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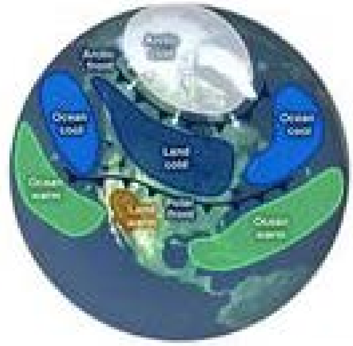

Water System Adaptation To Hydrological Changes

Module 7
Adaptation Principles and Considerations

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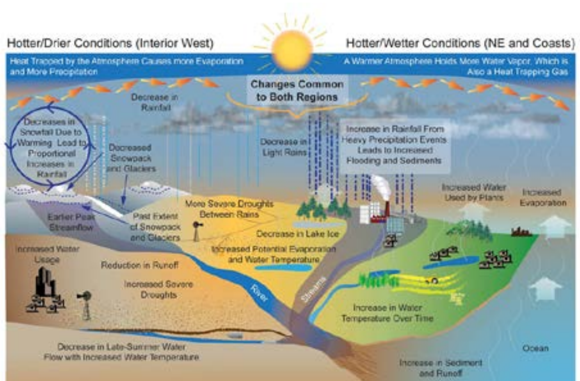
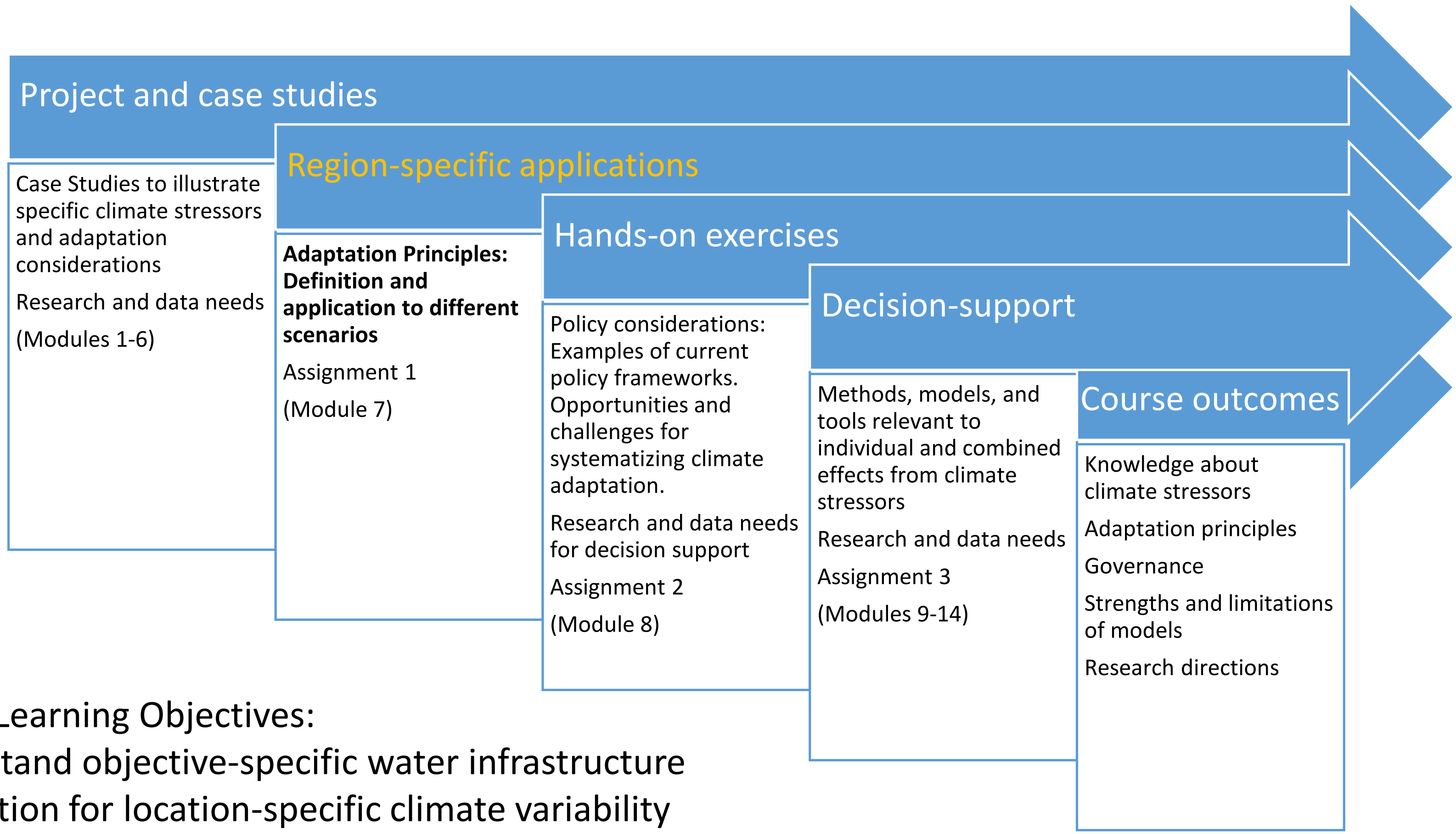


Course Roadmap



Module 7 Learning Objectives:

- Understand objective-specific water infrastructure adaptation for location-specific climate variability
- Develop climate projections for assessing risk at local watersheds
- Consider adaptation planning/design in time and spatial context

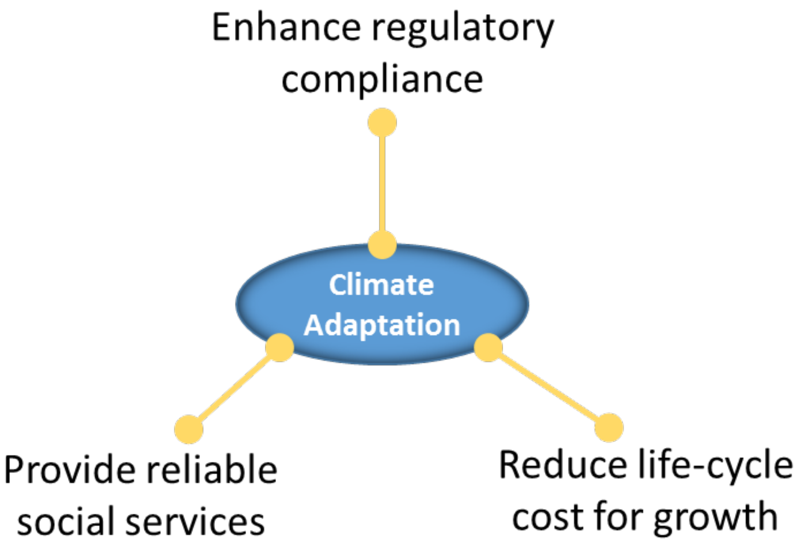
Key Topics: Module 7

Water system adaptation is location-specific and objective-dependant. Major adaptation factors for efficiency and sustainability are:

- Local climate projections and hydrological parameters
- System interactions at local scales
- Management objectives defining data needs and adaptation approach

Key considerations for all three types of water infrastructures

- Climate and hydrological projection uncertainty
- Land use changes important to define the climate adaptation basis
- Climate vulnerability assessed in three approaches
- Climate risk communication in planning time frame, uncertainty, and cost



Triple bottom line

General Adaptation Steps and Considerations

Water System Adaptation is a Continuous Iterative Process

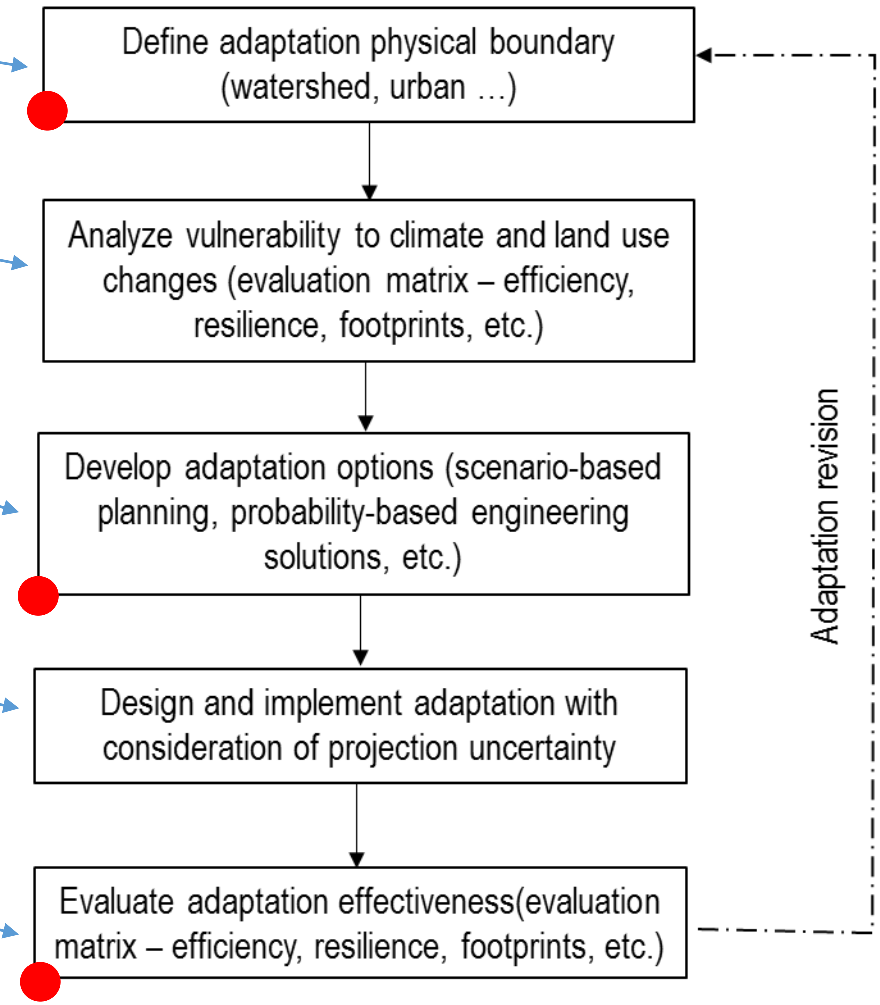
First step for decision-makers and technical managers

Critical step for hydrological analysis of climate vulnerability in top-down, bottom-up, or other hybrid approaches

This step needs integrated modeling and quantitative analysis of future scenarios to determine if adaptation objectives can be met

Design adaptation actions to meet the objectives (uncertainty, resilience, economics, etc.)

Very important step in adaptation. Iterative process through periodic effectiveness evaluation and planning

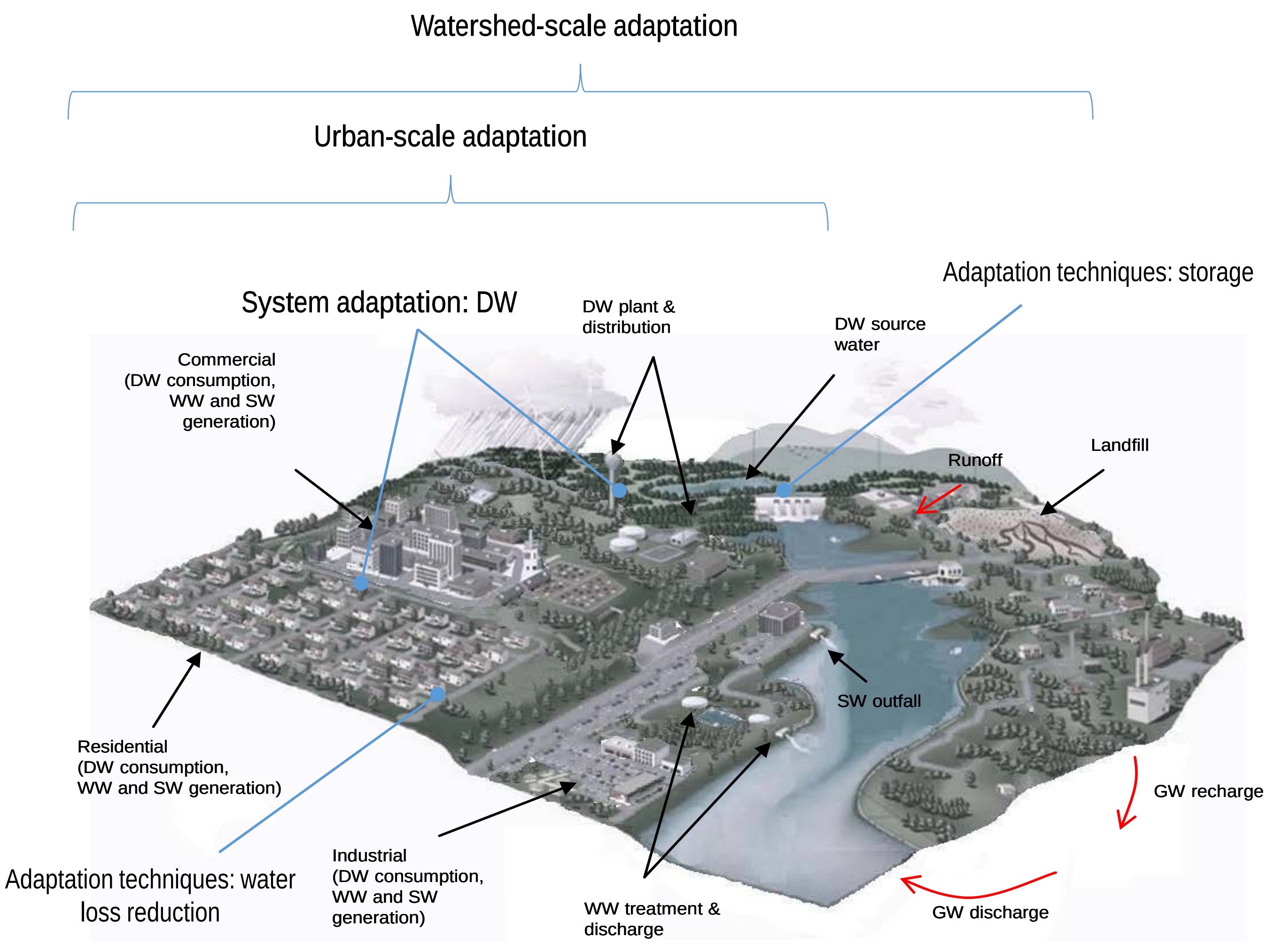


● Intensive stakeholder involvement

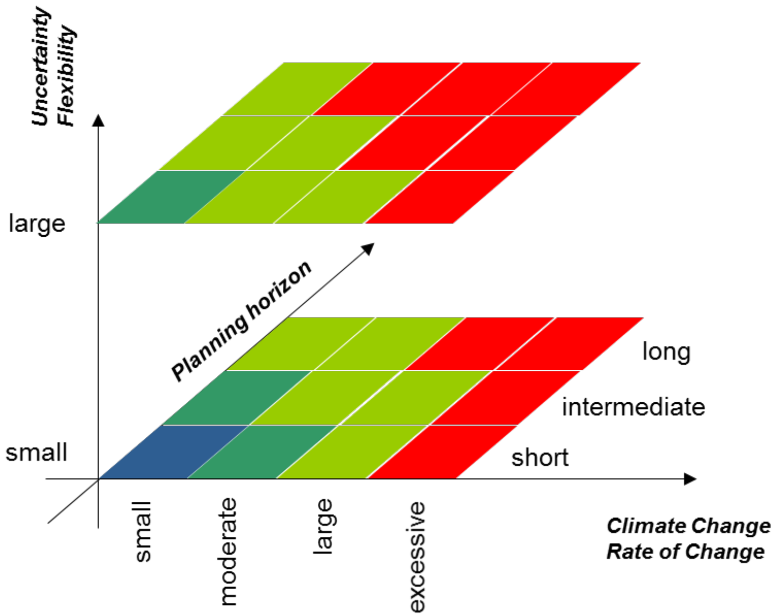
General Adaptation Steps and Considerations

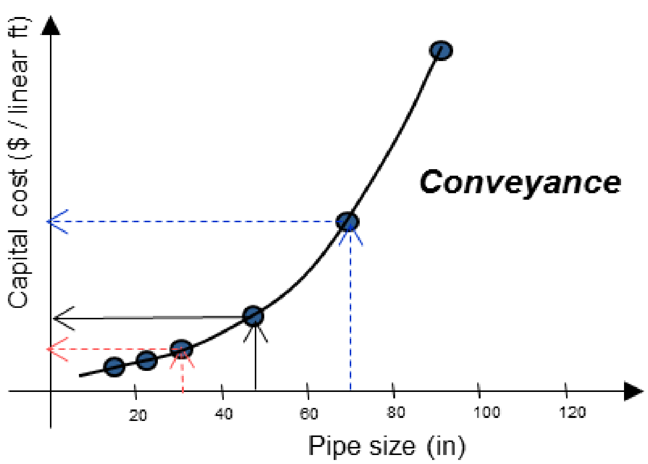
Adaptation in Systems Context for Effectiveness:

Adaptation often takes place in difference scales, affecting one and another



General Adaptation Steps and Considerations





Time frame for water infrastructure adaptation

- Longer time frame lead to more uncertainties in climate and land use projections and hence in hydrological design parameters
- Engineering means for managing the design uncertainty can be cost-prohibitive
- Water infrastructure has about 30-year time frame in master planning, the same time horizon for climate impact realization

General Adaptation Steps and Considerations

Technical considerations for assessment and adaptation under uncertainty

1. • **Long-term** (30-50 yrs) climate predictions
2. • **Short-term** (daily – yearly) climate – water monitoring
3. • **Integrated** watershed hydrologic modeling

probability sustainability

Top-Down

- Climate modeling and projections
  1) Emission scenarios
  2) Global circulation models (GCMs)
  3) Regional climate models (RCMs)
- Watershed modeling
  1) Land use
  2) Hydrology – flow
  3) Hydrology – water quality

Future impacts
(*uncertainty*)

Capacity reserve
(*resilience-cost*)

Bottom-up

- Watershed management: vulnerability
  1) Baseline
  2) Management goals
  3) Acute and long-term changes
- Water infrastructure: Risk management
  1) Current and future capacity and demands
  2) Design basis and resilience

General Adaptation Steps and Considerations

In summary, major considerations include:

Objectives

- Adaptation objectives: subject, timeframe, goals, cost/budgeting
- Policy and regulatory needs

Climate risk assessment

- Climate projection and hydrologic impact assessment at local inland / coastal watersheds
- Climate risk assessment relative to current design by top-down (model based) or bottom-up (asset based) approach
- Hydrological effects of both climate and land use changes
- Uncertainty evaluation for design basis

Adaptation design and implementation

- Multi-system interactions
- Water infrastructure and urban form difficult to change
- Technical and cost comparison of adaptation options
- Stakeholders' involvement in developing and implementing adaptation options

Adaptation effectiveness monitoring

- Hydroclimatic and precipitation change monitoring, and adaptation revision
- Water infrastructure evaluation
- Analysis of performance indicators against adaptation objectives

Define Climate Risk for Adaptation

- For water infrastructures, climate is only one of the principal factors, but it is one with large projection uncertainties
- Other factors include land use changes, urban form, human behaviors, aging infrastructure, etc. All interact with the climate, affecting design variables
- Hydrological changes in flow / water quantity and water quality are the key design variables

Define Water System Risk for Adaptation

Changes in design storm and watershed hydrology:

- Significant changes in design storm (intensity, volume, and return interval)?
- Significant changes in coastal hydrology, including inundation from sea level rise and storm surge?
- Large changes in surface runoff, stream flow, and thus nutrient transport in watersheds?

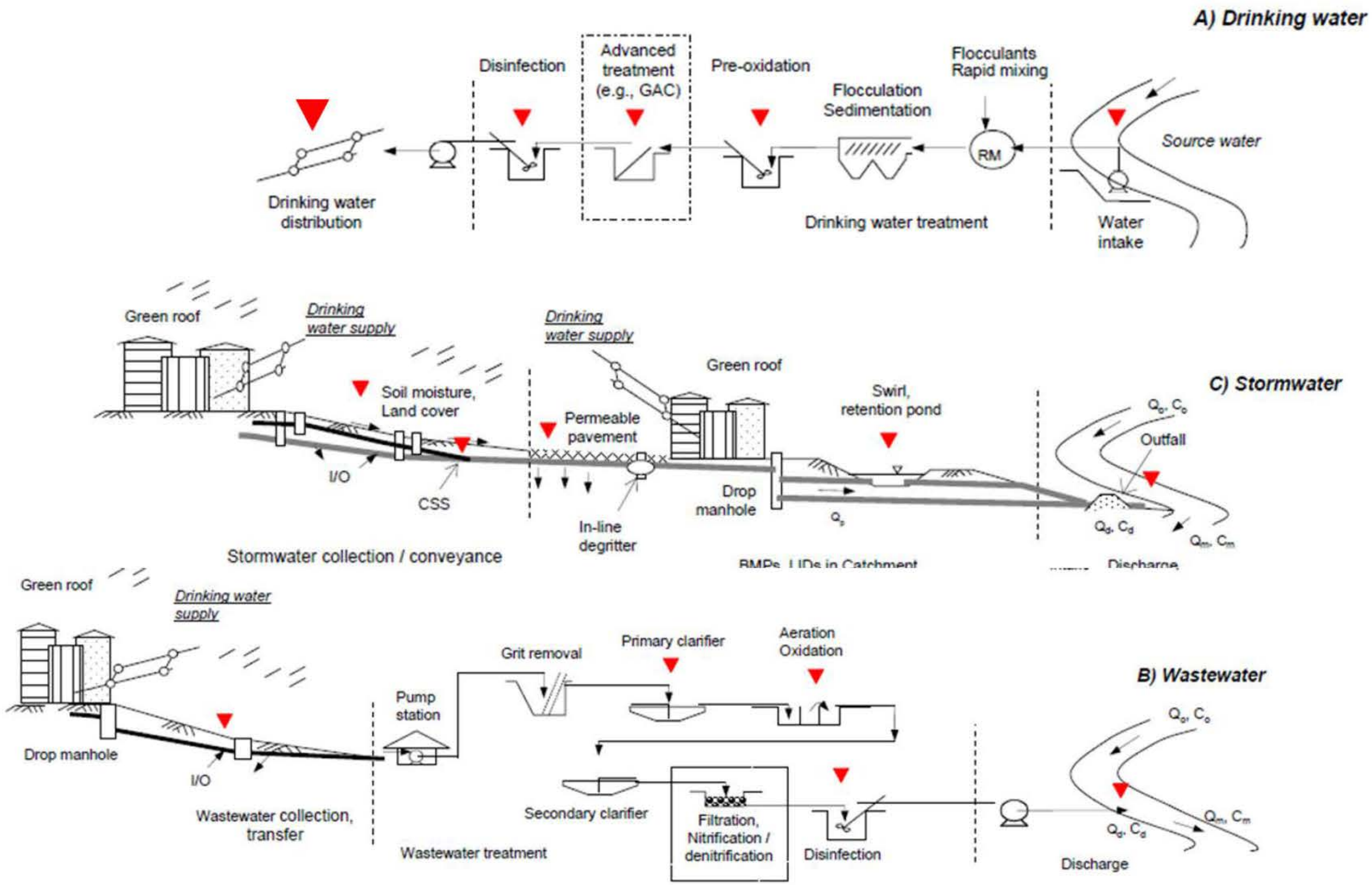
Urban development and human interactions:

- More land use converted to impervious surfaces, and thus greater runoff?
- Changes in spatial distribution of non-point and point source in future urban development?
- Changes in water demand and wastewater generation?

Design basis under current and future climate

- Changes in design storm, design wind, and evapotranspiration (ET)?
- Changes in surface runoff, stream flow, and pollutant transport in watersheds?
- Significant change in water availability?

Impacts on Drinking Water Infrastructure



Process unit likely affected by changes in climate and hydrological variables

Typical Impacts on Wastewater Infrastructure

Major Operation Unit	Function	Major Design Criteria*		Vulnerability to Climate Change**			Adaptation	
		Physical	Chemical, biological	Physical	Hydraulic Function	Water Quality Function	Function	Example
Wastewater collection								
Wastewater collection	Wastewater collection from all users in a service area	WW yield: 0.38 m^3/person-day; Flow velocity: 0.6-4.6 m/s; Flow rate: 1.5 m^3 /person-day (laterals and branches)	Sulfur and methane gases generation	Likely High	Likely High	Likely Low	Pipe I/O flow management; Wastewater reuse and separation.	Pipe leak detection; Dual pipe system; Onsite wastewater treatment
Wastewater pumping and conveyance	Wastewater transfer to a central location(s) for treatment	I/O rate: < 0.45 m^3/day-km-cm; Flow: 0.95 m^3/ca-day (main); Flow velocity: 0.6-4.6 m/s	Sulfur and methane sewer gas management; Fire hazard prevention.	Likely High	Likely High	Likely Low	I/O management; Flow velocity & abrasive damage control.	Pipe leak detection Drop manholes; In-line degritter
Wastewater treatment								
Preliminary treatment (screening, degritting)	Solids and debris removal in headworks	Screen debris removal: >5.1-cm Flow (grit chamber): ~0.328 m/s; Aerated grit chamber: 2-5 min residence time	Not applicable	Likely Low	Likely Low	Likely Low		
Primary treatment - Sedimentation tank	Removal of settleable solids and 25-35% BOD	Peak flow <0.71 lps/m^2; Maximum weir load: 2.16 lps/m; Water depth: >2.1m.	Target removal rates: BOD: 20-40%, TSS: 35-65%; Settleable biosolids: 50-75%.	Likely Low	Likely Medium	Likely Medium	Flow equalization facilities to smooth flow variations; Process monitoring	Monitoring and increased maintenance
Secondary treatment - Trickling filters	Biological treatment to remove BOD and macronutrients	Filter depth: 1.5 - 3.0 m; Hydraulic loading: 0.012 - 0.047 lps/m^2, or 0.047- 0.47 lps/m^2 (high rate).	Normal: 0.08 - 0.40 kg BOD/m^3-day; High-rate: 0.48 - 1.44 kg BOD/m^3-day.	Likely Low	Likely High	Likely High	Process control for resilience in shock loading Process flow stabilization	Trickling filter retrofitting; Change recirculation ratios; Process monitoring and control for weir loading.
Secondary treatment - Activated sludge process	High efficiency of BOD and nutrient removal	Weir loading: 1.44 lps/m; Hydraulic loading: 0.47-0.57 lps/m^2 0.38 lps/m^2 with nitrification	Maximum BOD loading: 0.24-0.64 kg/day/m^3; Aeration rate: 93.5-125 m^3 oxygen / kg BOD	Likely Low	Likely High	Likely High	Process control for resilience in shock loading Increase treatment capacity reserve.	Modify cell age and sludge return rate; Improve aeration efficiency; Increase aeration capacity.
Secondary and final clarifier	Settleable biosolid removal	Surface settling rate: 50-62 lps/m^2	Not applicable	Likely Low	Likely Low	Likely Low	Enhance biomass setting	Operational adjustment
Nitrogen removal	Successive nitrification and denitrification	Varies. See U.S. EPA (2009b).	Varies. See U.S. EPA (2009b).	Likely Low	Likely Low	Likely High		
Chlorination	Treatment effluent disinfection	>15 min contact time in chlorination contact basin	<200 fecal coliform / 100 ml	Likely Low	Likely Low	Likely Low		
Treatment process	Overall specifications of each process unit for treatment objectives	Process flow rate; Flow rate variance.	Surface water quality standards for discharge control	Likely Low	Likely Medium	Likely High	Increase treatment capacity reserve to against source water variations and water demand changes	Process optimization, retrofitting, or change and expansion
Wastewater effluent discharge								
Treatment effluent discharge	Treatment effluent discharge under a permit	Varies depending on discharge regulations	Varies depending on discharge regulations	Likely Low	Likely Medium	Likely High	Discharge limits sensitive to the impacts on receiving streams; Compliance to discharge limits.	Adjust treatment process for likely to-be-revised discharge limits.

Note: * Summarized from "10-state" wastewater treatment standards and Lin (2001). These design criteria are for general guidance.
** - Qualitative rating given for major climate changes in precipitation and hydrology, excluding the extreme meteorological events.
I/O - wastewater inflow and outflow by infiltration and exfiltration; WW - wastewater.

Develop Design Storm and Hydrological Parameters

Inland areas

- Example of design storm differences due to hydrological change
- Uncertainties and use of climate model projections
- More details in Module 10&12

Coastal areas

- Example of design precipitation and design wind
- Uncertainties from climate model projections
- Importance of model validation. More details in Module 10

Questions on Design Basis

Inland regions focusing on precipitation:

- Are current precipitation and other design values appropriate for next 30 years in master planning?
- How to derive a design value, for example, the 24-hr precipitation at 10-year recurrence interval under future climate?
- How much uncertainty is associated with the derived design values?
- How do hydrological parameters change in future climate, when considering land use and land cover changes?
- Then how to incorporate the new design parameters in planning and engineering?

Coastal regions:

- How much inundation from future sea level rise and storm surge?
- How will salt water intrusion change from current conditions?
- What the degree of coastal flooding in the future?

Inland: Define Precipitation Changes

Design precipitation is one of the most common and important factors in hydrological and water infrastructure planning and engineering

Past precipitation in observation records

- Stationary climate. Past observations will repeat statistically in the future.
- Design storm and other atmospheric parameters (wind, ET, etc.) at a given recurrence interval
- Non-stationary climate detection by examining long-duration precipitation observations

Future precipitation in model projections

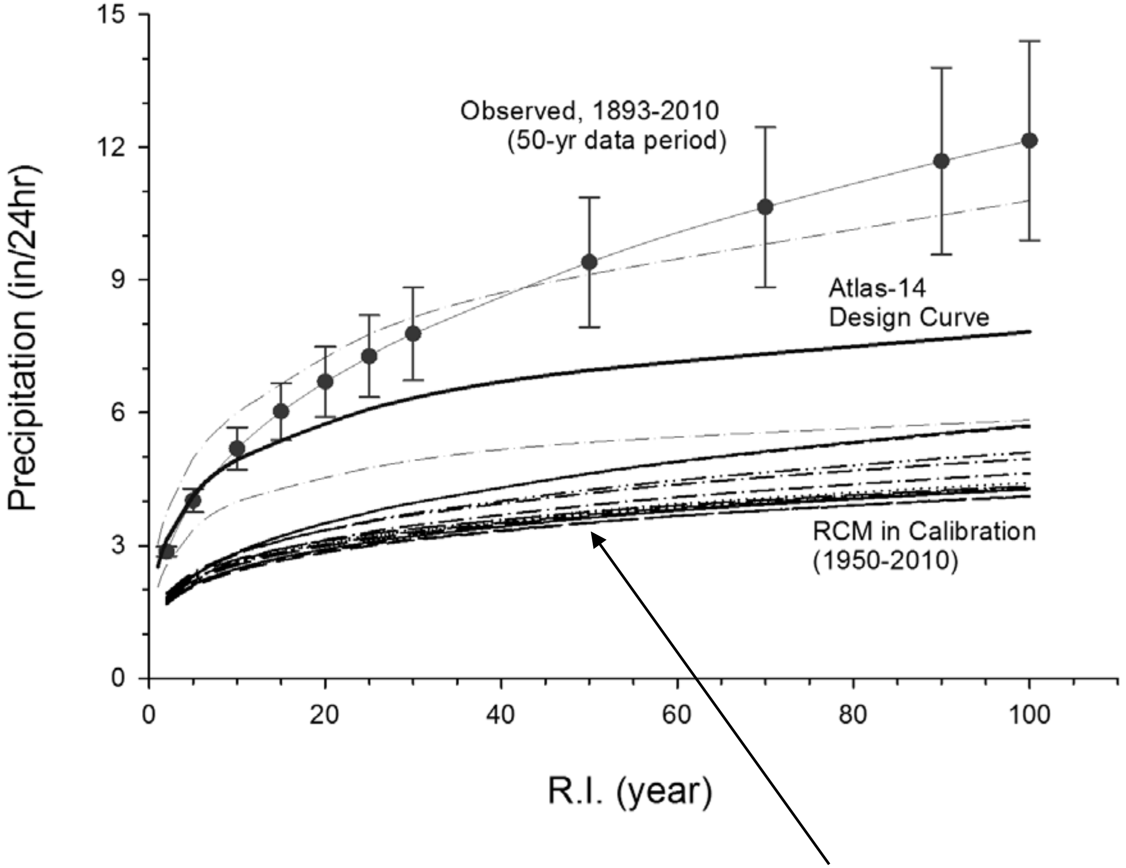
- Non-stationary climate in model simulation.
- Design storm (precipitation, wind, etc.) at a given recurrence interval

Precipitation Intensity-Depth-Frequency (IDF)

- ✓ Determine catchment runoff and other hydrological processes
- ✓ Normally in regional association
- ✓ Regional IDF design curves such as NOAA precipitation Atlas-14
- ✓ Fine-tuned for locations of interest

Changing Design Storms

Design storm determination in Lawrence, Massachusetts (U.S.A.)



All RCMs significantly under-predict design storm across the board

Observation

- High-intensity precipitation has changed since 1990s, and potentially into future

Future Projection

- Regional climate models under-estimate the design storms for calibration period
- Post-processing of RCM data is necessary for projections and in design storm revision
- More details in Module #10 on design storm development from climate models

Coastal Areas: Define Precipitation Changes, Sea Level Rise and Storm Surge Inundation

- Example of design precipitation and design wind
- Uncertainties from climate model projections
- Importance of model validation
- More details in Module 10

Define Precipitation Changes, Sea Level Rise and Storm Surge Inundation

- Precipitation projection and flooding risk management. Similar technical approach on design storms as for the inland precipitation changes (slide #16)
- Sea level rise is happening, and can be projected with fine certainty. Uncertainties in sea ice and ocean circulation
- Storm surge is a major variable for coastal water infrastructure. It can be modelled with accuracy for planning and engineering
- Compounding effect of sea level rise on storm surge is potentially large and should be considered in planning

(More on storm surge modeling in Module 6 & 11)

General Adaptation Steps and Considerations

In summary, major considerations:

Objectives

- Adaptation objectives: subject, timeframe, goals, cost/budgeting
- Policy and regulatory needs

Climate risk assessment

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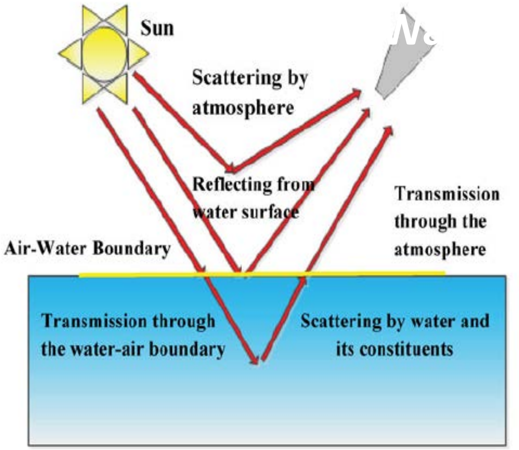
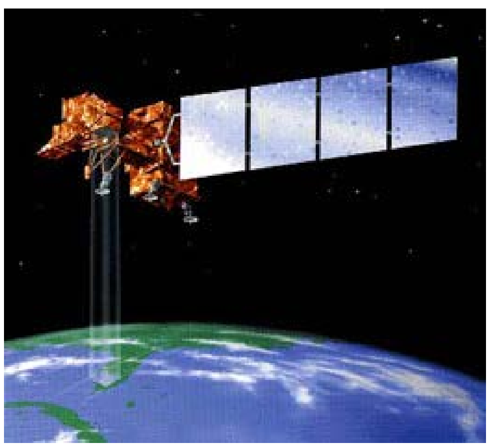
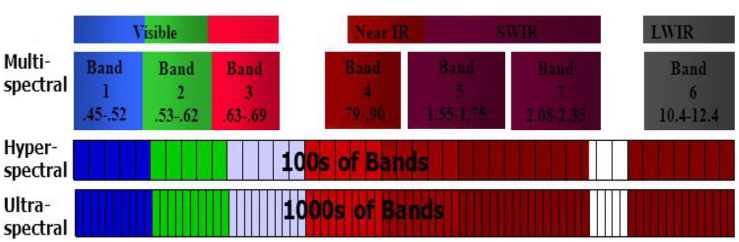


Reflectance measurement (adapted from Liew, n.d.).

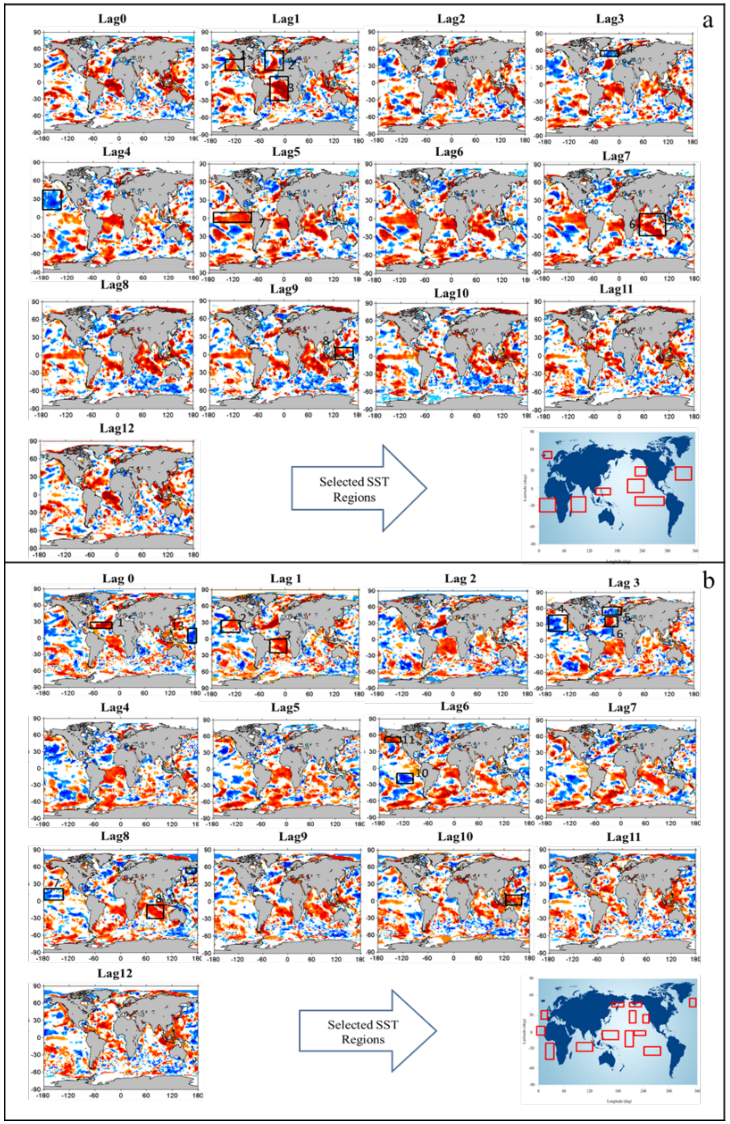




Monitor Stressor Change Impacts and Adaptation Effects

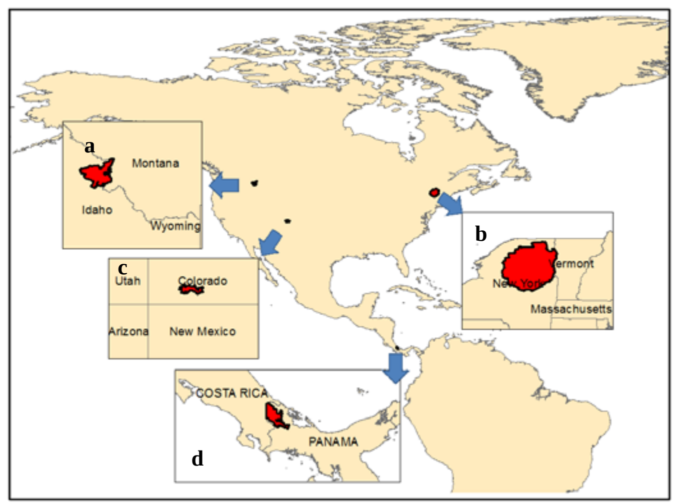
- The methods and techniques are available for timely assessment, providing spatial and temporal analysis
- These methods must be economical and accessible
- Examples in satellite-based monitoring techniques to assess:
  - water quality changes in surface water bodies
  - watershed hydrology (e.g., soil moisture, precipitation) teleconnection with global systems
  - urban heat island effects for urban forms in adaptation

Example of Monitoring Precipitation Change Impacts



- Relate precipitation variability to surface sea temperature (SST) anomalies (Left)
- Forecast precipitation changes using SST observations by artificial neural network (ANN) techniques

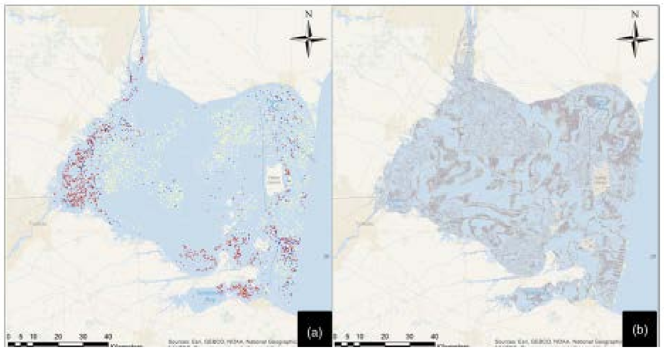
Chang et al. (2015). *Hydrological Processes*, **29(3)**, 339-355.



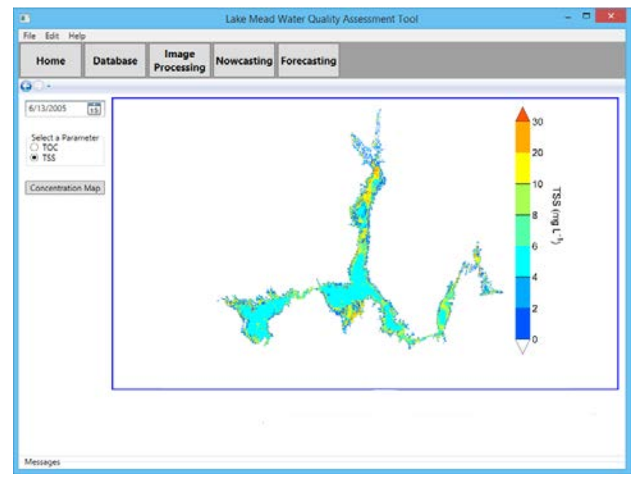
Locations of selected sites in North and Central America; a) Selway-Bitterroot Wilderness; b) Adirondack State Park; c) Weminuche Wilderness; d) La Amistad International Park

Example of Monitoring Water Quality Change Impacts

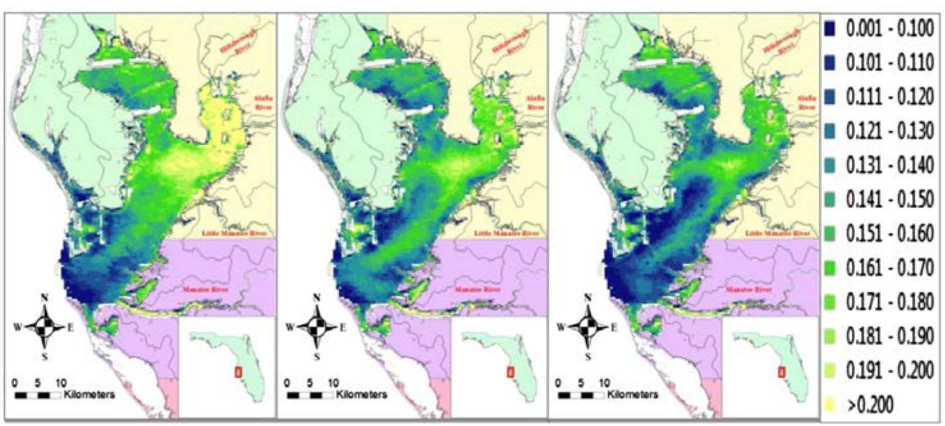
Satellite-based microcystin concentration map during the blue algae bloom in western Lake Erie (Chang et al. 2015)



Satellite-based daily monitoring and nowcasting of total organic carbon (TOC) concentration in Lake Mead, the source water of the Las Vegas water plants (Imen et al., 2016)



Satellite-based phosphors concentration map in Tampa Bay, showing the pollution source from rivers and climate effects through the years (Chang et al. 2013)



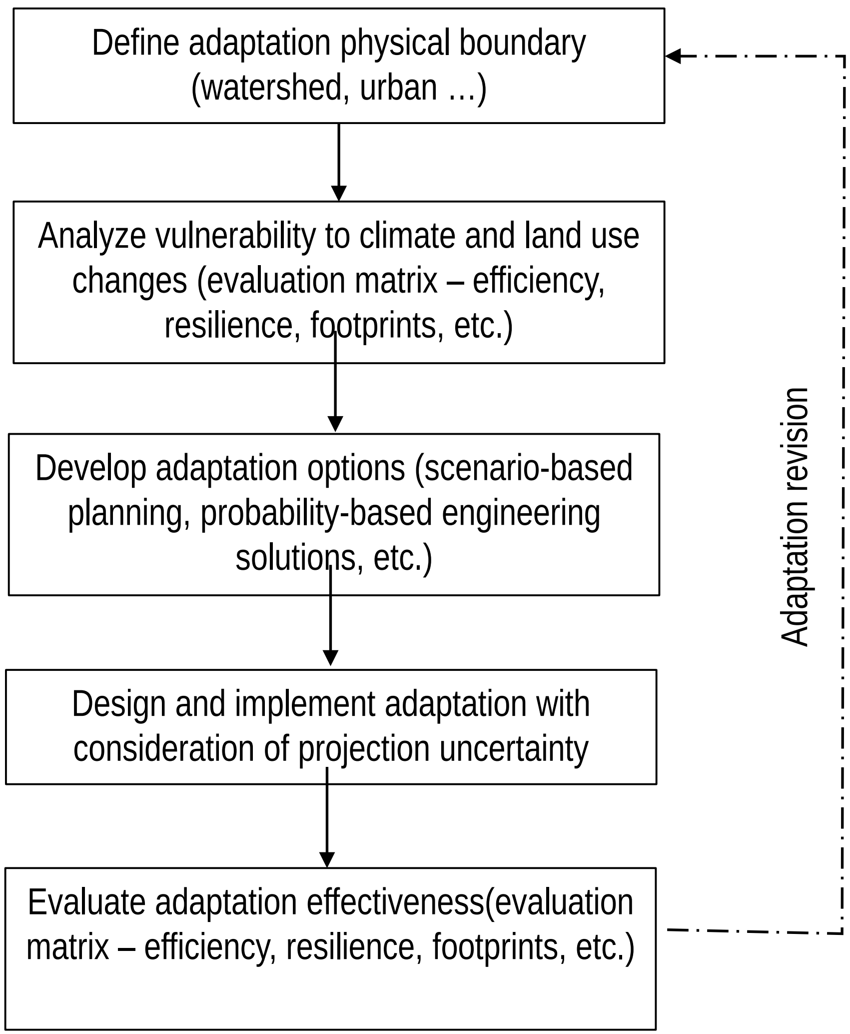
(a) 2004 (b) 2005 (c) 2006

Monitoring Impacts and Adaptation Effectiveness

In summary,

- The methods and techniques available for timely assessment, providing spatial and temporal analysis
- They must be economical and accessible
- Examples in satellite-based monitoring techniques to assess
  - ✓ Water quality changes in surface water bodies
  - ✓ Watershed hydrology (e.g., soil moisture, precipitation) teleconnection with global systems
  - ✓ Urban heat island effects for urban forms in adaptation
- Results used to revise and adjust adaptation objectives and options

Summary: Impact Assessment and Adaptation Development Steps



Adaptation is objective-dependant

So are the data needs in climate projections and hydrological parameters

Monitoring is a critical part of hydrological adaptation with three essential functions:

- Update climate projections in order to reduce uncertainty and improve design basis
- Evaluate adaptation effectiveness and determine whether the adaptation objectives are met
- Analyse if additional adaptation measures are needed

Summary and Research Questions

Summary:

- Climate adaptation principles (i.e., revision and updating of hydrological variables) for managing uncertainties
- Design basis specific to location and adaptation objectives
- Quantifying projection uncertainties to manage the risk in adaptation
- Systems modeling of climate, watershed, and water infrastructure helpful in design basis development (See module #11)
- Deterministic *vs* adaptive engineering, due to the climate uncertainties (See slide #23 in Module 9). This requires iterative climate risk assessment – adaptation – evaluation (See previous slide)

Research Questions

Research question:

- Describe how to gather and incorporate climate data (precipitation and temperature) into the planning and sizing of a stormwater retention pond in a local park
- List major steps for developing an assessment and adaptation program for climate and hydrological impacts in your country

Looking ahead to the next module…..

- Next module: Policy considerations in water infrastructure adaptation to hydrological impacts
- Scoping of project topics