United States Environmental Protection Agency

Climate Change Impacts on Water Resources, and Water Supply Security through Adaptation

Dr. Y. Jeffrey Yang, P.E., D.WRE

Beijing, China
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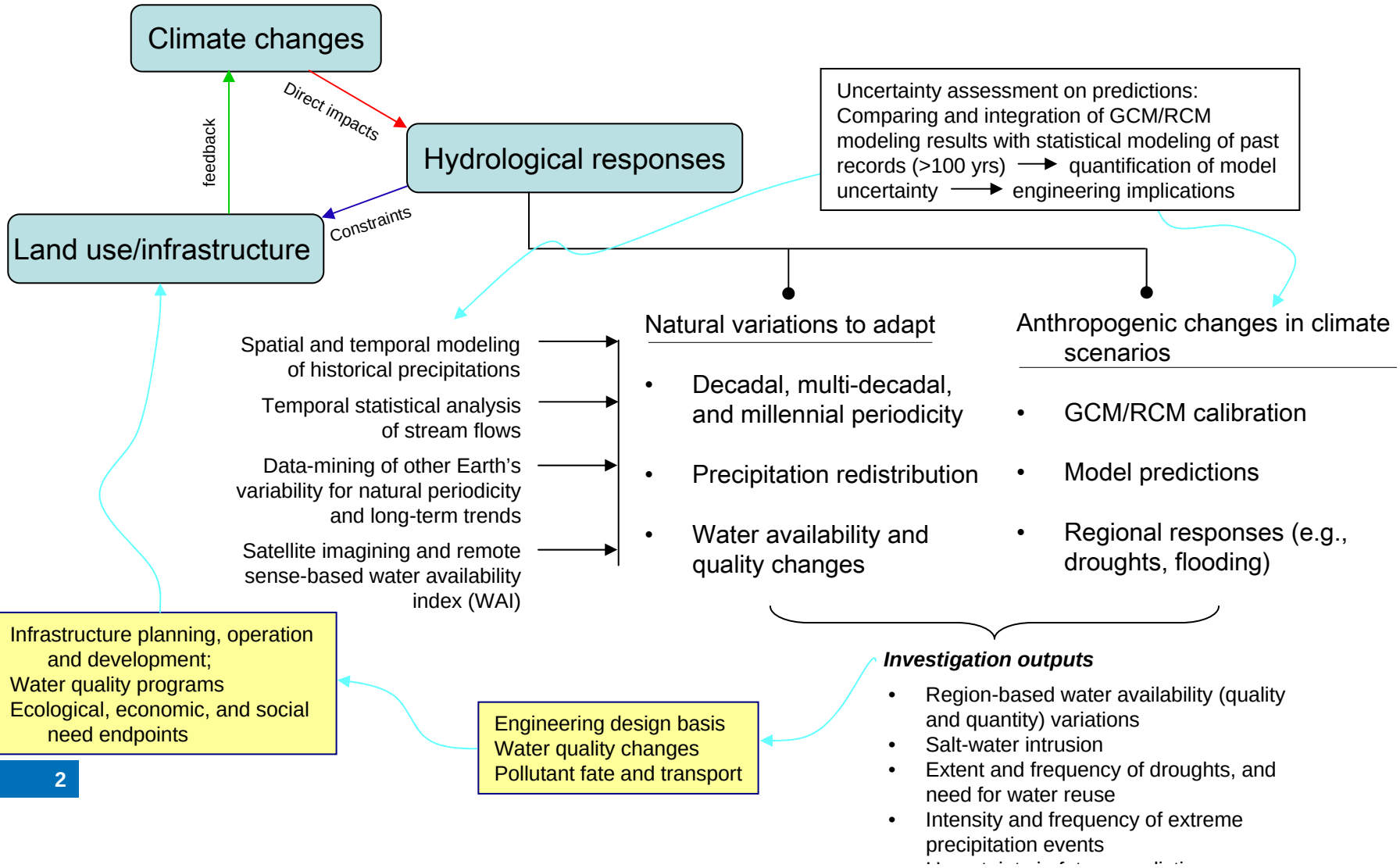
Office of Research and Development
National Risk Management Research Laboratory

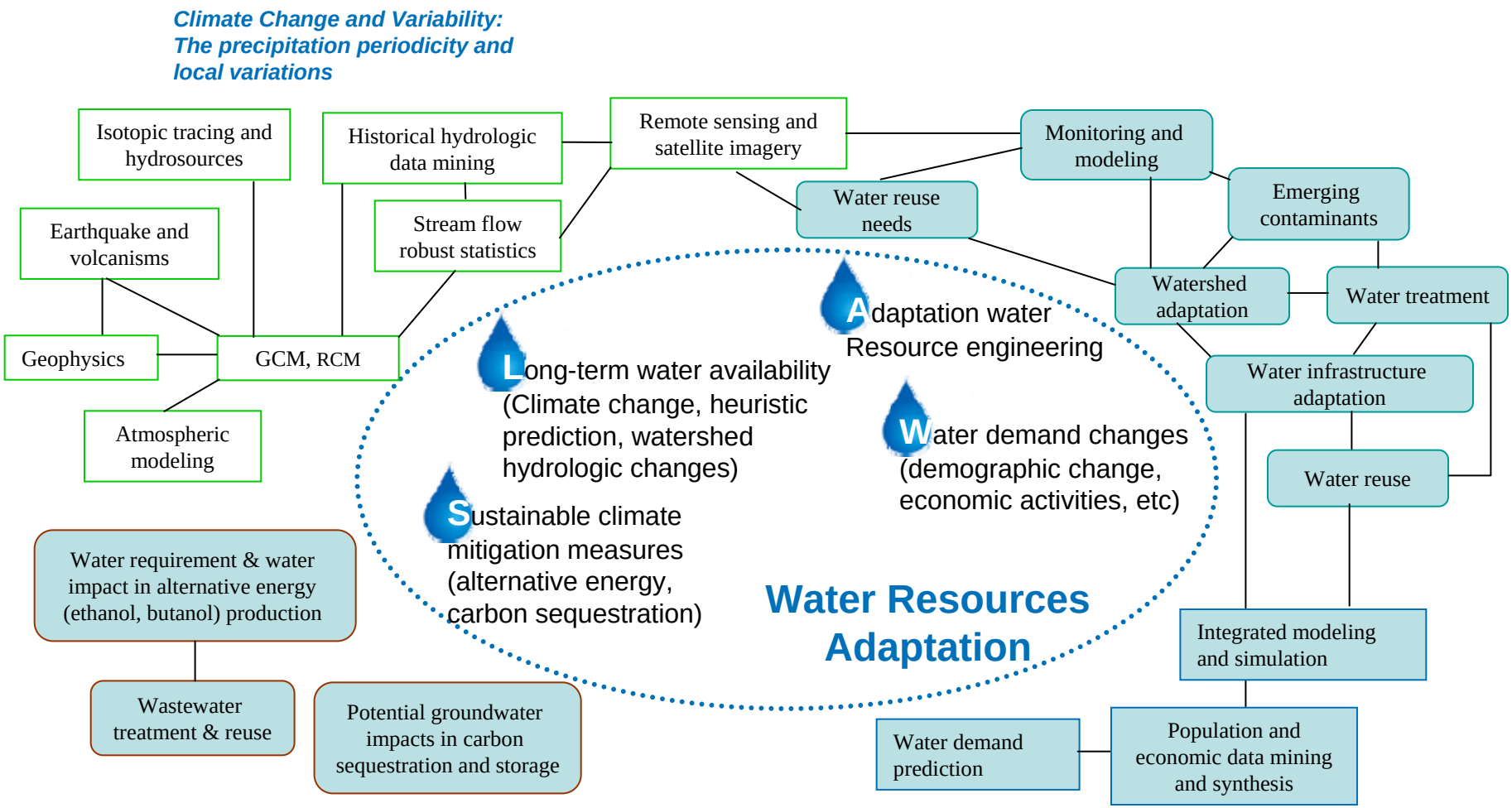
Outline

- Overview U.S.EPA Water Resources Adaptation Program (WRAP) on Climate Changes
- Climate change, precipitation variability, and water availability
- Three example areas of WRAP adaptation research:
  - Multi-scale infrastructure assessment and adaptation strategy;
  - Alternative water resources development and utilization;
  - Pressurized pipe leak detection / water conservation
- Discussions

Define hydrological Change and Water Quality Impacts Affecting Water Programs



Water Resources Adaptation Program (WRAP)



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Climate Change and Variability: The precipitation periodicity and local variations

Hydroclimatic Periodicity Hierarchy

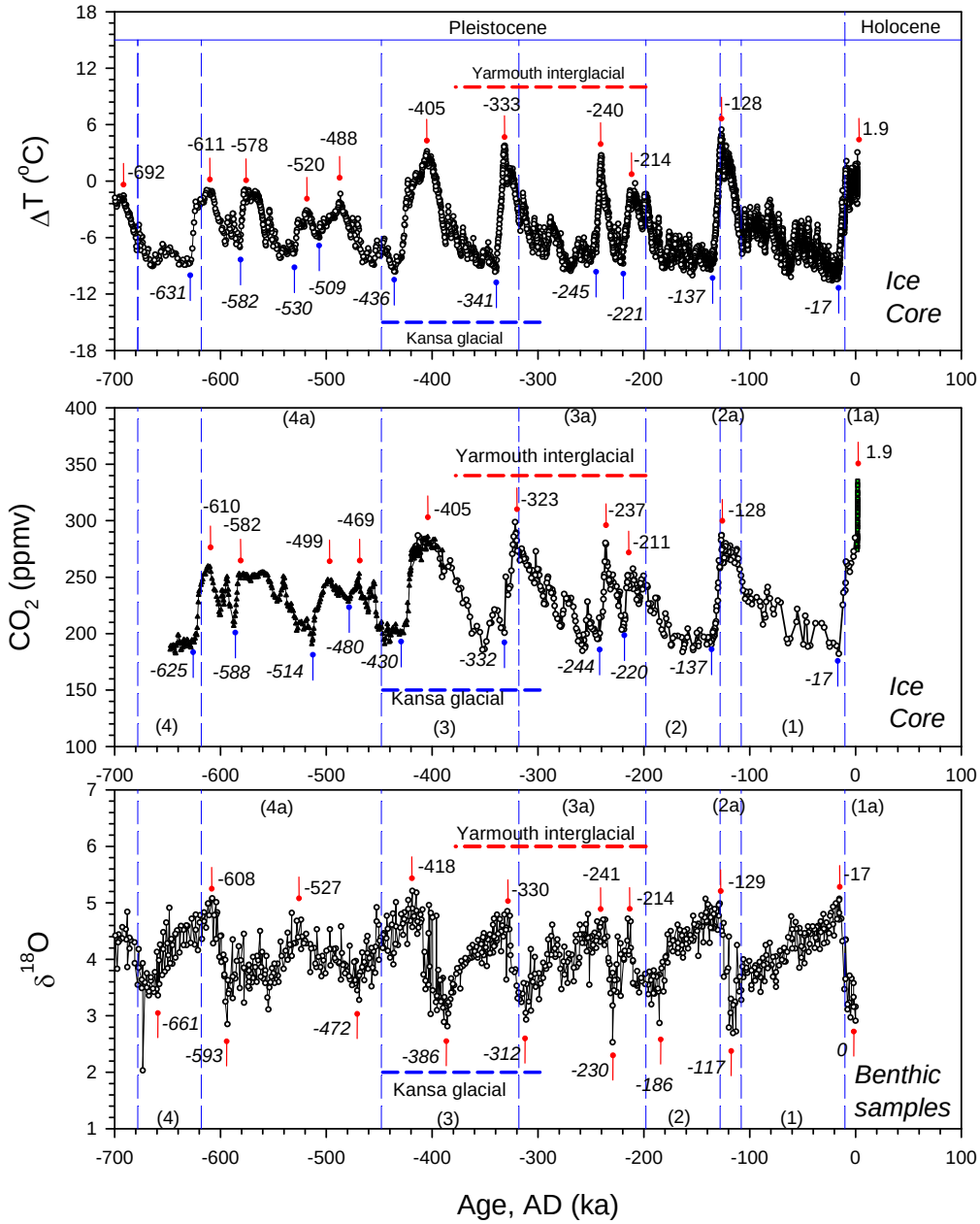
Table 1 Climatic proxy data used for the periodicity analysis.

	Data type	Data duration*	Time Resolution$	Geographic location	Latitude	Longitude	Source#
Polar Ice Core							
Camp Century	$\delta^{18}O$	1.967 to 1.242 (*0.725*) Kyr	1 yr	Greenland	77°10' N	66°08' W	Clausen et al. (1988)
Crete	$\delta^{18}O$	1.985 to 0.555 (*0.43*) Kyr	1 yr	Greenland	71°07' N	37°19' W	Clausen et al. (1988)
Dye 2	$\delta^{18}O$	1.974 to 1.742 (*0.232*) Kyr	1 yr	Greenland	66°23' N	46°11' W	Clausen et al. (1988)
Dye 3	$\delta^{18}O$	1.872 to -1.699 (*3.571*) Kyr	1 yr	Greenland	65°11' N	43°49' W	Clausen et al. (1988)
NGRIP	$\delta^{18}O$	2.0 to -123 (*125*) Kyr	50(D) yr	Greenland	75°06' N	42°19' W	Jouzel et al (2001) NGICP members (2004)
Law dome	CO_2	1.008 to -1.992 (*3.0*) Kyr	1-81(D) yr	Antarctica	66°44' S	112°50' E	Etheridge et al. (1996)
Vostok	CO_2	-2.34 to -417 (*419*) Kyr	1-5996 yr	Antarctica	72°28' S	106°48' E	Petit et al (1999)
EPICA Dome C	T (δ^2H)	2.0 to -800 (802) Kyr	5.8-1088 yr	Antarctica	75°06' S	123°24' E	Jouzel et al (2001)
	CO_2	-389 to -647 (258) Kyr	1947-3114 yr				Siegenthaler et al. (2005)
Benthonic Sediment							
Foraminifera	$\delta^{18}O$	2.0 to -800 (802.0) Kyr	96-3859(D) yr	Worldwide	--	--	Zachos et al (2001) Chaisson & Ravello (1977) Howell et al (1998)
Climate Station							
CA047902	Precip	2.003 to 1.867 (0.136) Kyr	0.08 yr	California (US)	34°25' N	119°40' W	Williams Jr. et al. (2007)
NY301752	Precip	2.006 to 1.854 (0.152) Kyr	0.08 yr	New York (US)	45°4' N	89°2' W	Williams Jr. et al. (2007)
WI475474	Precip	2.006 to 1.863 (0.143) Kyr	0.08 yr	Wisconsin (US)	42°42' N	74°55' W	Williams Jr. et al. (2007)

Note: * - Time in unit of thousand years (kyrs) after (+) and before (-) the date.
- In addition to the literature, the raw data are available at http://www.ncdc.noaa.gov/paleo/icgate.html.
$ - Age difference between adjacent samples. D for duplicate samples.

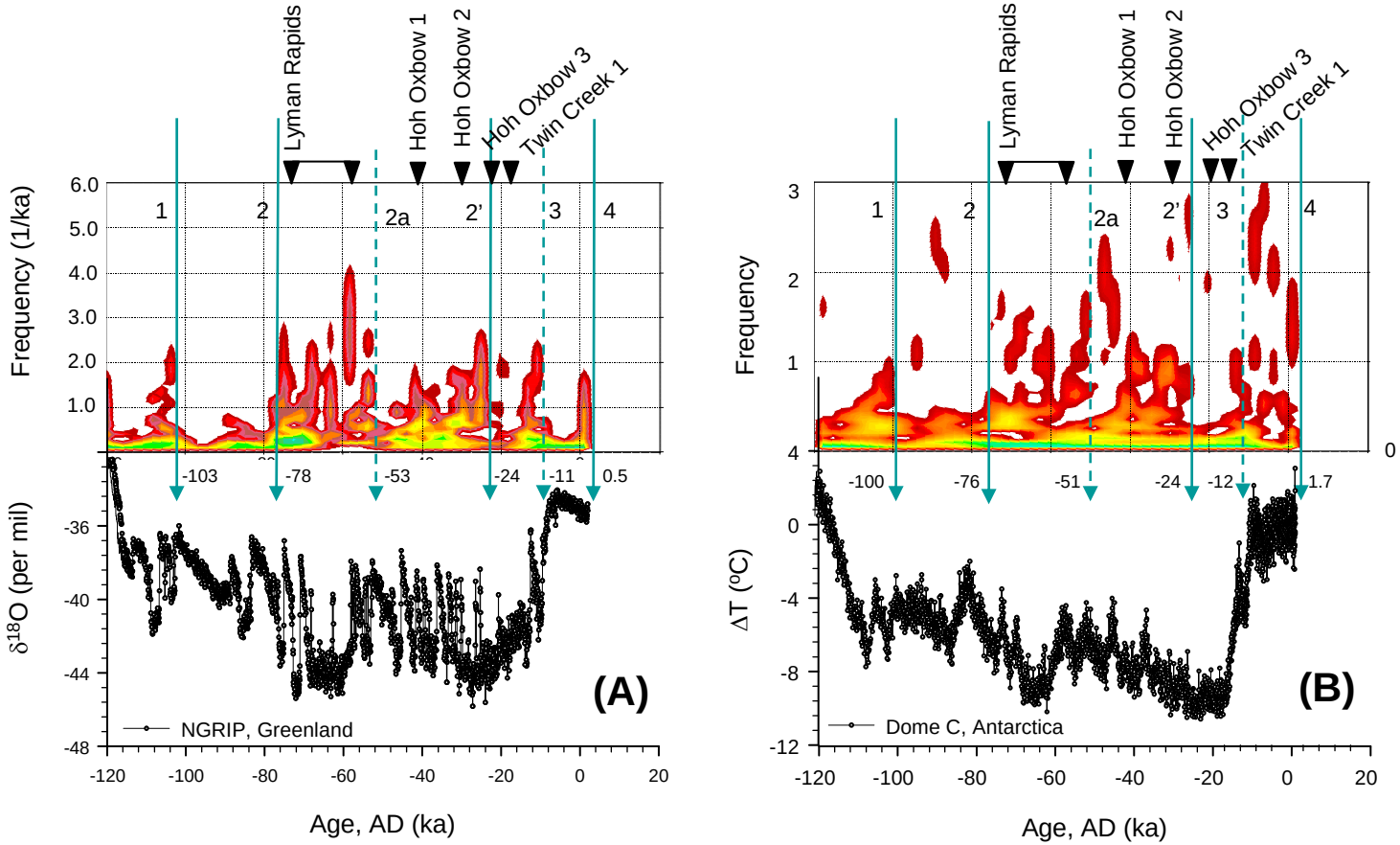
Yang & Goodrich (2008). In Environmental Geology

Hydroclimatic Periodicity Hierarchy in Polar Ice Cores: The Variations in Pleistocene-Holocene Period



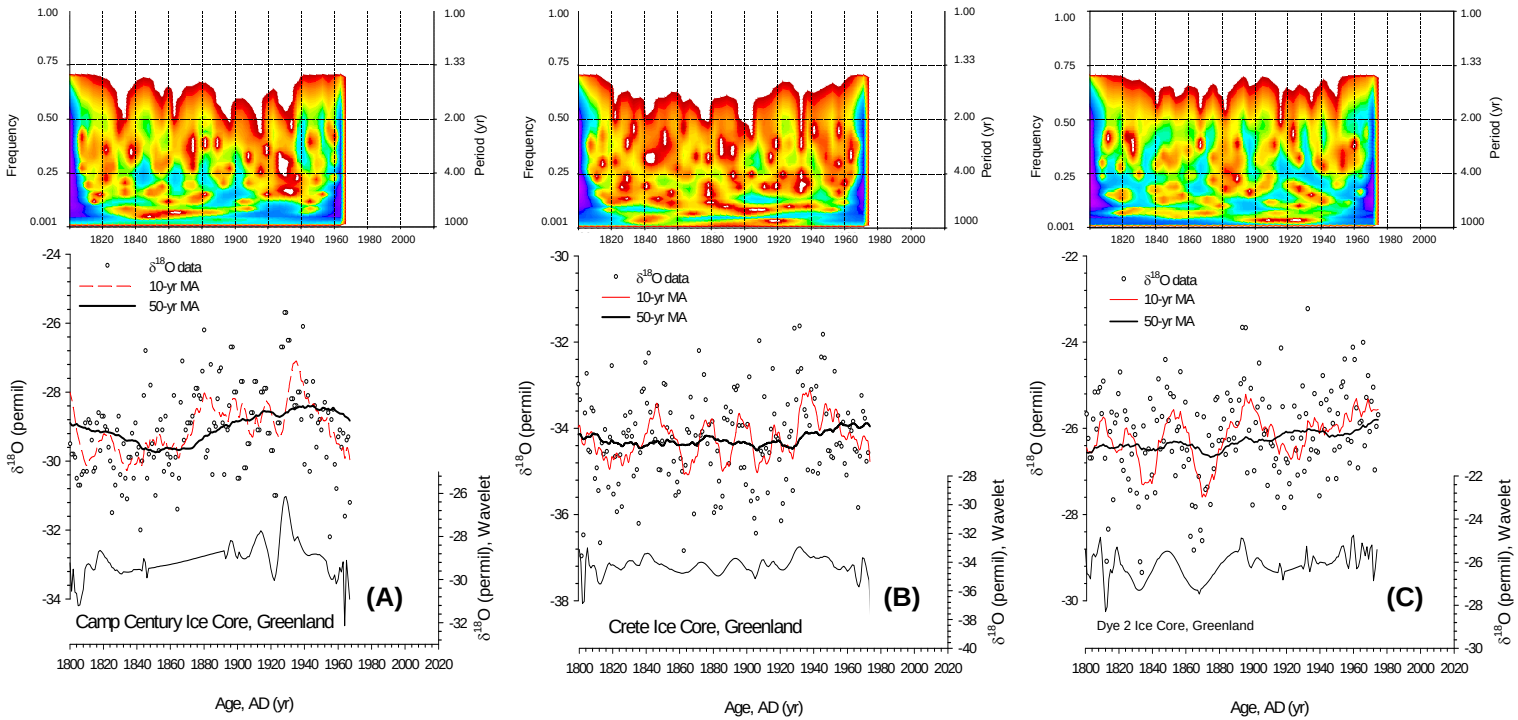
Yang & Goodrich (2008). In Environmental Geology

Hydroclimatic Periodicity Hierarchy: Global Variations in Wisconsin Glaciation Period



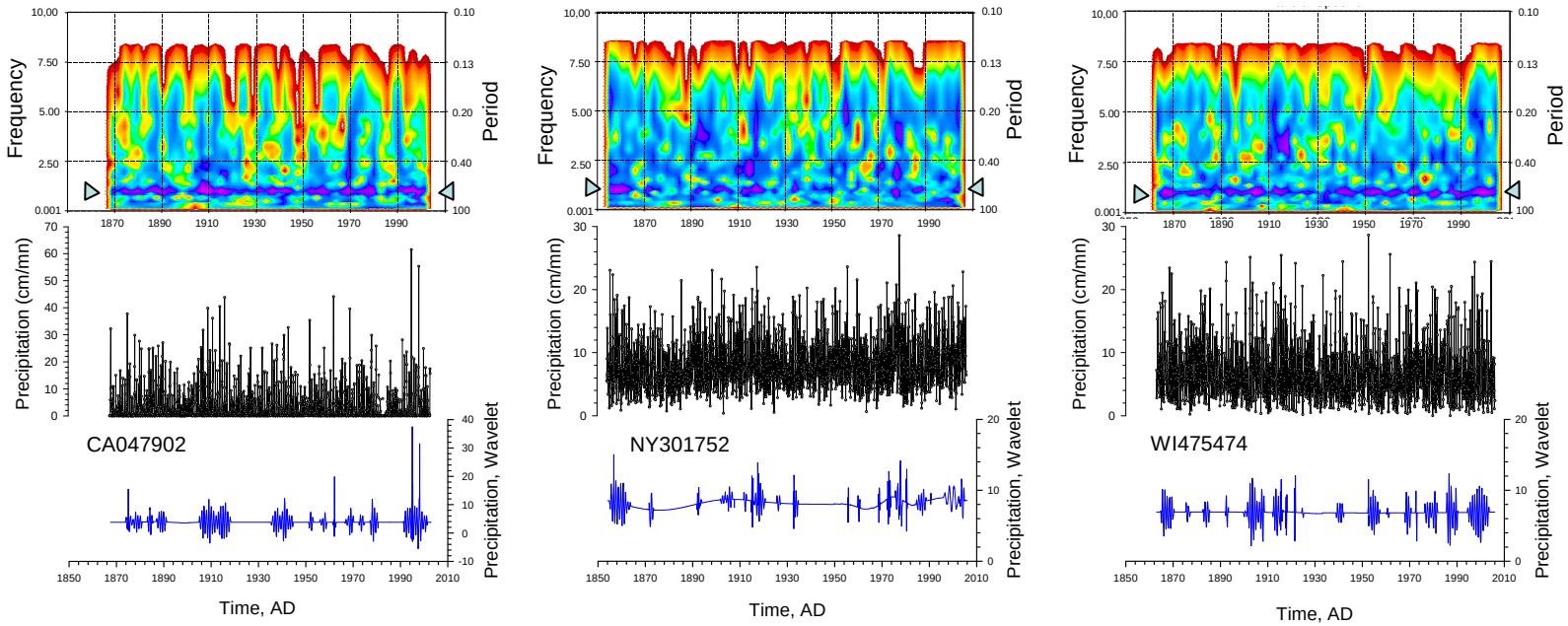
Yang & Goodrich (2008). In Environmental Geology

Hydroclimatic Periodicity Hierarchy in Greenland Ice Cores: Regional Differences



Yang & Goodrich (2008). In Environmental Geology

Hydroclimatic Periodicity Hierarchy



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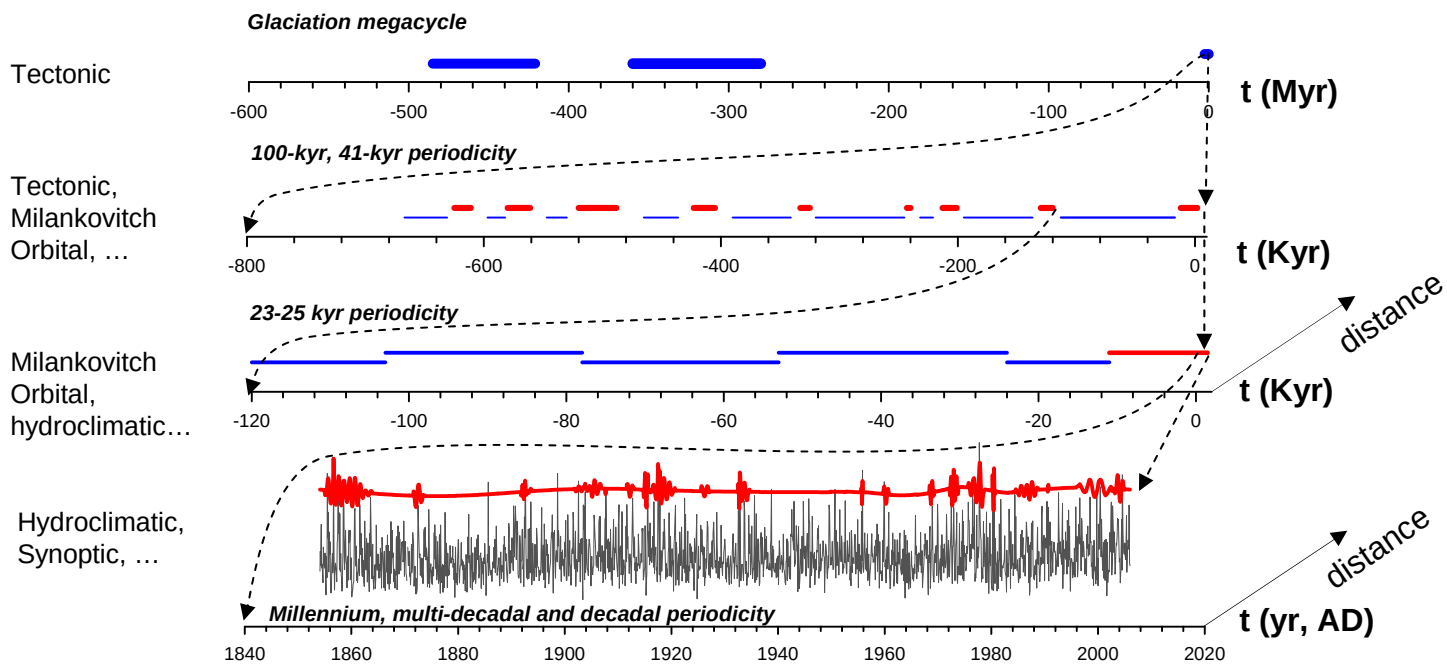
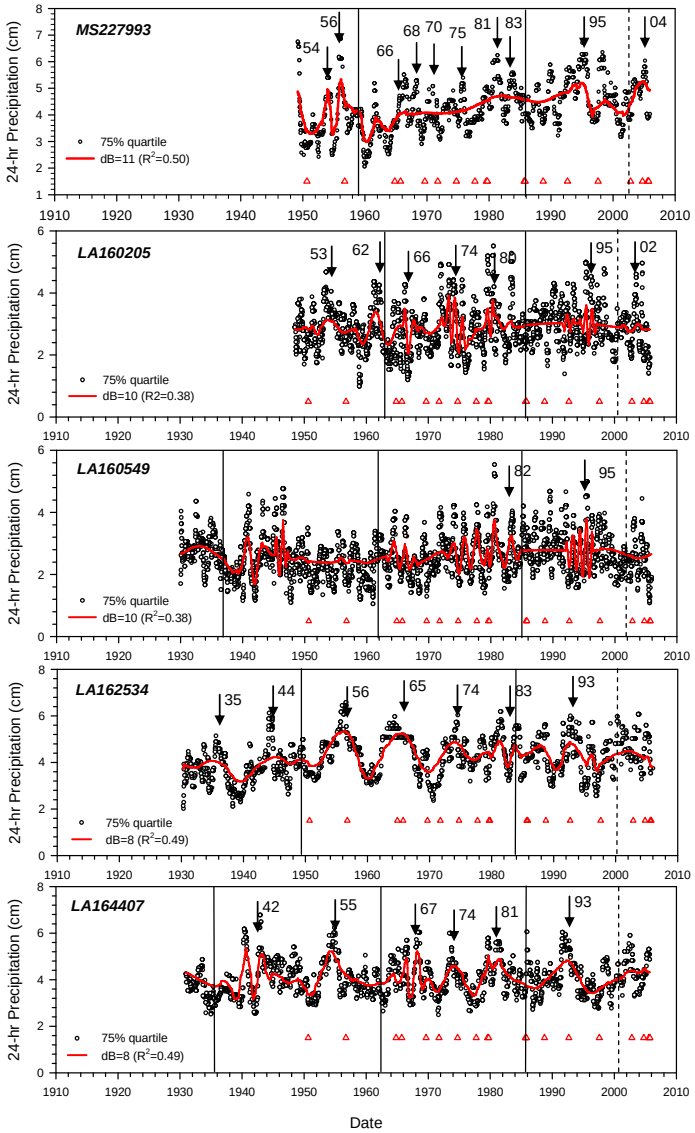
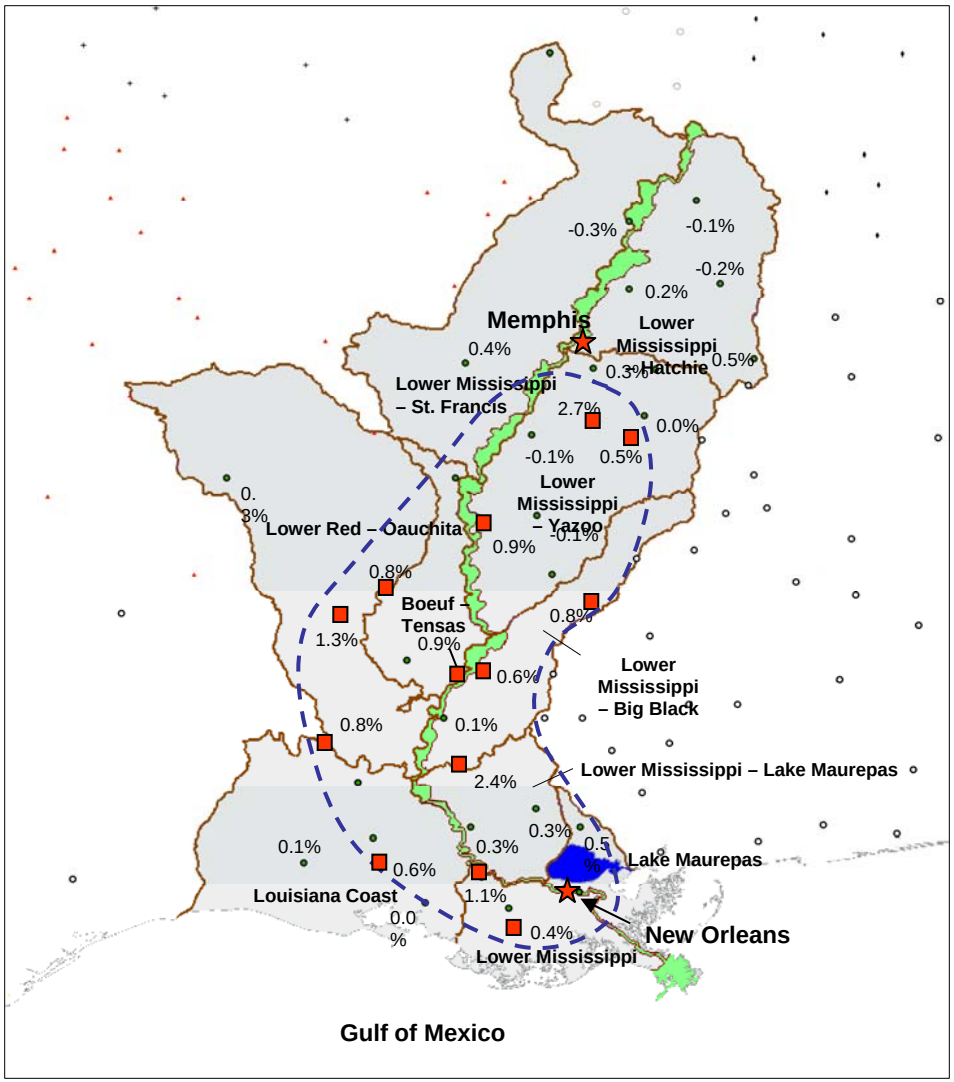
Hydroclimatic Periodicity Hierarchy



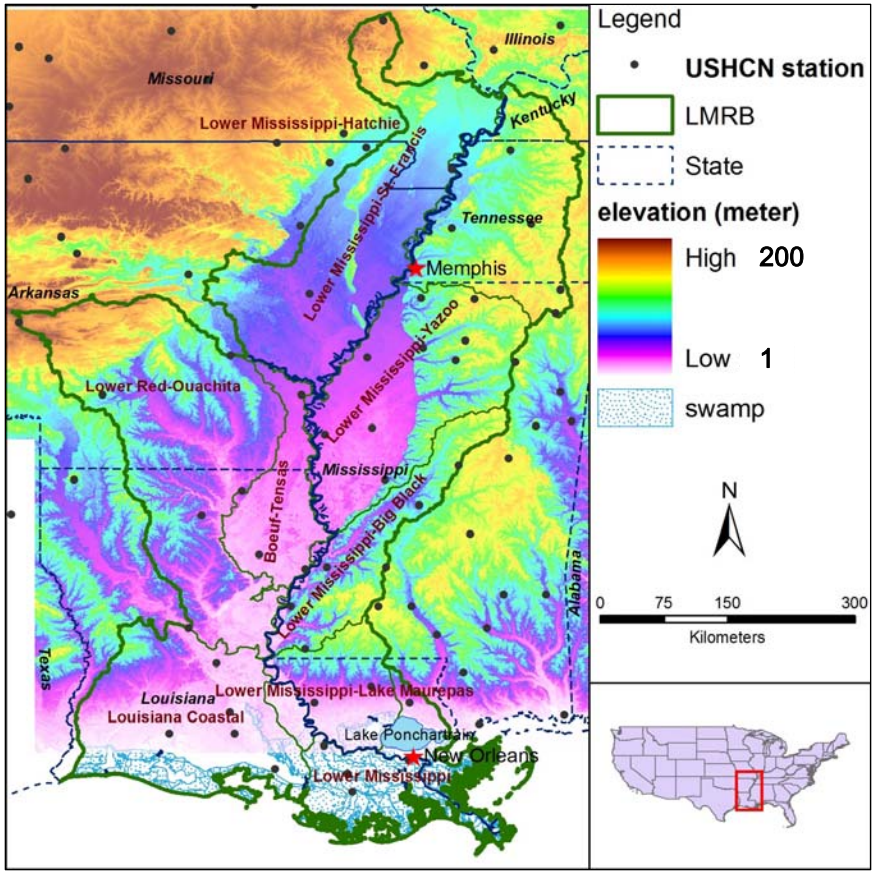
Yang & Goodrich (2008). In Environmental Geology

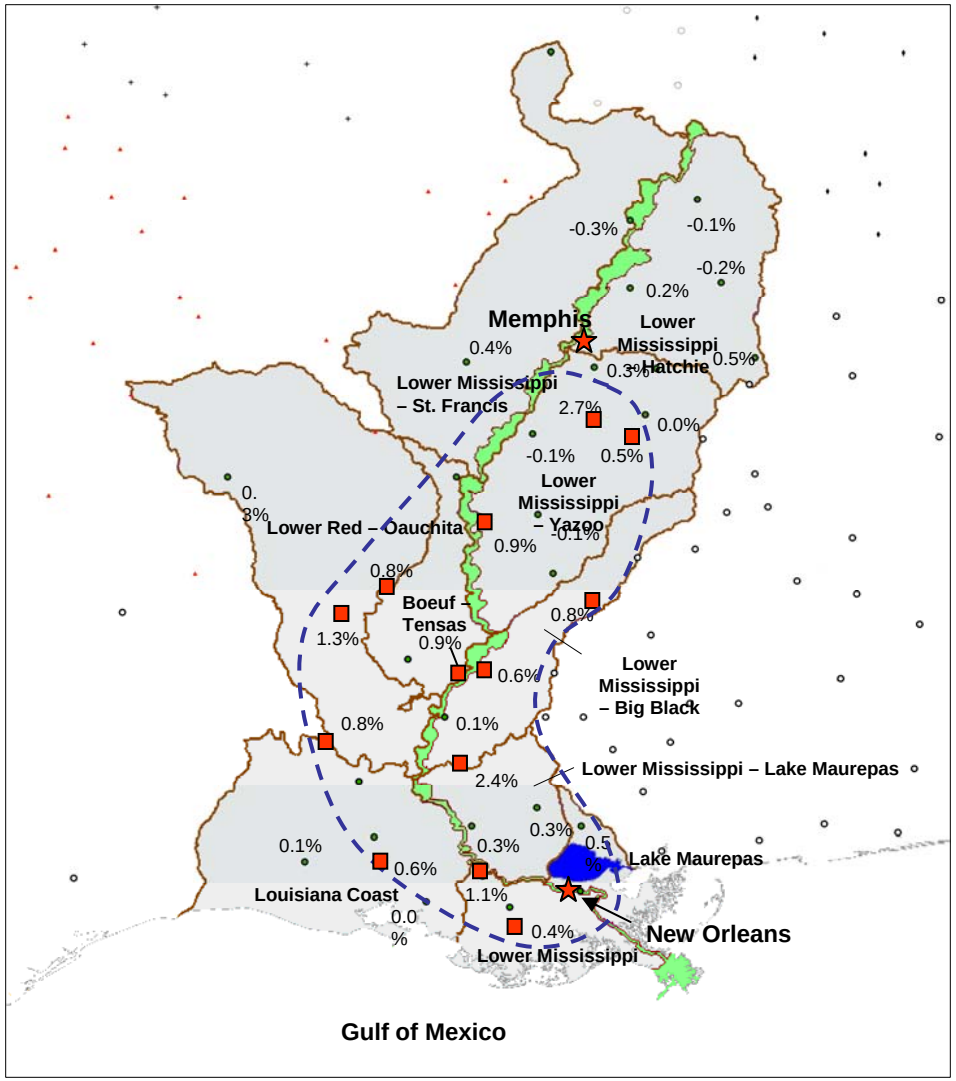
Local Precipitation Variability – Lower Mississippi River Basin, U.S.



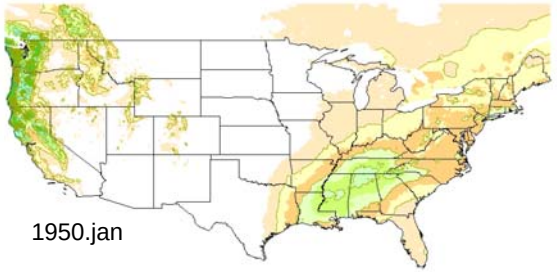


Local Precipitation Variability: Land Feedback in LMRB, U.S.





GCMs and RCMs: Model Prediction and Applications in Water Resources Adaptation



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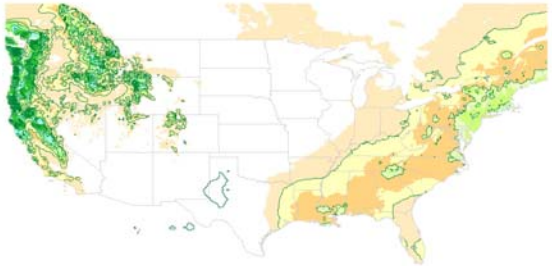

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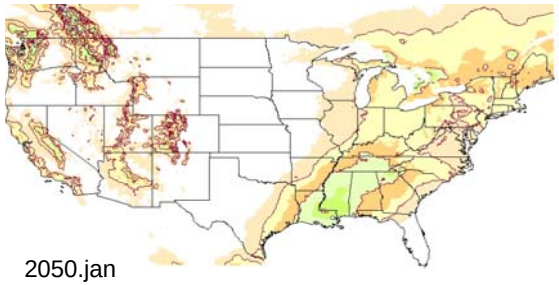

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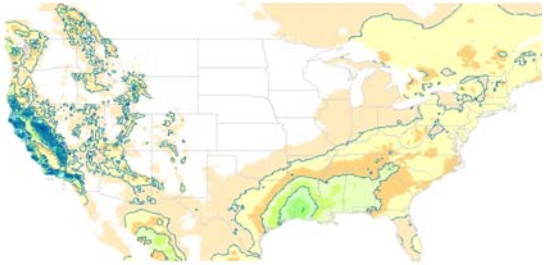

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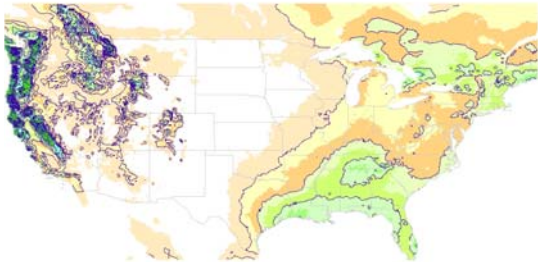

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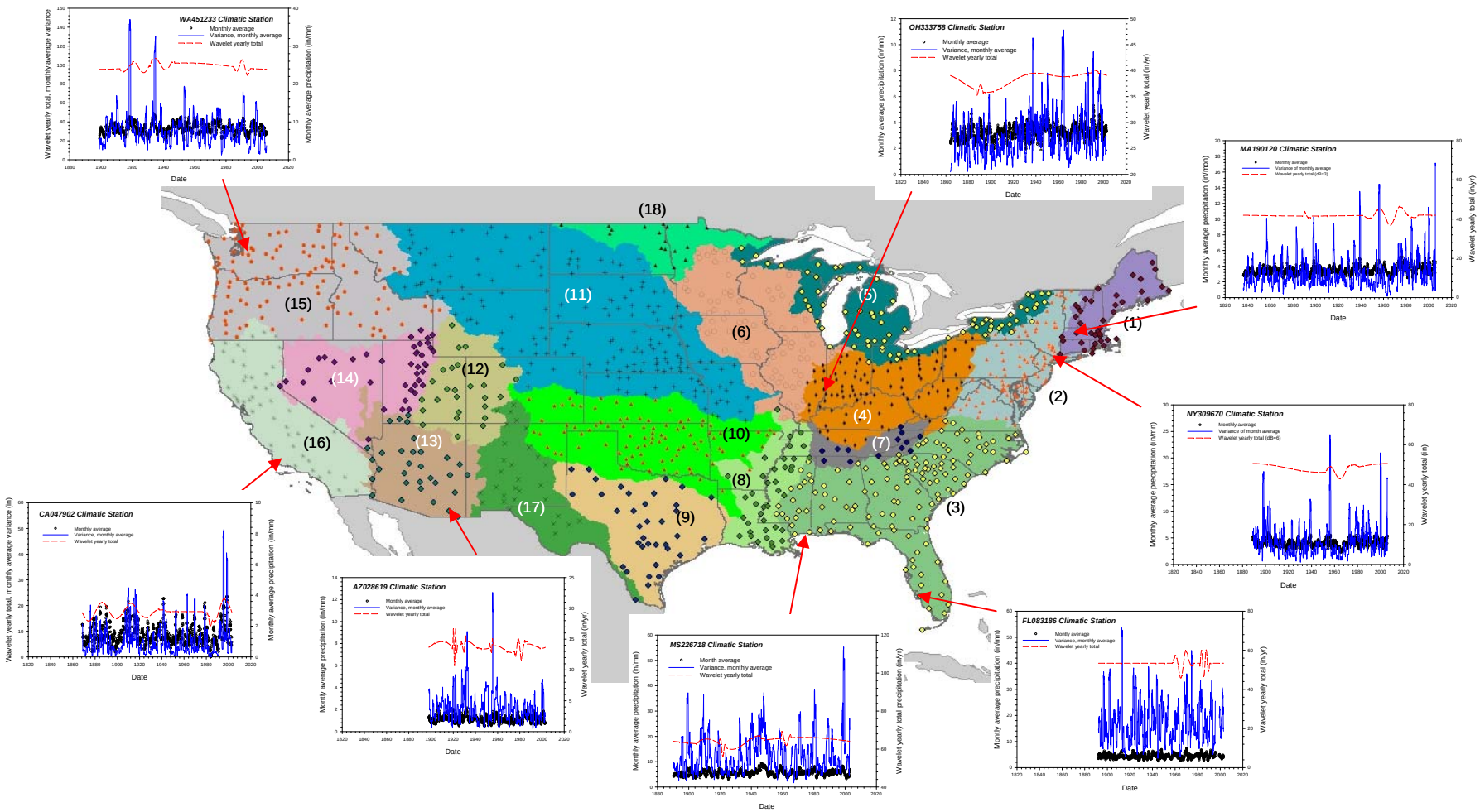
HADCM3 Climate Model Predictions

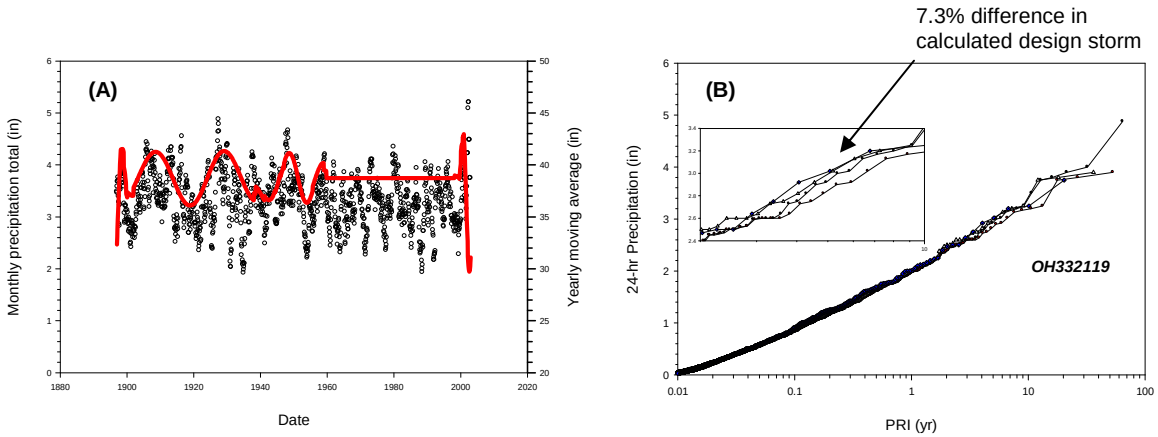
Nationwide Hydrological Characterization and Regional Studies: Map it Out



Watershed basins in color: 1) ***New England***; 2) ***Mid-Atlantic***; 3) ***South Atlantic – Gulf of Mexico***; 4) ***Ohio region***; 5) Great Lakes; 6) Upper Mississippi; 7) Tennessee region; 8) Lower Mississippi; 9) Texas – Gulf of Mexico; 10) Arkansas – White Red; 11) Missouri; 12) Upper Colorado; 13) ***Lower Colorado***; 14) Great Basins; 15) ***Pacific Northwest***; 16) ***California***; 17) Rio Grande; and 18) Souris – Red Rainy.

Yang et al. (2008)

Nationwide Hydrological Characterization and Regional Studies: Impacts on infrastructure functionality



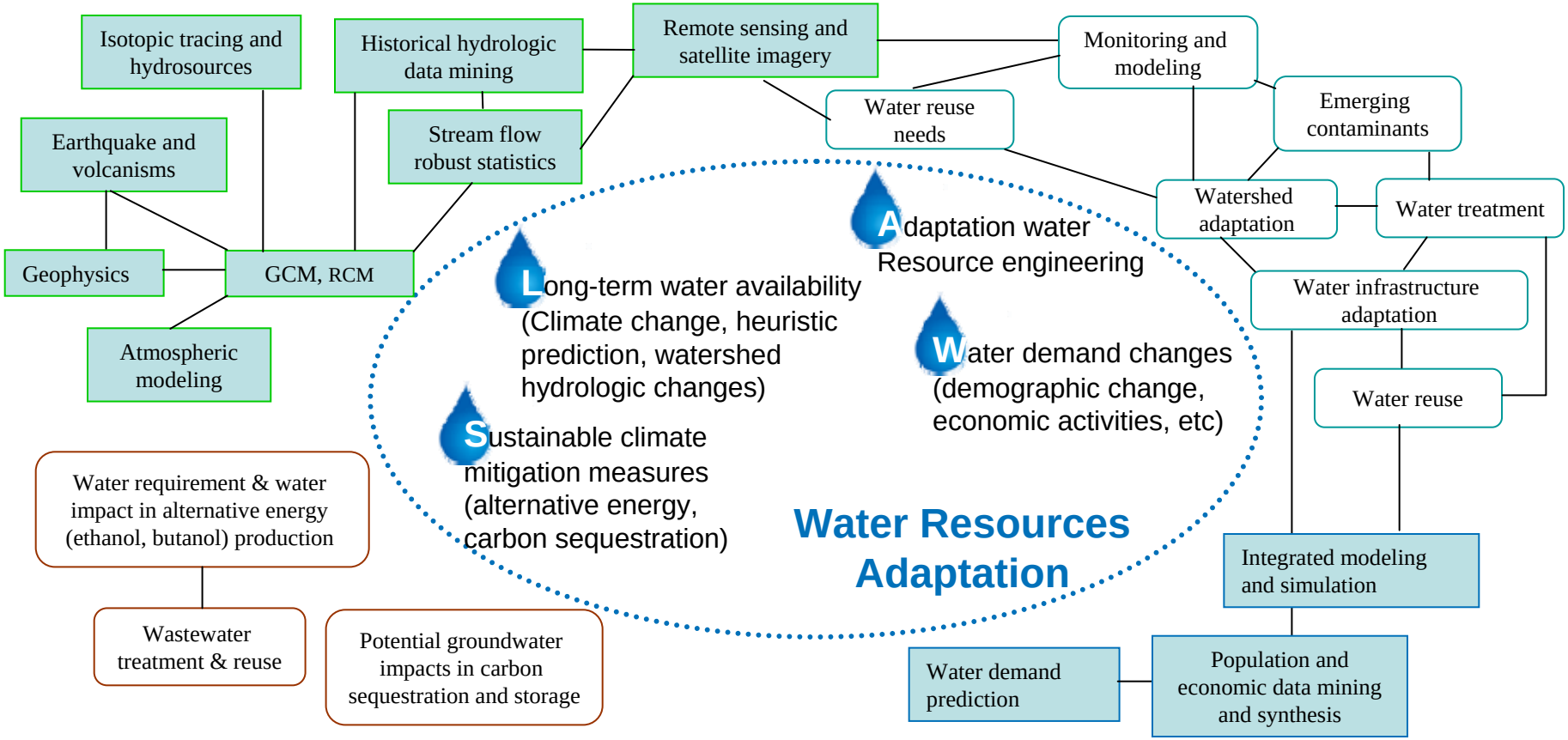
Global change	Characteristics	Likelihood of impacts			Likely region of manifestation (examples)
		DW supply	Storm water	Wastewater	
Direct climatic impacts					
Drought	Cyclic drought, increased frequency and duration	Very likely			Southwestern states, south California and Florida
Flash floods	High precipitation intensity	Likely	Very likely	Likely	New England and north Atlantic states, Ohio River basins
Early snow melt	Change of hydrologic region in receiving rivers and groundwater replenishment	Likely	Very likely		Northwestern states (e.g., Washington, Oregon)
Sediment and nutrient loading in surface water	Increased sediments (turbidity) and nutrients (e.g., N,P) in source water of drinking water plants	Very likely			Atlantic East coast, Ohio River basins, and Midwest
Salt water intrusions	Increased salt water intrusion due to anticipated sea level rises	Very likely	Possible	Likely	East Coast and Gulf Mexico costal areas particularly the permeable Floridian aquifer systems, California Central Basin and aquifers along the coast
Indirect climatic impacts					
Alternative water resources development	Water quality in increased alternative water resources (e.g., wastewater reuse) development	Likely	Possible	Possible	California, Florida, southwestern United States, High Plain states
Ethanol and alternative energy production	High water usage demand in raw material production and increased use of pesticides and agriculture chemicals	Likely	Likely	Likely	Midwest and High Plains states in the Mississippi River basin
Groundwater overproduction	High demand excessively lowers groundwater table and accelerates dissolution of inorganic contaminants	Very likely			High arsenic levels in Silurian-Devonian sandstone aquifers

Yang et al. (2008)

Major factors impacting infrastructure services:

- Flow rate – facility capacity: CSO, wastewater collection and treatment, storm water retention…
- Flow velocity – water quality and physical structure: sediment content, NPS pollutions, collection structure…
- Water availability – wastewater collection pipe sizing, drinking water supply, stream flow regulation for ecological and water quality management
- Alternative water resources – pollutants and salt management
- Salt water intrusion – all water, wastewater and storm water infrastructure

Sustainable Water Supply and Water Resource Adaptation to Global Changes



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Climate Change and Water Resources Adaptations

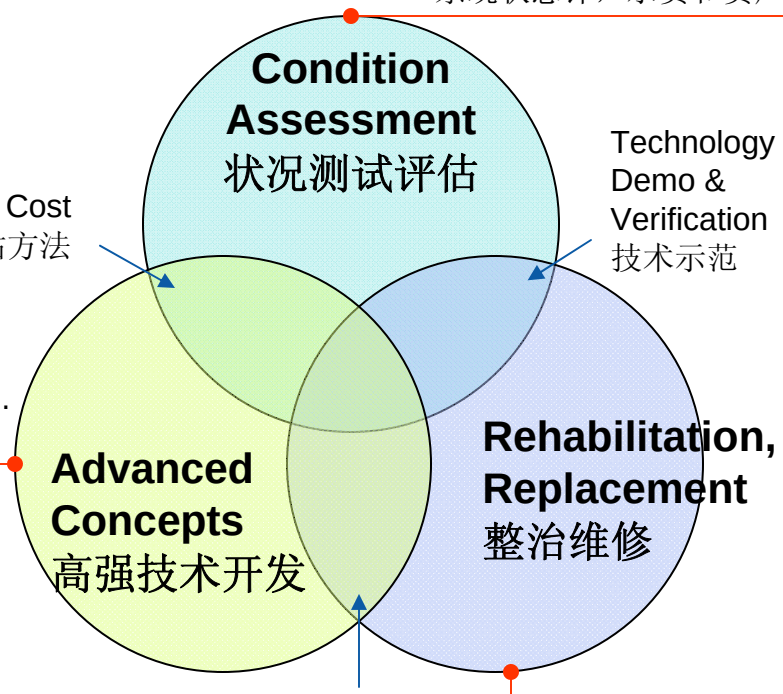
Water Infrastructure Adaptation and Sustainability Research

Condition assessment, water quality and asset management…
系统状态评，水资和资产系统管理

- CCTV and other non-intrusive methods
  闭路电视和其它非破坏性方法
- Gravity sewer IF/EF detection methods
  重力管网渗入 / 渗出探测方法
- Pressured network (e.g, drinking water pipe) leak detections
  压水管道破裂漏水的探测
- Advanced data analysis, management, and decision support systems
  管网资料收集、管理、分析和决策支持系统的研究

Economics and Life Cycle Cost
成本核算，工程评估方法

Technology Demo & Verification
技术示范



Global change, energy, sustainability…
气候变化、能耗、持久性发展。。。

- Multi-scale infrastructure assessment and adaptation strategies
  多层次水系统评价、适应策略研究开发
- Dual systems and non-centralized system management
  双管水网系统，分散型水处理及管网系统
- Energy-saving and water conservation
  水处理、水网节能节水技术
- Alternative water sources development and utilization
  非常规水源开发与利用
- Innovative collection system designs
  污水收集系统高强技术工艺

Integrated Management & Decision Support Systems
全方位管理决策系统

Water quality, system rehabilitation and replacement…
水质、系统维修。。。

- Pressure pipe rehabilitation technology demo/verification
  压水管道维修保养技术研究、开发与鉴定
- Pressure pipe rehabilitation methods and materials
  压水管道维修方法及材料的研究
- Gravity sewer rehabilitation methods and technologies
  污水重力管网修保养技术方法评估和应用
- Odor and corrosion control
  污水怪味和腐蚀的控制与管理

What we know 现状

U.S. water infrastructure is critical for providing essential services

美国三水(污水、排水、饮用水）基础工程是保证社会服务的关键

- Protect public health and the environment 保护公众和环境健康
- Support and sustain our economy 支持经济的持续性发展
- Comply with Safe Drinking Water Act and Clean Water Act 保证饮用水和水资源法律的贯彻执行

Significant investment in water infrastructure

大规模投资已建成了现有三水基础工程

- Over 16,000 POTWs, serving 190 million people； 1万6千个公共污水处理厂为1.9亿人提供服务
- About 54,000 community water systems, serving 264 million people；
  大约5万4千个社区供水系统为2.64亿人提供优质饮用水
- 724,000 miles wastewater sewers； 120万公里的污水管网
- 1,000,000 miles water distribution lines. 170万公里的饮用水管网系统

Much more needed over the next couple decades

今后二十年需要更多的投资

- $54 billion needed for collection systems (2000 CWNS); 540亿投资于污水收集（00普查结果）
- $183 billion needed for distributions systems (2005 DWNS). 1830亿用于饮用水管网（05普查结果）

Sustainable infrastructure assessment, rehabilitation and management technologies needed

着重于开发基础工程评估、维修、管理技术方法，促使基础工程的持续性发展

Research challenges 研究目的

- How do the major factors (climate change, population growth, urban/suburban expansion, etc.) affect US water infrastructure and threat to public health and the environment?

  主要因素 （气候变化、人口增长、城建扩张，等等）会怎样对三水基础设施的影响，对公众健康和环境的危害？

- What are effective and economic technologies to be developed or identified for drinking water and wastewater infrastructure condition assessment, rehabilitation and for leakage reduction from distribution systems and by-pass of POTWs?

  什么是经济有效的污水和饮用水技术？ 它们能用于三水基础设施的评估、维修保养，和减少管网漏水和水资污染

- How drinking water distribution systems and wastewater collection systems be designed and operated for energy and water quality sustainability into the future?

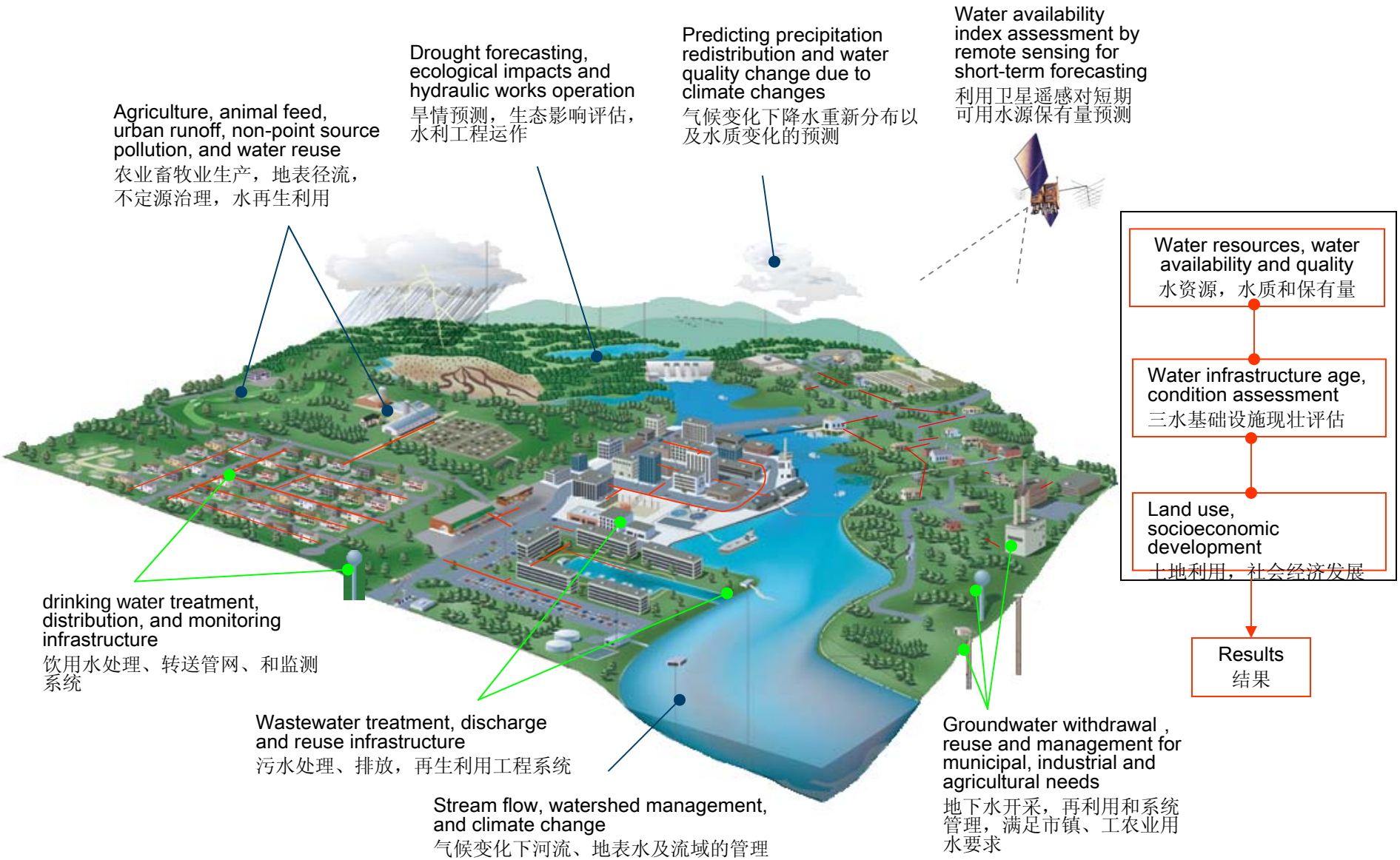
  从系统设计着手，怎样减少三水基础设施能耗和增强水质保护？

- How can the dynamics of drinking water and wastewater infrastructure deterioration and failure be better understood in support of comprehensive asset management?

  加强三水基础设施水动力损耗的研究工作。怎样利用这些知识对基础设施进行综合管理？

Multi-scale infrastructure assessment and adaptation strategies： Major elements at watershed scale

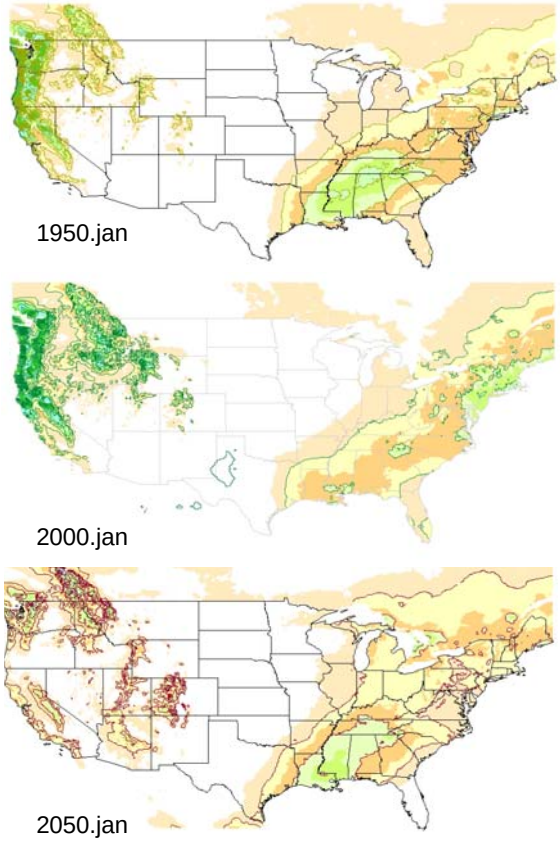
多层次三水基础设施系统评价和整体适应策略：流域层面的考虑因素



Multi-scale infrastructure assessment and adaptation strategies: Effect of climate change and water availability

多层次三水基础设施系统评价和整体适应策略： 气候变迁和水源保有量

HADCM3 Climate Model Predictions



- Climate change, precipitation redistribution, and socioeconomic developments directly affect water availability and quality. In addition to the traditional factors, they are important in long-term water infrastructure planning and engineering

  气候变迁、降雨重新分布、和社会经济发展都能直接影响水质和水量，是三水基础设施长期规划和工程设计需要考虑的主要因素

- Climate model predictions, robust statistical forecasting, GIS spatial analysis, remote sensing detection, and other methods are commonly used at EPA for quantitative characterization

  EPA研究手段：大气模型预测，统计预告，GIS时空分析，以及遥感监测，等等

- Initial EPA research results indicate that region-specific changes need custom-designed infrastructure adaptation techniques for sustainability. Examples:

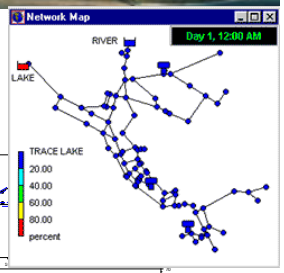
  EPA初步研究结果表明，基础设施的适应策略应根据区域性的特征来设计。例如：

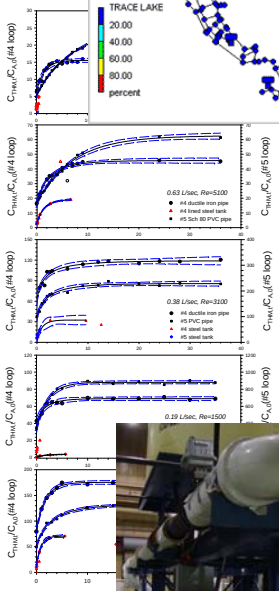
  - Increased drought: Water reuse and infrastructure (e.g., dual systems)
    干旱： 水再生利用，相应的水基础设施（例如：双管水管网系统）
  - Heavy precipitation and flood: Conveyance capacity; emergency water supply; CSO; POWTs capacity
    暴雨，洪水： 水管设计流量，灾区饮水供应，排洪排污管网，污水处理能力
  - Salt water intrusion: pipe corrosion and integrity, DW treatment in coastal areas
    海水陆向入侵： 沿海地区水管腐蚀与保护，饮用水处理工艺变化
  - Biotoxin, microbes in surface water sources: Drinking water treatment, advanced oxidation technologies

    地表水中微生物、生物毒素：饮用水处理工艺变化，先进氧化灭菌技术应用

Multi-scale infrastructure assessment and adaptation strategies: Advanced water distribution management concepts

多层次三水基础设施系统评价和整体适应策略：供水系统新型运行管理方法





- For future climate and socioeconomic conditions, water treatment and distribution system operations are systematically optimized for the best combination of energy consumption, water age/water quality, and operational economics.

  预测未来气候变迁和社会经济发展，优化供水系统，力求最佳系统能耗、水滞时间/水质变化、和操作管理耗费

- Research focus on alternative treatment and distribution network design and operation (e.g., central *vs* decentralized), pump operations / energy consumption, and chlorine (disinfection) addition operations

  研究重点：饮用水、污水处理及管网的整体设计、运行（例如：集中式，分散式），水泵运行和系统能耗，管网网端氯消菌站运作

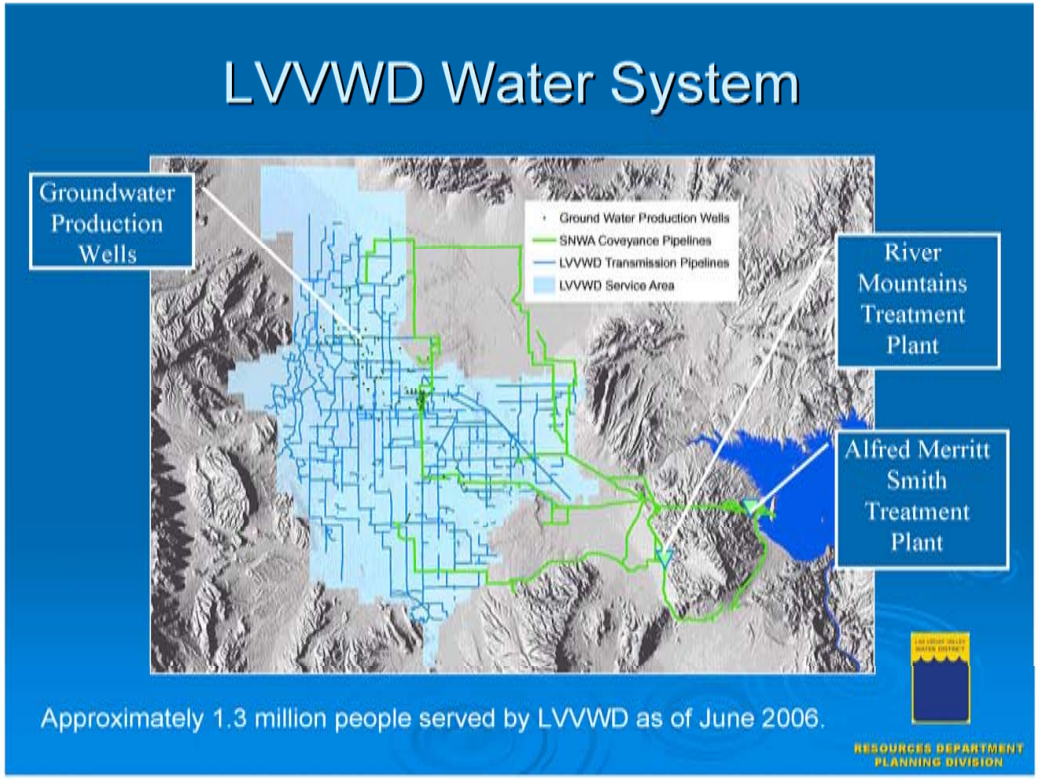
- In EPA studies, pilot-scale distribution pipe systems and EPANet models are used to study the water quality changes (e.g., chlorine decay and DBP formation kinetics), to calculate energy consumption for alternative network configurations and operational modes. Networked sensors are used for data collection and system optimization.

  EPA研究利用了T&E实验站的环形输水管道实验系统和EPANet水网计算机设计模型，在不同设计运行条件下，进行管网系统水质变化和能耗的研究；用水质转感器联网来采集数据和系统优化设计

- Research completed or ongoing: pipe corrosion, biofilm growth, pipe material and water quality, energy auditing, etc. Field demonstration to be at water utilities.

  已完成或正展开一系列的研究项目： 管体腐蚀，管壁生物菌膜生长，管材与水质，能耗计算，等等

Multi-scale infrastructure assessment and adaptation strategies: Apply advanced management concepts to Field Systems
多层次三水基础设施系统评价和整体适应策略：实际应用



- Las Vegas is a good example of water supply security and infrastructure adaptation to meet the socioeconomic needs

  位于美国西部的那斯维加斯市是个典型例子。保证水供应来满足社会经济发展的需要以成为适应性水基础设施的关键

- LVVWD is the water authority. It has tried to meet water needs for 1.3 million people and the local economy. The population has doubled in the last decade while the source water in Lake Meade has been in constant decrease because of drought and climate changes

  那斯维加斯市供水局力图满足1百三十万居民和当地经济的供水要求。居民总数在过去的十年中番了一番。由于干旱和气候变化，作为主要水源的LAKE MEADE，水源保有量一直下降

- EPA and LVVWD are working together, to optimize the water supply system operation (e.g., re-chlorination) under current and future conditions in populations, climate and water availability

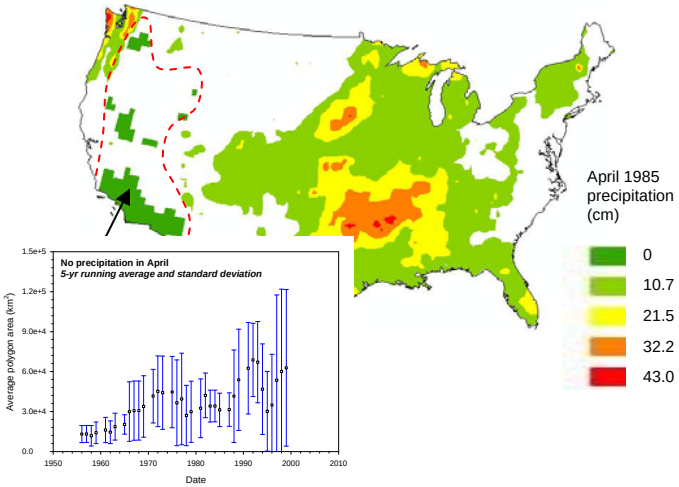
  EPA和那市供水局正开展合作，对供水系统进行优化，以保证现在和未来条件下供水的水质、水量

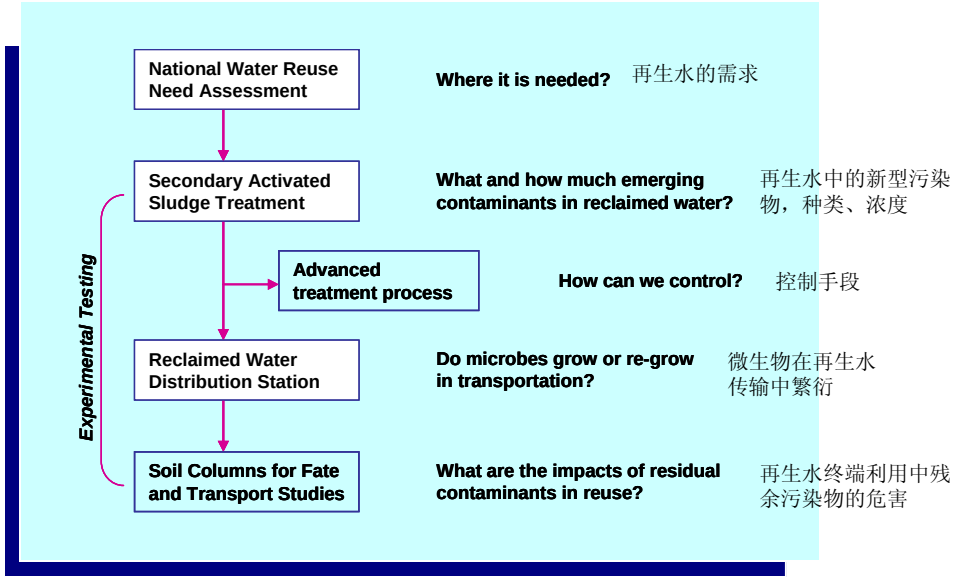
United States Environmental Protection Agency

Water Resources Adaptation Techniques for Water Supply Security: Examples

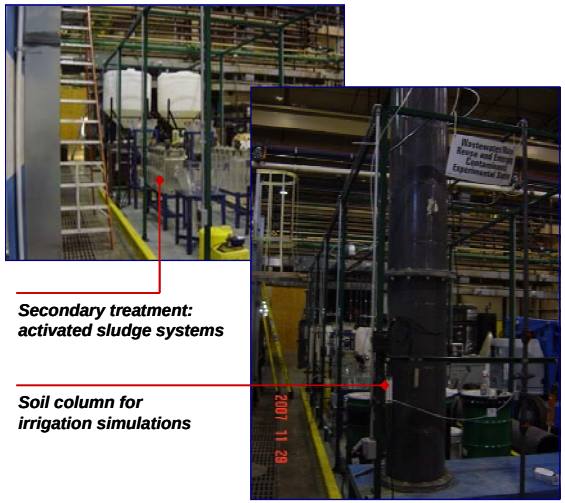
Alternative water sources development & utilization
非常规水源开发与利用

National water reuse need spatial analysis
再生水需求分析



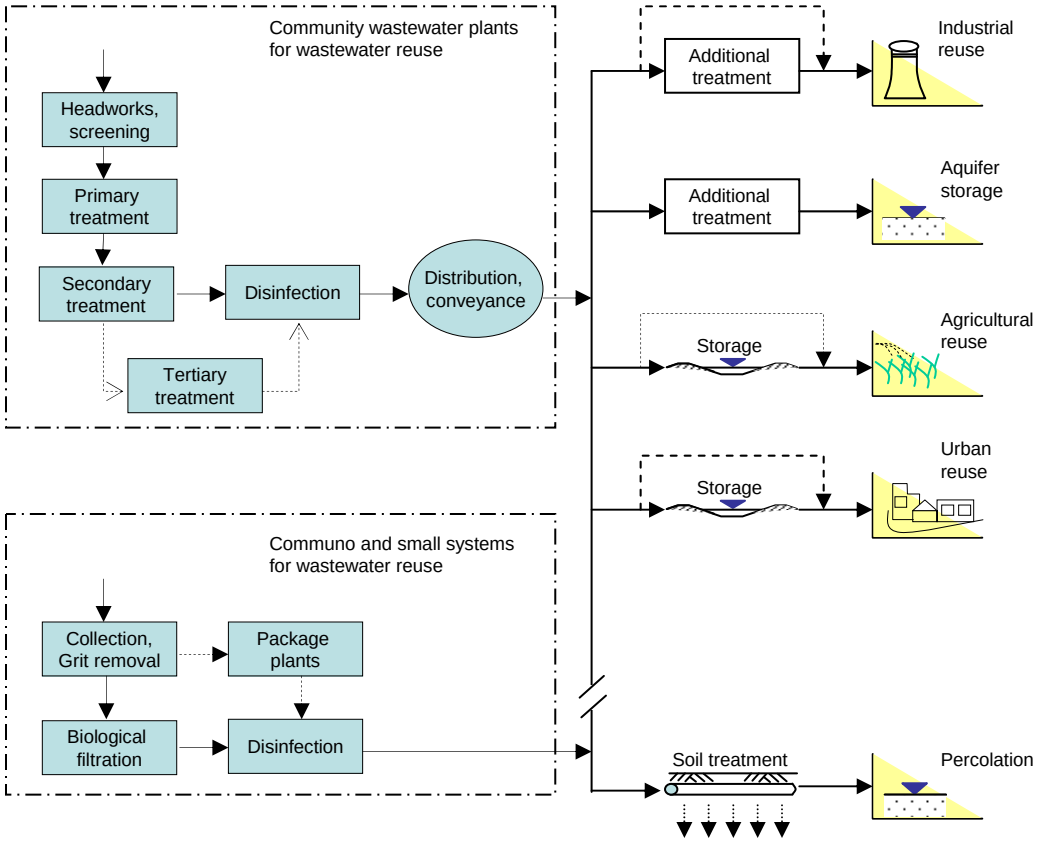


Wastewater reuse experimental testing
污水再生水处理和使用测试



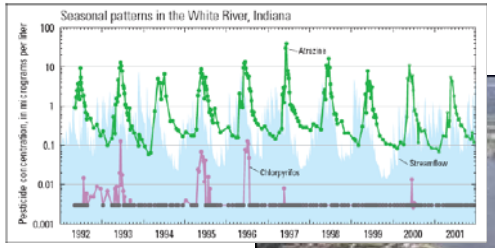
Low-pressure MBR development for wastewater reuse
污水再生的低能耗生物膜反应器开发

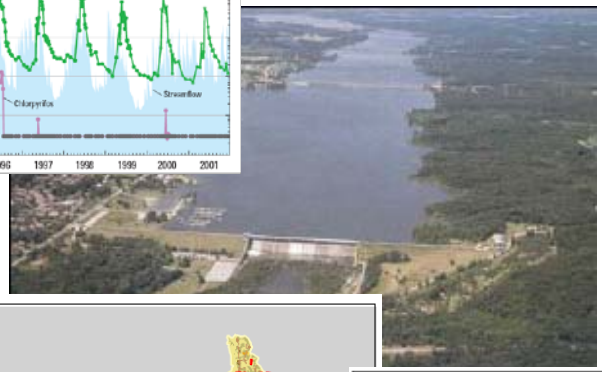
Adaptation: Alternative Water Resources

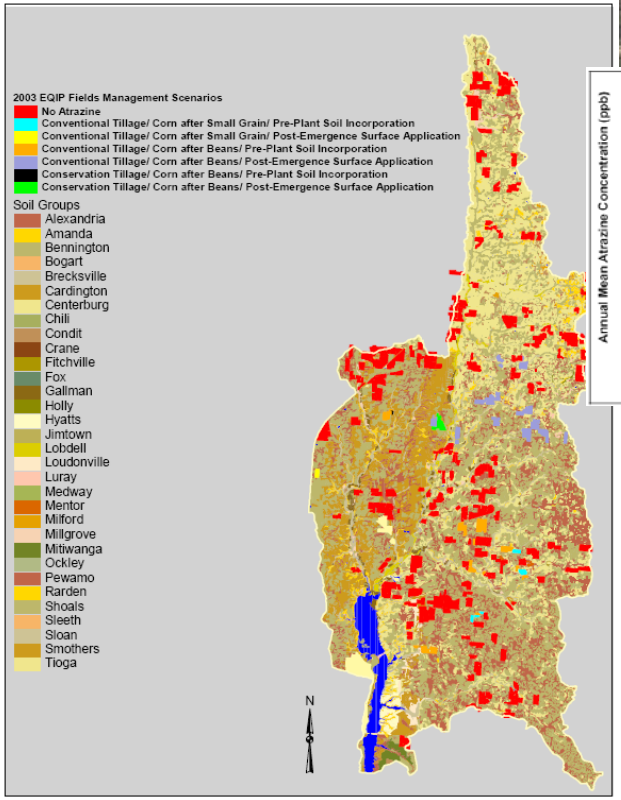


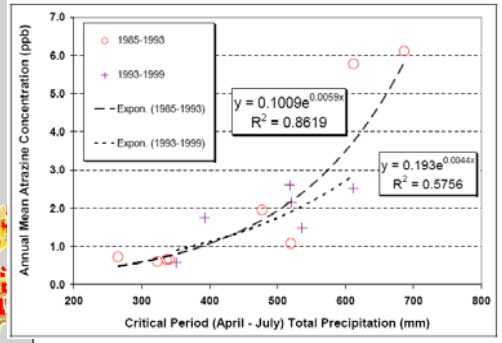
- Reclaimed water quality criteria for end-use scenarios: spray and drip irrigation, aquifer storage and recovery (ASR)
- Treatment of pathogen and emerging contaminant in conventional activated sludge system, and advanced treatment needs for wastewater reuse
- Fate and transport of emerging contaminants and pathogens in secondary and indirect potable reuse
- Contaminants: 17β-estradiol, 4-nonylphenol, aldicarb, atrazine, *Giardia, Cryptosporidium*

Adaptation: Watershed BMP and Carbon Storage









At a watershed level, how to define and deploy BMPs for both non-point source pollution control and increased carbon storage?

The Big Walnut Creek watershed studies (Columbus, Ohio)

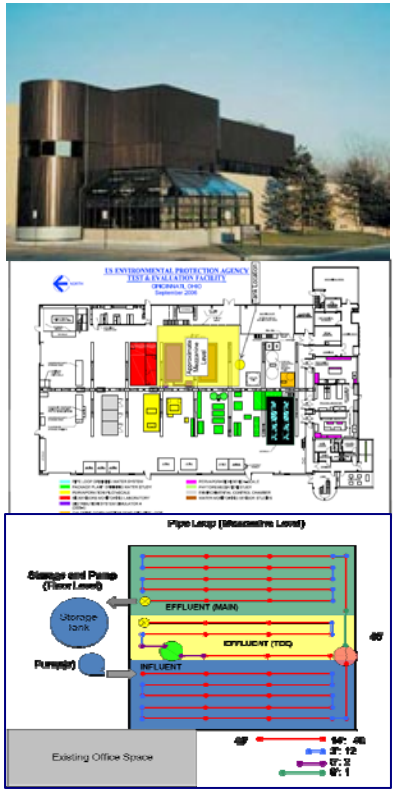
- Soil conservation, carbon retention, and pollutant release are closely related in a watershed. Possible to use BMPs for carbon storage and for water quality management?
- Project started in 2001 with the purpose to reduce atrazine loading from agriculture land to drinking water sources for the city of Columbus, Ohio
- Publications. For example: S. T.Y. Tong, A.J. Liu, and J.A. Goodrich. 2007. Climate Change Impacts on Nutrient and Sediment Loads in a Midwestern Agricultural Watershed. Journal of Environmental Informatics, Vol. 9 (1), 18-28.
- More detailed studies on carbon storage in Big Walnut Creek Watershed and BMP studies in other watershed basins are needed.

Pressurized pipe leak detection, network rehabilitation: Overview

压水管道破裂水漏的探测和管网维修：概要

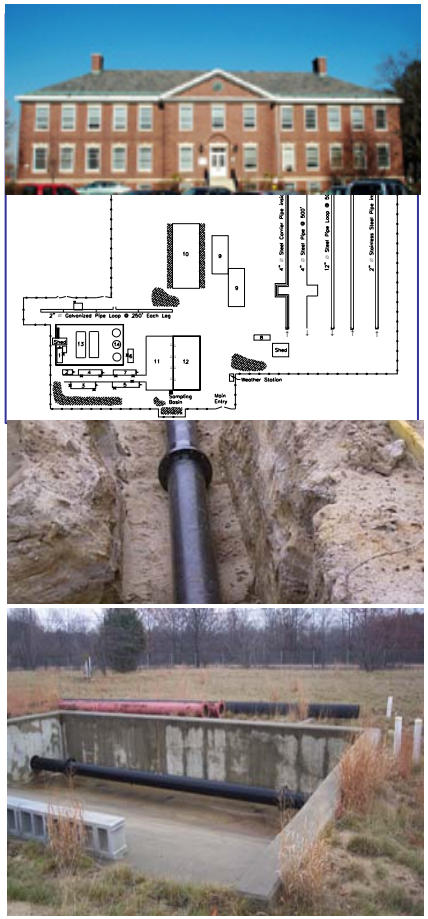
Pilot-scale Experimental Station at EPA T&E facility (Cincinnati, OH)

辛辛那提T&E小型管裂探测实验台



Field-scale Experimental Station at EPA-Edison Facility (New Jersey)

新泽西州爱迪生大型管裂测试中心



- EPA leak detection research is to find economic and effective technologies to reduce water loss and prevent water contamination and quality deterioration in the pipe

  EPA压水管道破裂水漏的研究，旨在研究开发精确实用的方法手段，用来减少成品水流失，防止管网中水质污染

- Two major research centers: pilot-scale experimental station at Cincinnati T&E facility, field-scale experimental station at New Jersey Edison facility

  EPA二大研究中心：辛辛那提T&E小型管裂探测实验台，新泽西州爱迪生大型管裂测试中心

- Non-intrusive detection focus:

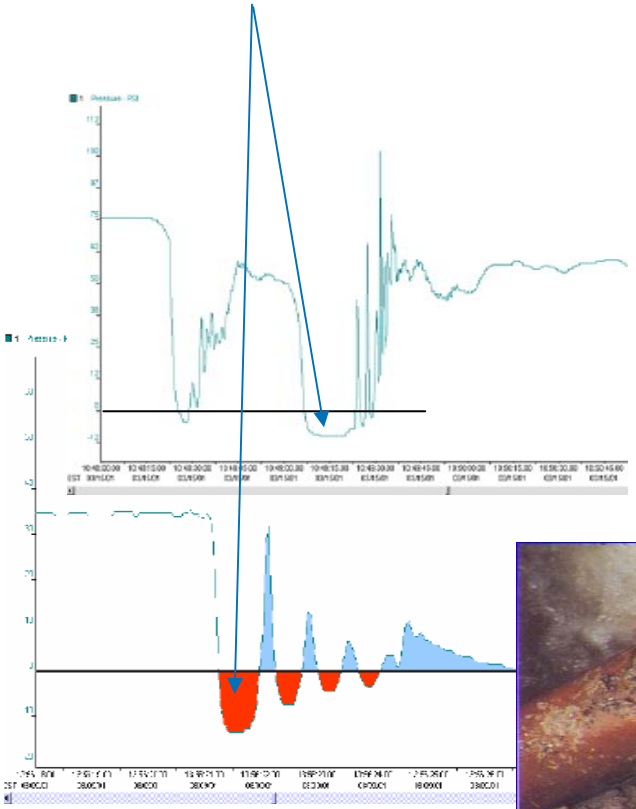
  非侵入性探测手段：

  Sonar; laser; zoom cameras; 声纳，激光，高精度成相
  In-line SmartBall; smart pigs; 在线微体智能球，智能猪
  Acoustic sensor monitoring; 声波传感器监测
  Ultrasonic thickness testing; 超声波管厚测试
  Broadband electromagnetic testing; 宽带电磁
  Magnetic flux leakage; 磁流遗矢法

Pressurized pipe leak detection, network rehabilitation: Pipe leak and water quality

压水管道破裂水漏的探测和管网维修：管漏与水质

Transit negative pressure (suction) in network operations
水管中产生的瞬时负压，产生反向倒吸



- Approximately 15-20%, up to 50% finished drinking water not accounted for. A large fraction is lost to ground through corrosion pit holes and breaks in distribution pipes

  供水管道的腐蚀、孔洞及断裂能造成15-20%成品水流失，可高达50%

- Many in ground without detection for years

  许多管漏在地下很多年，通常很难发现

- Transit negative pressure occurs in network operations normally in short duration (<10 sec), but repeats constantly creating inflows from outside of pipes

  供水管网操作中，在孔洞附近产生瞬时（<10秒）负压，导致地下水回流进入管道

- Resulted in water quality deterioration: rapid chlorine residual loss, and biological contaminants in drinking water

  回流直接造成水质变坏：氯残余（氧化消毒）的迅速丢失、生物污染物的存在和繁衍

Pressurized Pipe Leak Detection, Network Rehabilitation: Networked acoustic sensor detection research

压水管道破裂水漏的探测和管网维修: 联网式声波传感器探测研究

- Acoustic detection technology has been commercially available for pipe leak detections and widely used in the U.S. It is relatively economical compared to other non-intrusive leak detection technologies

  声波探测技术比较成熟，已广泛应用。相比之下，它比较经济

- Disadvantage: The detection performs during night time without background noise and the detection accuracy varies normally in a long segment between two sensor locations

  缺点：由于噪音的干扰，水网测试只能在晚上进行。可以确认大致在二个转感器之中管漏，但不能确定具体地点。

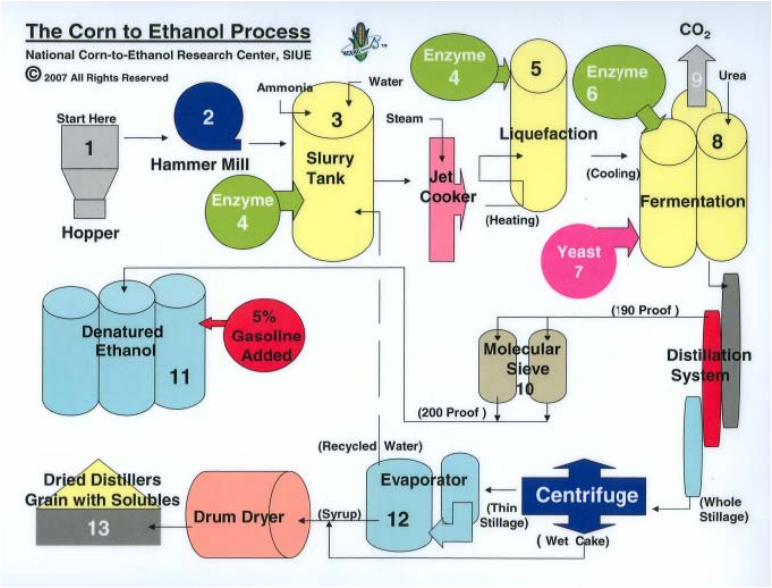
- EPA research aims to yield acoustic detection techniques more accurate and precise, and more robust from background noise interference. The approach uses networked acoustic sensors, newly generated algorithms, and a designated detection sequencing.

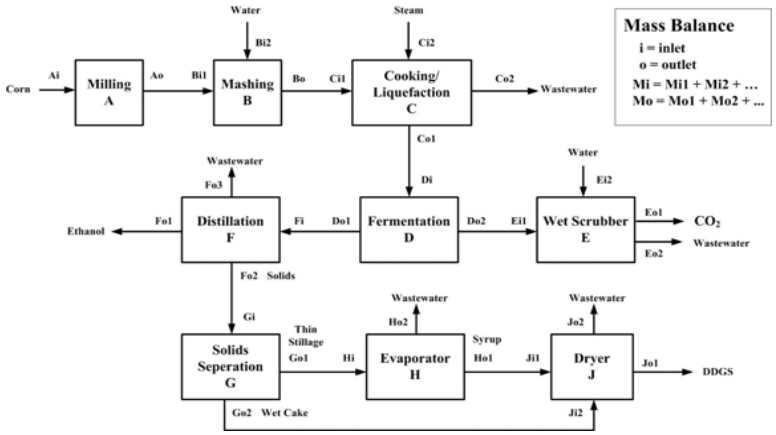
  EPA研究着重于新型声波探测技术的开发，以提高探测的精确度和准确率到底（管漏的地点）， 和抗干扰能力。其方法是利用声波探头联网，新型探测公式和探测程序

- The research is ongoing at EPA T&E facility in Cincinnati

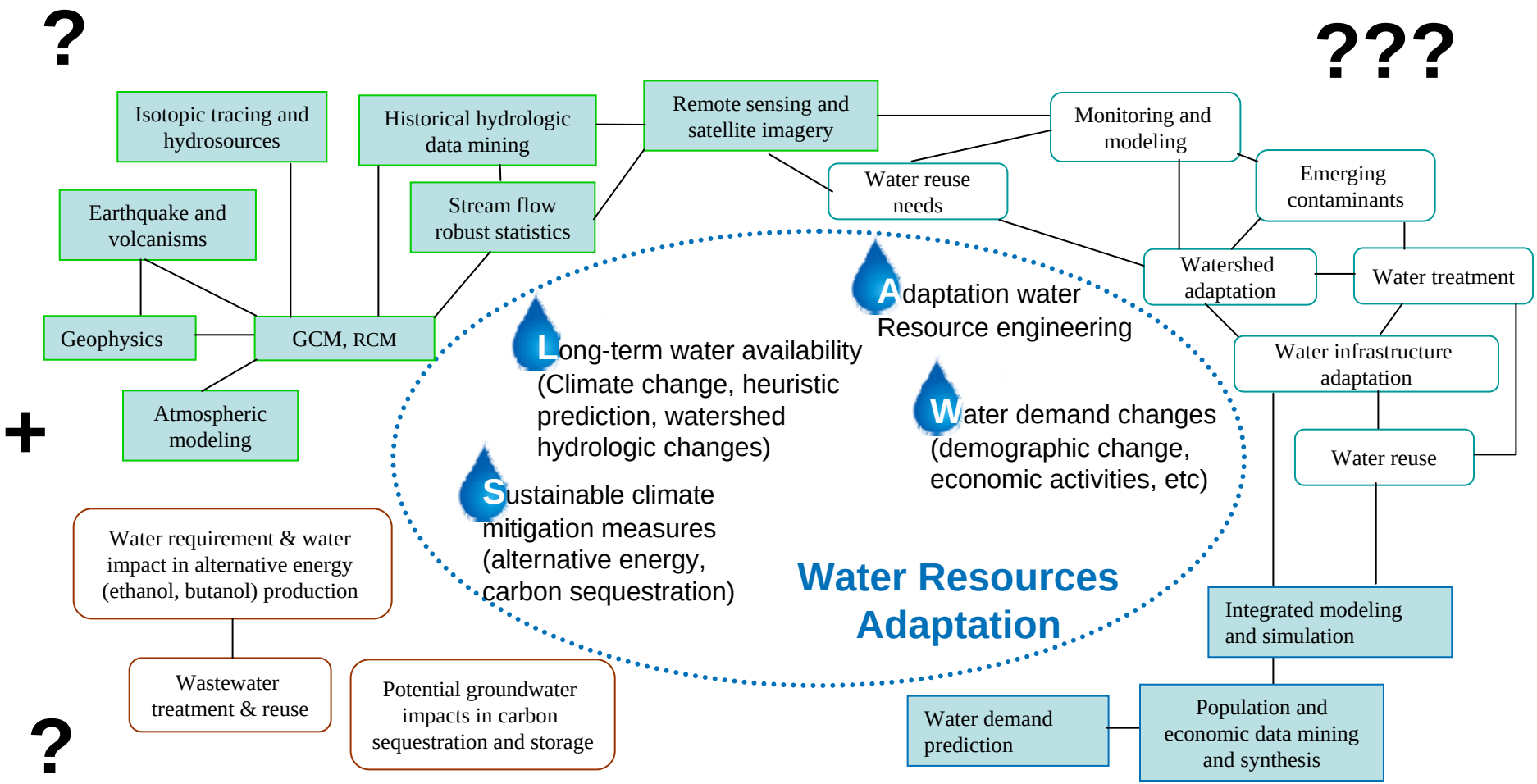
  EPA新型声波探测技术的开发正在Cincinnati的EPA T&E 实验中心进行

Mitigation: Water resources impact and adaptation in alternative energy productions





Uncertainties and The Need for Adaptive Approaches to Secure Water Supplies



Climate Change and Water Resources Adaptations

Summary

- Hydroclimatic variations and changes have been underway for some time. Various methods are used to predict the future with less uncertainties. Adaptation is a proactive approach to increase system resilience to the likely future changes
- Atmospheric circulation, oceanic, topographic and land use feedbacks all affect the hydrologic process and therefore the sustainability of water resources engineering and management
- The effect is region-specific, requiring custom-designed adaptation strategies
- Watershed adaptation and water infrastructure adaptation are critical to assure amber and high-quality water supplies and water program sustainability. The EPA WRAP research centers around these two research fronts

United States Environmental Protection Agency

Questions

Thank you!
谢谢

yang.jeff@epa.gov