a stochastic manner.

USGS

Eventually, all things merge into one, and a river runs through it.

Norman Maclean



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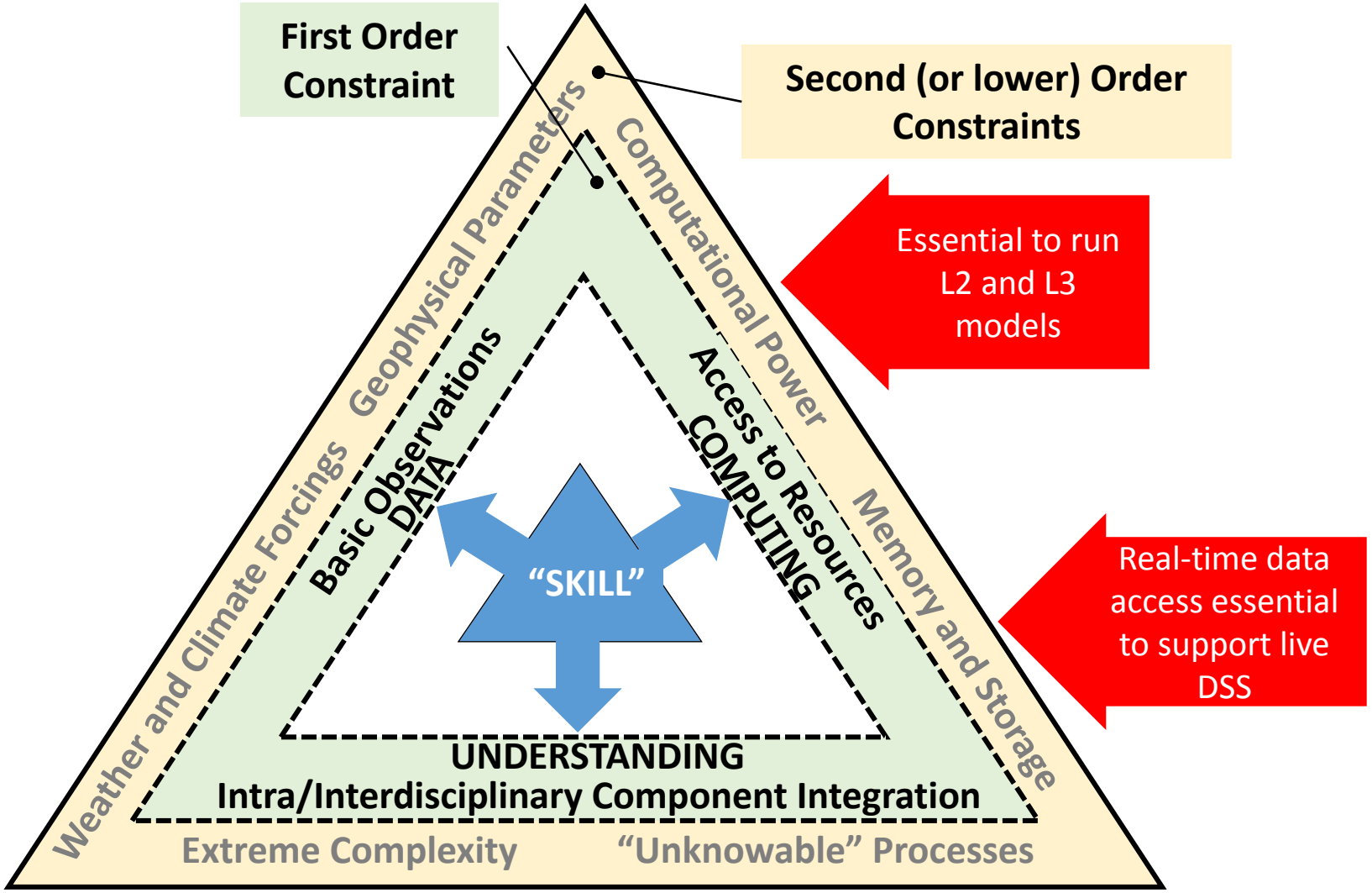
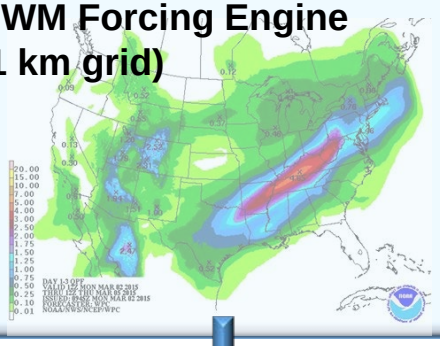
USGS

Earth Intelligence: Limits to Improving Capacity

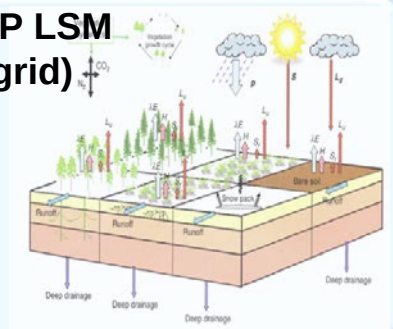


National Water Model Initial Operating Capability: Model Chain

1. NWM Forcing Engine (1 km grid)

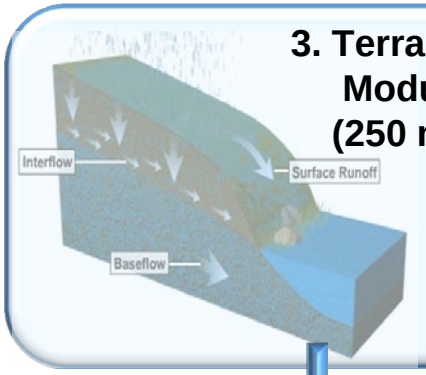


2. NoahMP LSM (1 km grid)

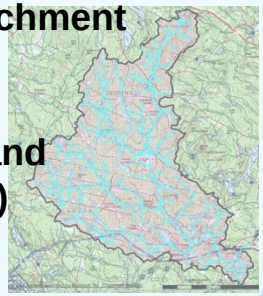


2-way coupling

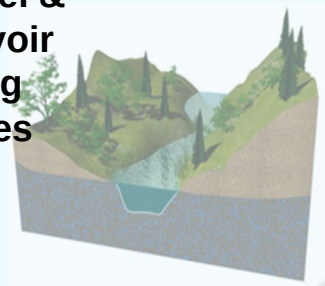
3. Terrain Routing Module (250 m grid)

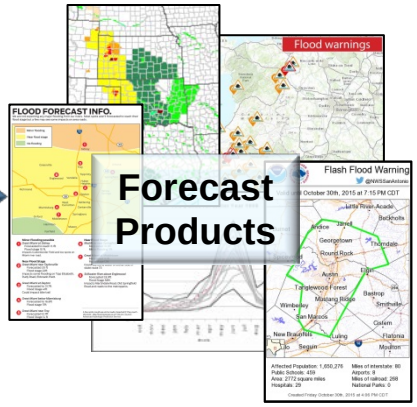


4. NHDPlus Catchment Aggregation (2.7M unique catchments and river reaches)



5. Channel & Reservoir Routing Modules





Forecast Products

NWM uses NCAR supported community WRF-Hydro system

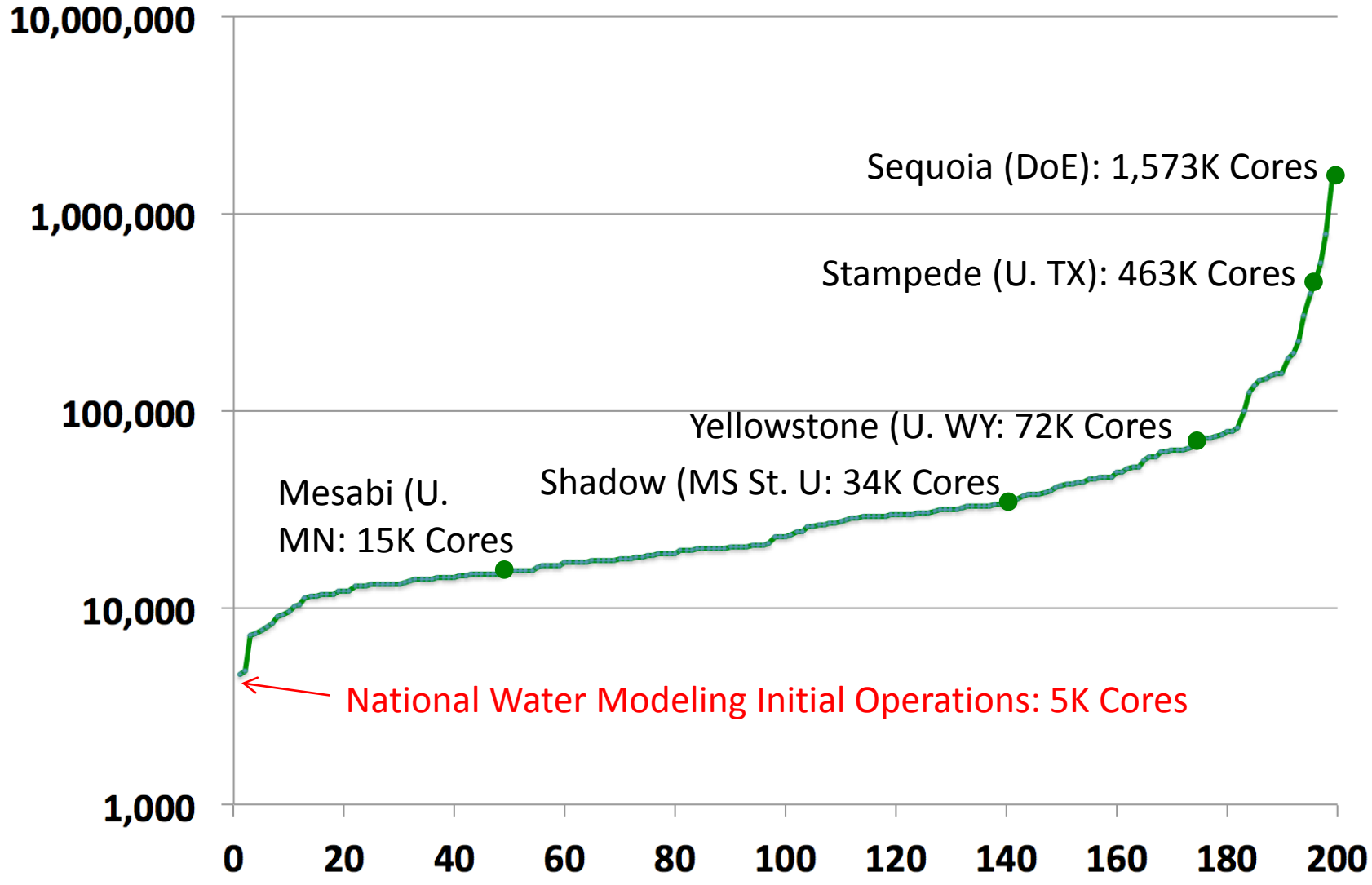
NWM: *http://water.noaa.gov/about/nwm*

WRF-Hydro: *https://www.ral.ucar.edu/projects/wrf_hydro*

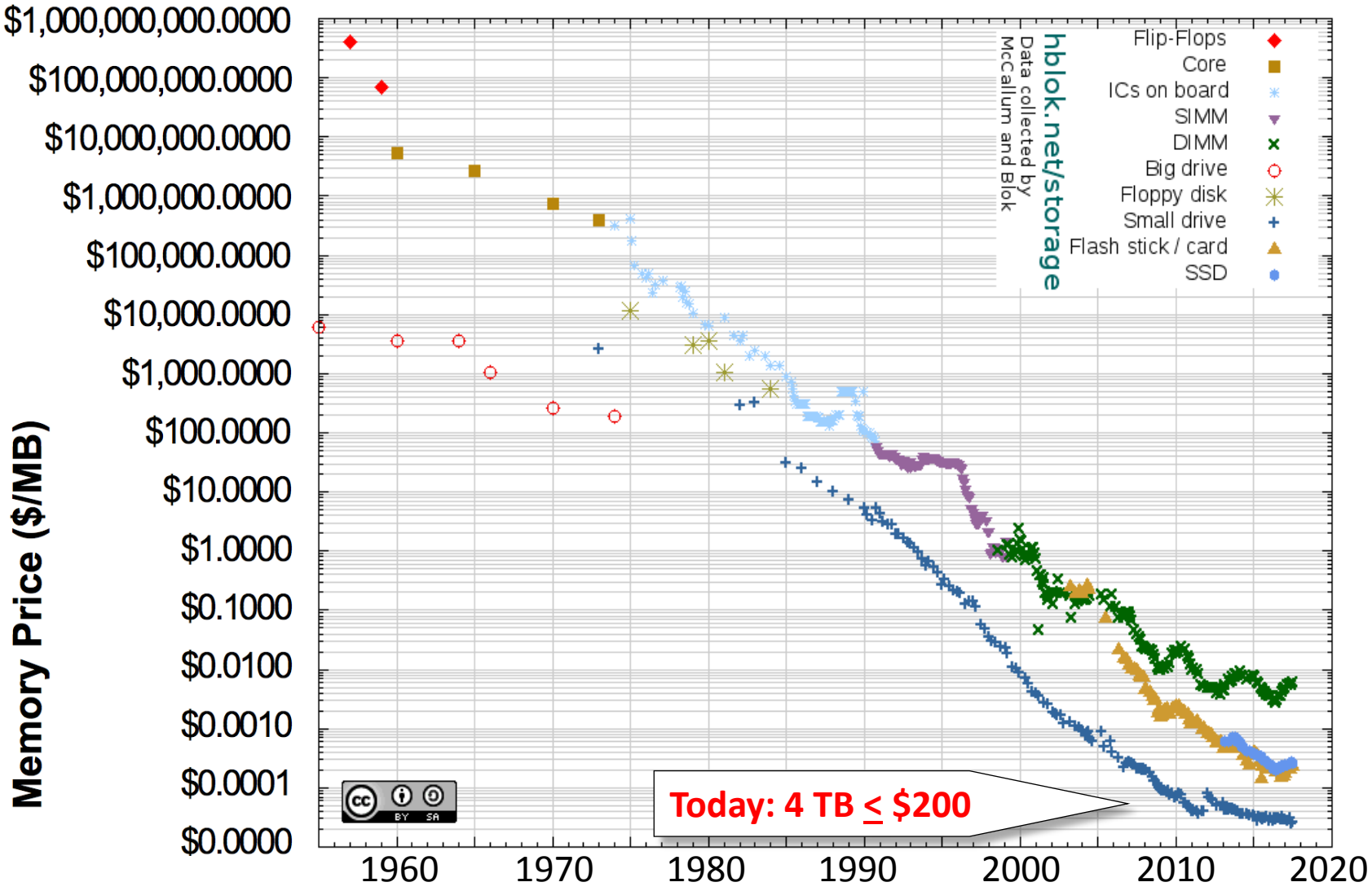
National Water Model Operational Configurations

	Analysis & Assimilation	Short-Range 'Flood Prediction'	Medium-Range 'Flow Prediction'	Long-Range 'Water Resources'
Cycling Frequency	Hourly	3-Hourly	Daily	~Daily (16 mem)
Forecast Duration	- 3 hrs	0-2 days	0-10 days	0-30 days
Spatial Discretization & Routing	1km/250m/NHD+ Reach	1km/250m/NHD+ Reach	1km/250m/NHD+ Reach	1 km/catchment /NHD+ Reach
Meteorological Forcing	MRMS blend/ HRRR-NAM bkgnd.	Downscaled HRRR	Short-range + Downscaled GFS	Downscaled & bias-corrected CFS

Top 200 Supercomputers in U.S. 2015 (Total Number of Cores)



Historical Price of Memory and Storage



Which is the Best Model?