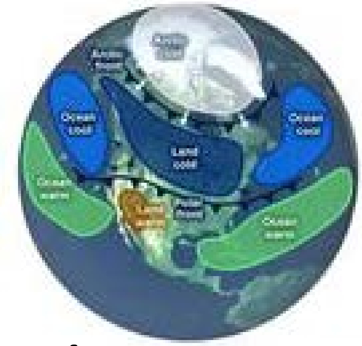
MAGEEP Education Network



Water System Adaptation to Hydrological Changes

Module 10
Basic Principles of Incorporating Adaptation Science into Hydrologic Planning and Design

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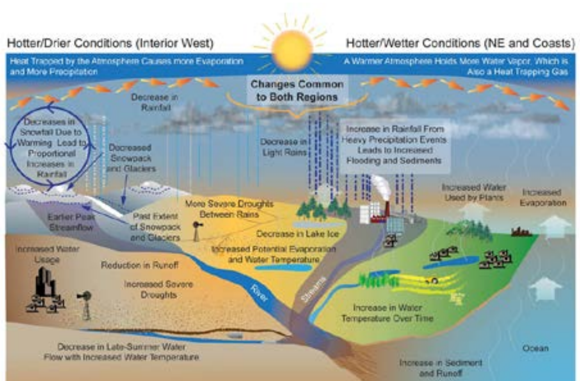
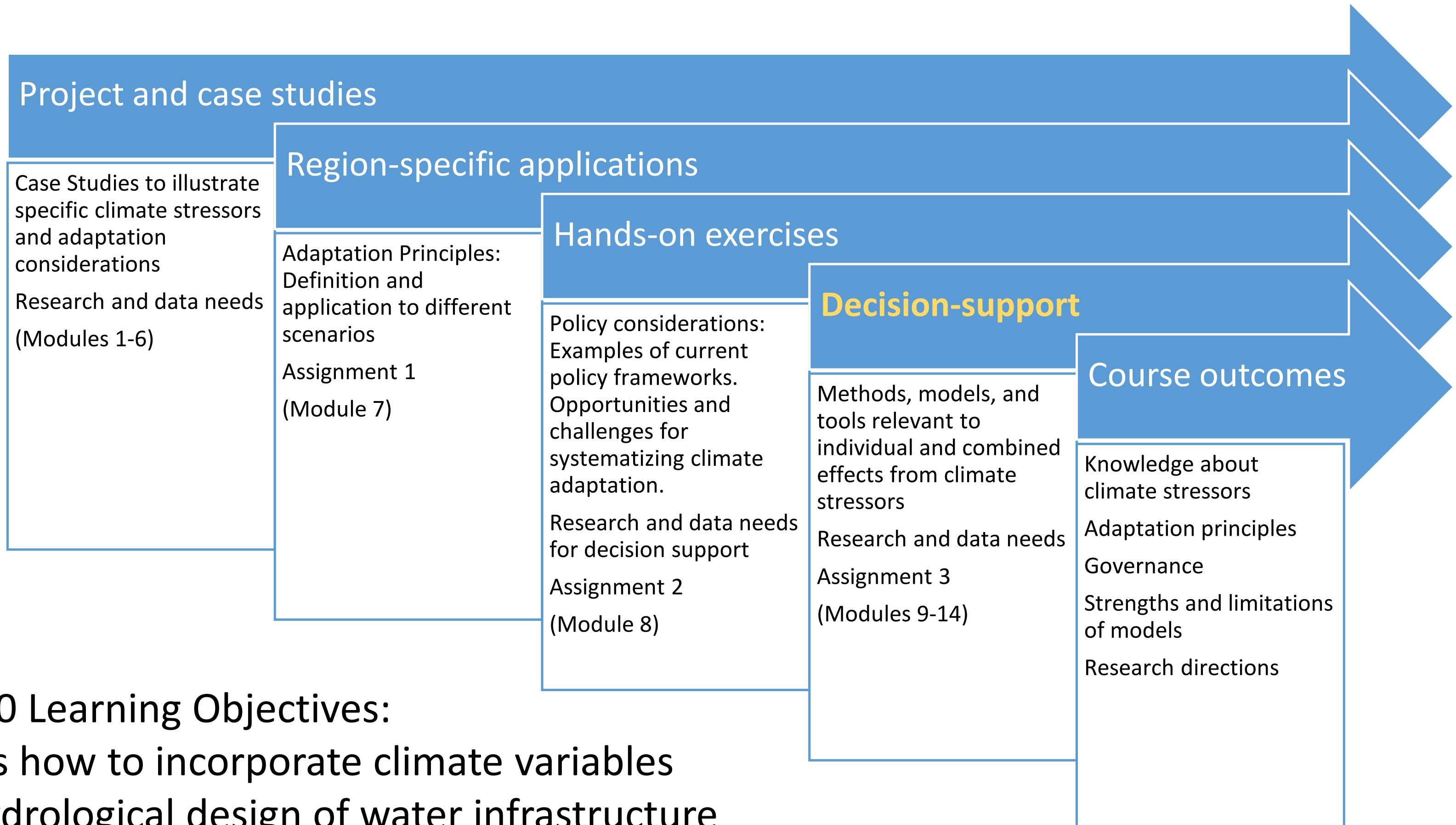


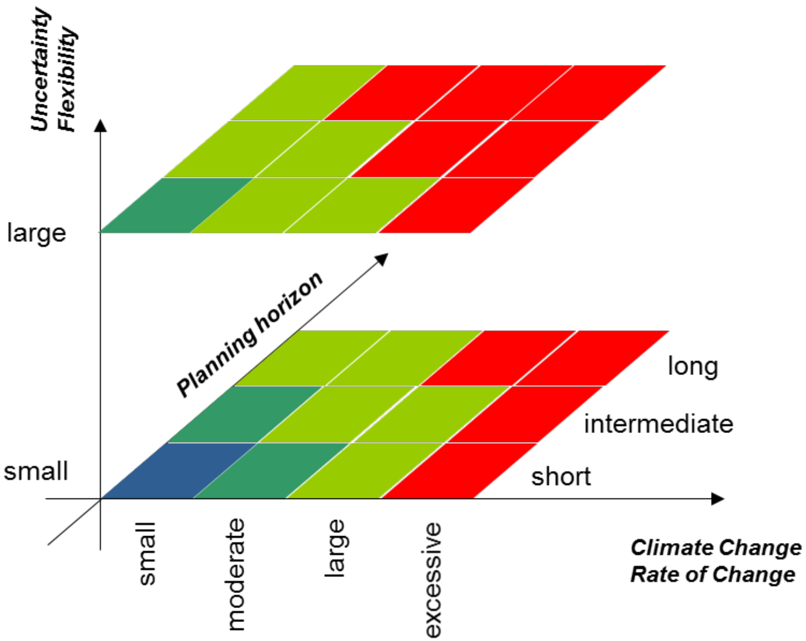
Course Roadmap

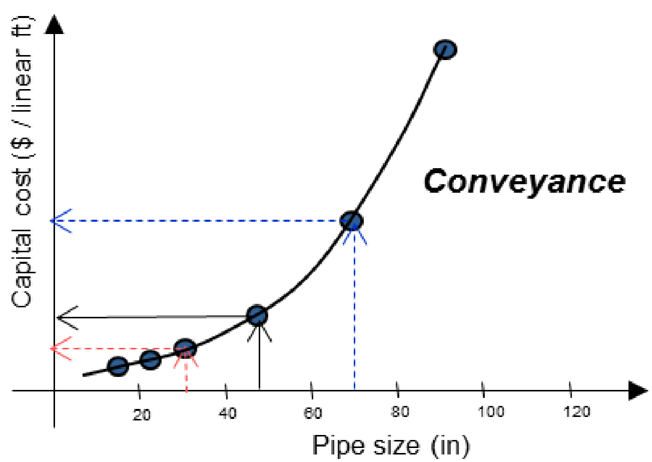


Module 10 Learning Objectives:

- Discuss how to incorporate climate variables into hydrological design of water infrastructure
- Become familiar with the concept of capacity reserve and adaptive design to manage risk in climate uncertainties

Key Topics: Module 10





- Water system adaptation is objective-dependant
  - Increase resilience in the time of planning framework
  - Assure water supply in both current and future hydroclimatic conditions
- How to incorporate adaptation in current water resource planning
  - Consider climate as a variable not a constant
  - Assess both climate and land use changes in watershed hydrology
  - Reevaluate the water infrastructure design basis

Principal Climate and Hydrological Impacts

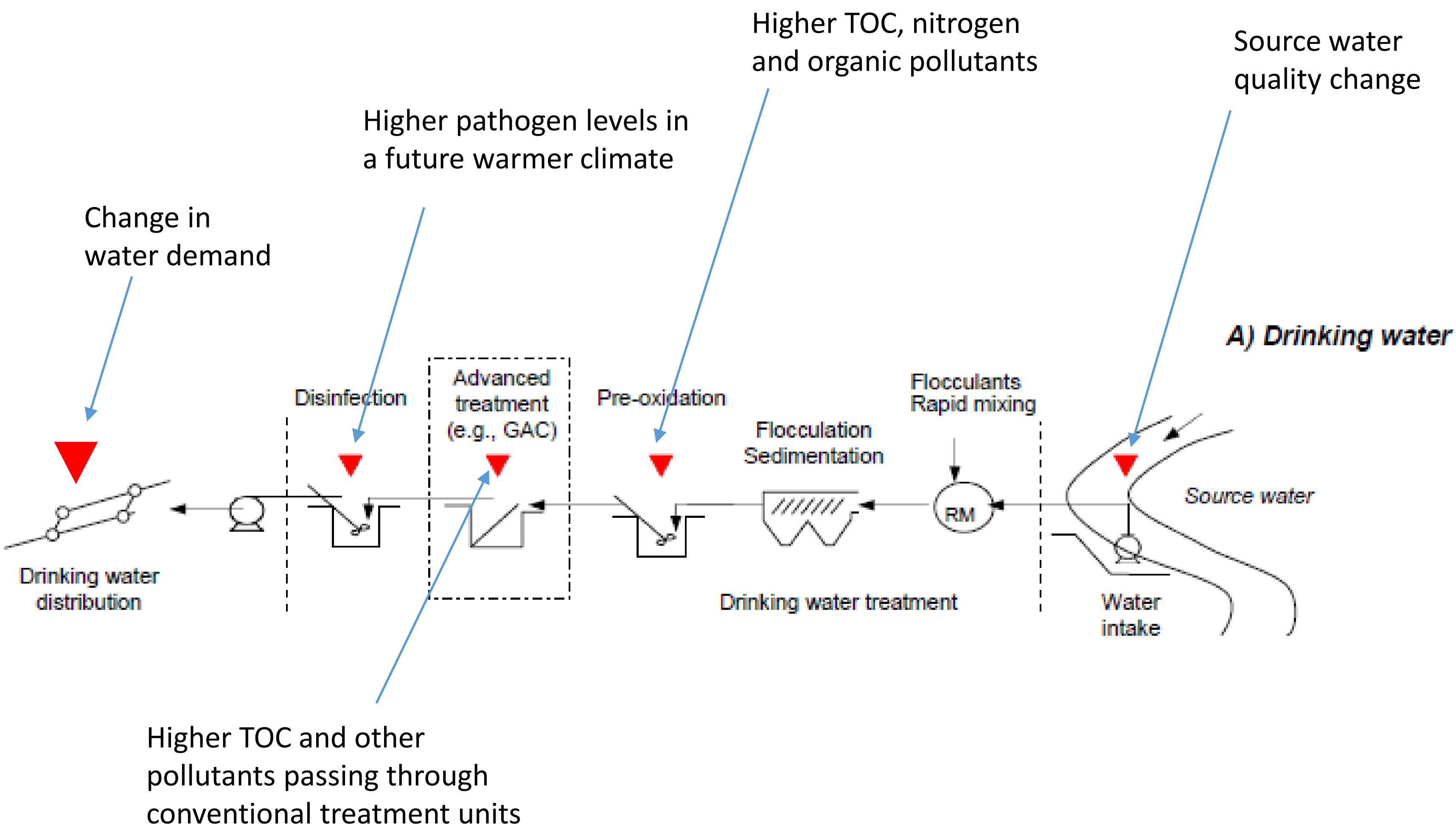
Direct Impacts:

- Changes in watershed hydrology
  - Source water for water supply (quality and quantity): Surface water and groundwater changes
  - Stream carrying capacity limiting water discharge
  - Stream erosions and overland runoff
- Changes in coastal hydrology
  - Inundation from sea level rise and storm surge
  - Coastal flooding and salt water intrusion

Human Interactions:

- Water demand change in a warmer climate: human and agricultural consumption, minimum ecological stream flow, and so on
- Compounding between urban development and precipitation change, affecting catchment/watershed hydrology

Impacts on Drinking Water Infrastructure

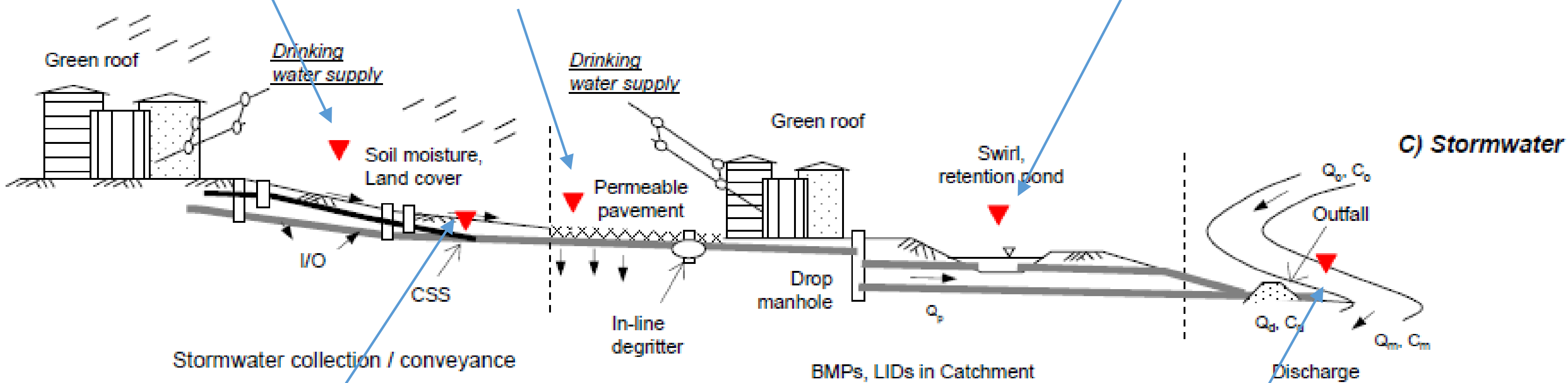


Impacts on Stormwater, Wastewater and Drinking Water Infrastructure

Changes in precipitation and land cover can significantly affect surface runoff properties

Changes in precipitation can affect green infrastructure designs (e.g., permeable pavement, green roof, etc.)

Changes in precipitation and hence runoff can significantly impact BMP designs, such as swirl and retention ponds



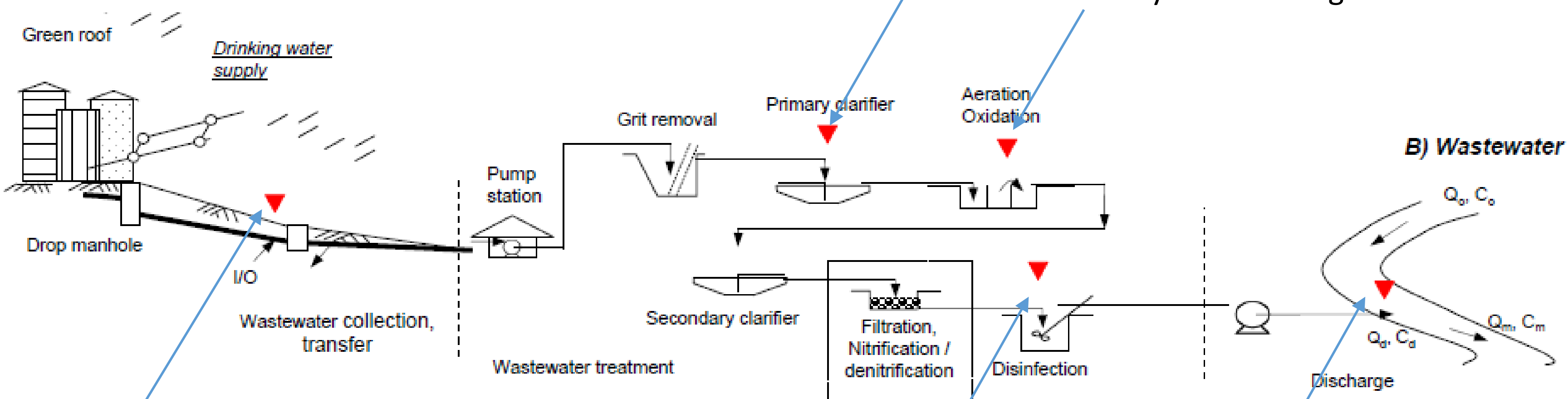
Changes in precipitation and land cover can impact combined sewer system (CSS) in combined sewer overflows (CSO)

Stormwater discharge limits may change due to stream's carrying capacity in future climate

Impacts on Wastewater Infrastructure

High solids from higher runoff may impact grit removal

Higher organics, nutrients, etc. likely affect biological oxidation



Intense precipitation could impact collection systems by infiltration and exfiltration (I/O)

Pathogens at warmer temperature, but impact uncertain and potentially low

Discharge to surface water body likely to be more restrictive, without further surface water impairment

Typical Climate 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.

How to Adapt?

Two fundamental principles

- Revise precipitation and hydrological design basis
- Manage design uncertainties – the capacity reserve concept and adaptive engineering for economics and resilience

Adaptation design considerations

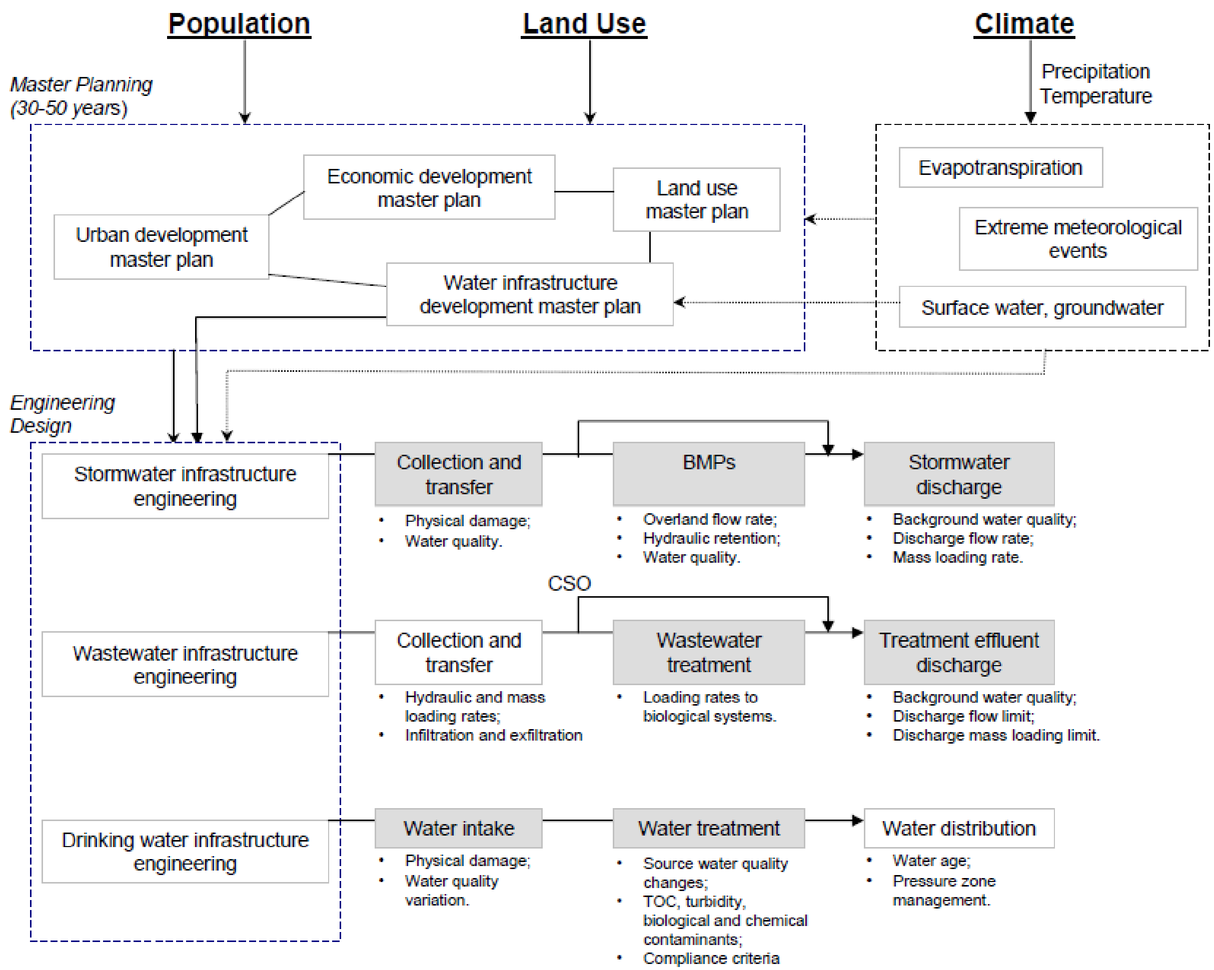
- A changing climate in precipitation, temperature, wind, and ET
- Precipitation changes interact with land use, affecting the design parameters of each water infrastructure
- Excessive uncertainties of climate model projections must be considered in planning and engineering
- Infrastructure difficult to change once built; new engineering approach necessary for adding or changing the capacity reserve

Developing Design Basis for Adaptation

Current design basis development:

- Stationary climate. Past observations will repeat statistically in the future.
- Design storm (wind, ET, etc.) at a given recurrence interval (RI)

Design basis development with hydrological change consideration:



Pertinent Questions on Design Basis

Inland regions focusing on precipitation:

- Are current precipitation and other design values not applicable?
- How to derive a design value, for example, the 24-hr precipitation at 10-year recurrence interval?
- How much uncertainty is associated with design values?
- How do hydrological parameters change when land use and land cover will changes in the future?
- 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 degree of coastal flooding in the future?

Inland: Define Precipitation Changes

Past precipitation in observation records

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

Future precipitation in model projections

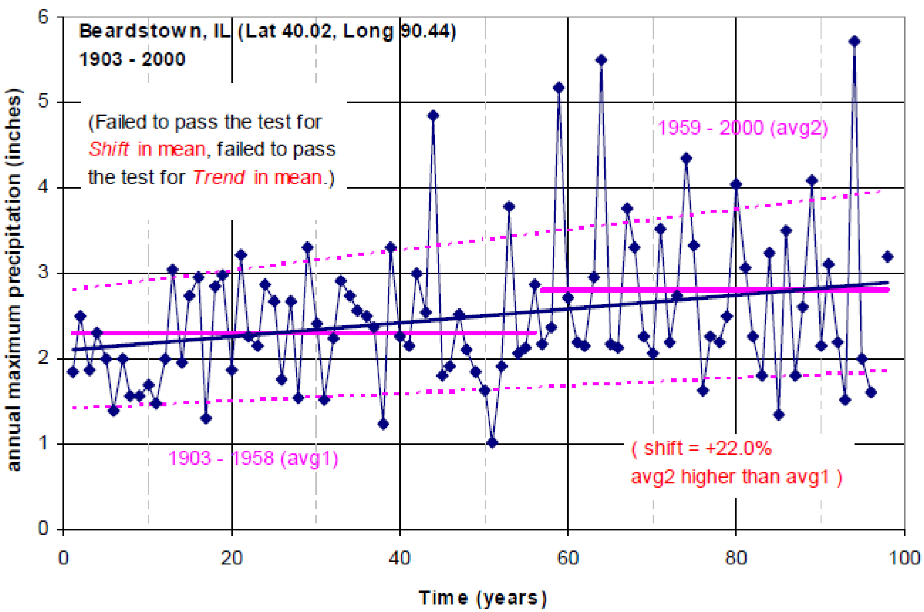
- Non-stationary climate in model simulation.
- Design storm (precipitation, wind, etc.) at a given recurrence interval

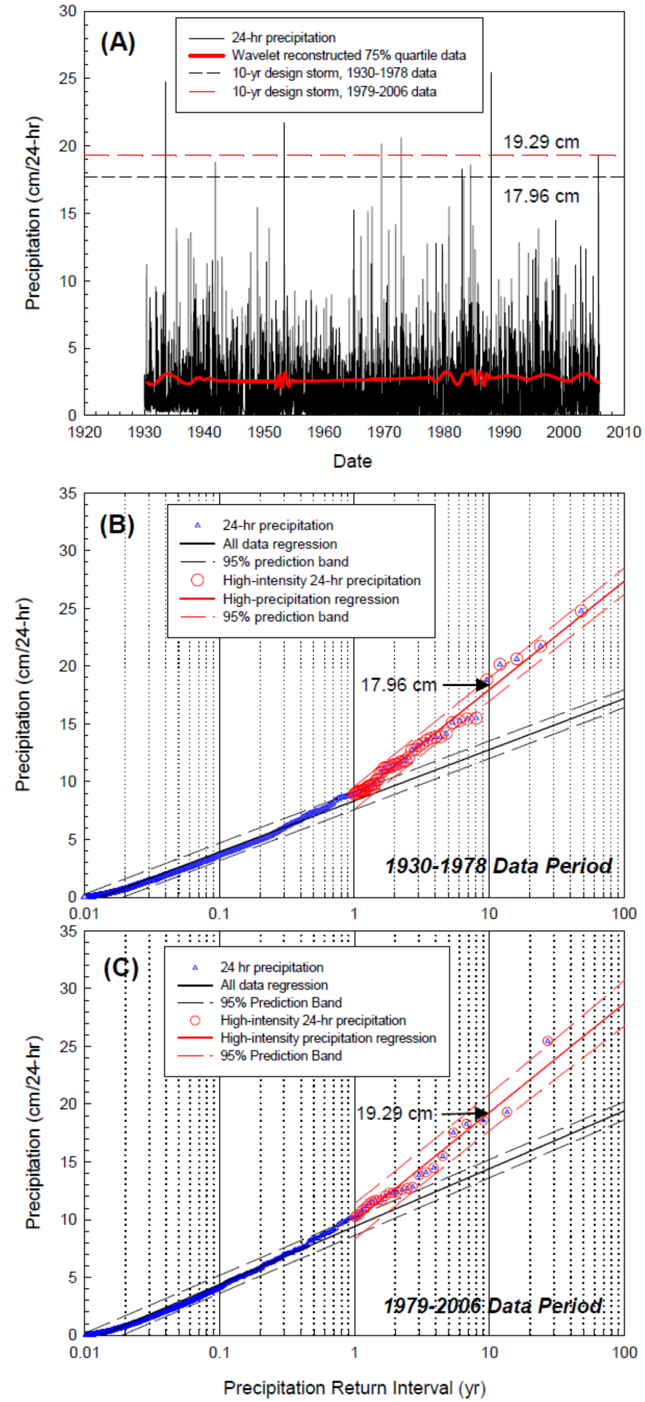
Precipitation Intensity-Depth-Frequency (IDF)

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

Design Precipitation Procedures in U.S.

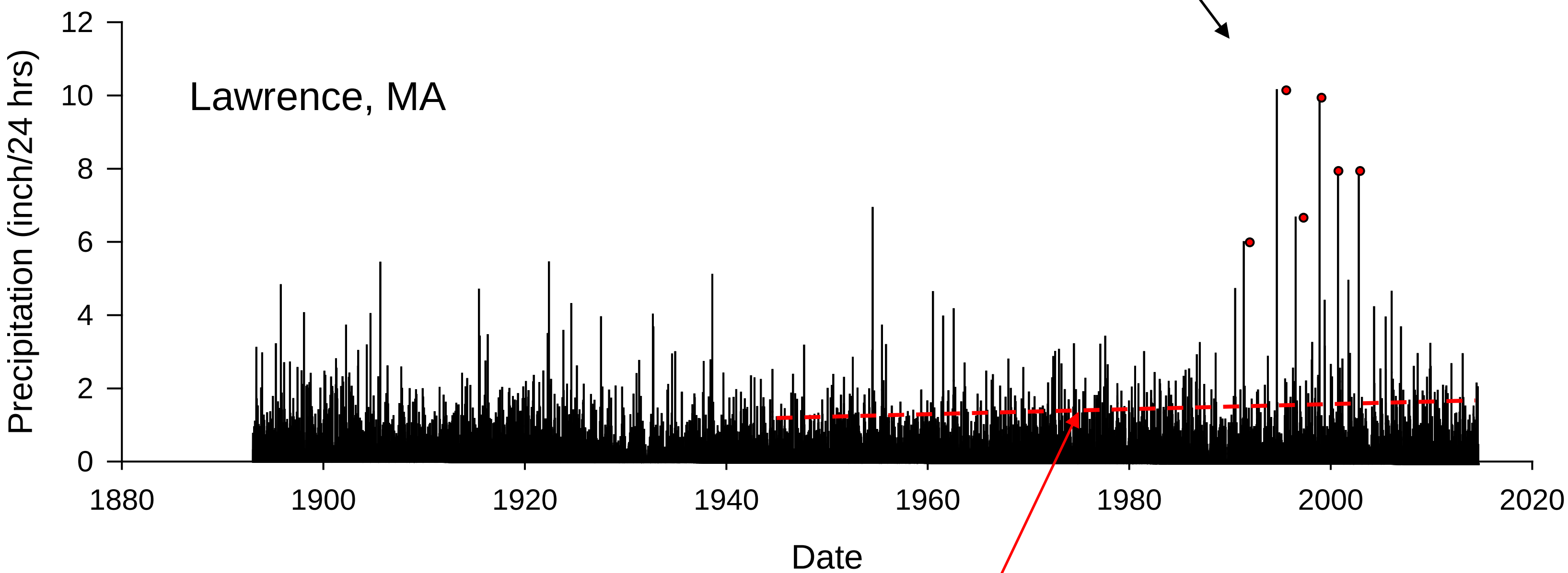
- Derived from standard design guides such as Atlas 14
- Determined from analysis of local long-range climate (precipitation, etc) data
- Combination of these two approaches





Changing Design Storms in Observation Data

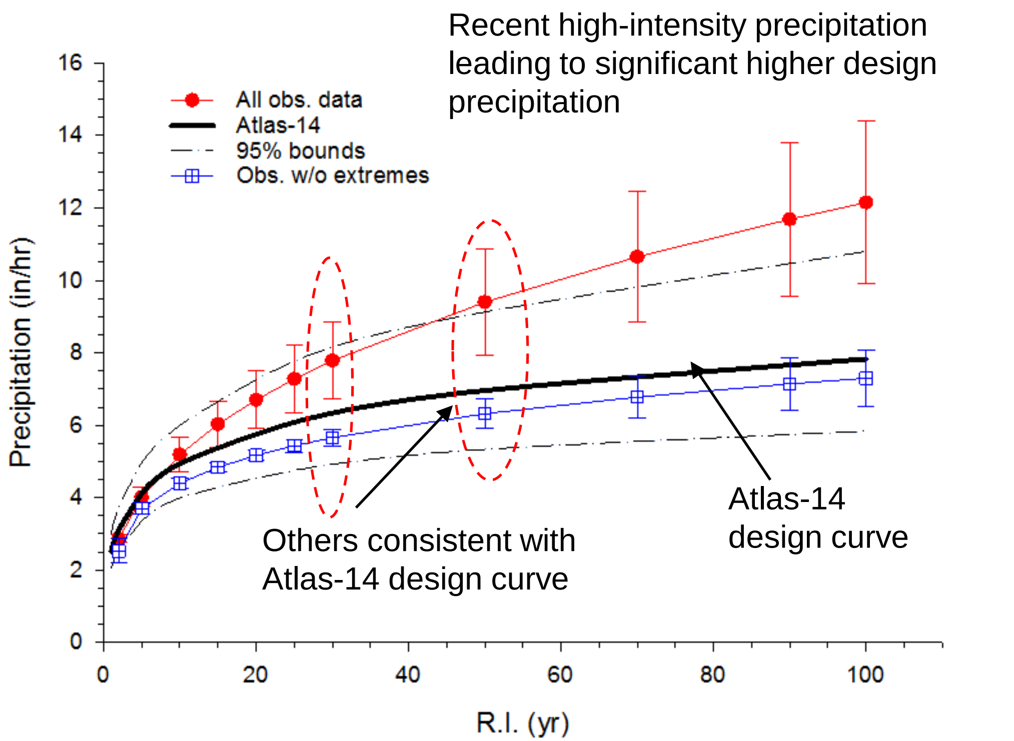
Increasing high-intensity precipitation since 1990s, and likely in future trends



Courtesy of Yang et al (2016)

Increasing intensity of high-frequency precipitation after 1950’s

Changing Design Storms in Observation Data



MA DOT Recommended Design Flood *

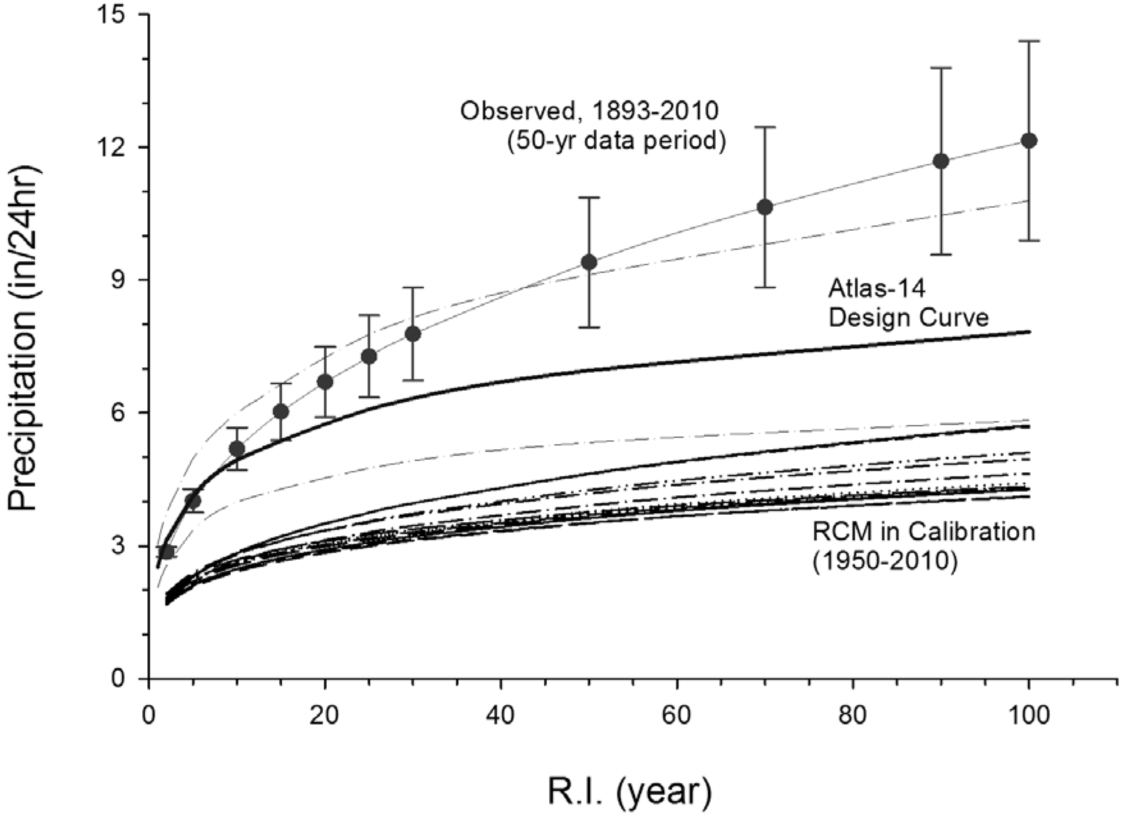
- ❑ <u>Storm drain</u>
  - 50-year RI for arterial and interstate
  - 5-year RI for local or connections
- ❑ <u>Culverts</u>
  - 50-year RI for arterial and interstate
  - 25-year RI for local or connections

**** - peak flow at a given precipitation***

As a rule-of-thumb, storm mains are designed for 25-year precipitation; streets and residential for 5-year events. Yet they vary among municipalities

Because of regional and local variability in climate, the design values may differ from place to place

Changing Design Storms for the Future:



All RCMs significantly under-predict design storm across the board

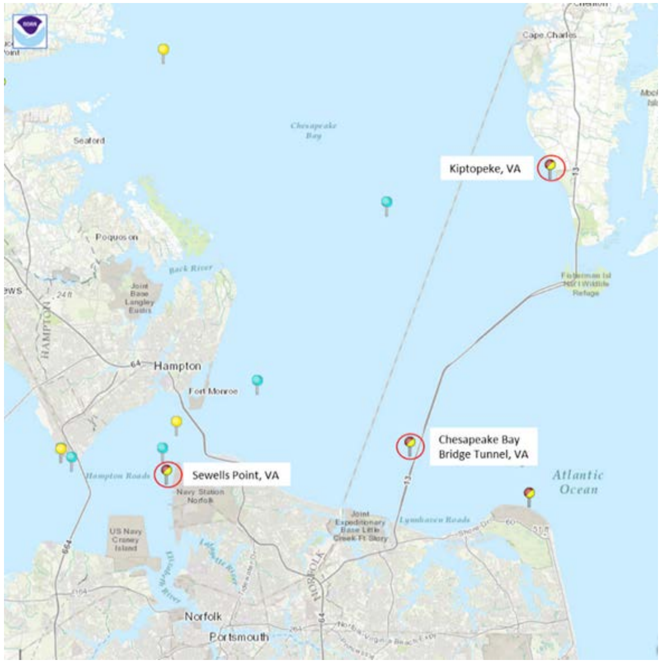
Observation

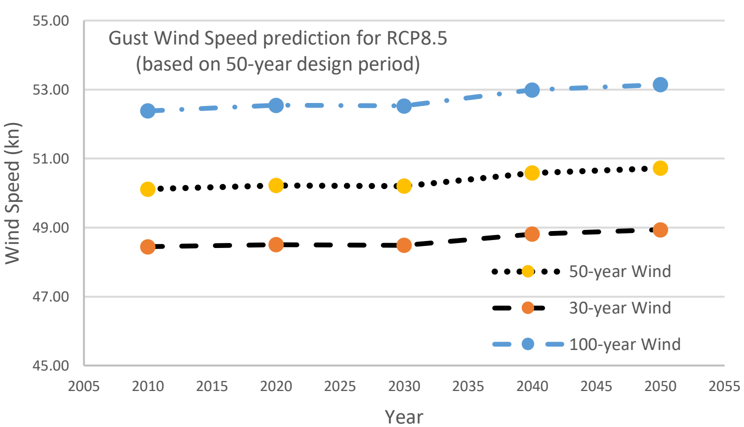
- High-intensity precipitation has changed since 1990s, and potentially into future

Future Prediction

- 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

Changing Design Winds for the Future: An Example in the U.S. Northeast





Courtesy of Liang et al. (2017)

Similar to Precipitation, other climate variables also change with time and such a change will continue into the future

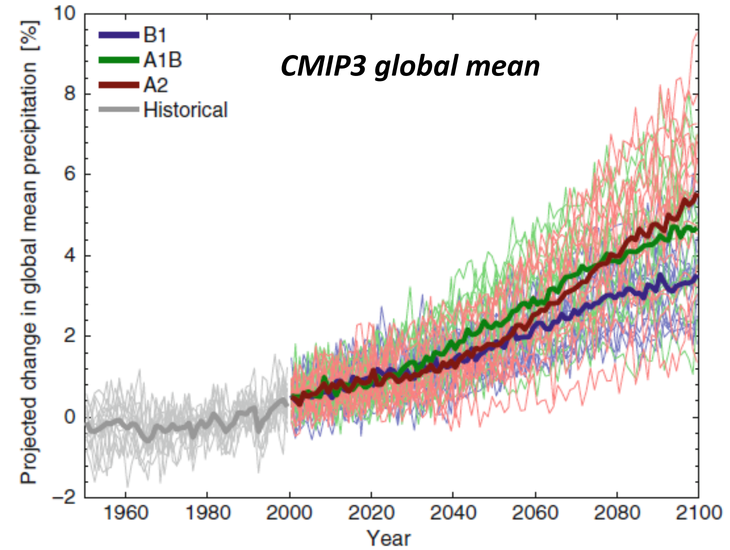
Example: Wind field changes in Chesapeake Bay region

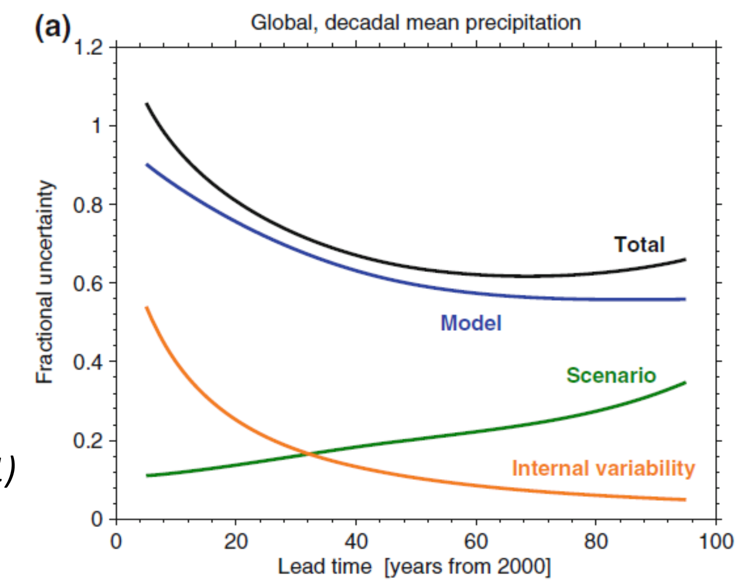
- Average wind and gust wind speed have changed since 1990s, and potentially into future
- GCM outputs are post-processed against historical observations and projected for design winds in period to year 2050
- Design gust wind speed at 30-year return interval increased modestly in the projection time frame.

Courtesy of Liang and Julius (2017)

How to Manage Projection Uncertainty

- Projection uncertainty is large and will likely remain in the foreseeable future
- The uncertainty comes from:
    - o Future emission pathways
    - o Model assumptions in climate projection
    - o Modeling of internal variables in the climate systems (e.g., AMO, ENSO, etc.)





Courtesy of Hawkins & Sutton (2011)

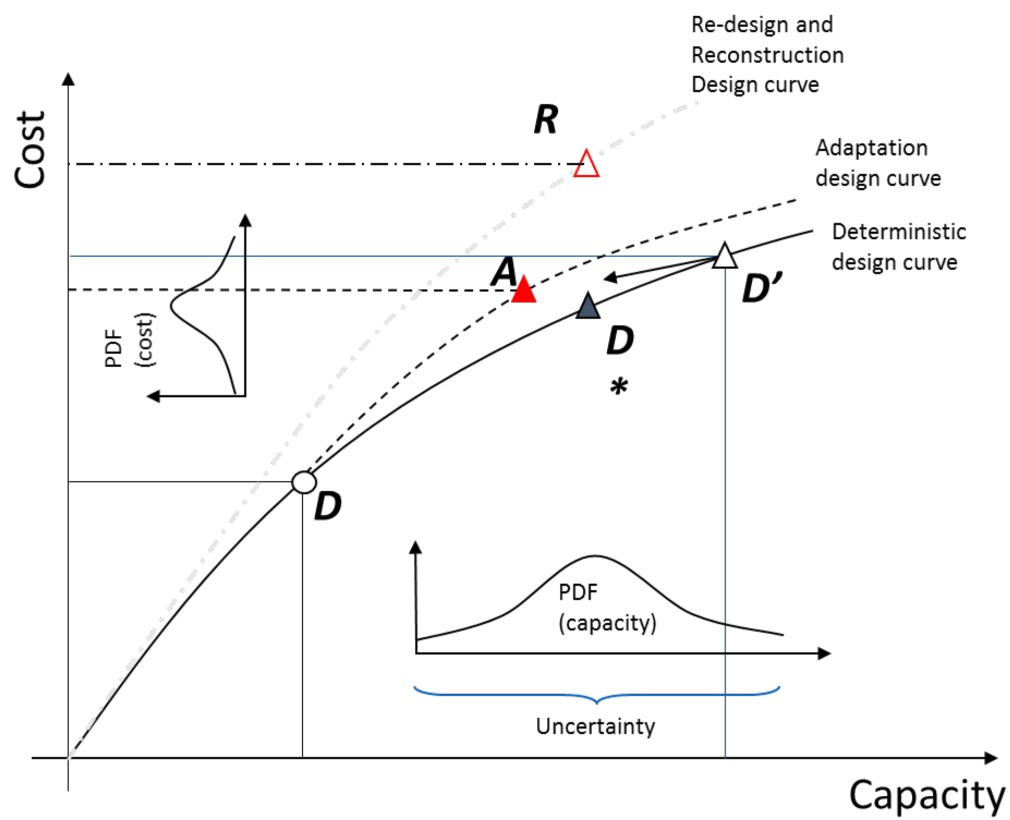
Engineering with Design Storm Uncertainties - Capacity Reserve Concept

Adaptation Objectives

- Developing adequate capacity reserve in systems to manage climate risk
- Using adaptive design and staged implementation to manage financial risk of climate uncertainty

Adaptation Approach

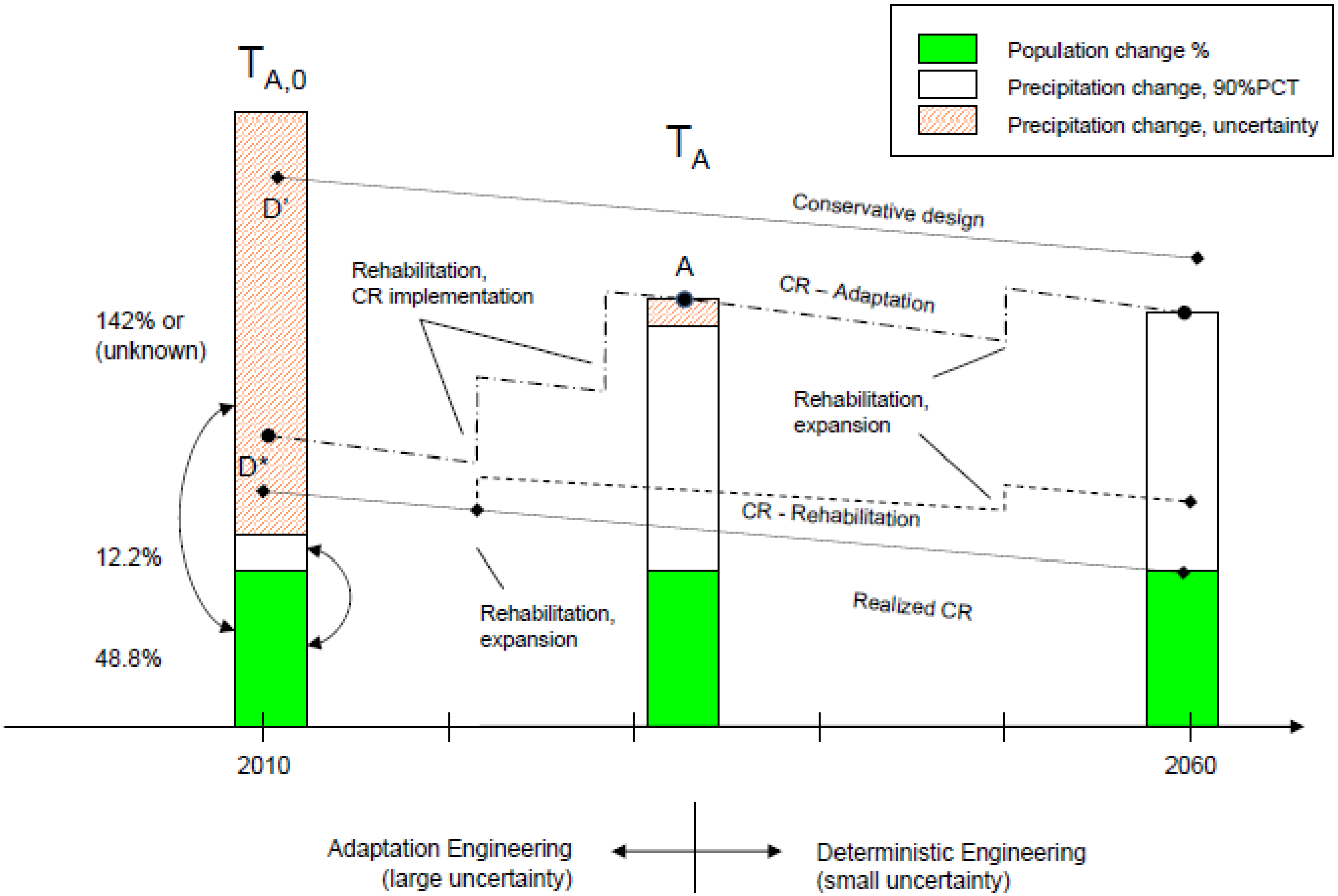
- Define capacity reserve (CR)
- Balance capacity reserve against engineering economics
- Use module design and implementation



Courtesy of Yang (2016)

Modular Design and Phased Implementation: Deterministic vs Adaptive Engineering

Staged implementation in adaptive engineering



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

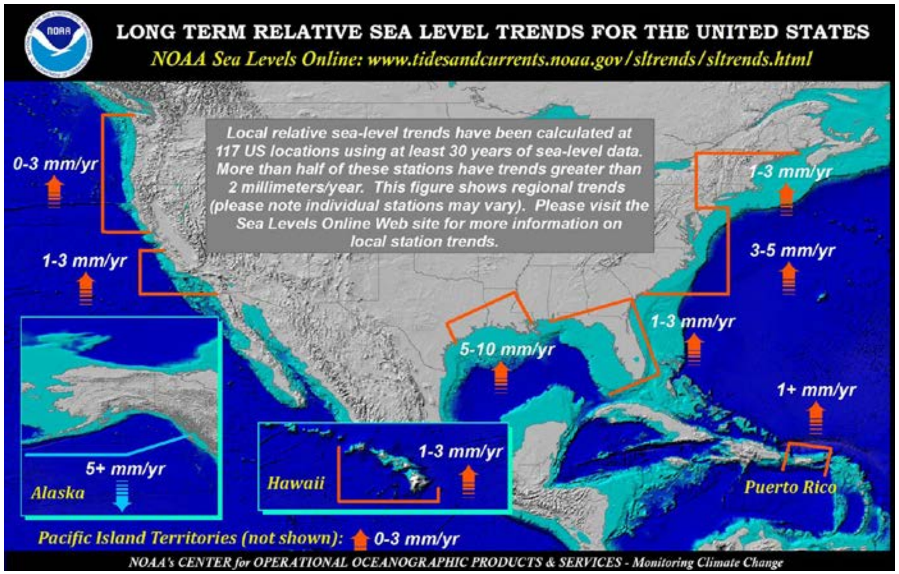
- Precipitation projection and flooding risk management follow similar paths as inland precipitation changes. Focus on design storms in future climate
- Sea level rise is happening, and can be projected with fine certainty
- Storm surge is a major variable for coastal water infrastructure. It can be modelled with high resolution and accuracy
- Compounding effect of sea level rise on storm surge is potentially large and should be considered now

Coastal Area: Inundation

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

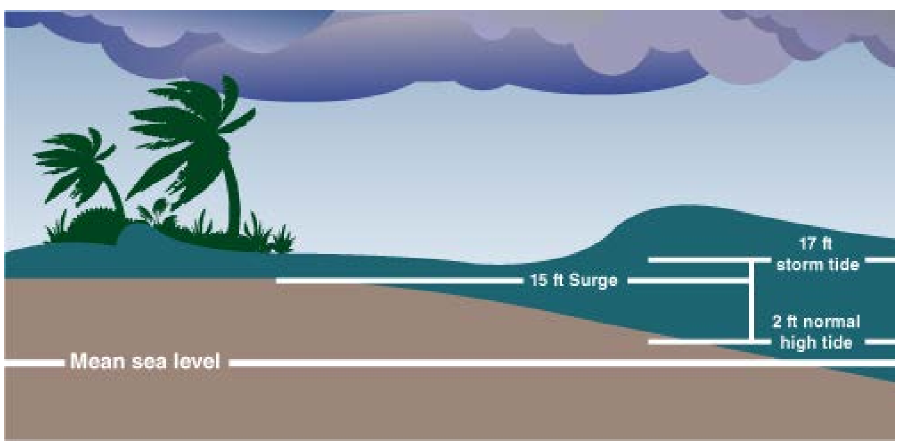
Storm surge in Mattapoisett, Massachusetts in the 1991 Hurricane Bob

Inundation from Storm Surge under Sea Level Rise



Inundation from sea level rise:

Regional permanent change, but at a slow rate of ~inches/decade



Inundation from storm surge:

Temporary hydrologic impacts

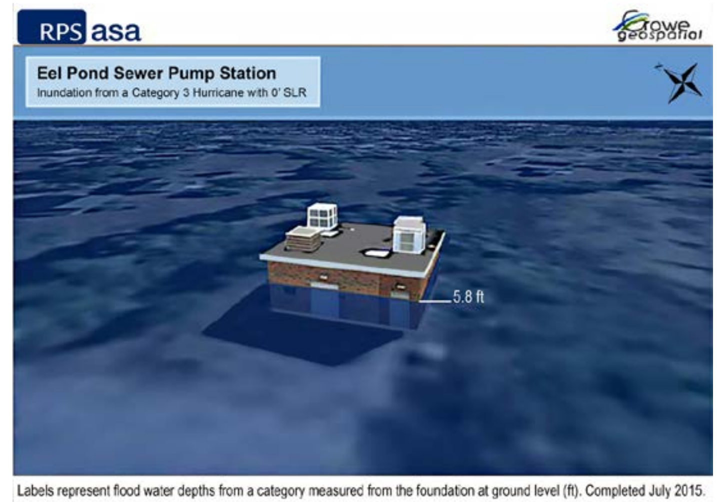
Dependent upon hurricane grade and local topography

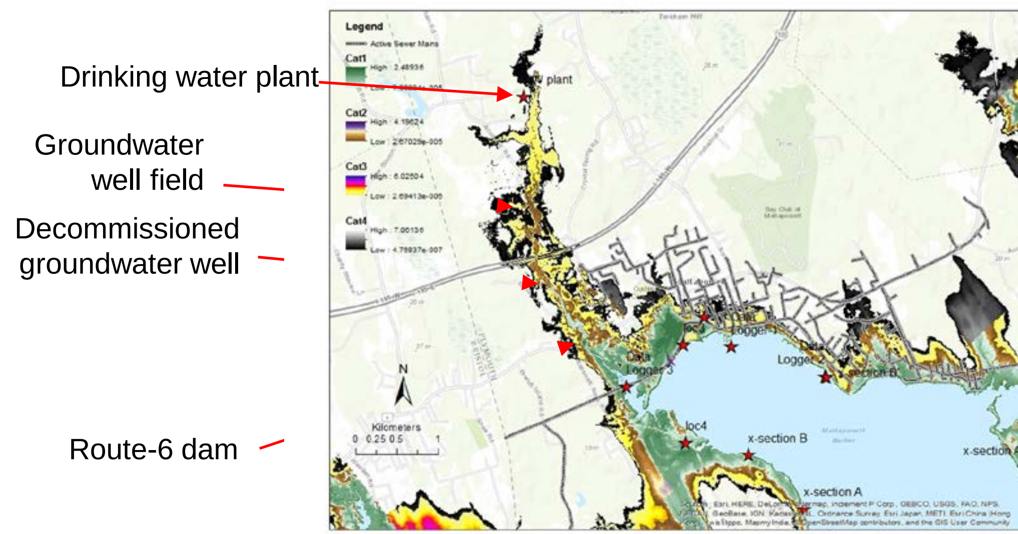
Compounding effects with sea level rise

Adaptation Principles for Other Storm Surge and SLR Impacts

Other storm surge and sea level rise impacts

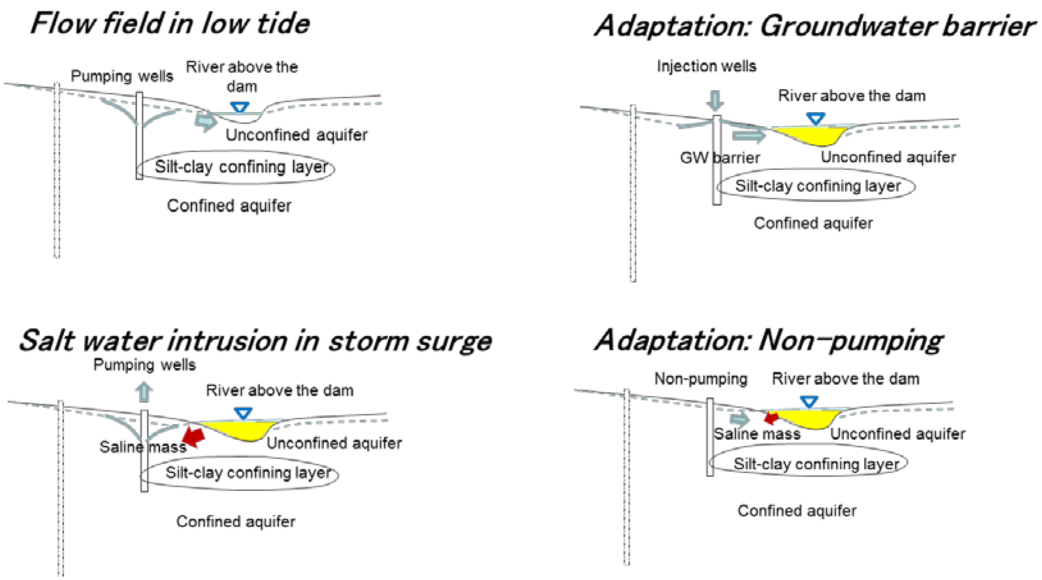
- Salt water intrusion in coastal streams and aquifers, impacting water supply and water discharge;
- Reduced hydraulic gradient under a rising sea level, impacting urban stormwater and wastewater pipes and conveyance;
- Inundation affecting operation of pumping stations and other physical structures
- Coastal urban flooding affecting all water infrastructures





Adaptation Principles for Other Storm Surge and SLR Impacts

- Because of the impacts on multiple dimensions (e.g., inundation, salt water intrusion, etc.) in a small coastal region, systems modeling and analysis are often critical to develop adaptation basis
- Engineering and management means are available to manage and mitigate the risk to water infrastructures
- Necessary to analyze the risk and adaptation actions for short-term disruptive events (e.g., storm surge) and long-term projected sea level rise impacts
- Often citizen and stakeholder engagement is critical in adaptation design for projected future impacts from sea level rise and storm surge



Summary and Research Questions

Summary:

- Water system adaptation principles – Revision and updating of climate-related hydrological variables
- Design basis specific to location and objectives
- Projection uncertainties and ways to manage the risk
- Systems modeling necessary (See module #11)
- Deterministic vs adaptive engineering

Research question:

- Describe how to gather and incorporate hydroclimatic data (precipitation and temperature) into the planning and sizing of a stormwater retention pond in a local park

Research Questions

- What does the non-stationary climate mean for hydrological design basis?
- Discuss ways to incorporate climate projection into planning and design of stormwater sewers
- Describe a general process in developing hydrological design parameters (e.g., maximum runoff) for storm water drainage ssytem

Looking ahead to the next module.....

- Next module: Methods and tools – climate models
- Scoping of project topics