Developing Effective Water Infrastructure Systems for Climate Change Preparedness

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May 14, 2010

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Climate Change Impacts - Global

Graphic adapted from the National Geographic Society web-site accessed Feb 12, 2009.

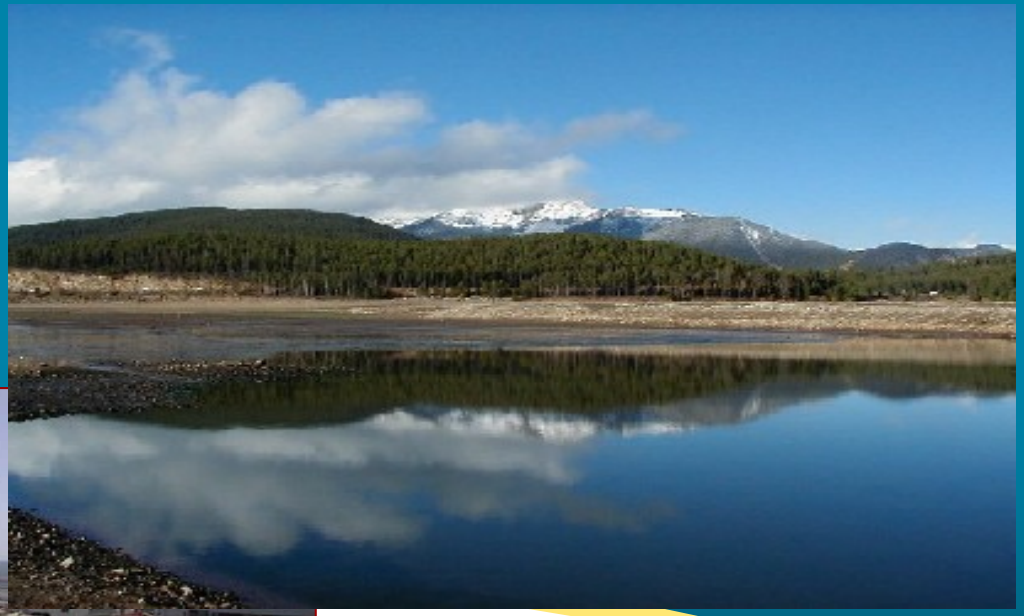
External pressures on the water cycle

Population Growth

Increased Urbanization

Climate Change

What are the likely impacts of climate change and implications for water systems?



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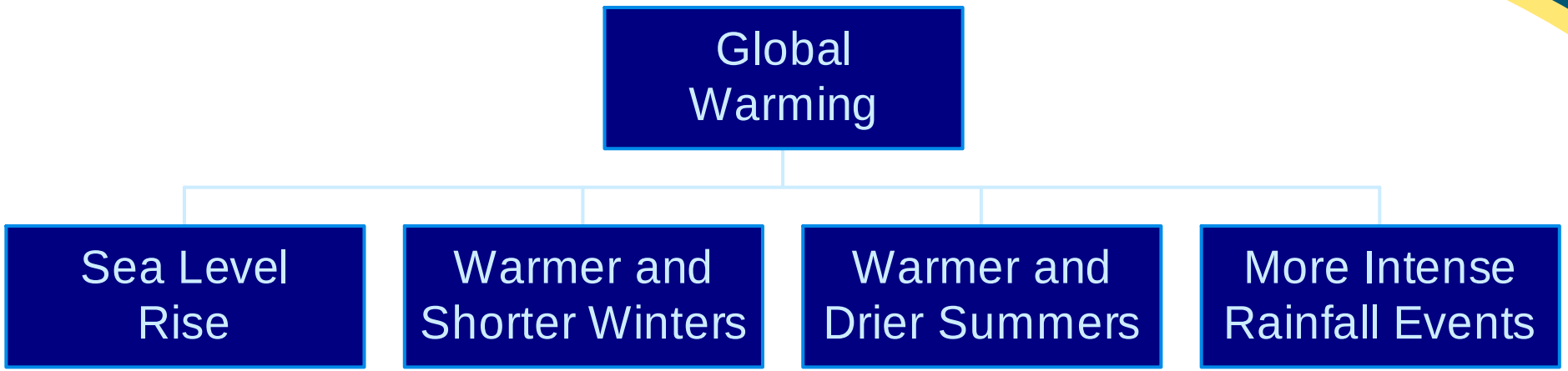
Some Useful Definitions for Adaptation Planning

- **Impacts** of Climate Change
  - ***Changes*** in climatic systems; hydrologic systems; geo-chemical systems; terrestrial and aquatic ecosystems; and human systems that affect the operating environment of water systems
- **Implications** of Climate Change
  - The implied ***consequences*** of these changes in the operating environment on the performance of utility assets or asset systems.

Four Major Influences of Global Warming



Impacts & Implications of Sea Level Rise

- Increased coastal erosion and damage from coastal storms
  - Direct storm & flood damage to facilities
  - Impairment of outfalls under storm conditions
- Physical loss or damage to wetlands and coastal landforms
  - Altered marine, estuarine and coastal wetland ecosystems
- Increased water temperature, salinity and acidity of coastal and estuarine waters
  - Altered biology and chemistry of receiving waters

Impacts & Implications of Warmer & Shorter Winters

- Decreased snow packs & diminished glacial storage
- More rain vs. snow and earlier spring melting
- Altered infiltration and groundwater recharge
- Lower summer/fall base flows in surface waters
  - Lower summer/fall reservoir levels
  - Seasonal changes in surface water flow regimes
  - Altered biology and chemistry of receiving waters

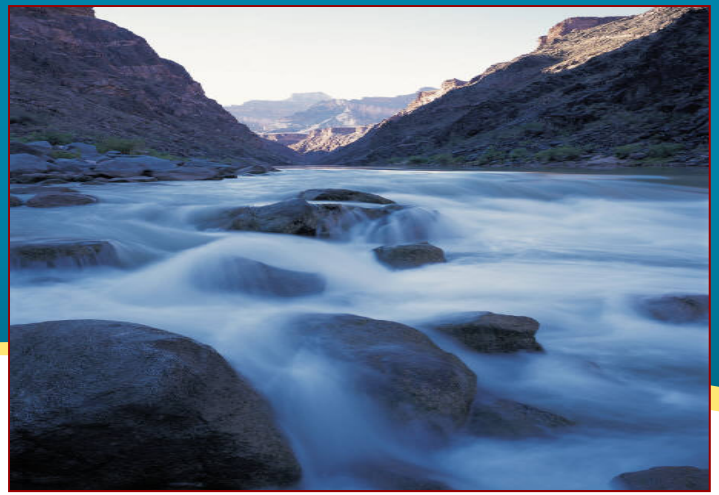
Impacts & Implications of Warmer & Drier Summers

- Changes in watershed vegetation
- Increased wildfire & invasive species risks
- Changes in agriculture & forestry practices
- Increased irrigation demands with longer growing seasons
- Increased urban water demands from dry spells & heat waves
- Possible groundwater drawdowns & in-stream flow reductions
  - Changes in quantity & quality of surface water flows
- Increased water temperatures and lower DO
- Evaporation losses from surface waters and reservoirs
  - Altered biology and chemistry of receiving waters
- Increased hot weather and extreme hot weather conditions
  - Operating challenges to distribution, conveyance, & treatment facilities

Impacts & Implications of More Intense Rainfall

- Increased erosion and sedimentation
  - Increased pollutant loads from erosion & sediment
  - Increased siltation and eutrophication potential
- Increased overflows of untreated sewage
  - Impacts on receiving water quality from upstream sources
  - Increased challenges to wet weather operations
- Increased Ag & Urban non-point source pollution
  - Effects of increased upstream loadings on receiving water
  - Increased challenges to stormwater management facilities
- Increased Flood Risk
  - Direct storm & flood damage to storage, treatment, and other facilities

A Risk Based Approach to Assessing Climate Change Impacts



THE WORLD BANK

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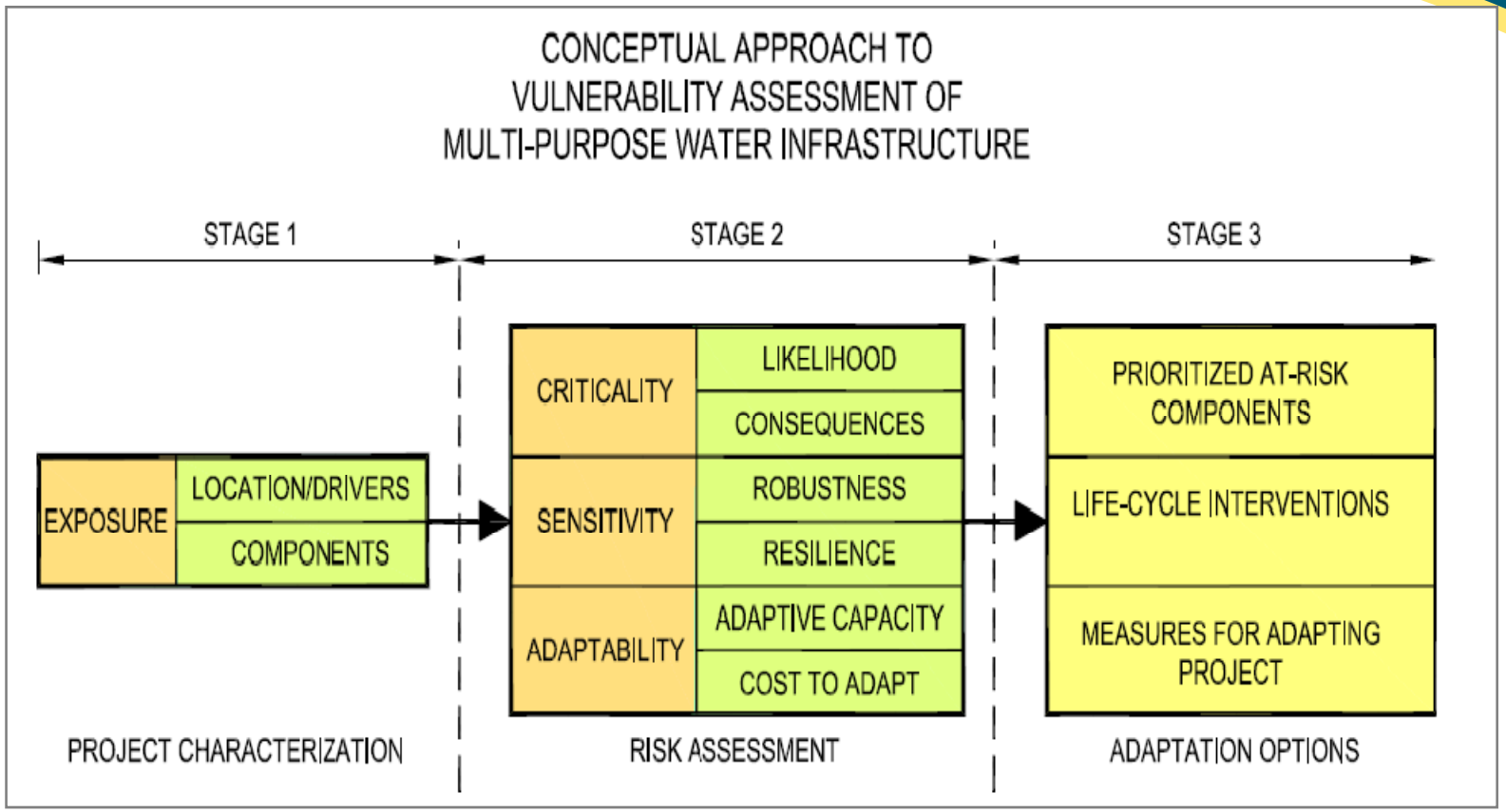
General Approach to Assessment

- ***Stage 1 – Characterize System & Components***
- ***Stage 2 – Develop and Apply Vulnerability Assessment Methodology***
- ***Stage 3 – Prioritize & Identify Adaptations***

Vulnerability Assessment Methodology



Stage 1 – Project Characterization

Characterize the project by:

- ***Exposure to Climate Change Risk***
- ***Performance objectives & key components***
- ***Hydrologic drivers of risk for each component***

Project Exposure

Exposure is a function of:

- ***Geography***
- ***Project purpose and configuration***
- ***Hydrologic drivers – e.g., extreme floods, changes in flow and water levels, increased siltation***

Dam and Reservoir Example - Components by Project Purpose

- ***Water Supply* – Dam, storage, intakes, outlets**
- ***Hydropower* – Intakes, tunnels, penstocks, powerhouses, tailraces**
- ***Flood Control* – Dam, storage, spillways**
- ***Navigation* – Locks & dams, gates, fill/empty systems**
- ***Multi-Purpose* – Some or all of the above**

Reservoir Storage Example – Diamond Valley Reservoir, CA

Yield & Storage

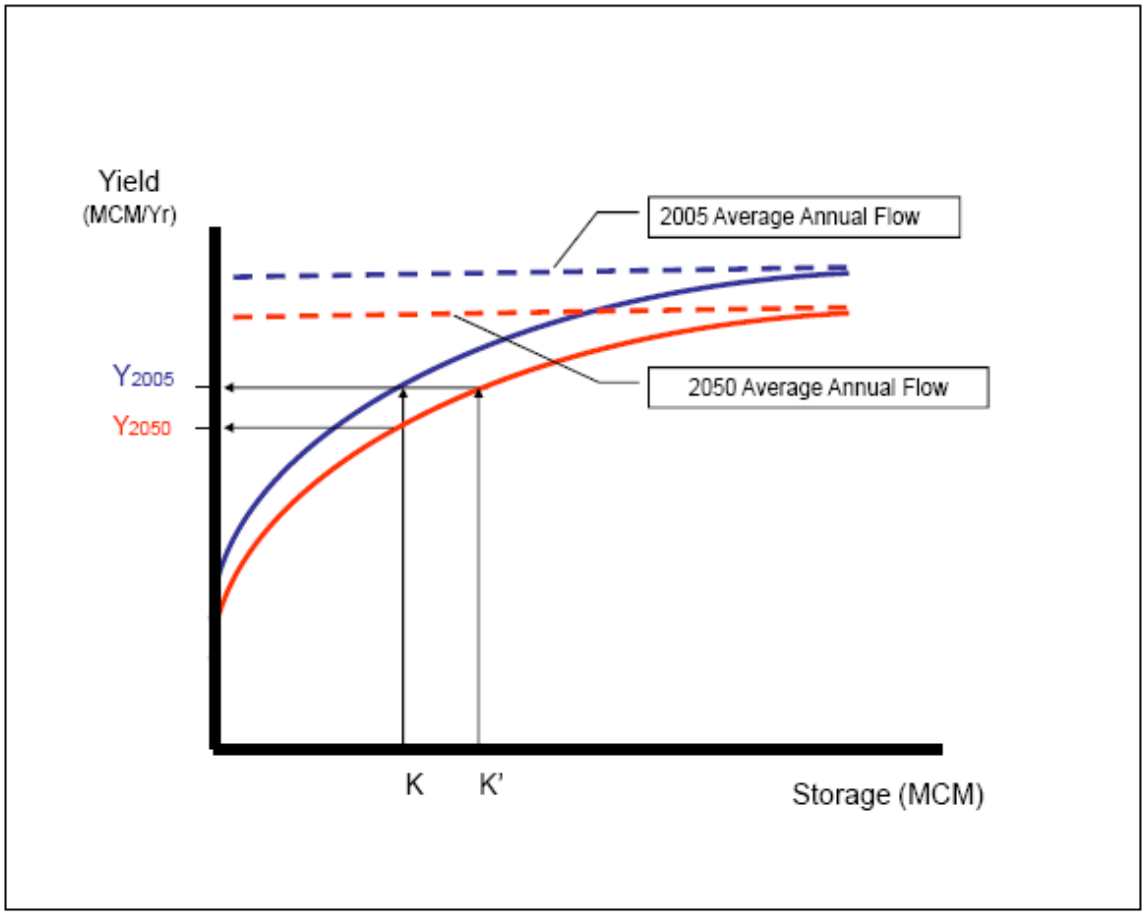


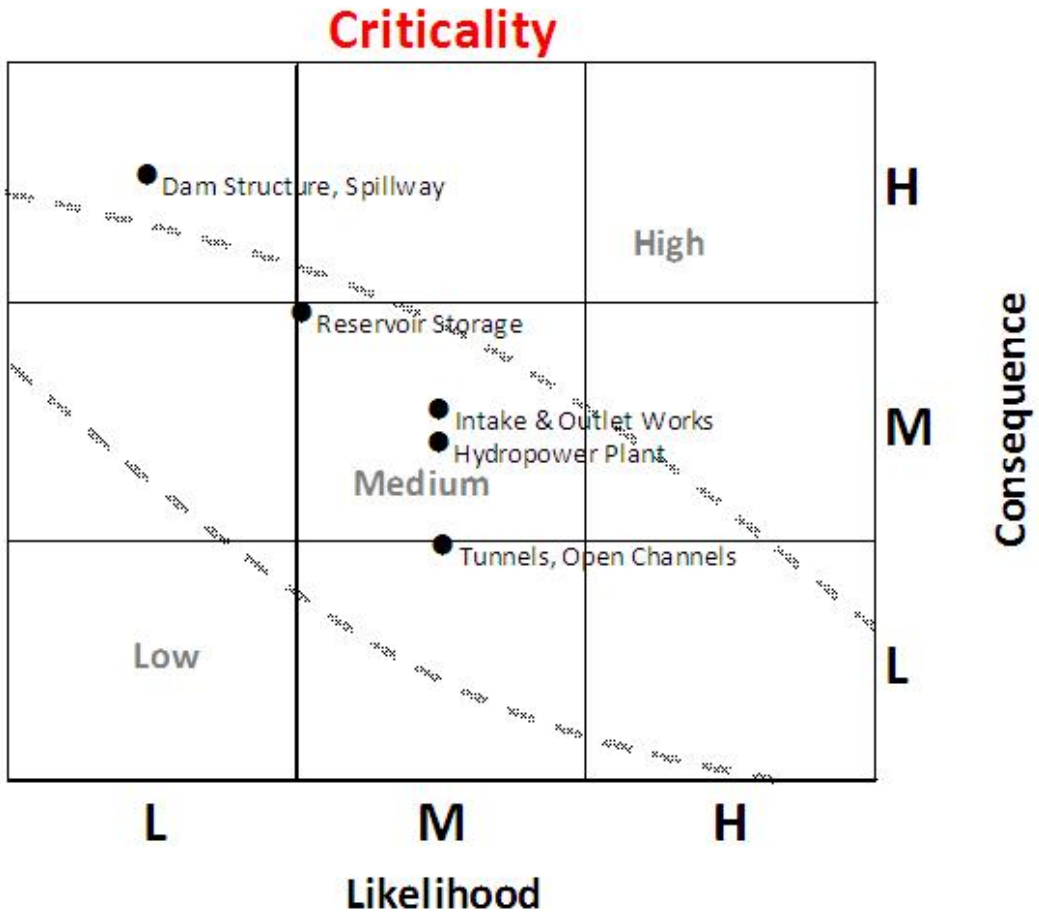
Figure 5.11 Impact of Climate Change on Reservoir Yield and Adaptations

Stage 2 – Risk Assessment

Evaluate each component with respect to three indicators of vulnerability:

- ***Criticality – Likelihood and consequence of component "failure"***
- ***Sensitivity – How susceptible a component is to climate change impact***
- ***Adaptability – Practicality of altering a component to deal with climate change impact***

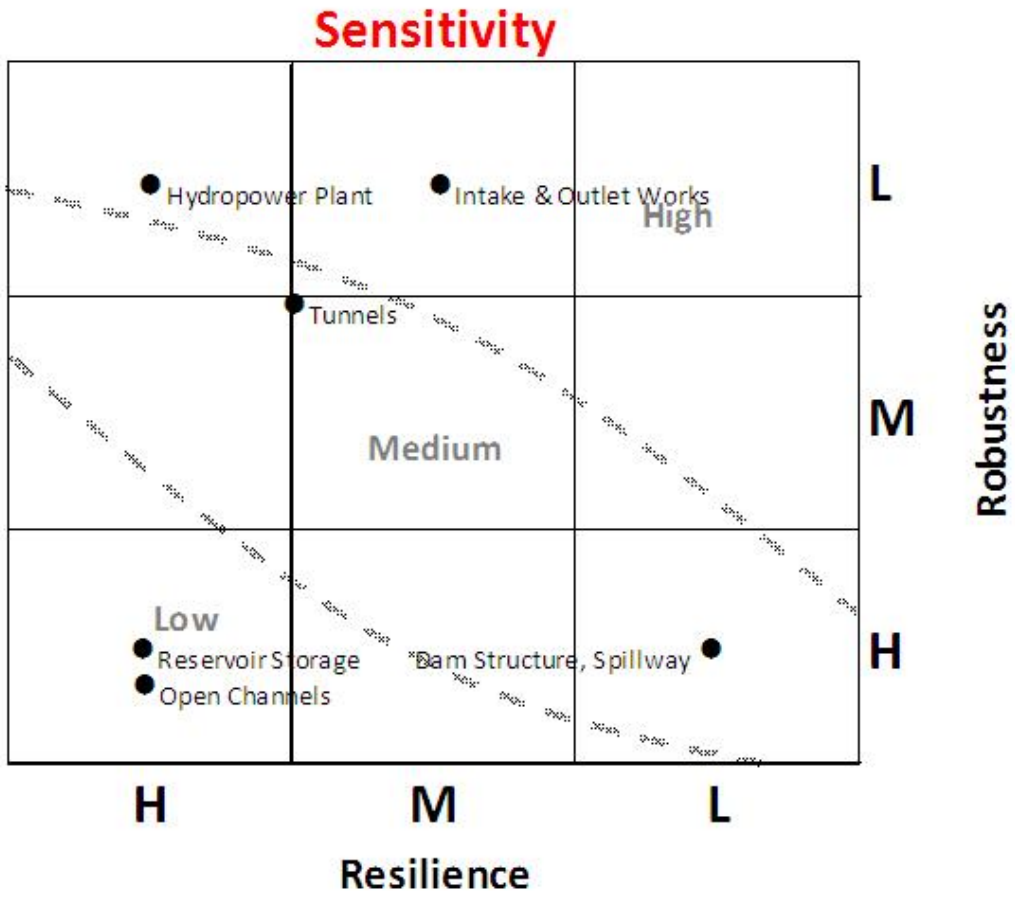
Criticality Component Map



Criticality Indicators

Component	Dam Structure	Reservoir Storage	Spillway(s)	Intake & Outlet Works	Hydropower Plant	Tunnels	Open Channels
Key Hydrologic Driver(s)	Extreme Flood	Runoff, Siltation	Extreme Flood	Water Level Variability, Siltation	Increased or Decreased Flow Rates	Increased Flow Rates	Increased Flow Rates
Definition of Failure	Overtopping sufficient to damage structure	Unable to provide design yield	Insufficient spill capacity, dam overtops	Inability to operate at extreme high or low reservoir levels	Wasted energy generation capacity, or stranded investment of excess generating capacity	Inadequate Discharge Capacity (increased head losses and lower capacity)	Inadequate Discharge Capacity (increased head losses and lower capacity)
Likelihood	Low	Low to medium	Low	Medium	Medium	Medium	Medium
Consequence	High – affects safety	Medium to High – affects function (firm yield)	High – affects safety	Medium – affects function	Medium – affects function (power generation)	Low to Medium – affects efficiency	Low to Medium – affects efficiency
Overall Criticality	**High to Medium** (Safety)	**Medium to High** (Functionality, fulfills primary purpose of storing water)	**High** (Safety)	**Medium** (Functionality, efficiency, safety)	**Medium** (Functionality, efficiency)	**Medium** (Functionality, efficiency)	**Medium** (Functionality, efficiency)

Sensitivity Component Map



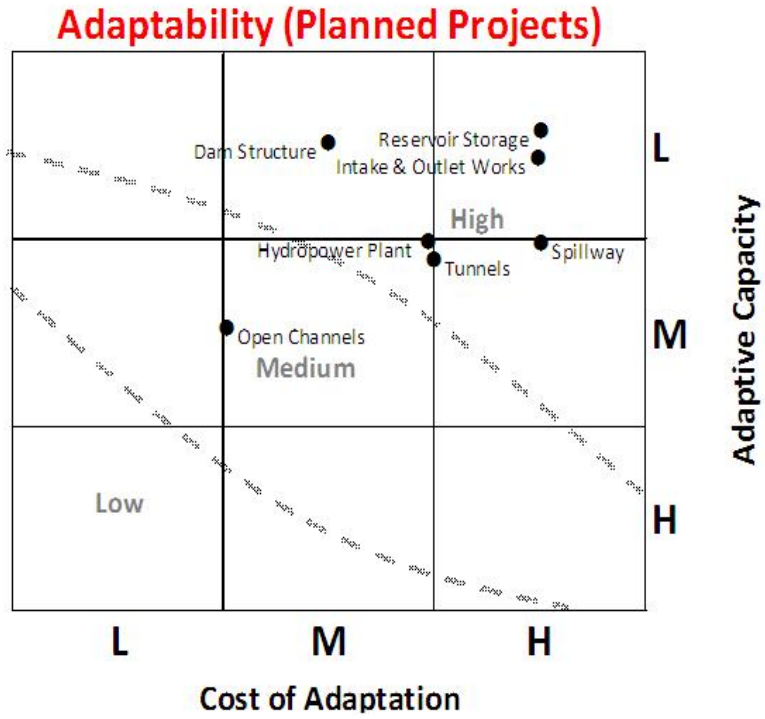
Sensitivity Indicators

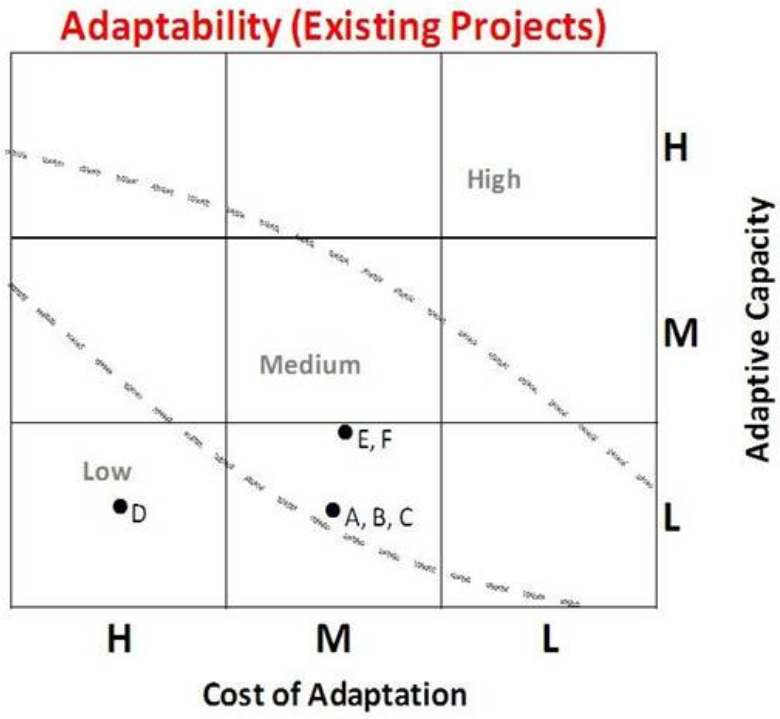
Component	Dam Structure	Reservoir Storage	Spillway(s)	Intake & Outlet Works	Hydropower Plant	Tunnels	Open Channels
Key Hydrologic Driver	Extreme Flood	Runoff, Sedimentation	Extreme Flood	Water Level Variability	Inadequate or Excess Generating Capacity	Increased Flow Rates	Increased Flow Rates
Robustness	High – designed for range of conditions	High	If designed well, high	Low	Low - Requires structural changes	Low to Medium	High
Resilience	Low - would require a substantial outage duration	High - recovers well if water supply returns	Low	Medium	High - Powerplant able to continue at original design capacity if water supply returns.	Medium to High	High
Overall Sensitivity	**Medium**	**Low**	**Medium**	**High**	**High to Medium**	**Medium to High**	**Low**

Component Sensitivity

Component	Overall Sensitivity	Remarks
Dam Structure	Medium	Design already considers structural requirements for water level fluctuations and extreme floods; incremental change. But, if failure occurs, little resilience.
Reservoir Storage	Low	Design can only do so much, water resource is critical. Places greater emphasis on project siting and basin-wide planning
Spillway(s)	Medium	Similar to dam structure; incremental change. May need to handle different extreme floods or incorporate redundant mechanisms to account for uncertainties.
Intake & Outlet Works	High	Sensitive to water levels, but for projects not yet constructed redundant design may help cope with uncertainty. Can still function as designed after a failure, assuming there are no structural damages.
Hydropower	High to Medium	Equipment performs best under conditions of certainty, but can run if within design range. Once the failure period (excess or insufficient generating capacity) ends, the hydropower plant can operate per usual (assuming the rest of the components are intact, e.g. spillway, and have prevented structural damages to the hydropower facility).
Tunnels	Medium to High	Performs best under conditions of certainty. However, can still transport water as designed after a failure, assuming there is no structural damage to the tunnels.
Open Channels	Low	Open channels allow for greater flexibility in design and operation phases, as the cost is much less than that of a tunnel; open channels can generally be designed with excess capacity for less cost than tunnels.

Adaptability Component Map





Adaptability Indicators – Future Projects

Component	Dam Structure	Reservoir Storage	Spillway(s)	Intake & Outlet Works	Hydropower Plant	Tunnels	Open Channels
Key Hydrologic Driver	Extreme Flood	Runoff, Sedimentation	Extreme Flood	Water Level Variability	Inadequate or Excess Generating Capacity	Increased Flow Rates	Increased Flow Rates
Adaptive Capacity	Low	Low	Low to Medium	Low (same as reservoir)	Low to Medium	Low to Medium	Medium
Cost of Adaption	Medium	High	High	High (same as reservoir)	Medium to High	Low to High	Low to Medium
Overall Adaptability	**High**	**High**	**High**	**High**	**High to Medium**	**High to Medium**	**Medium**

Component Scoring by Attribute

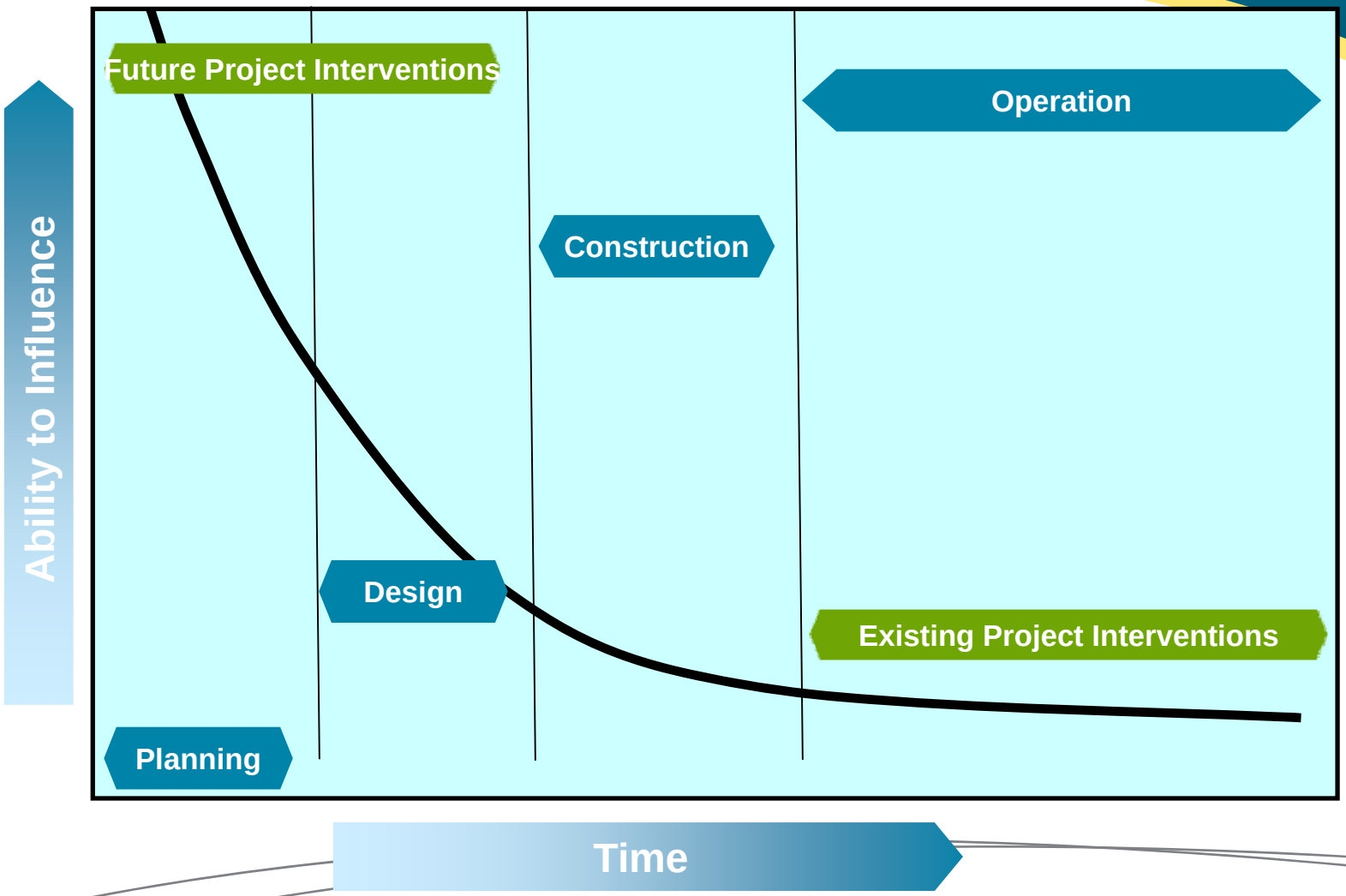
Indicator	Key to Attribute Scoring
Criticality	Likelihood of Failure: Low = 1; Med = 3; High = 5
	Consequence of Failure: Low (affects reliability/availability) = 1; Med (affects performance) = 3; High (affects safety) = 5
Sensitivity	Robustness: Low = 5; Med = 3; High = 1
	Resilience: Low = 5; Med = 3; High = 1
Adaptability	Adaptive Capacity (Planned Projects): Low = 5; Med = 3; High = 1 Adaptive Capacity (Existing Projects): Low = 1; Med = 3; High = 5
	Cost of Adaptation (Planned Projects): Low = 1; Med = 3; High = 5 Cost of Adaptation (Existing Projects): Low = 5; Med = 3; High = 1

Stage 3 – Adaptation Options

Investigate options for adapting project components to climate change:

- ***Structural vs. Non-structural***
- ***"No regrets" vs. Climate-justified***
- ***Life-cycle considerations***

Life-Cycle Interventions



Operational Adaptation Strategies

- Key for existing water infrastructure
- Non-structural measures are cost-effective, where practical
- Reliant upon sound historical and real-time watershed data
- New York City water supply as an example

New York City Climate Change Program

NYC Water Supply System - Concerns

- Can City help manage flooding?
- Consistently sufficient supply?
- Water quality threatened?
- Will demand increase?

"Quantity and quality…largely determined by the hydrology and ecology of the watersheds."

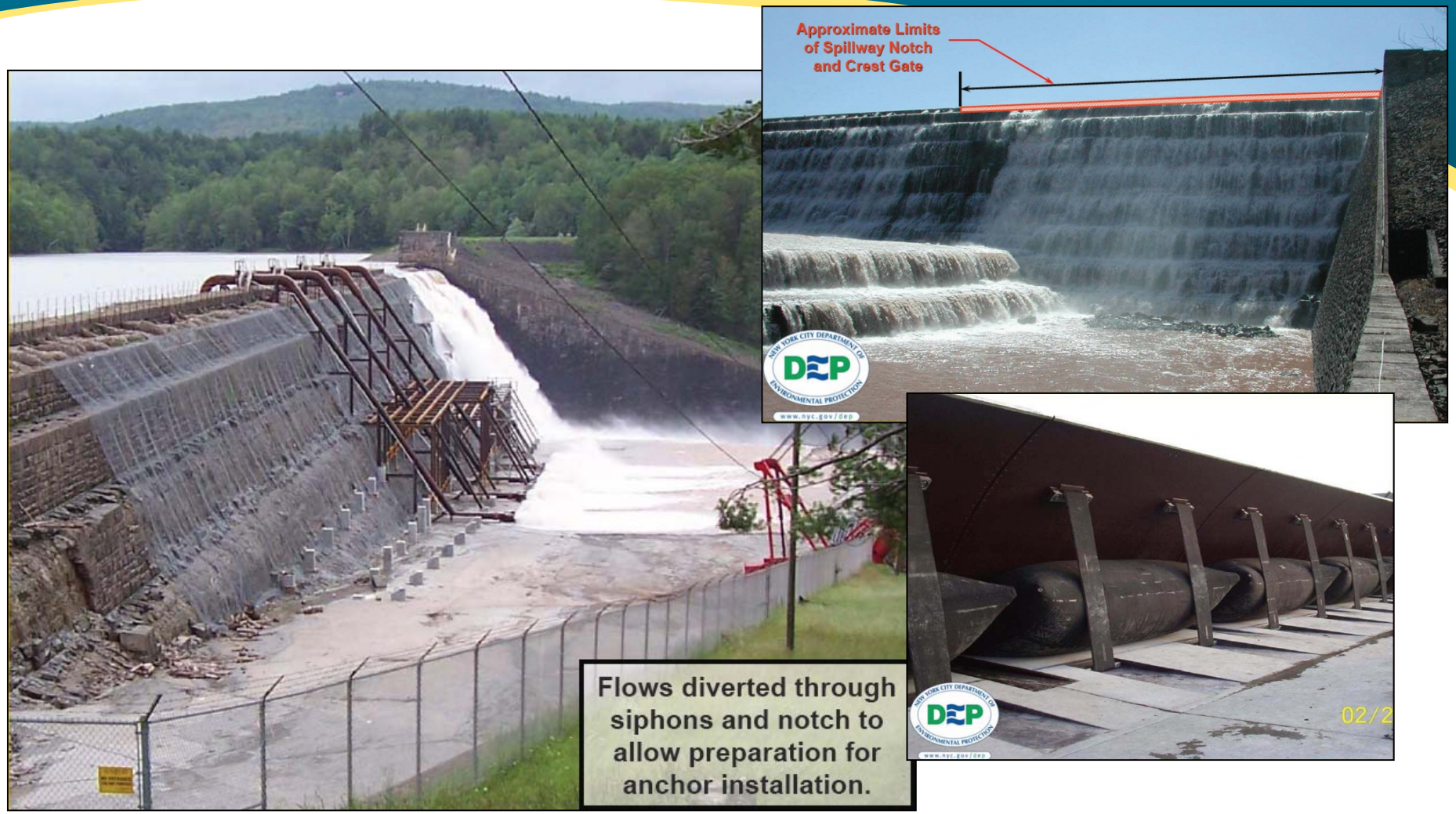
NYC – System Exposures & Vulnerabilities

- Extreme Rainfall and Drought
  - Higher annual rainfall, events larger & more intense; longer growing season;
  - Less precipitation as snow and more as rain;
  - Peak Catskills snowmelt already coming earlier
- Reduced Storage
  - Record rainfall leading to calls for flood control “voids”
  - Risk of not refilling to meet water supply mission
- Encroachment of Salt Fronts
  - Sea level rise could threaten Chelsea Intake
  - Additional stress on the system overall

NYCDEP Adaptation Strategies and Drivers

- Release management
  - “Voiding” of reservoir for flood management
  - Conservation releases to meet potential fisheries requirements
- Watershed management to reduce turbidity
- Use facility rehab cycles as opportunities for CC adaptation

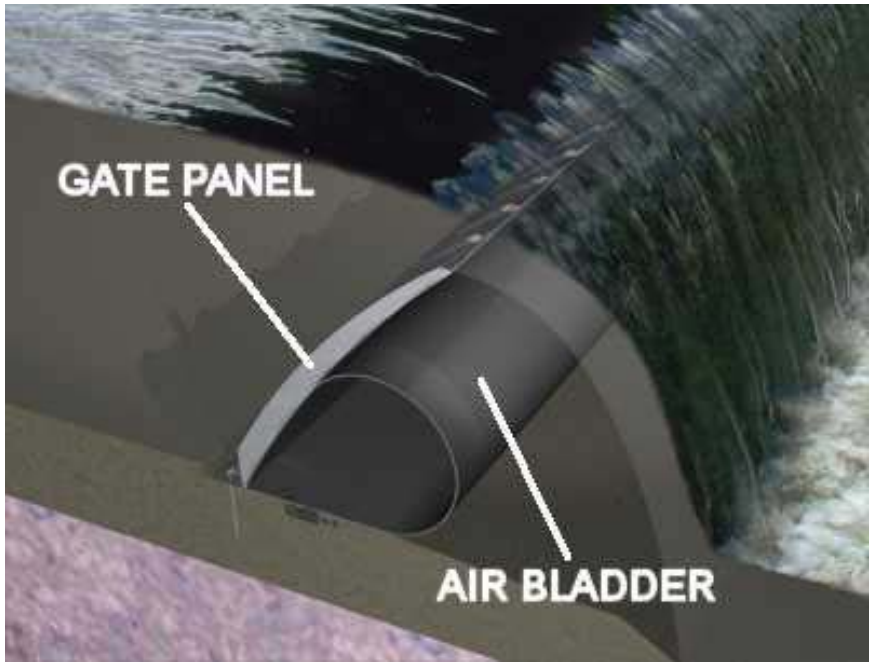
Gilboa Spillway Adaptation



Source: New York City Dept. of Environmental Protection

Gilboa Operational Adaptation

- Spillway modification allows for flexible operation
- Snowmelt prediction guides strategy
- “Voiding” of reservoir enables flood management without impacting water supply



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Graphic adapted from the National Geographic Society web-site accessed Feb 12, 2009.

Australia and Climate Change Impacts Black Saturday Bushfires 2009

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Drought

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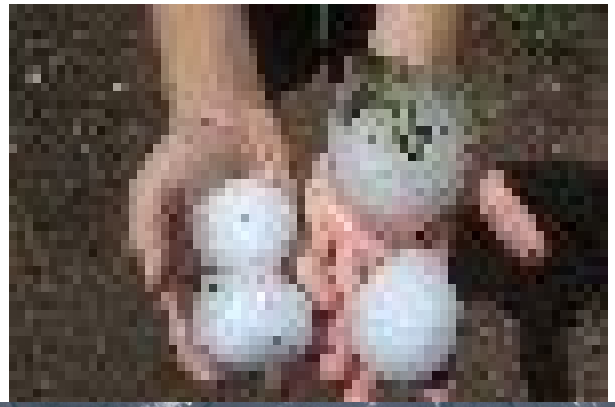
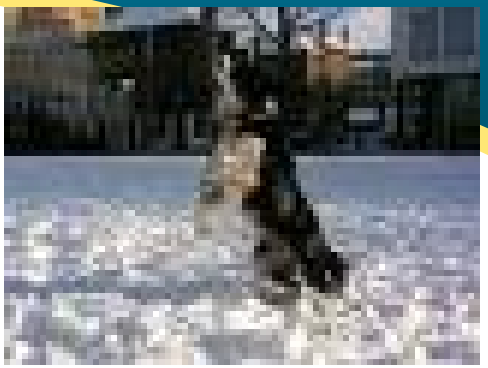
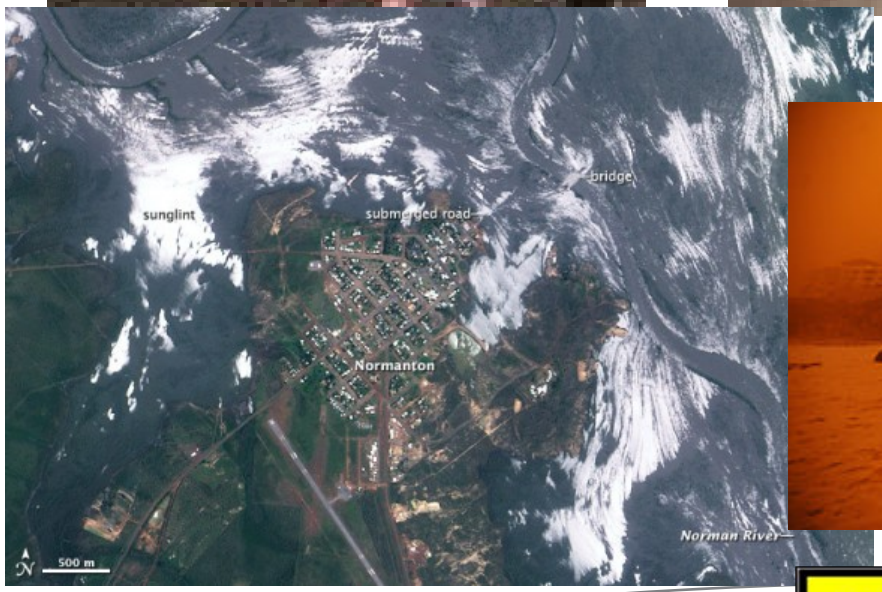
Floods and Severe Weather Events 2009







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Sea Level Rise and Coastal Inundation

Seaspray Surf Club –2007Gippsland Storm Event

Great Ocean Road Apollo Bay –2005Minor Storm Surge Event

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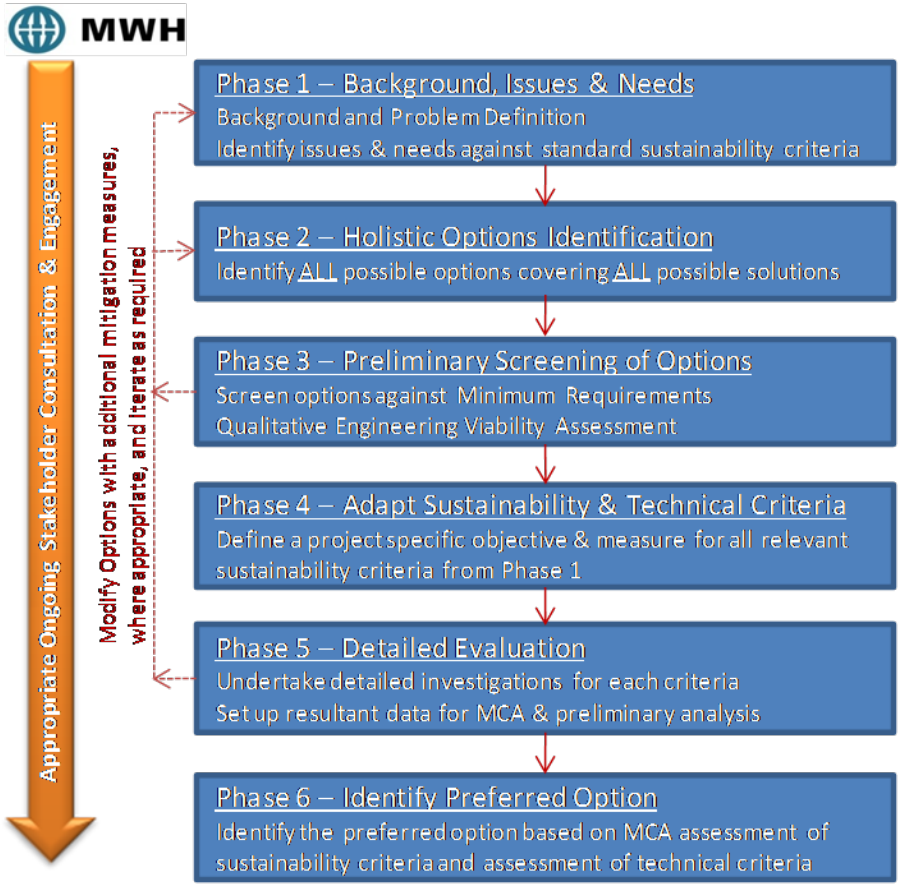
"*us*" Process – Incorporating Sustainability into Decisions



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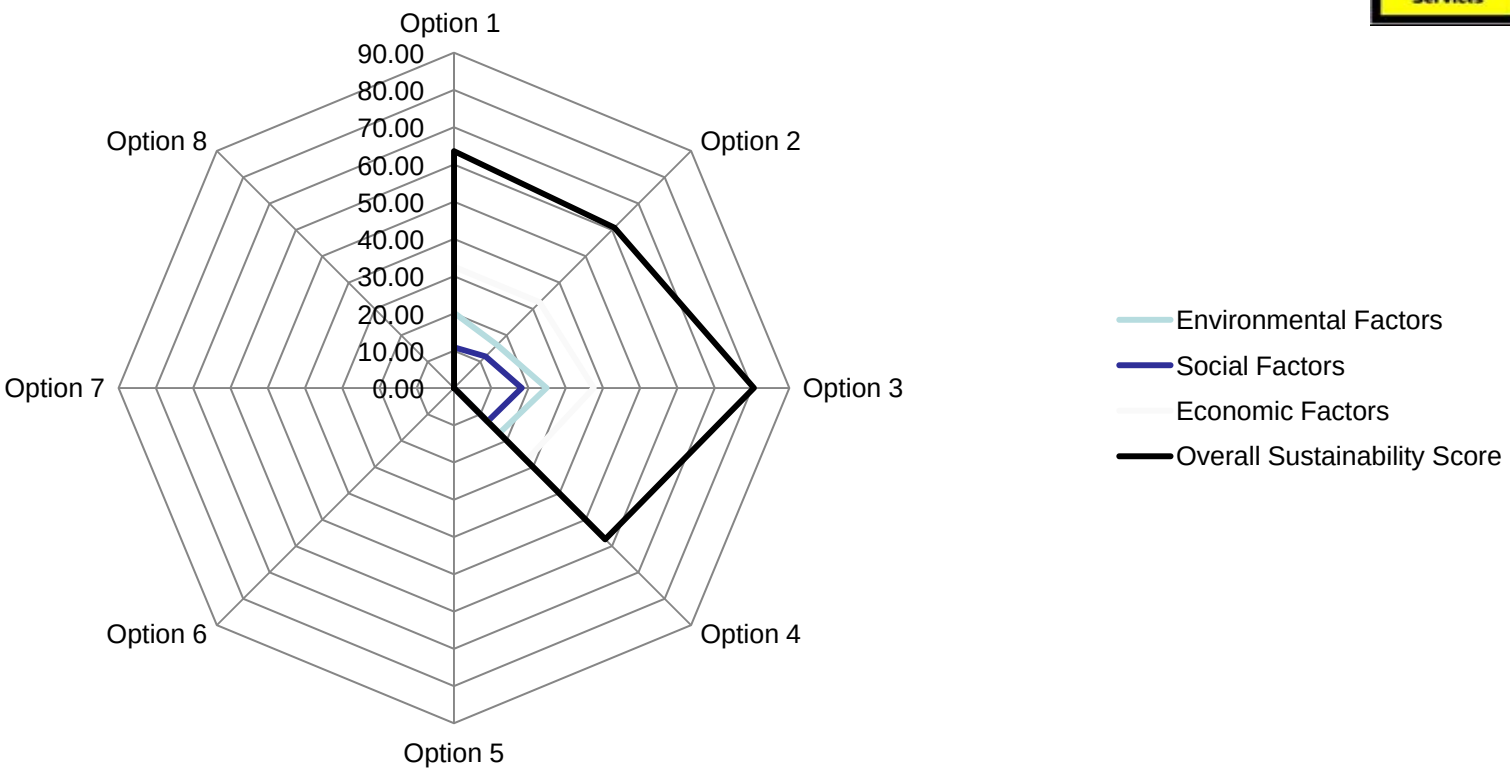
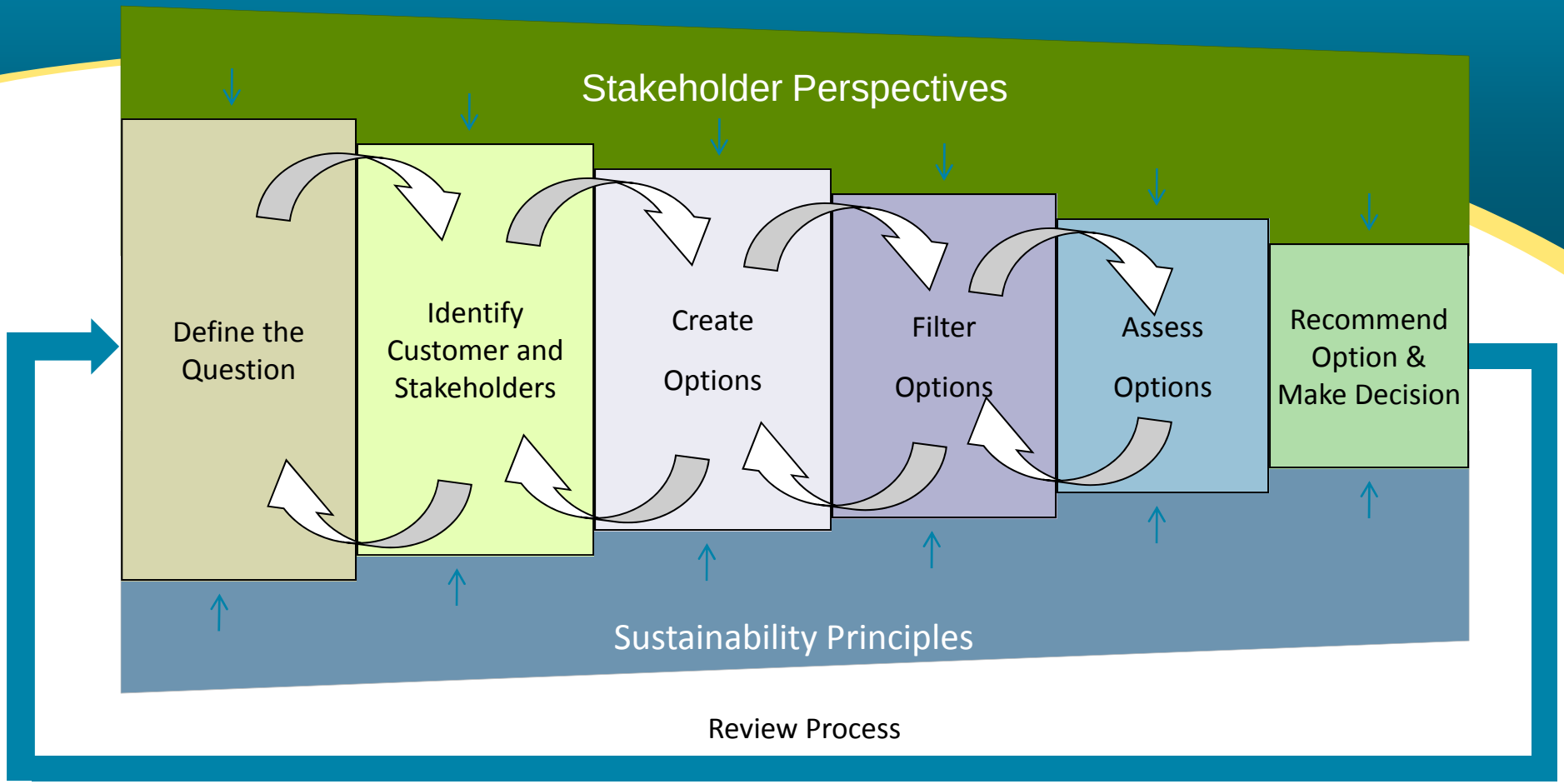
Sustainability Scorecard

US Sustainability Scorecard



Deciding Sustainably



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Summary

- ***Adaptation planning for climate change impacts is essential***
- ***Risk management tools weigh impacts and consequences***
- ***Assessing vulnerability at component level is a starting point***
- ***Adaptation options exist throughout the project life-cycle***
- ***Use a sustainability approach to balance short and long term decisions***

Nashville's K.R. Harrington Water Treatment Plant - under water May 4, 2010