CGE HANDSTRAINING MATERIALS ON VULNERABILITY AND ADAPTATION ASSESSMENT

Water Resources

Outline

- ❑ Vulnerability and adaptation with respect to water resources
- ❑ Hydrologic implications of climate change for water resources
- ❑ Integrated Water Resources Management as an integrating framework
- ❑ Methods, tools and data requirements to assess vulnerability in water resources
- ❑ Adaptation responses by systems and sectors
- ❑ WEAP model presentation

Effective V&A Assessments

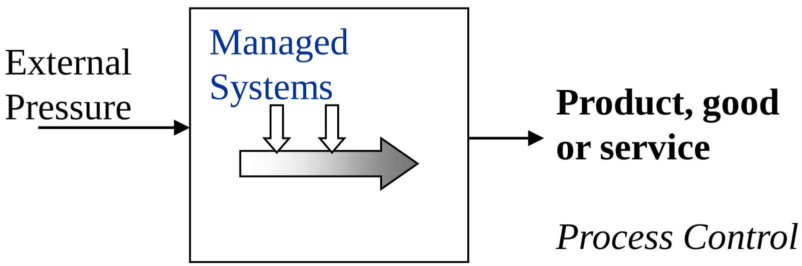
- Vulnerability assessments (VAs) are central to shaping climate change adaptation decisions
- Defining V&A assessment
  - Often V&A in the water sector focuses on analysis over assessment
  - In general, the focus is on biophysical impacts, e.g., hydrologic response, crop yields, land use, etc.
- Assessment is an integrating process requiring the interface of physical and social science and public policy
- General questions
  - What is the assessment trying to influence?
  - How can the science/policy interface be most effective?
  - How can the participants be most effective in the process?
- General problems
  - Participants bring differing objectives/ expertise
  - These differences often lead to dissention/ differing opinions

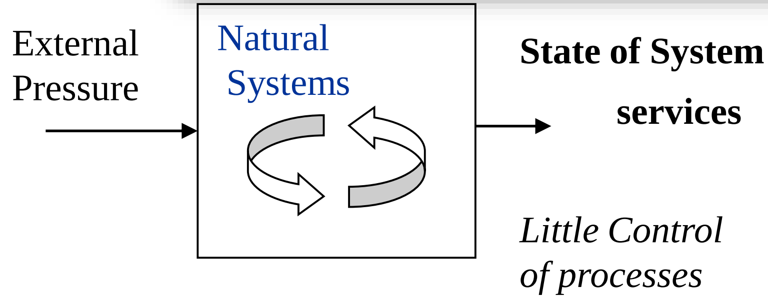
Effective V&A Assessments (continued)

- To be valuable, the assessment process requires
  - Relevancy
  - Credibility
  - Legitimacy
  - Consistent participation
- An interdisciplinary process
  - The assessment process often requires a tool
  - The tool is usually a model or suite of models
  - These models serve as the interface
  - This interface is a bridge for dialogue between scientists and policy makers

Water Resources – A Critical V&A Sector

- ❑ Must consider both managed and natural systems
- ❑ Human activity influences both systems





Example: Agriculture

Example: Wetlands

Ecosystem services diagram, source: metrovancouver.org

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Spatial and Temporal Impacts on Water Resources

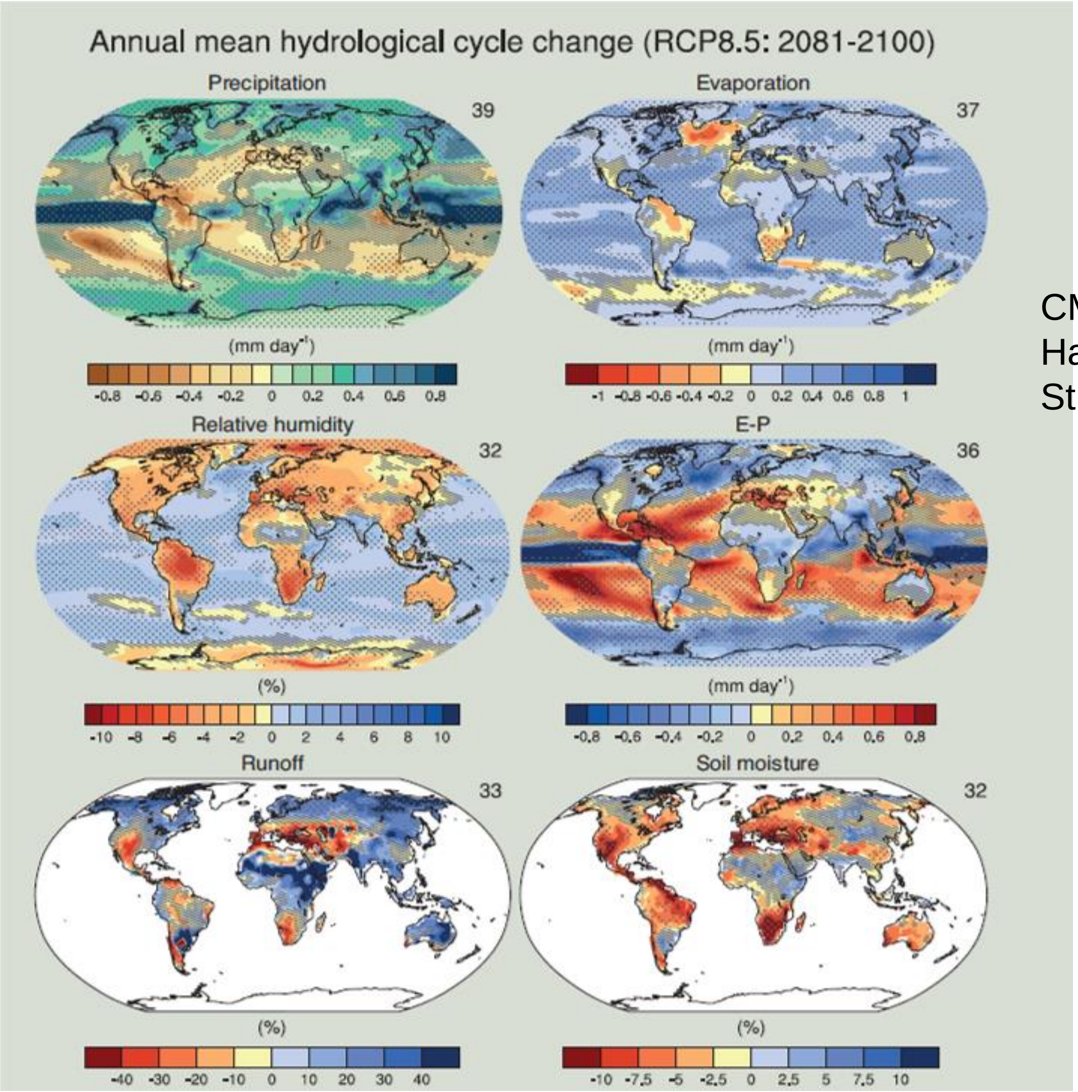
- Impact on annual water availability
  - Agriculture planning
- Impact on seasonal water availability
  - Irrigation water availability
  - Installed power capacity
- Impact on inter annual water availability
  - Planning for water resource's structure
- Regional Variability of Water availability
  - Change in Cropping pattern
- Extreme events
  - Drought – reduced flows in dry seasons
  - Floods – higher flows during wet season
  - Urban storm

AR5 Projected changes in Water towards the end of the 21st Century

Component	Key issues and impacts
Evaporation – precipitation	• Changes in evaporation exceed precipitation (less runoff and recharge) in Central North America; Central America, Northern South America, Southern Chilean Coast, Southern Africa, western Europe, the Mediterranean, and south-central Asia • Precipitation exceeds evaporation (more runoff and recharge) in the high latitudes, eastern North America, Northwest South America; Central Africa, India and east Asia
Groundwater	• Surface water recharge is strongly tied to groundwater variability in unconfined aquifers • Increased abstraction from population growth and reduced surface water availability could result in declining groundwater levels, particular in areas experiencing warming and precipitation deficits
Streamflow	• Significant regional variation range in run-off and stream flow. Stream flows in high-latitude rivers increase • Increased precipitation intensity leads to greater floods and can exacerbate droughts as well
Coastal zones	• Increased inundation and coastal flooding causing in salinization of groundwater and estuaries • Changes in the timing and volume of freshwater run-off affecting salinity, sediment and nutrient availability • Changes in water quality may come as a result of the impact of sea level rise on storm-water drainage operations and sewage disposal in coastal areas • Changes to the zonation of plant and animal species as well as the availability of freshwater for human use as a result of salinity advancing upstream due to decreased stream flow
Water quality	• Higher water temperatures may degrade water quality. This can be made worse by presence of pollution • Changes in flooding and droughts may affect water quality through sediments, nutrients, dissolved organic carbon, pathogens, pesticides and salt • Sea level rise is projected to extend areas of salinization of groundwater and estuaries
Demand, supply and sanitation	• Climate change will likely add further stress to water service issues including: supply, demand and governance

Source: IPCC, 2013

Hydrologic Implications of Climate Change

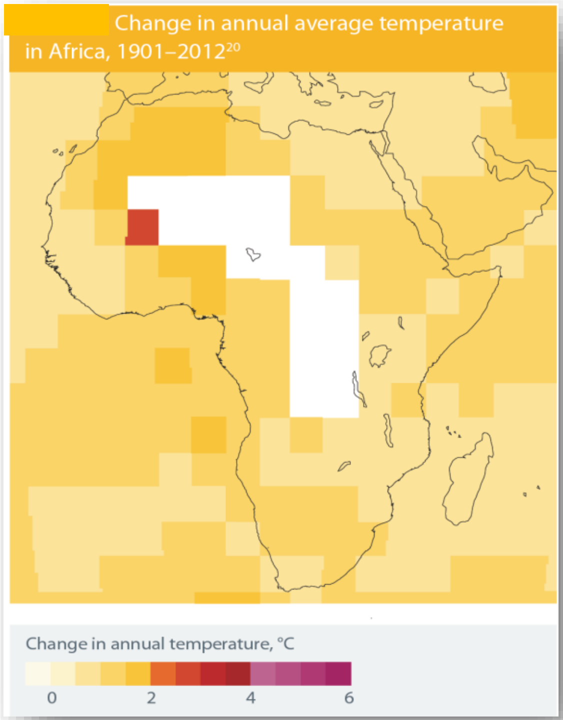


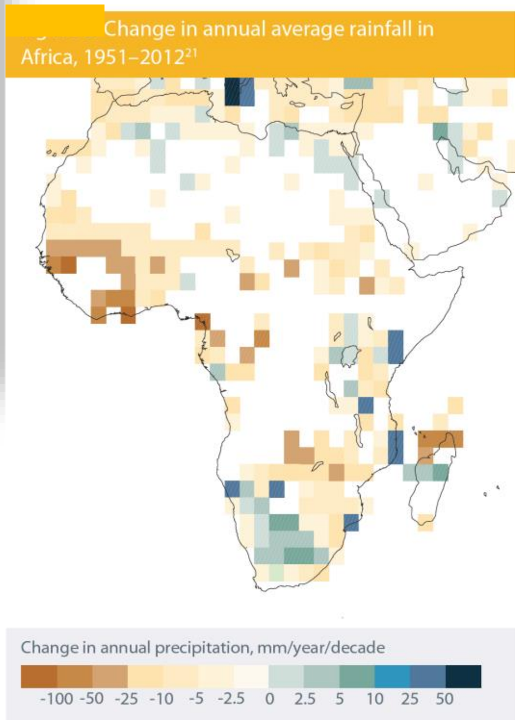
CMIP5 models used
Hatch: MMEMean < 1 Std
Stripe: MMEMean > 2 Std

Annual mean changes in precipitation (P), evaporation (E), relative humidity, E – P, runoff and soil moisture for 2081–2100 relative to 1986–2005 under the Representative Concentration Pathway RCP8.5.

Source: IPCC Climate Change 2013: Technical Summary, p.45

African Region – AR5 Summary - Observed

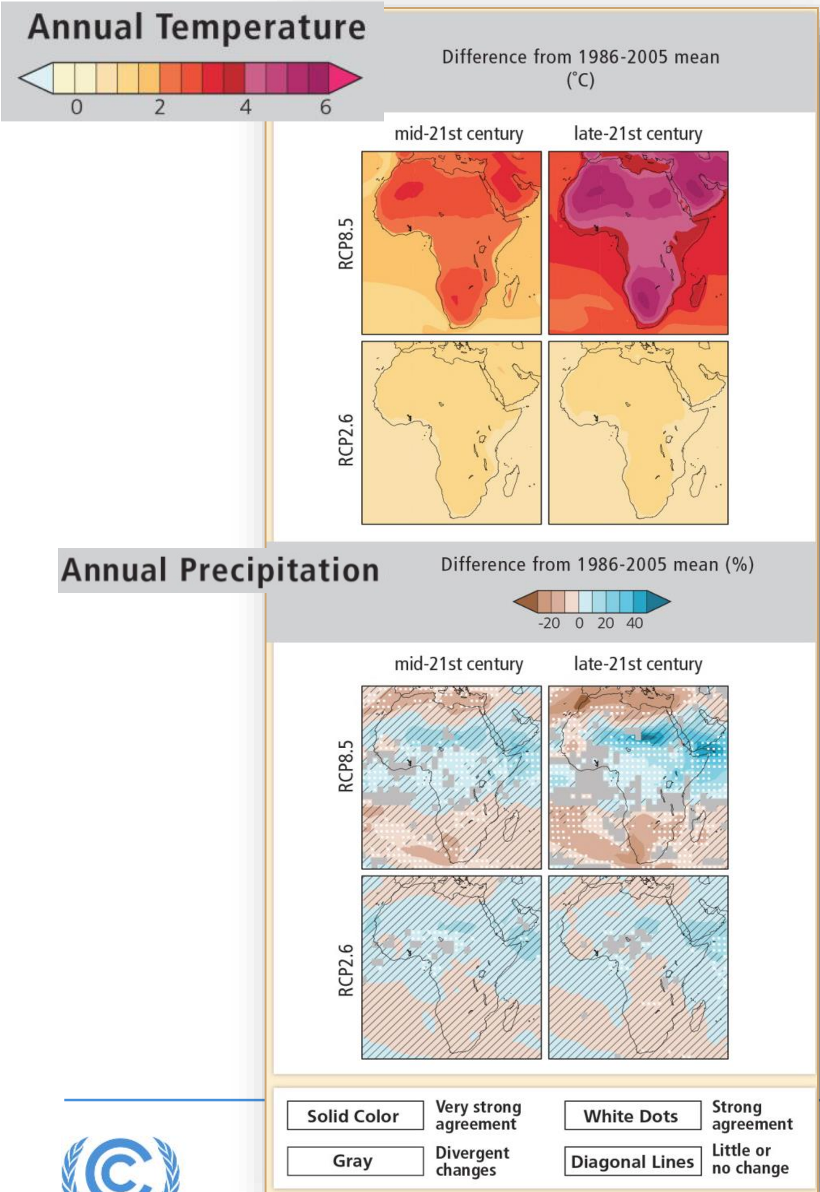




- Observed temperature: surface temperatures across most of Africa have increased by 0.5° C or more during the last 50–100 years(high confidence)
- Observed rainfall: lack of sufficient observational data to draw conclusions about trends in annual rainfall over the past century
- Observed extreme events: evidence suggests that climate change has changed the magnitude and frequency of some extreme weather and climate events, general lack of data for Africa
- Observed sea level rise: rate of sea-level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (high confidence).

http://cdkn.org/wp-content/uploads/2014/04/J1731_CDKN_FifthAssesmentReport_WEB.pdf

African Region – AR5 Summary – Climate Change



- Projected temperature trends: Climate projections suggest increases in temperature. Increases in average temperatures are very likely in the mid- and late-21st century under both low- and high emissions scenarios
  - Changes in average temperature are projected to be greater over northern and southern Africa and relatively smaller over central Africa
- Projected rainfall trends: Most areas of the African continent do not show changes in annual average rainfall under low-emissions scenarios, a very likely decrease in annual average rainfall over areas of southern Africa beginning in the mid-21st century under a high-emissions scenario
- Projected extreme events: heavy rainfall, heat waves and drought, will become increasingly important and will play a more significant role in disaster impacts

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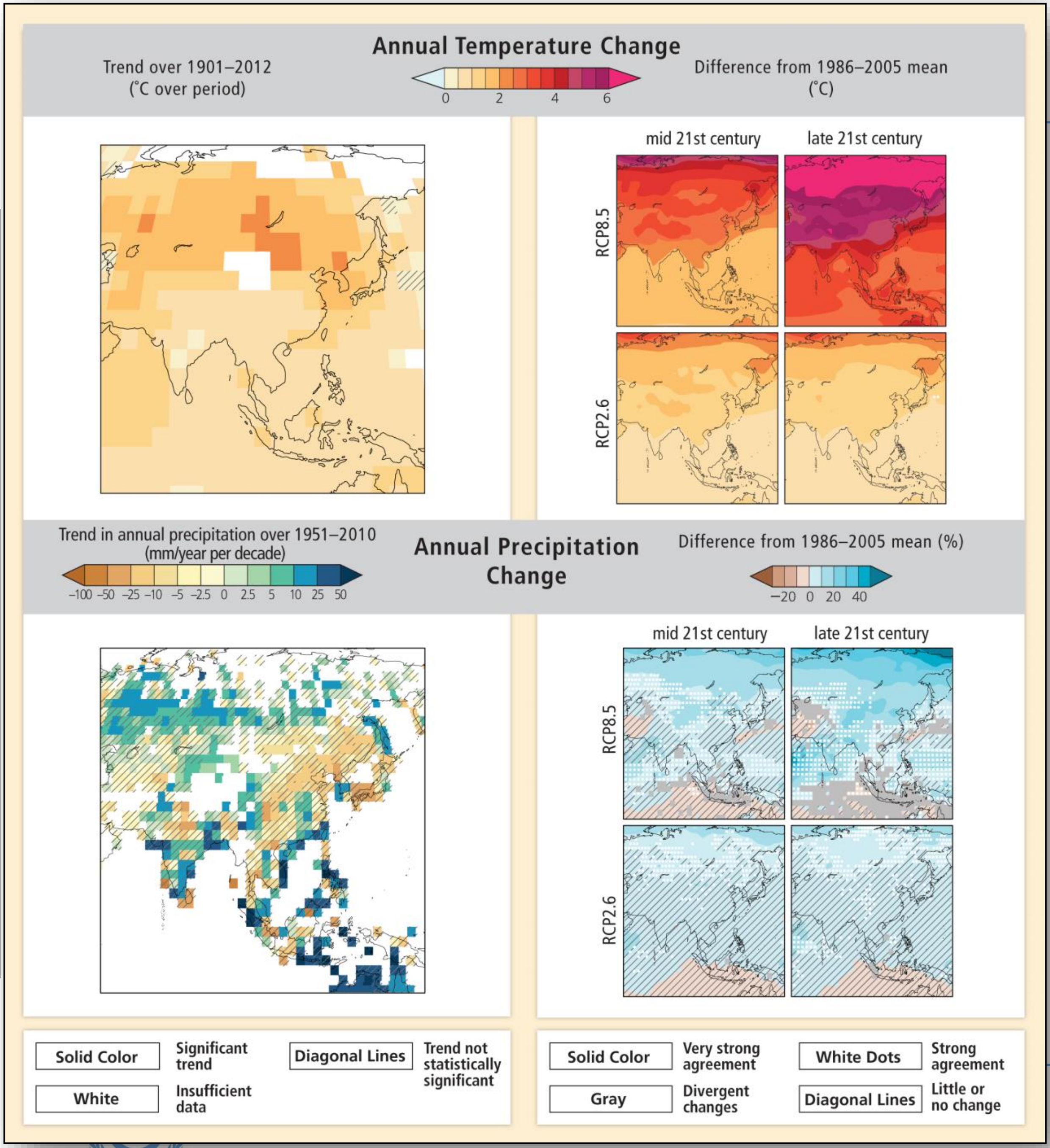
Asia Region – AR5 Summary



- Observed and projected changes in annual average temperature and precipitation in Asia
- CMIP5 multi-model mean projections of annual average temperature changes and average percent change in annual mean precipitation for 2046-2065 and 2081-2100 under RCP2.6 and 8.5
- Strong: >66% of models agree on sign of change
- Gray : >66% of models show change greater than the baseline variability but agree on sign of change

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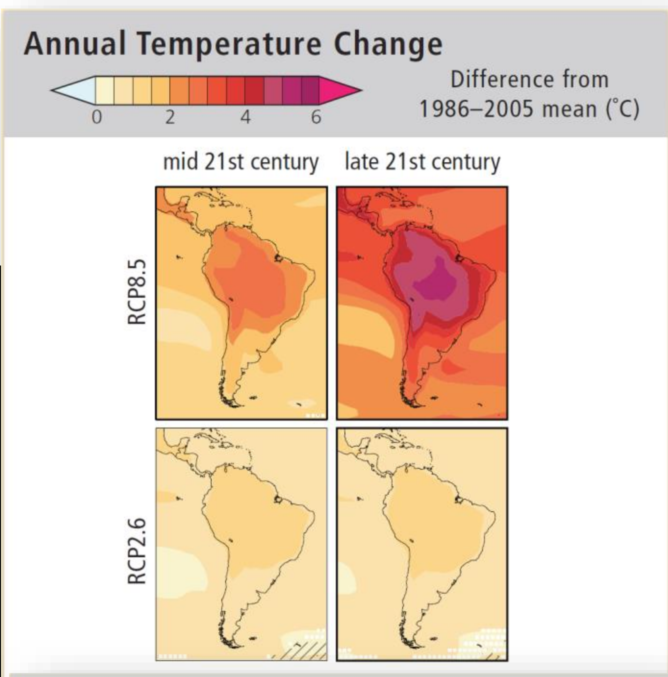
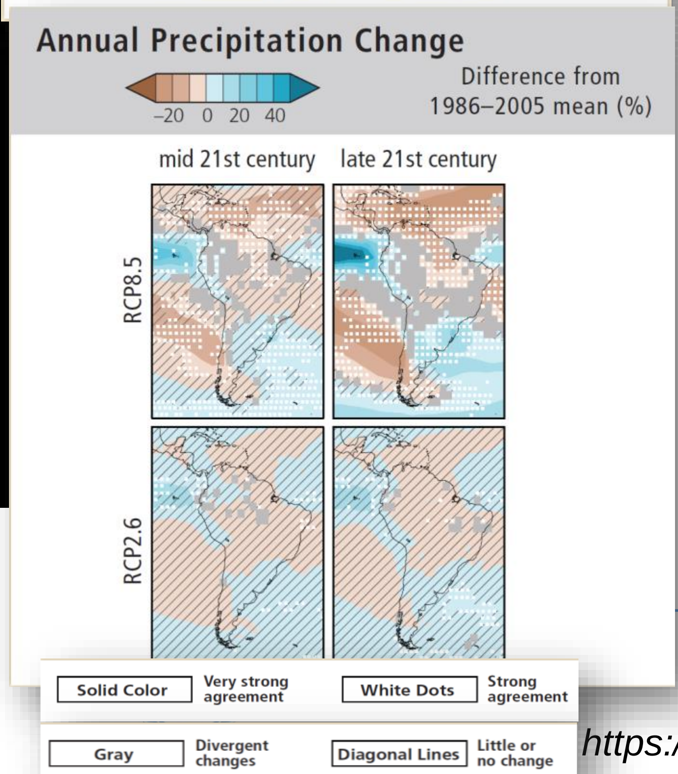
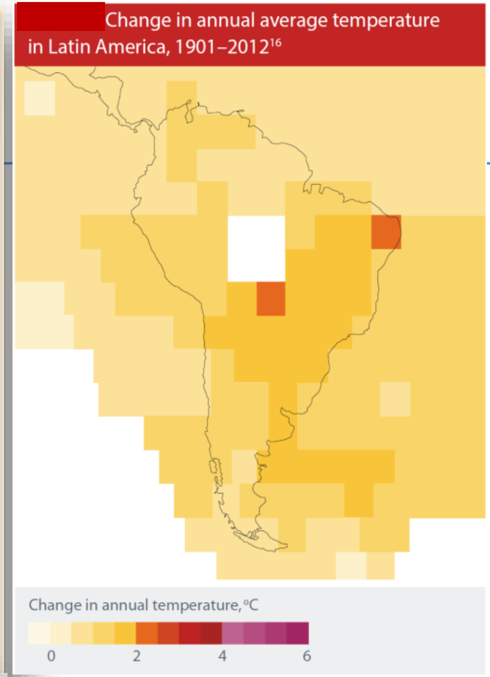
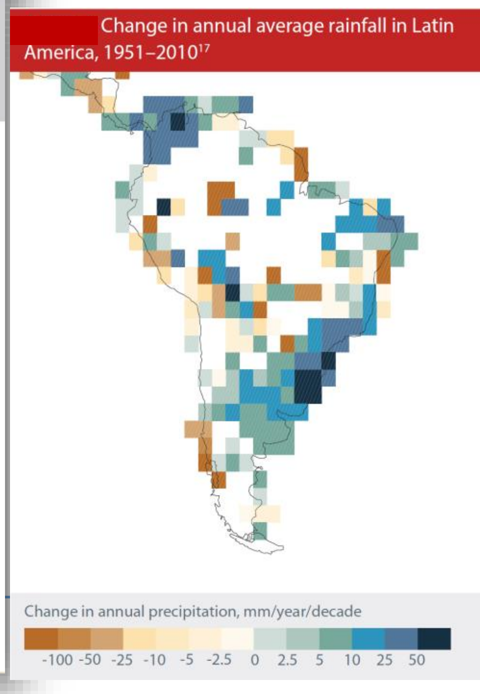








Central and South American regions Region – AR5 Summary

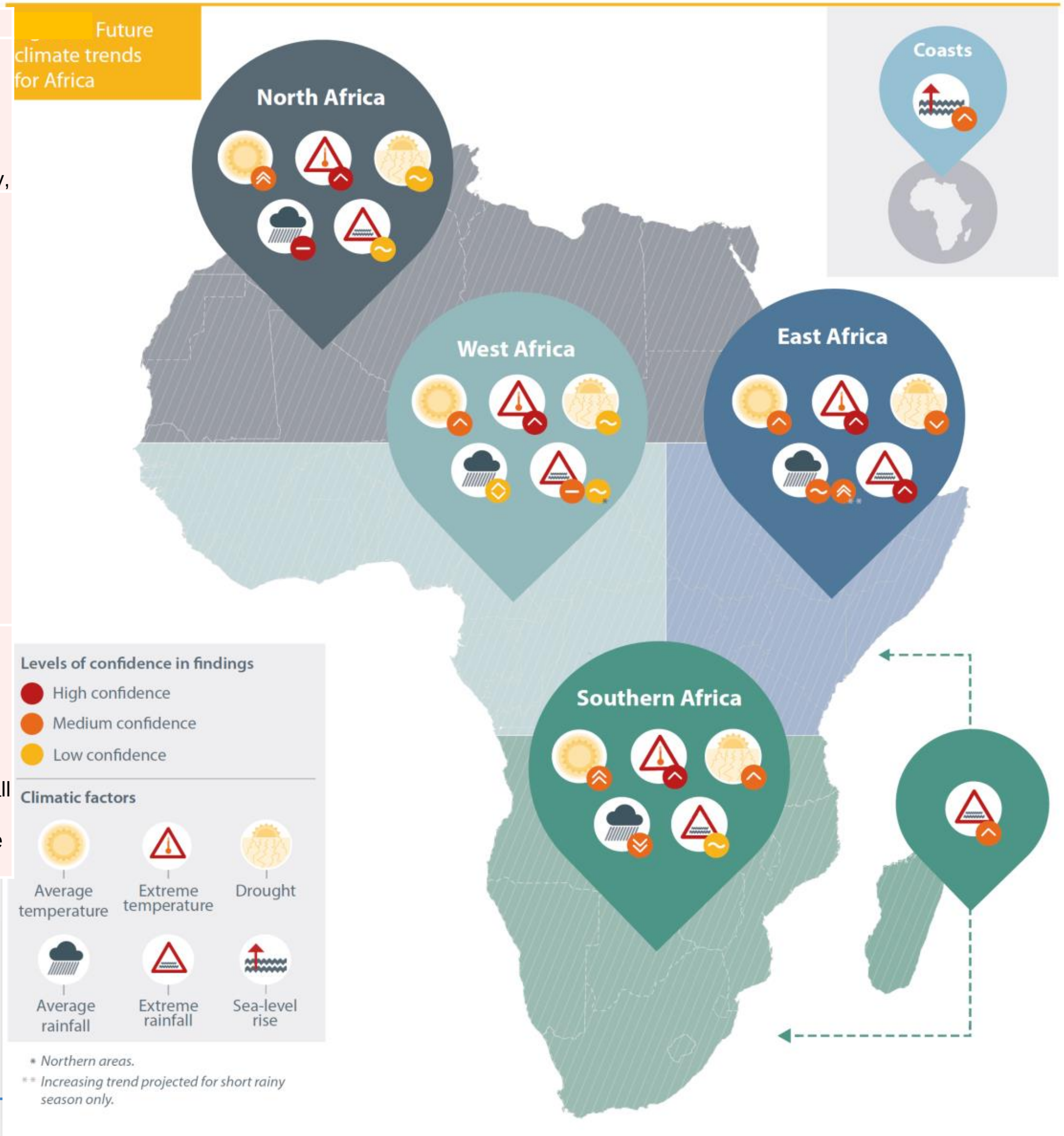
- ❑ Significant trends in precipitation and temperature have been observed in Central America & South America (high confidence)
- ❑ changes in climate variability and in extreme events have severely affected the region (medium confidence)
- ❑ Climate projections suggest increases in temperature, and increases or decreases in precipitation for CA and SA by 2100 (medium confidence)
- ❑ Strong: >66% of models agree on sign of change
- ❑ Gray : >66% of models show change greater than the baseline variability but agree on sign of change

https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap27_FINAL.pdf

Impacts for Africa that can be attributed to climate change - IPCC 5th Assessment Report

	North Africa	West Africa	East Africa	Southern Africa
Projected temp-erature	Rise under a high-emissions cenario, with more of a rise in inimum temperatures	Rise by between 3° C and 6° C by the end of the 21st century	Rise in temperature in middle and end of this century	Warming of 3.4–4.2° C warming towards end century,
Projected rainfall	By the end of this century likely to receive less rainfall	Many global models indicate a wetter main rainy season with a small delay in the onset of the rainy season by the end of the 21st century.	End of the 21st century, the climate in eastern Projections indicate shorter spring rains in the mid-21st century for Ethiopia, Somalia, Tanzania and southern Kenya, and longer autumn rains in southern Kenya and Tanzania Africa will be wetter	Show drying in the southwest, extending northeast from the Namibia and Botswana deserts
Projected extreme events	Number of heat wave days will increase, projections for extreme rainfall are inconsistent.	Risk of drought are inconsistent, increase in rainfall intensity,	More heavy rainfall over the region with high certainty and more extremely wet days , increase in the frequency of hot days	Rsk of severe droughts in southwestern regions will be high, extremely low rainfall and extremely high rainfall may become more common

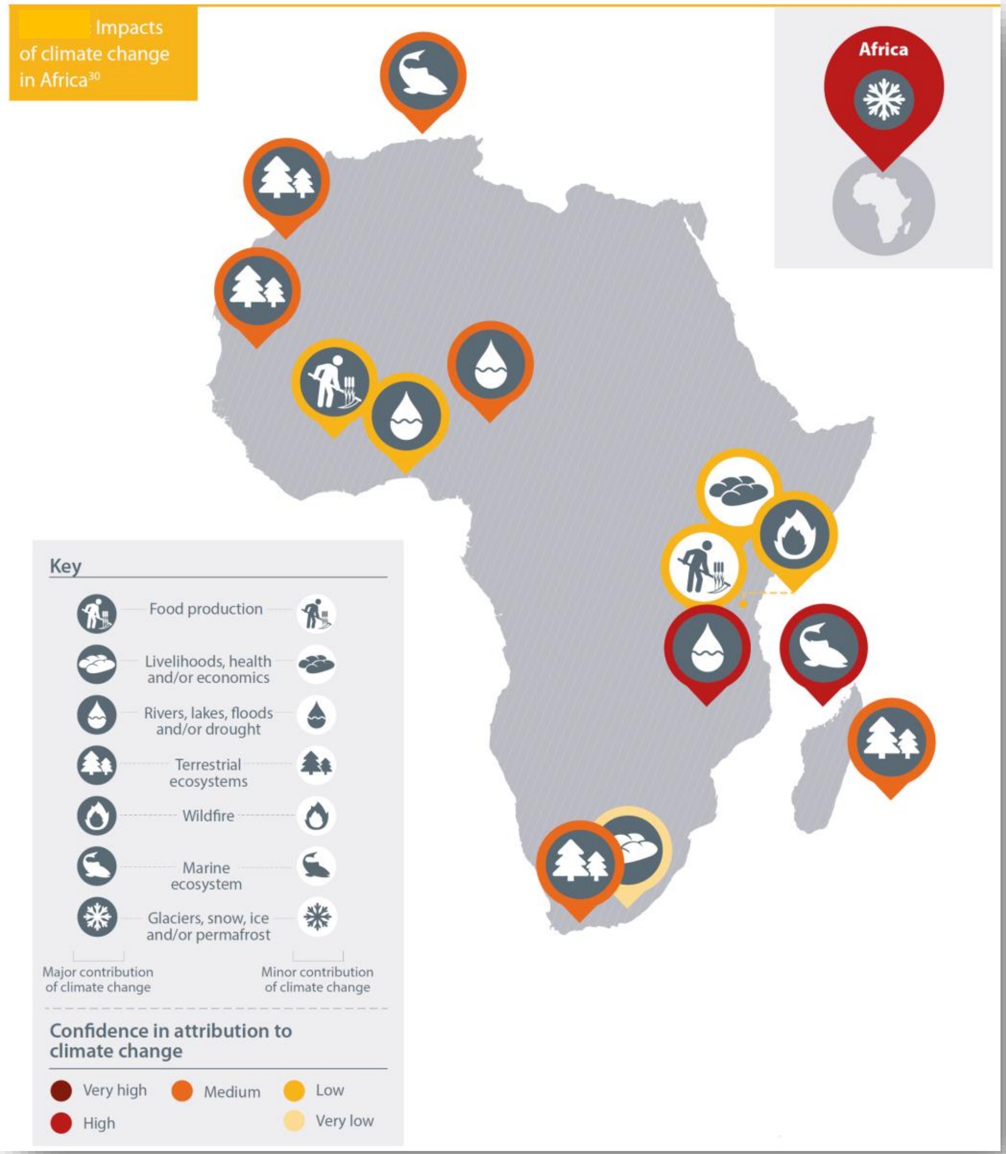
Symbol	Rainfall	Temperature	Extreme rainfall, extreme temperature, sea-level rise
	up to 30% increasing trend	1–6°C increasing trend	–
	up to 10% increasing trend	1–4.5°C increasing trend	increasing trend
	both increasing and decreasing trends	–	both increasing and decreasing trends
	up to 10% decreasing trend	–	decreasing trend
	up to 30% decreasing trend	–	–
	inconsistent trend	inconsistent trend	inconsistent trend
	no or only slight change	inconsistent trend	inconsistent trend



http://cdkn.org/wp-content/uploads/2014/04/AR5_IPCC_Whats_in_it_for_Africa.pdf

IPCC 5th Assessment Report (2013) Impacts in Africa

- Potential impacts of climate change are likely to be substantial without further adaptation:
  - Climate change will amplify existing stress on water availability in Africa (high confidence)
  - Climate change will interact with non-climate drivers and stressors to exacerbate vulnerability of agricultural systems, particularly in semi-arid areas (high confidence)
  - African ecosystems are already being affected by climate change, and future impacts are expected to be substantial (high confidence).
  - shifting ranges of some species and ecosystems due to elevated carbon dioxide (CO2) and climate change, beyond the effects of land use change and other non-climate stressors (high confidence)
  - Ocean ecosystems, in particular coral reefs, will be affected by ocean acidification and warming as well as changes in ocean upwellings, thus negatively affecting economic sectors such as fisheries (medium confidence
  - Climate change is a multiplier of existing health vulnerabilities (high confidence), including insufficient access to safe water and improved sanitation, food insecurity, and limited access to health care and education
  - Despite implementation limitations, Africa's adaptation experiences nonetheless highlight valuable lessons for enhancing and scaling up the adaptation response, including principles for good practice and integrated approaches to adaptation (high
  - confidence).



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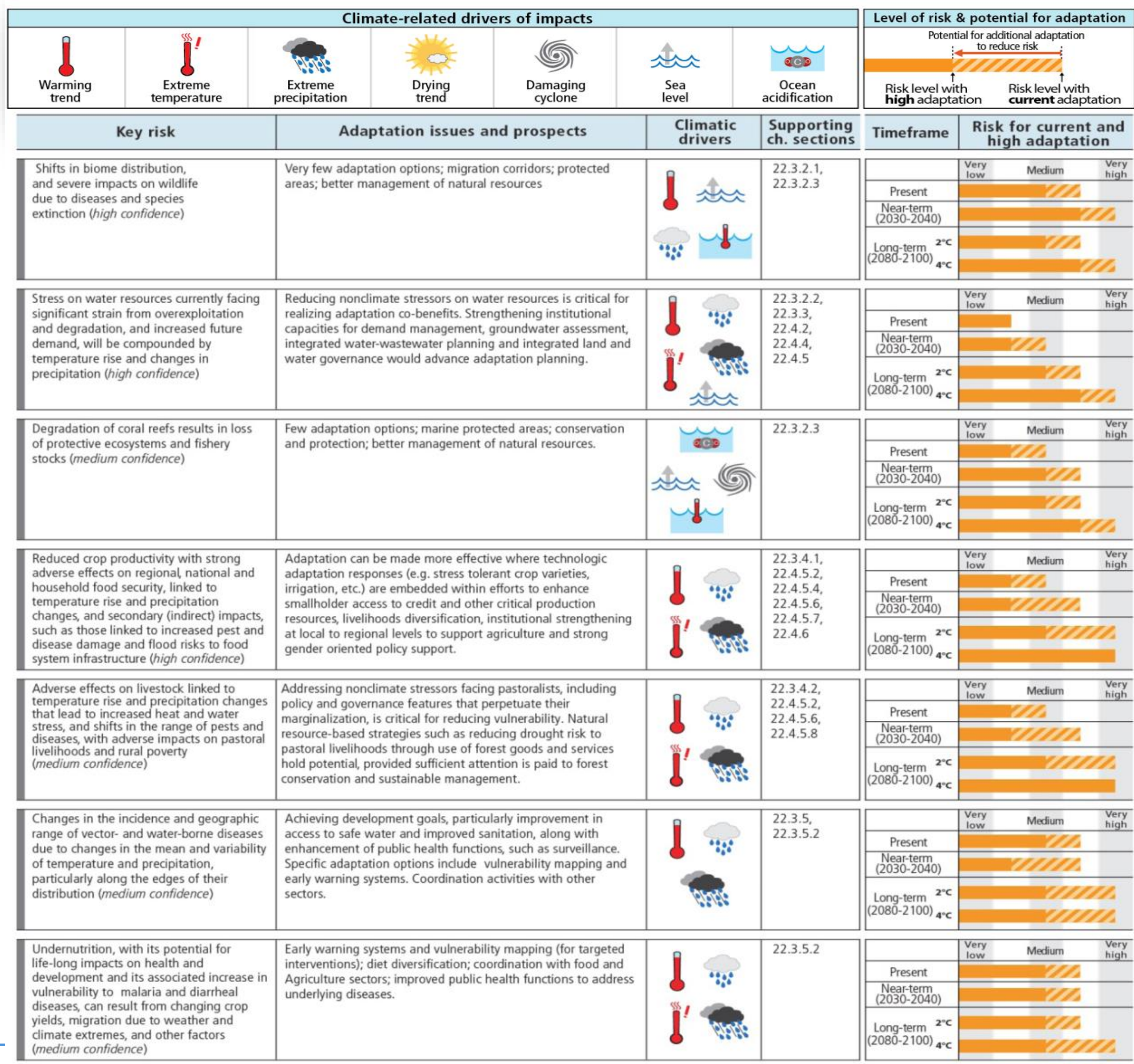
Key risks from climate change and the potential for risk reduction through mitigation and adaptation - AR5 Representation

- Key risks from climate change and the potential for risk reduction through mitigation and adaptation in Africa
- Key risks are identified based on assessment of the literature and expert judgments, with supporting evaluation of evidence and agreement in the referenced chapter sections



Key risk	Adaptation issues and prospects	Climatic drivers	Supporting ch. sections	Timeframe	Risk for current and high adaptation
Shifts in biome distribution, and severe impacts on wildlife due to diseases and species extinction (*high confidence*)	Very few adaptation options; migration corridors; protected areas; better management of natural resources		22.3.2.1, 22.3.2.3	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C / 4°C	
Stress on water resources currently facing significant strain from overexploitation and degradation, and increased future demand, will be compounded by temperature rise and changes in precipitation (*high confidence*)	Reducing nonclimate stressors on water resources is critical for realizing adaptation co-benefits. Strengthening institutional capacities for demand management, groundwater assessment, integrated water-wastewater planning and integrated land and water governance would advance adaptation planning.		22.3.2.2, 22.3.3, 22.4.2, 22.4.4, 22.4.5	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C / 4°C	
Degradation of coral reefs results in loss of protective ecosystems and fishery stocks (*medium confidence*)	Few adaptation options; marine protected areas; conservation and protection; better management of natural resources.		22.3.2.3	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C / 4°C	
Reduced crop productivity with strong adverse effects on regional, national and household food security, linked to temperature rise and precipitation changes, and secondary (indirect) impacts, such as those linked to increased pest and disease damage and flood risks to food system infrastructure (*high confidence*)	Adaptation can be made more effective where technologic adaptation responses (e.g. stress tolerant crop varieties, irrigation, etc.) are embedded within efforts to enhance smallholder access to credit and other critical production resources, livelihoods diversification, institutional strengthening at local to regional levels to support agriculture and strong gender oriented policy support.		22.3.4.1, 22.4.5.2, 22.4.5.4, 22.4.5.6, 22.4.5.7, 22.4.6	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C / 4°C	
Adverse effects on livestock linked to temperature rise and precipitation changes that lead to increased heat and water stress, and shifts in the range of pests and diseases, with adverse impacts on pastoral livelihoods and rural poverty (*medium confidence*)	Addressing nonclimate stressors facing pastoralists, including policy and governance features that perpetuate their marginalization, is critical for reducing vulnerability. Natural resource-based strategies such as reducing drought risk to pastoral livelihoods through use of forest goods and services hold potential, provided sufficient attention is paid to forest conservation and sustainable management.		22.3.4.2, 22.4.5.2, 22.4.5.6, 22.4.5.8	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C / 4°C	
Changes in the incidence and geographic range of vector- and water-borne diseases due to changes in the mean and variability of temperature and precipitation, particularly along the edges of their distribution (*medium confidence*)	Achieving development goals, particularly improvement in access to safe water and improved sanitation, along with enhancement of public health functions, such as surveillance. Specific adaptation options include vulnerability mapping and early warning systems. Coordination activities with other sectors.		22.3.5, 22.3.5.2	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C / 4°C	
Undernutrition, with its potential for life-long impacts on health and development and its associated increase in vulnerability to malaria and diarrheal diseases, can result from changing crop yields, migration due to weather and climate extremes, and other factors (*medium confidence*)	Early warning systems and vulnerability mapping (for targeted interventions); diet diversification; coordination with food and Agriculture sectors; improved public health functions to address underlying diseases.		22.3.5.2	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C / 4°C	

http://cdkn.org/wp-content/uploads/2014/04/AR5_IPCC_Whats_in_it_for_Africa.pdf

IPCC 5th Assessment Report (2013) Impacts in Asia

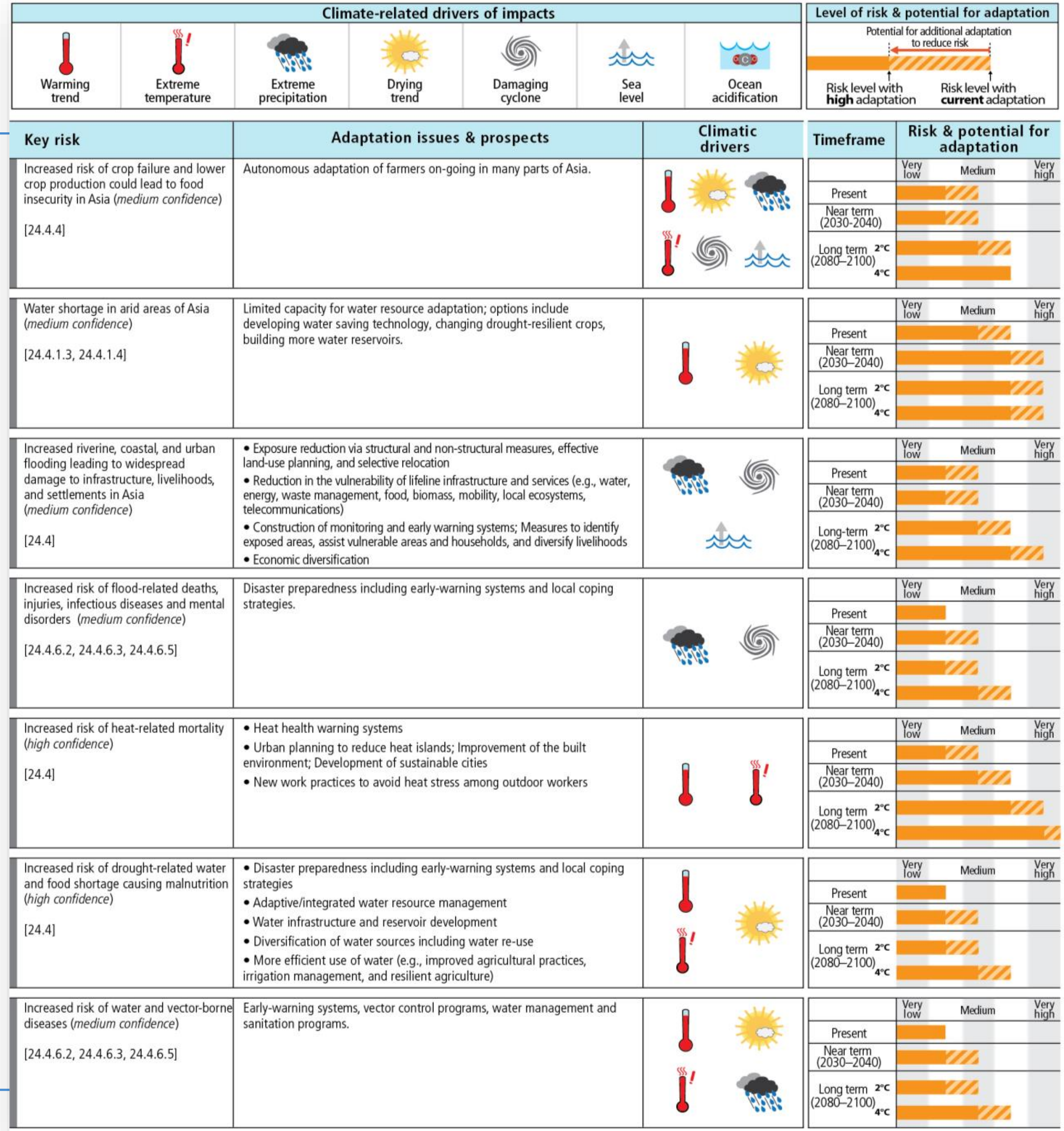
❑ Potential impacts of climate change are likely to be substantial without further adaptation:

- Warming trends and increasing temperature extremes have been observed over the past century (high confidence)
- Water scarcity is expected to be a major issue due to increased water demand and lack of good management (medium confidence)
- Decline in productivity and threat to food security (medium confidence)
- Terrestrial systems: shifts in the phenologies, growth rates, and the distributions of plant species (high confidence)
- Multiple stresses caused by rapid urbanization, industrialization and economic development will be compounded by climate change (high confidence)
- Extreme climate events (increases in floods and droughts) will have an increasing impact on human health, security, livelihoods (high confidence)

http://cdkn.org/wp-content/uploads/2014/04/CDKN-IPCC-Whats-in-it-for-South-Asia-AR5.pdf

AR5 Representation

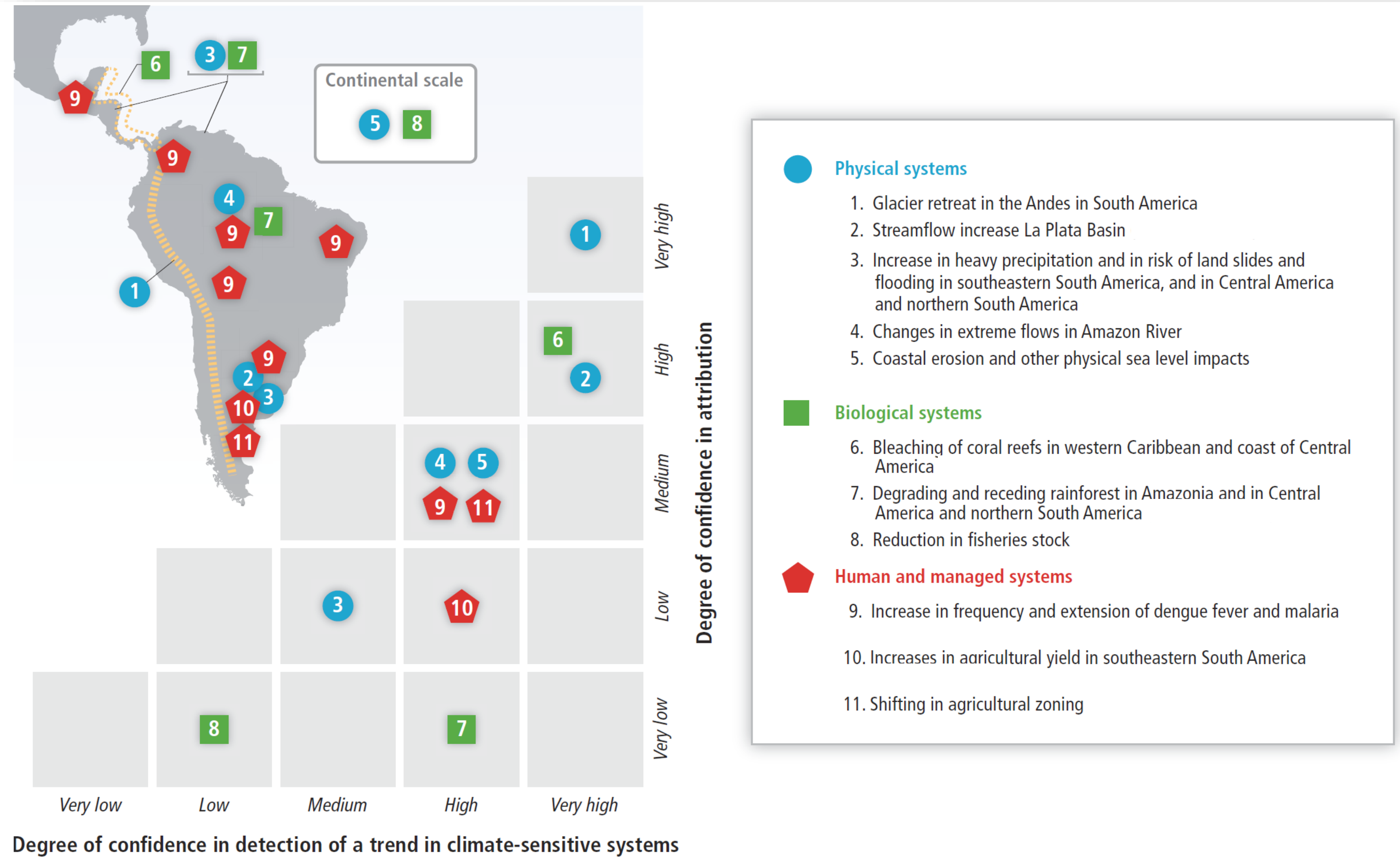
- Key risks from climate change and the potential for risk reduction through mitigation and adaptation in Asia
- Key risks are identified based on assessment of the literature and expert judgments, with supporting evaluation of evidence and agreement in the referenced chapter sections



Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Increased risk of crop failure and lower crop production could lead to food insecurity in Asia (*medium confidence*) [24.4.4]	Autonomous adaptation of farmers on-going in many parts of Asia.		Present; Near term (2030–2040); Long term (2080–2100) 2°C, 4°C	Very low – Medium – Very high
Water shortage in arid areas of Asia (*medium confidence*) [24.4.1.3, 24.4.1.4]	Limited capacity for water resource adaptation; options include developing water saving technology, changing drought-resilient crops, building more water reservoirs.		Present; Near term (2030–2040); Long term (2080–2100) 2°C, 4°C	Very low – Medium – Very high
Increased riverine, coastal, and urban flooding leading to widespread damage to infrastructure, livelihoods, and settlements in Asia (*medium confidence*) [24.4]	• Exposure reduction via structural and non-structural measures, effective land-use planning, and selective relocation • Reduction in the vulnerability of lifeline infrastructure and services (e.g., water, energy, waste management, food, biomass, mobility, local ecosystems, telecommunications) • Construction of monitoring and early warning systems; Measures to identify exposed areas, assist vulnerable areas and households, and diversify livelihoods • Economic diversification		Present; Near term (2030–2040); Long-term (2080–2100) 2°C, 4°C	Very low – Medium – Very high
Increased risk of flood-related deaths, injuries, infectious diseases and mental disorders (*medium confidence*) [24.4.6.2, 24.4.6.3, 24.4.6.5]	Disaster preparedness including early-warning systems and local coping strategies.		Present; Near term (2030–2040); Long term (2080–2100) 2°C, 4°C	Very low – Medium – Very high
Increased risk of heat-related mortality (*high confidence*) [24.4]	• Heat health warning systems • Urban planning to reduce heat islands; Improvement of the built environment; Development of sustainable cities • New work practices to avoid heat stress among outdoor workers		Present; Near term (2030–2040); Long term (2080–2100) 2°C, 4°C	Very low – Medium – Very high
Increased risk of drought-related water and food shortage causing malnutrition (*high confidence*) [24.4]	• Disaster preparedness including early-warning systems and local coping strategies • Adaptive/integrated water resource management • Water infrastructure and reservoir development • Diversification of water sources including water re-use • More efficient use of water (e.g., improved agricultural practices, irrigation management, and resilient agriculture)		Present; Near term (2030–2040); Long term (2080–2100) 2°C, 4°C	Very low – Medium – Very high
Increased risk of water and vector-borne diseases (*medium confidence*) [24.4.6.2, 24.4.6.3, 24.4.6.5]	Early-warning systems, vector control programs, water management and sanitation programs.		Present; Near term (2030–2040); Long term (2080–2100) 2°C, 4°C	Very low – Medium – Very high

https://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap24_FINAL.pdf

Observed impacts for Latin America that can be attributed to climate change - IPCC 5th Assessment Report



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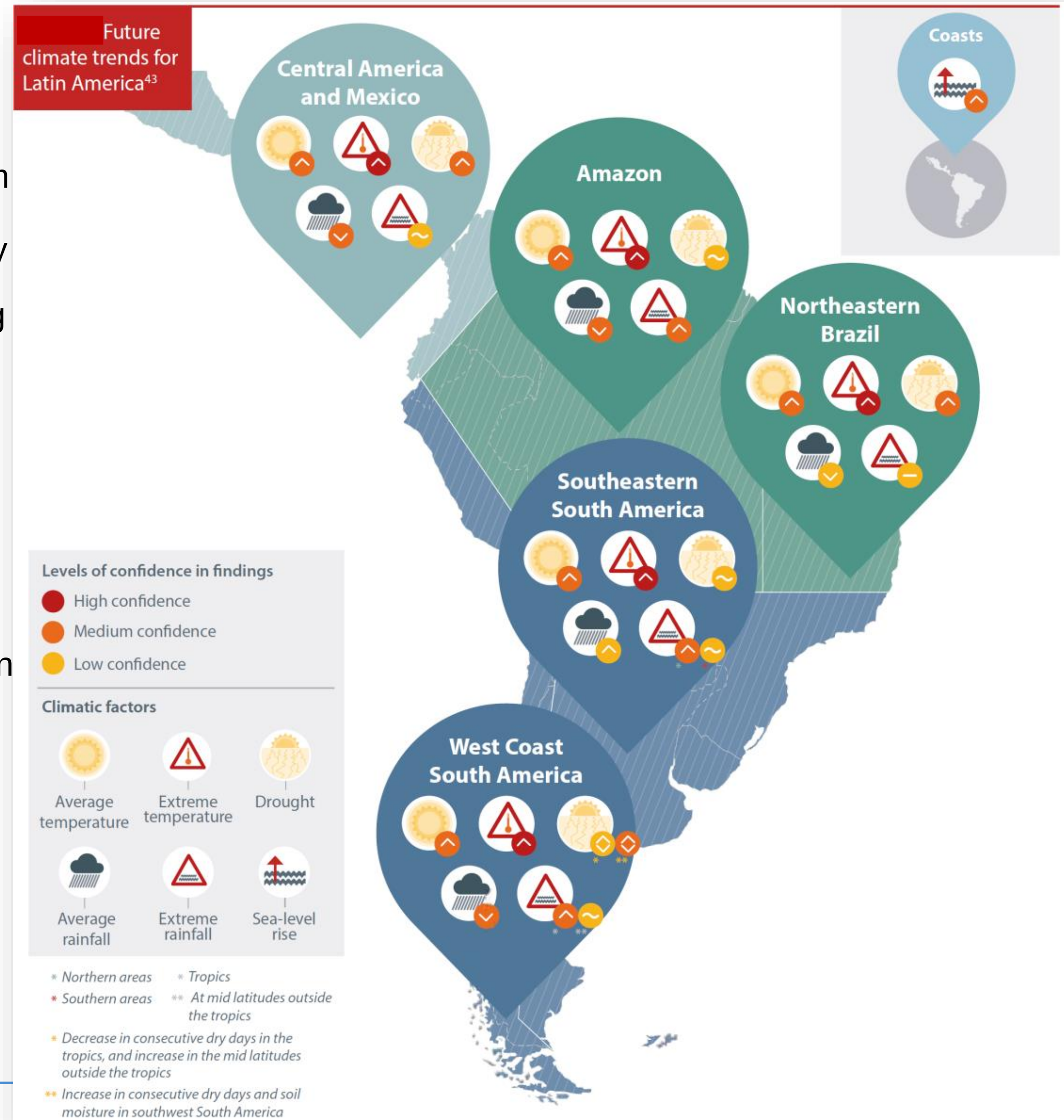
IPCC 5th Assessment Report (2013) Impacts in Latin America

- Potential impacts of climate change are likely to be substantial without further adaptation:
  - Climate projections suggest increases in temperature, and increases or decreases in precipitation for CA and SA by 2100 (medium confidence)
  - Changes in stream flow and water availability have been observed and projected to continue in the future in CA and SA, affecting already vulnerable regions (high confidence)
  - Changes in agricultural productivity with consequences for food security associated with climate change are expected to exhibit large spatial variability (medium confidence)
  - Renewable energy based on biomass has a potential impact on land use change and deforestation and could be affected by climate change (medium confidence)
  - Conversion of natural ecosystems is the main cause of biodiversity and ecosystem loss in the region and is a driver of anthropogenic climate change (high confidence).
  - Climate change is expected to increase the rates of species extinction (medium confidence)
  - Socioeconomic conditions have improved since AR4; however, there is still a high and persistent level of poverty in most countries, resulting in high vulnerability and increasing risk to climate variability and change (high confidence)



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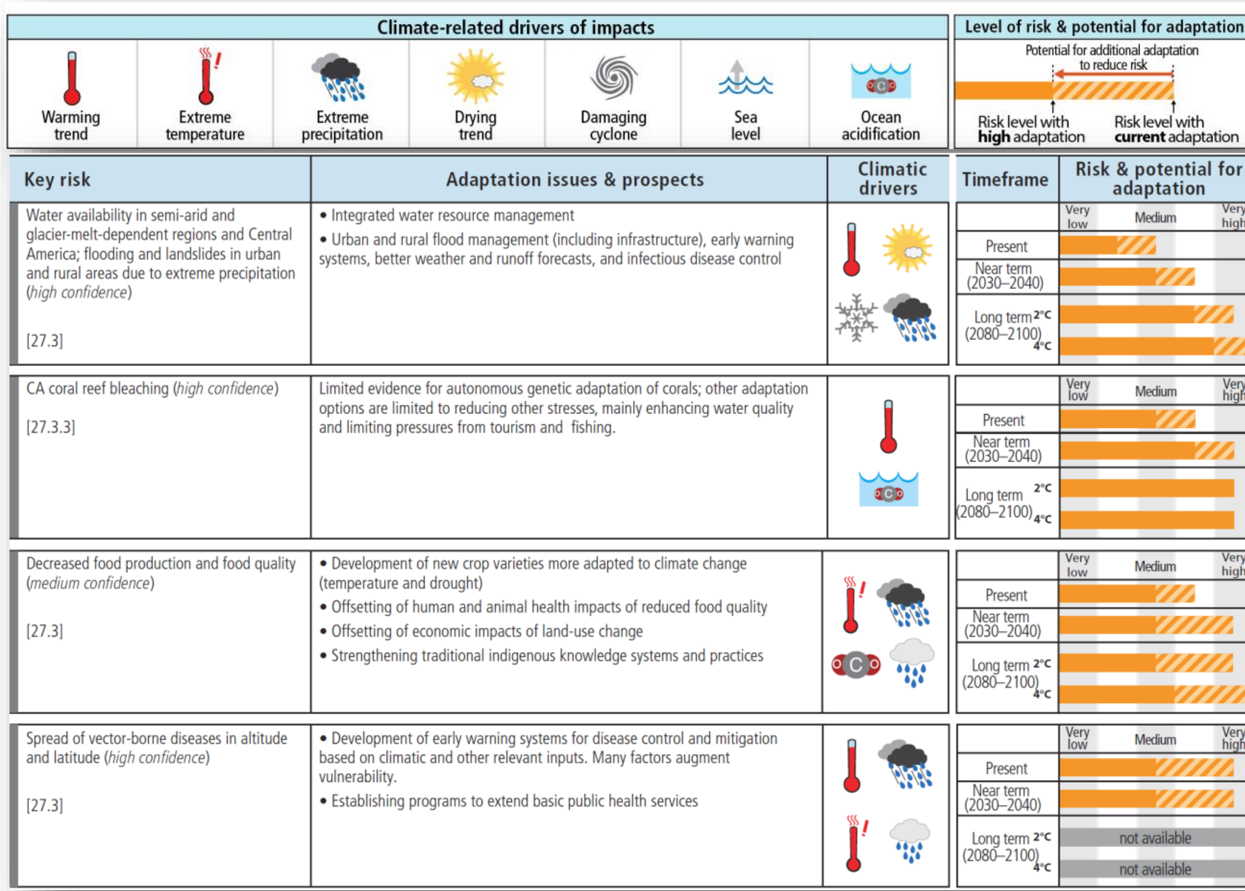
Key risks from climate change and the potential for risk reduction through mitigation and adaptation - AR5 Representation

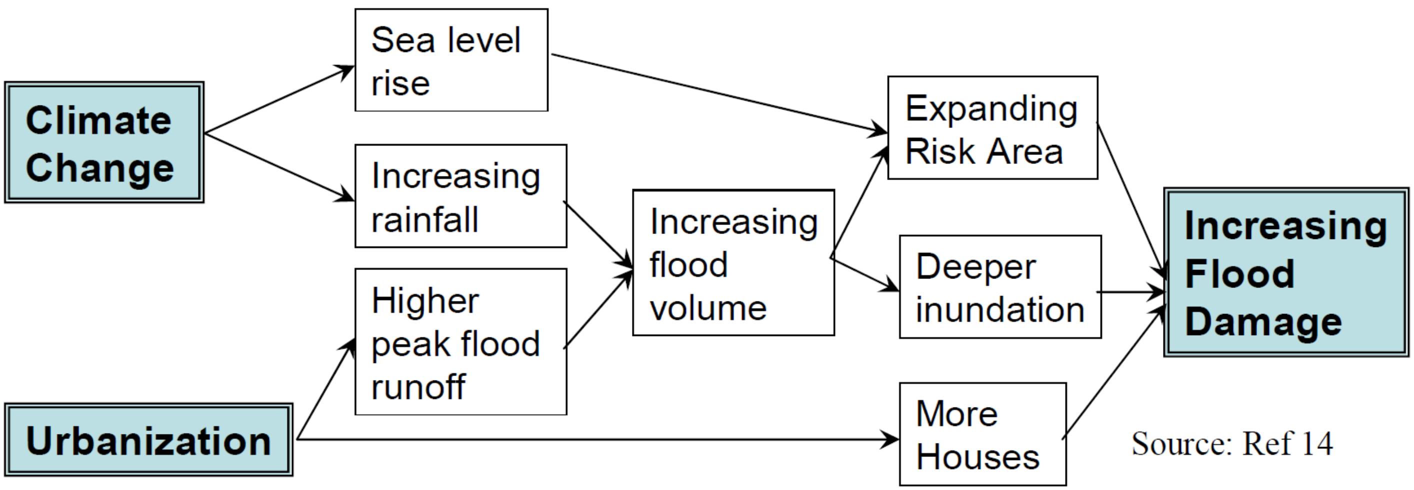
- Key risks from climate change and the potential for risk reduction through mitigation and adaptation in LAC
- Key risks are identified based on assessment of the literature and expert judgments, with supporting evaluation of evidence and agreement in the referenced chapter sections



Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Water availability in semi-arid and glacier-melt-dependent regions and Central America; flooding and landslides in urban and rural areas due to extreme precipitation (*high confidence*) [27.3]	• Integrated water resource management • Urban and rural flood management (including infrastructure), early warning systems, better weather and runoff forecasts, and infectious disease control		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
CA coral reef bleaching (*high confidence*) [27.3.3]	Limited evidence for autonomous genetic adaptation of corals; other adaptation options are limited to reducing other stresses, mainly enhancing water quality and limiting pressures from tourism and fishing.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Decreased food production and food quality (*medium confidence*) [27.3]	• Development of new crop varieties more adapted to climate change (temperature and drought) • Offsetting of human and animal health impacts of reduced food quality • Offsetting of economic impacts of land-use change • Strengthening traditional indigenous knowledge systems and practices		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Spread of vector-borne diseases in altitude and latitude (*high confidence*) [27.3]	• Development of early warning systems for disease control and mitigation based on climatic and other relevant inputs. Many factors augment vulnerability. • Establishing programs to extend basic public health services		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high; Long term 2°C: not available; 4°C: not available

https://www.ipcc.ch/report/ar5/wg2/

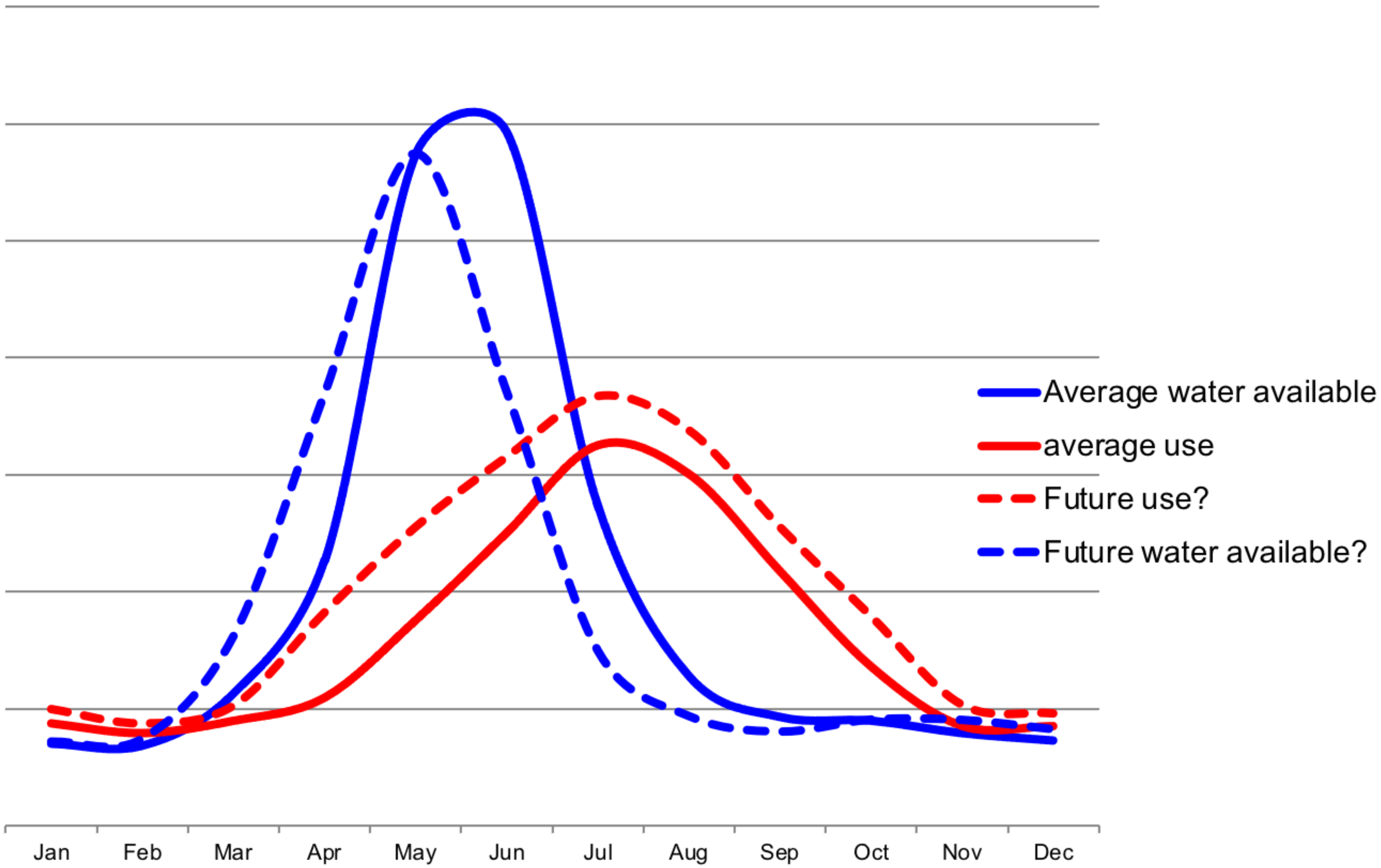
Example - Climate Change Impacts on Water Resources



Increasing flood damage due to climate change and urbanization

Ishiwatari, M. (2010b), Integrated Management of Urban Flooding for Climate Change Adaptation in Developing Countries, Climate Change Adaptation and Disaster Risk Reduction: Issues and Challenges Community, Environment and Disaster Risk Management, Vol. 4, Emerald Group Publishing Limited,, Bingley, pp.305–323

Why is Climate Change Important for Water Managers?



https://usu.instructure.com/courses/235322/files/41600259/download?wrap=1 Lecture20_MySQLClimateData.pptx

Outline

- Vulnerability and adaptation with respect to water resources
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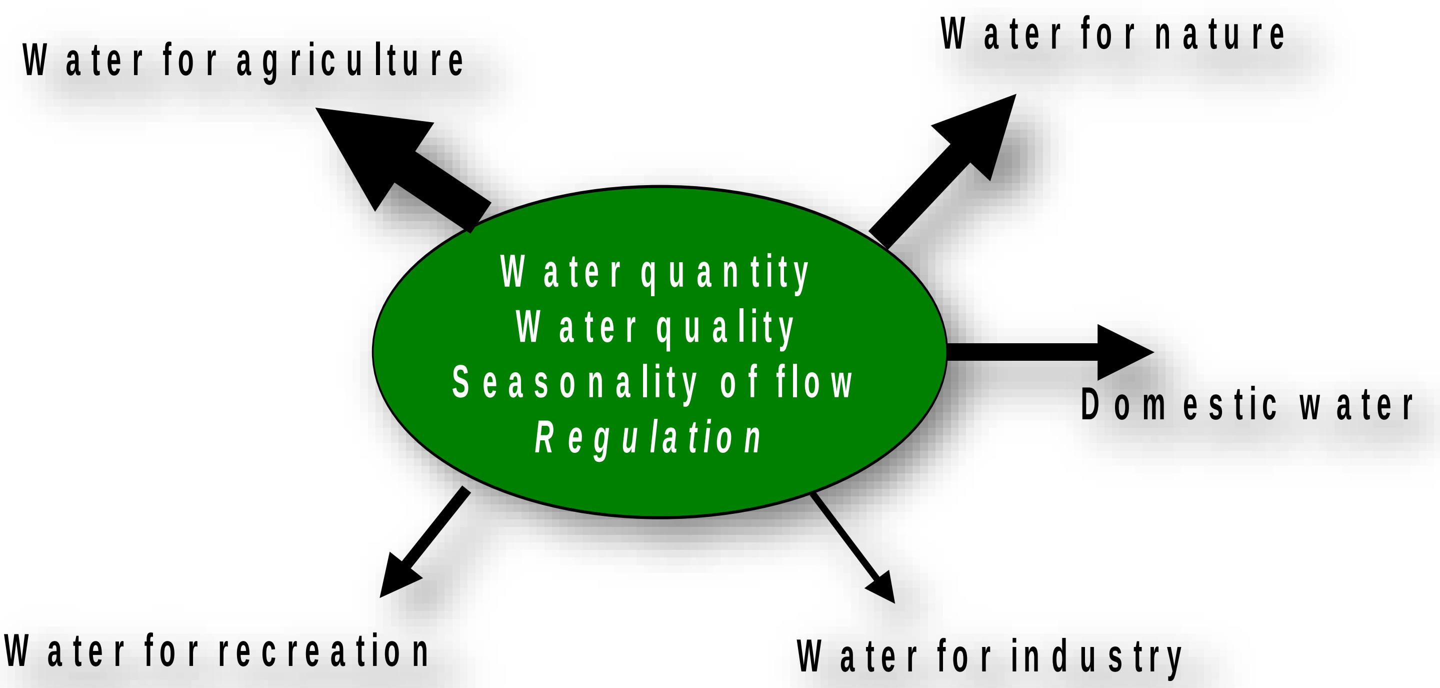
- WEAP model presentation

Integrated Water Resources Management as a V&A Framework

- Integrated water resource management (IWRM) is a systematic approach
  - Considers both demand and supply processes and actions
  - Stakeholders are closely involved in this approach
  - Facilitates adaptive management through continuous monitoring, review and improvement



Integrated Water Resources Management

Conventional water resources management

- Problems
  - Top-down
  - Fragmented decision-making processes
  - Little coordination between different sectors
  - Disproportionate emphasis on the supply side and technical aspects

Integrated Water Resources Management

- Integrates all forms and phases of the water cycle
- Integrates all water-related sectors
- Integrates a wide range of stakeholders
- Works on optimal water allocation to different water users through cooperation and coordination among users
- Demands integrated project formulation, the empowerment of partner country agencies, policy and institutional development and stakeholder involvement

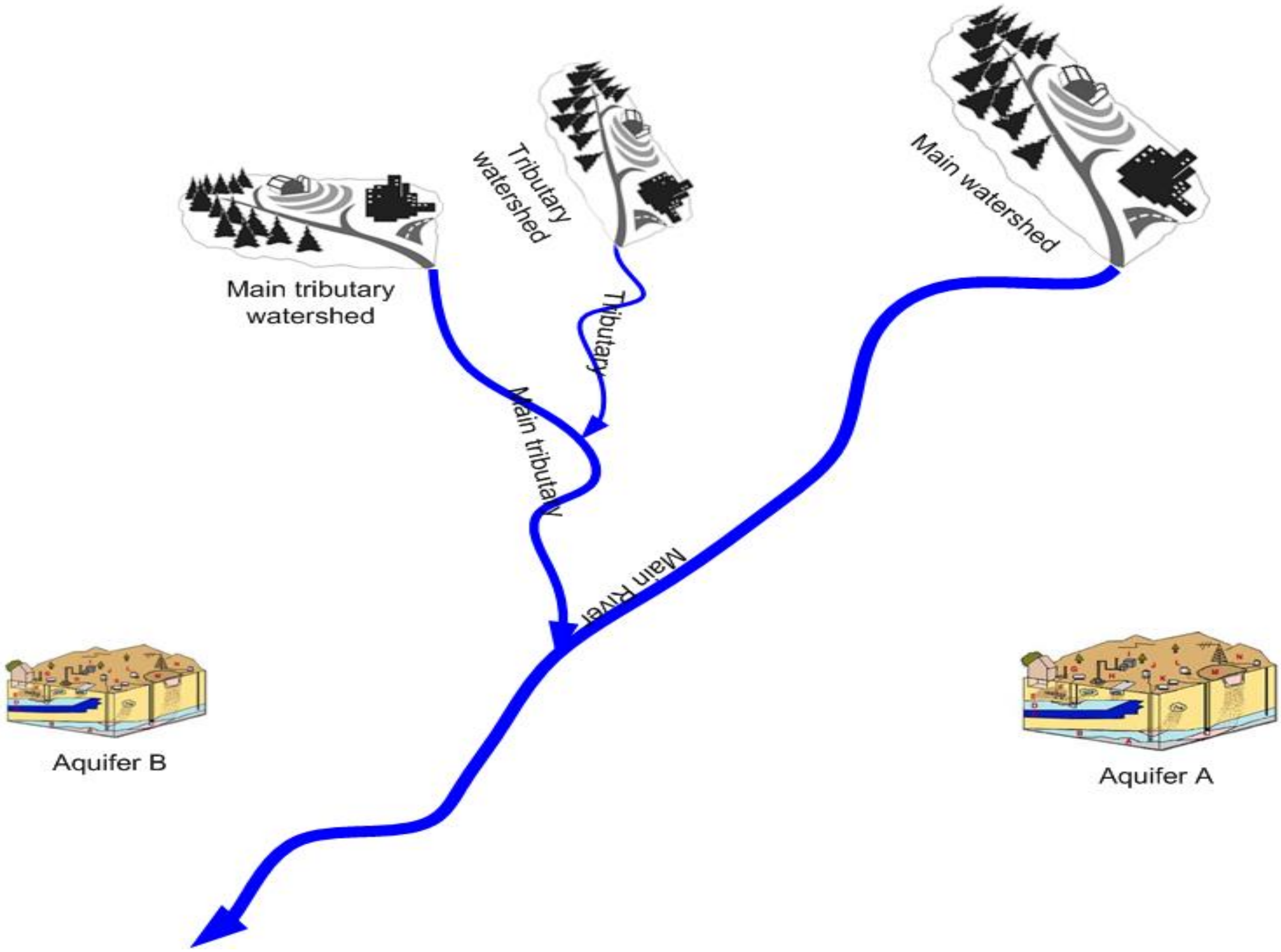
What Problems are We Trying to Address?

- An integrated framework can address
  - Water planning (daily, weekly, monthly, annual):
    - Local and regional
    - Municipal and industrial
    - Ecosystems
    - Reservoir storage
    - Competing demand
  - Operation of hydraulic infrastructures (daily and sub-daily):
    - Dam and reservoir operation
    - Canal operation and control
    - Hydropower optimization
    - Flood and floodplain inundation

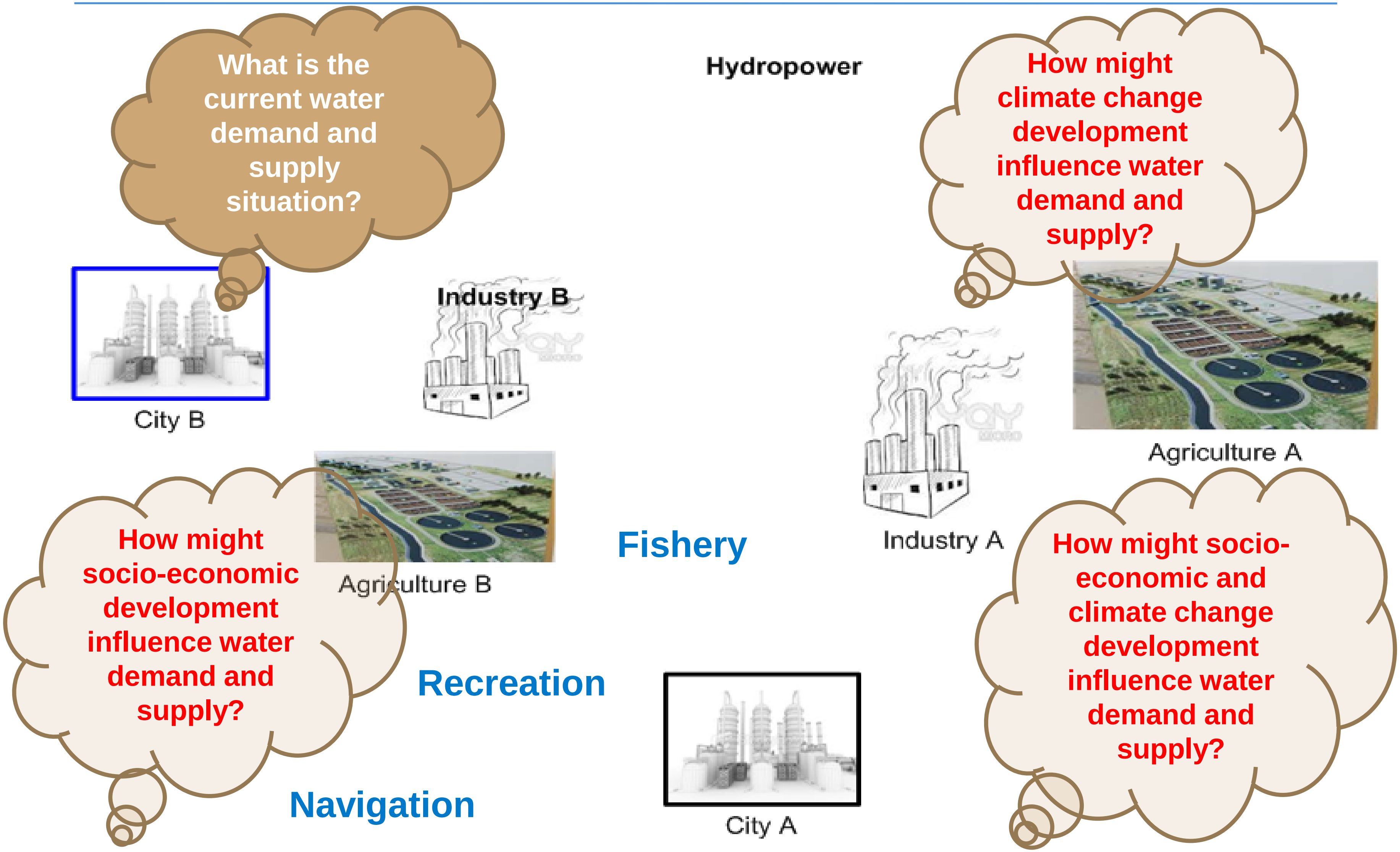
Outline

- ❑ Vulnerability and adaptation with respect to water resources
- ❑ Hydrologic implications of climate change for water resources
- ❑ Integrated Water Resources Management as an integrating framework
- ❑ Methods, tools and data requirements to assess vulnerability in water resources
- ❑ Adaptation responses by systems and sectors
- ❑ WEAP model presentation

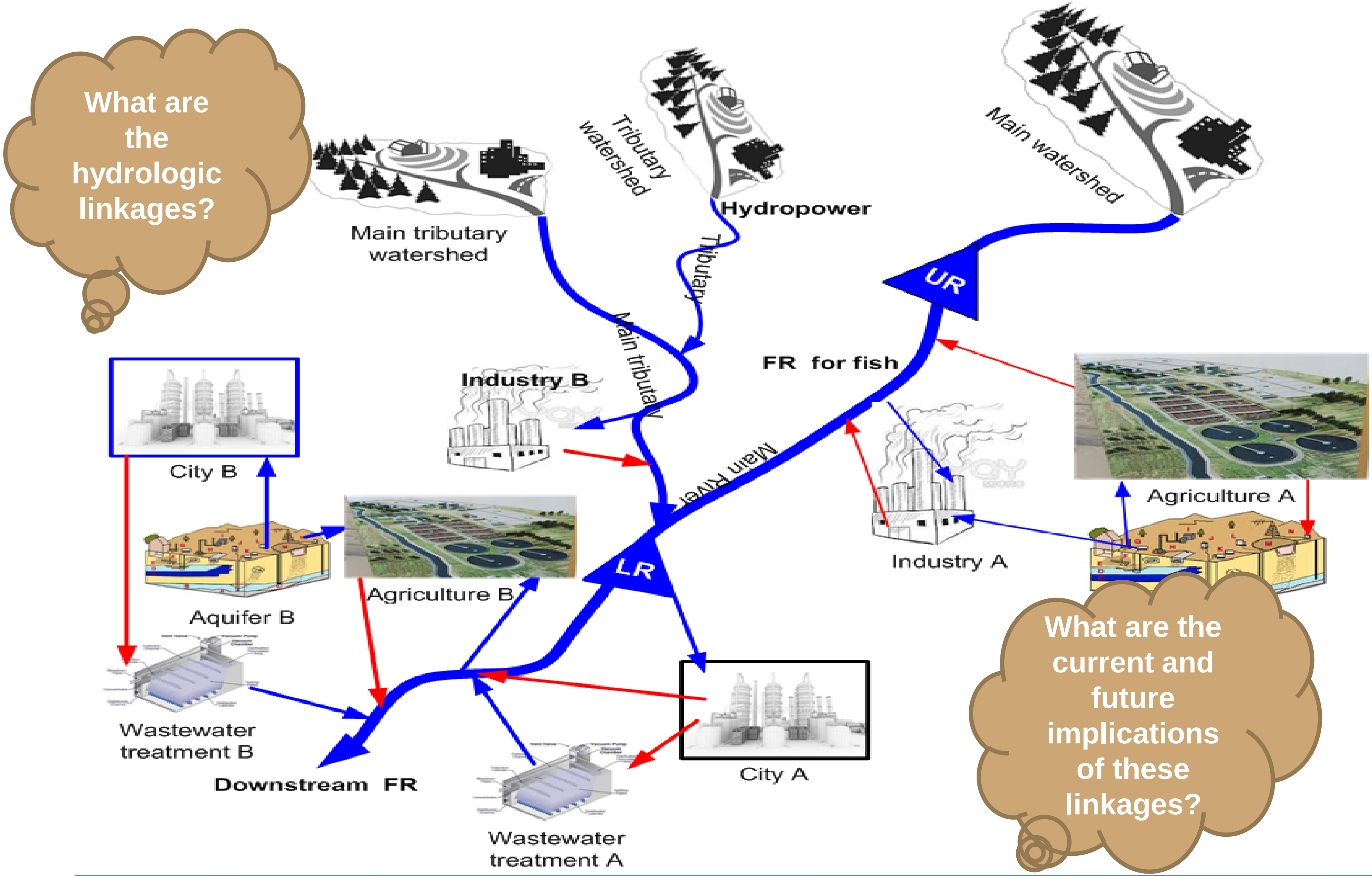
Rivers, watersheds, and aquifers



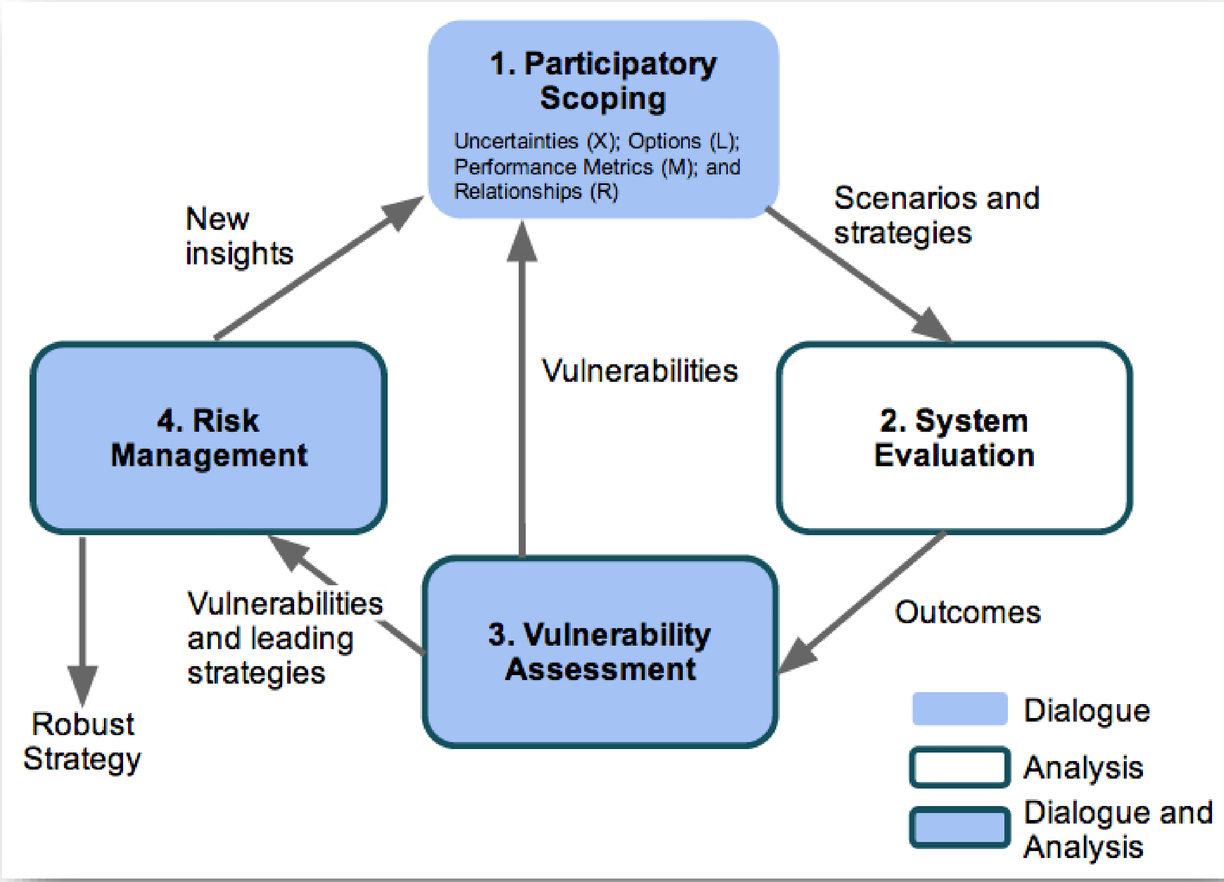
Water use Sectors Issues



Linking Supply with Demand Issues



Robust Decision Support as an IWRM Method



Source: Figure modified from Lempert et al. 2003

Which policy makers, planners, investors, implementers, water users, affected stakeholders, researchers, civil societies should be involved?

XLRM as an organizing tool for the analysis

Uncertainties (X)	**Decisions/options/levers (L)**
Climate conditions Historical conditions Extended drought Population growth	Develop new Infrastructure Expanded groundwater pumping capacity Impose regulatory constraints
Relationships or models (R)	**Performance metrics/goals (M)**
Surface/ groundwater hydrology model Water systems model	Surface water supply reliability Costs of obtaining supply

XLRM framework; Lempert, Popper, and Bankes, 2003

Which policy makers, planners, investors, implementers, water users, affected stakeholders, researchers, civil societies should be involved?

TOOLS IN WATER RESOURCE V&A STUDIES

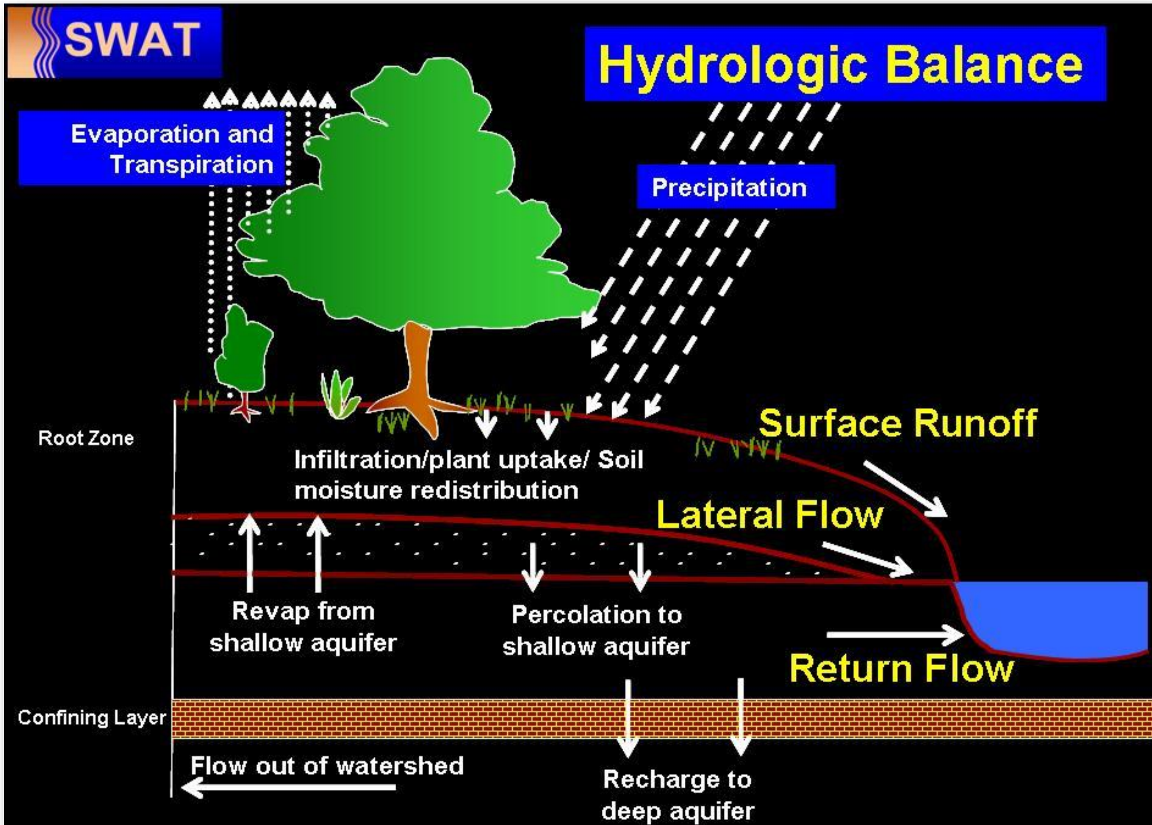
Tools in Water Resource V&A Studies – Biophysical Models

- Hydrologic models (physical processes):
  - Simulate river basin hydrologic processes
  - Examples – water balance, rainfall – run-off, lake simulation, stream water quality models
- Water resource system models (physical and management):
  - Simulate current and future supply/demand of system
  - Operating rules and policies
  - Environmental impacts
  - Hydroelectric production
  - Decision support systems (DSS) for policy interaction

Tools in Water Resource V&A Studies – Economic Models

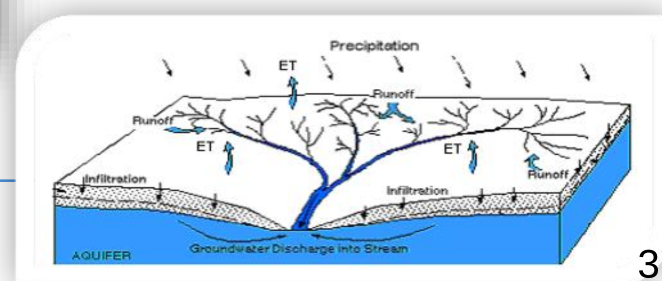
- Economic models:
  - Macroeconomic:
    - Multiple sectors of the economy
    - General equilibrium – all markets are in equilibrium
  - Sectoral level:
    - Single market or closely related markets (e.g., agriculture)
  - Farm level
    - Farm-level model (linear programming approach)
    - Micro-simulation

Hydrological Model – Supply Analysis



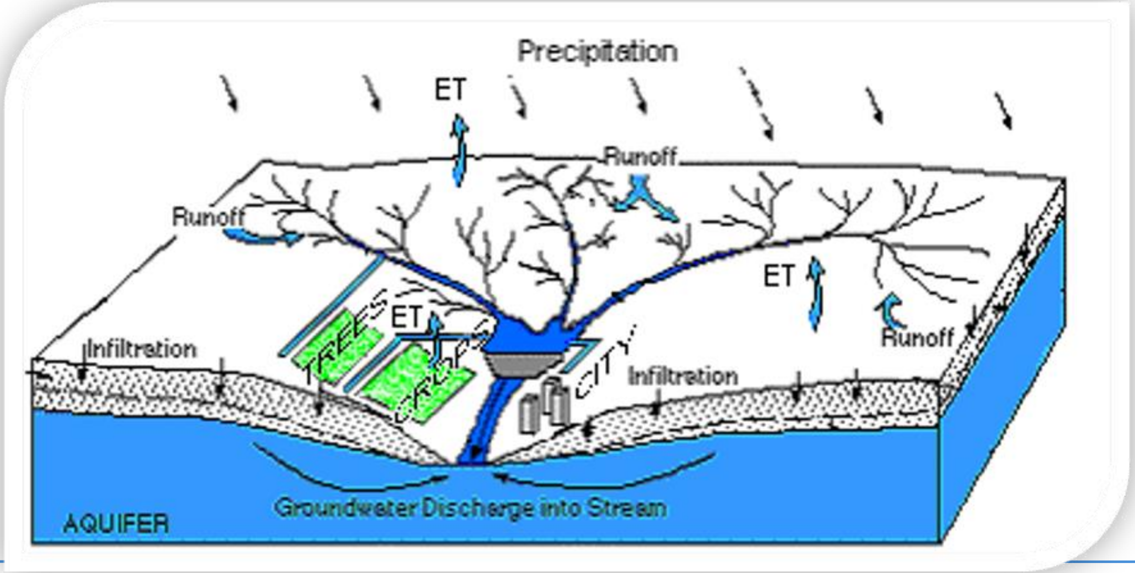
http://swat.tamu.edu/media/69296/SWAT-IO-Documentation-2012.pdf

- Critical questions:
  - How does rainfall on a catchment translate into flow in a river?
  - What pathways does water follow as it moves through a catchment?
  - How does movement along these pathways impact the magnitude, timing, duration, and frequency of river flows?



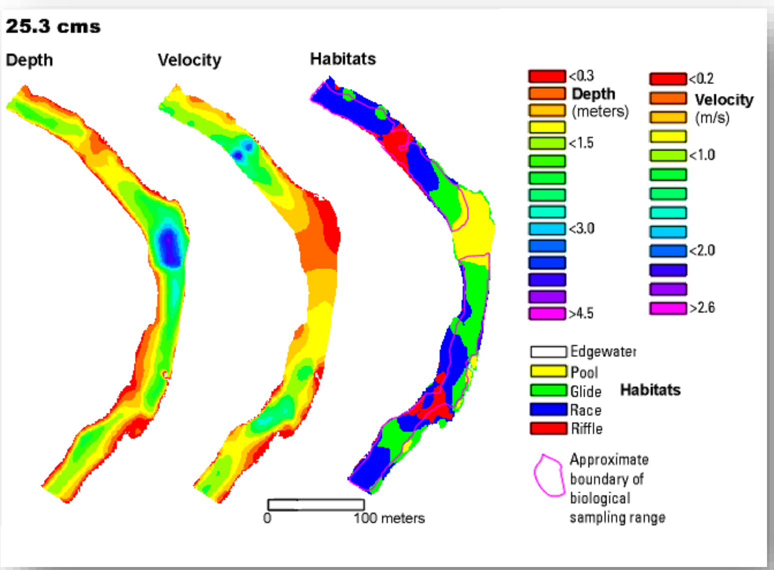
Planning Model – Demand Analysis

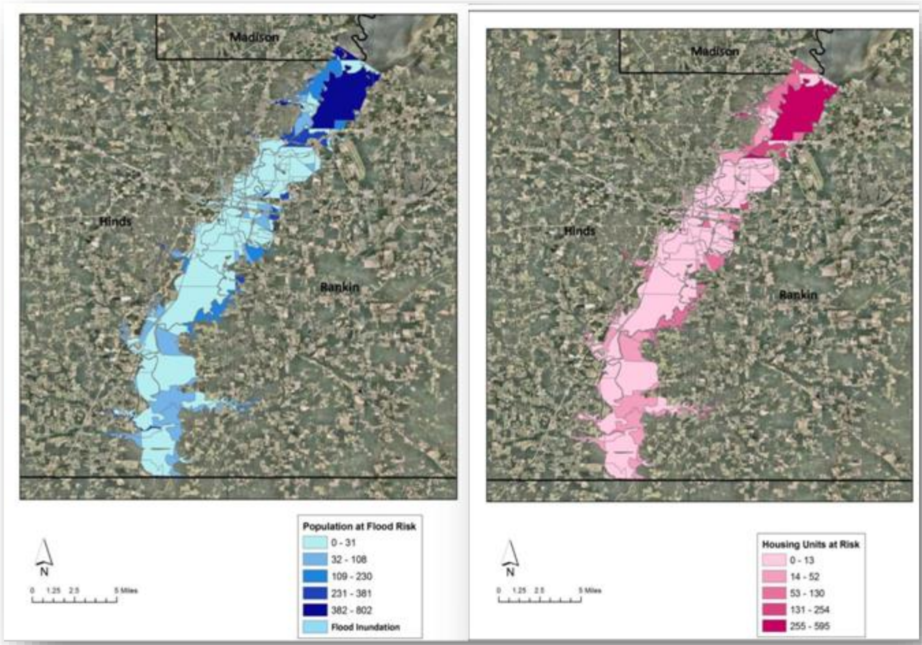
- Critical questions:
  - How should water be allocated to various uses in time of shortage?
  - How can these operations be constrained to protect the services provided by the river?
  - How should infrastructure in the system (e.g., dams, diversion works) be operated to achieve maximum benefit?
  - How will allocation, operations and operating constraints change if new management strategies are introduced into the system?



Hydraulic Model – Risk Analysis

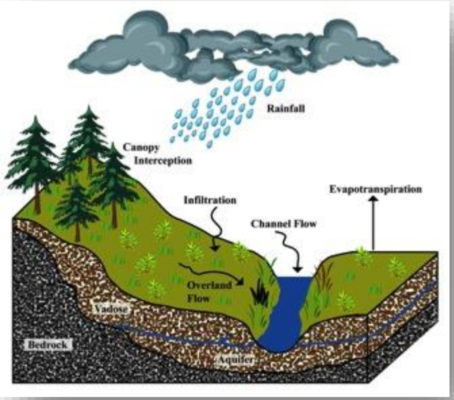
- Critical questions:
  - How fast and deep is the river flowing (flooding effects): identify risk factors and exposure to flooding that might affect the economical, social/infrastructural and environmental activities of a community
  - How do changes to flow and channel morphology impact sediment transport and services provided (fish habitats, recreation, etc)





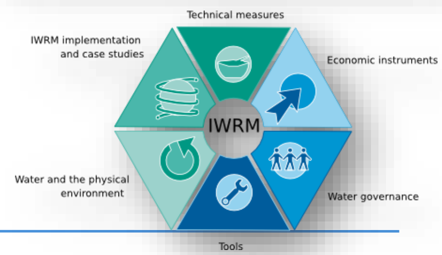
Tools to Use for the Assessment: Referenced Water Models

- Watershed hydrology
  - SWAT: http://www.brc.tamus.edu/swat/
  - WEAP21: http://www.weap21.org
  - HEC-HMS: https://www.hec.usace.army.mil/software/waterquality/hec-hms.aspx
  - MIKE+: https://www.mikepoweredbydhi.com/
  - HYMOS: https://hymos.software.informer.com/
- Hydraulic simulation
  - HEC-RAS: http://www.hec.usace.army.mil/software/hec-ras/
  - MIKE+: https://www.mikepoweredbydhi.com/
  - Delft3d: https://oss.deltares.nl/web/delft3d
- Water resource management models (planning and operation)
  - WEAP21: http://www.weap21.org
  - Aquarius: http://www.fs.fed.us/rm/value/aquariusdwnld.html
  - RIBASIM: https://www.deltares.nl/en/software/ribasim/
  - MIKE+: https://www.mikepoweredbydhi.com/
  - MODSIM: http://modsim.engr.colostate.edu/index.shtml
  - Riverware: http://cadswes.colorado.edu/creative-works/riverware
  - HEC-ResSim – reservoir operation modelling



http://hydrology.asu.edu/wiki/index.php/Models


http://i.ytimg.com/vi/BrLzvKASJXc/maxresdefault.jpg



http://www.iwrm-education.de/img/iwrm_overview2.png

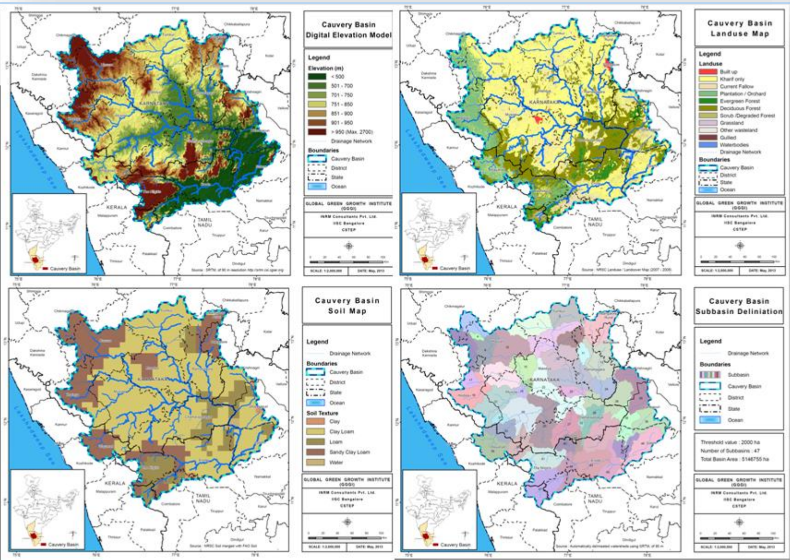
Current Focus – Planning and Hydrologic Implications of Climate Change

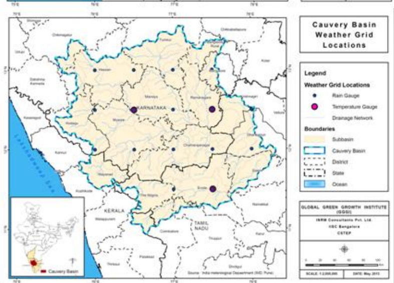
- Selected planning/hydrology models
  - Which can be deployed on PC
  - Extensive documentation
  - Ease of use
  - Public domain (or free to developing nations)
  - Technical support and user groups
- Selected models for workshop
  - SWAT (Soil Water Assessment Tool)
  - WEAP21 (Water Evaluation and Planning)

Physical Hydrology and Water Management Models - Supply

- SWAT (Soil Water Assessment Tool)
  - Can predict effect of management decisions on water, sediment, nutrient and pesticide yields on ungauged river basins.
  - Rainfall-runoff, river routing on a daily time step
  - Focuses on supply side of water balance
  - Features
    - Physically based
    - Distributed model
    - Continuous time model (long term yield model)
    - Uses readily available data (DEM, Landuse, Soil, Weather)
    - Used for long term impact studies (Climate Change)
    - Outputs have direct relevance for vulnerability assessment
      - Surface runoff, return flow, percolation, ET, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, water transfer

SWAT Data Requirement and Outputs

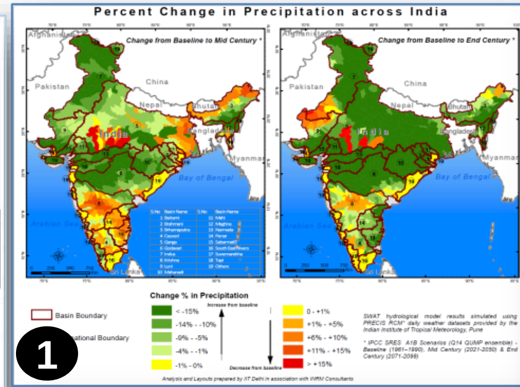


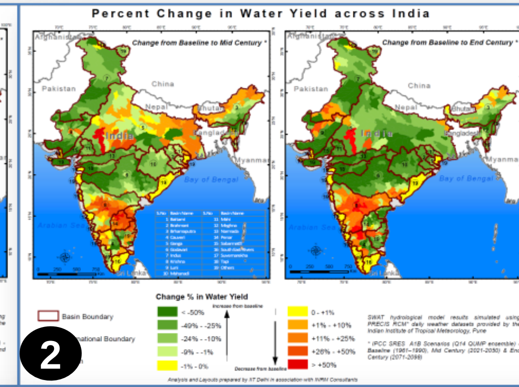


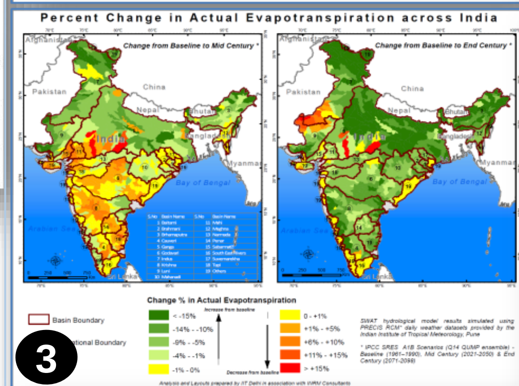
- **Data requirement**
  - DEM
  - Landuse
  - Soil
  - Subbasins
  - Weather Stations

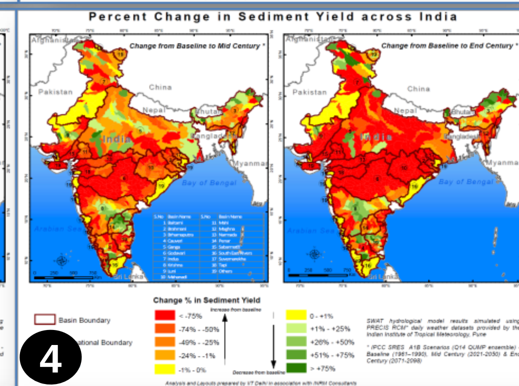
OUTPUTS

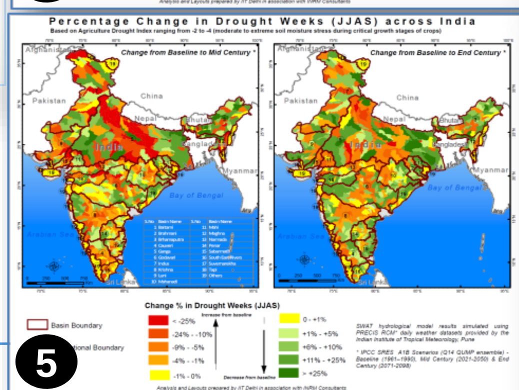
1. Change in precipitation
2. Change in Stream flow
3. Change in crop water demand
4. Change in sediment transport
5. Change in drought weeks
6. Change in Flood magnitude

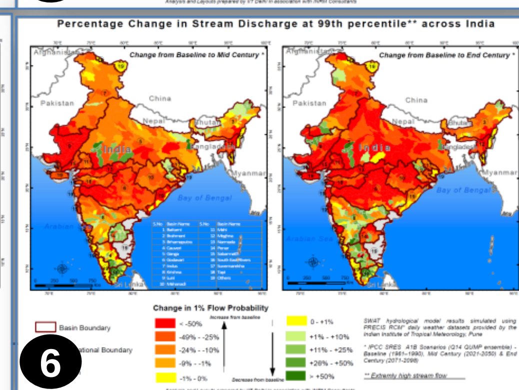






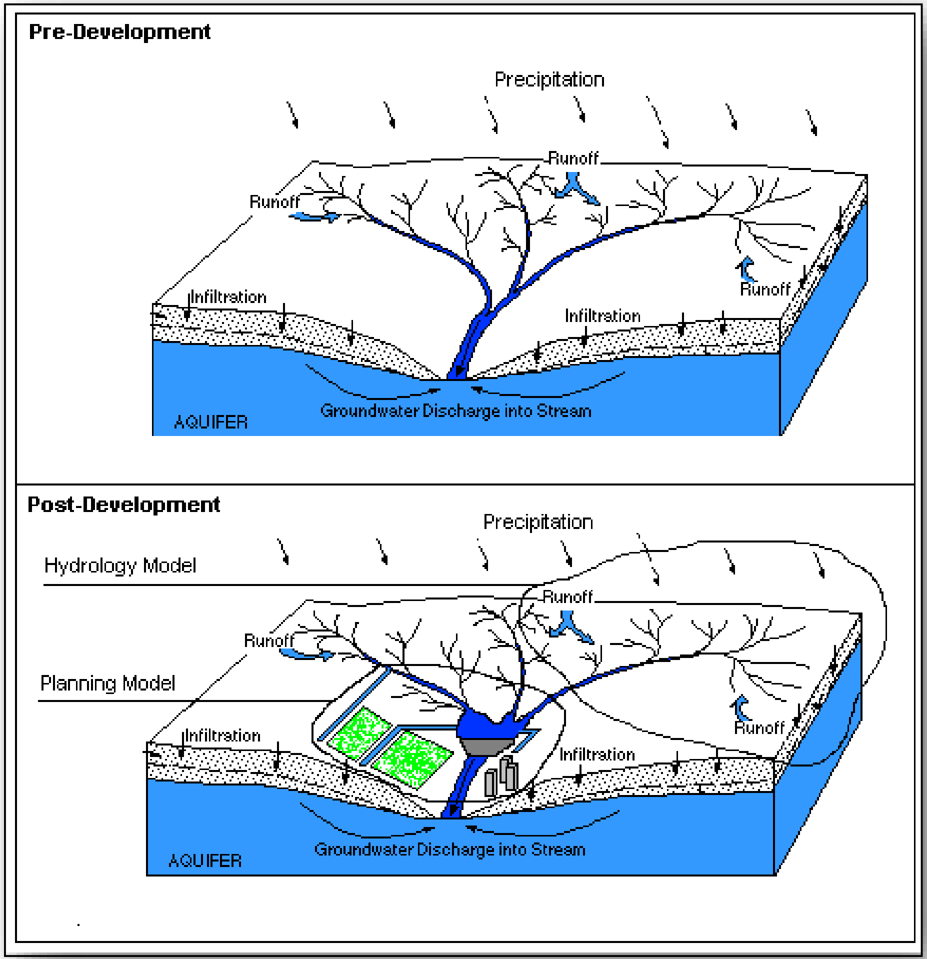






Physical Hydrology and Water Management Models - Planning

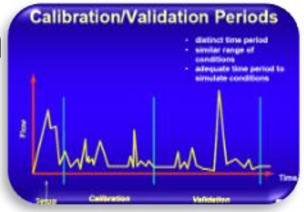
- WEAP21 [Developed by the Stockholm Environment Institute (SEI)]
- Advantages
  - Seamlessly integrates watershed hydrologic processes with water resources management
  - Can be climatically driven
  - Based on holistic approach of integrated water resources management (IWRM) – supply and demand



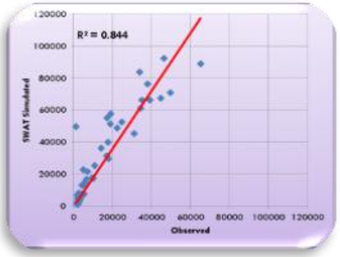
http://www.theclimatechangeclearinghouse.org/UtilPlanningAndMgt/IWRM/default.aspx

Calibration and Validation for Water Resource Models

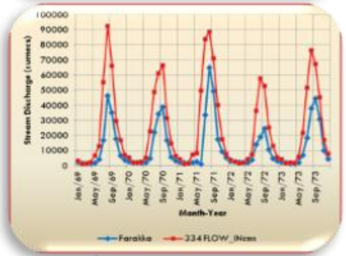
- ❑ Model calibration:
  - Process of estimating model parameters by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions.



- ❑ Model validation :
  - Comparison of model predictions (output) with an independent dataset using parameters determined during the calibration process.



- ❑ Model evaluation criteria:
  - Flows along mainstream and tributaries,
  - Reservoir storage and release
  - Water diversions from other basins
  - Agricultural water demand and delivery
  - Municipal and industrial water demands and deliveries
  - Groundwater storage trends and levels.
  - Water quality constituents (temperature, DO, BOD, turbidity, etc.)



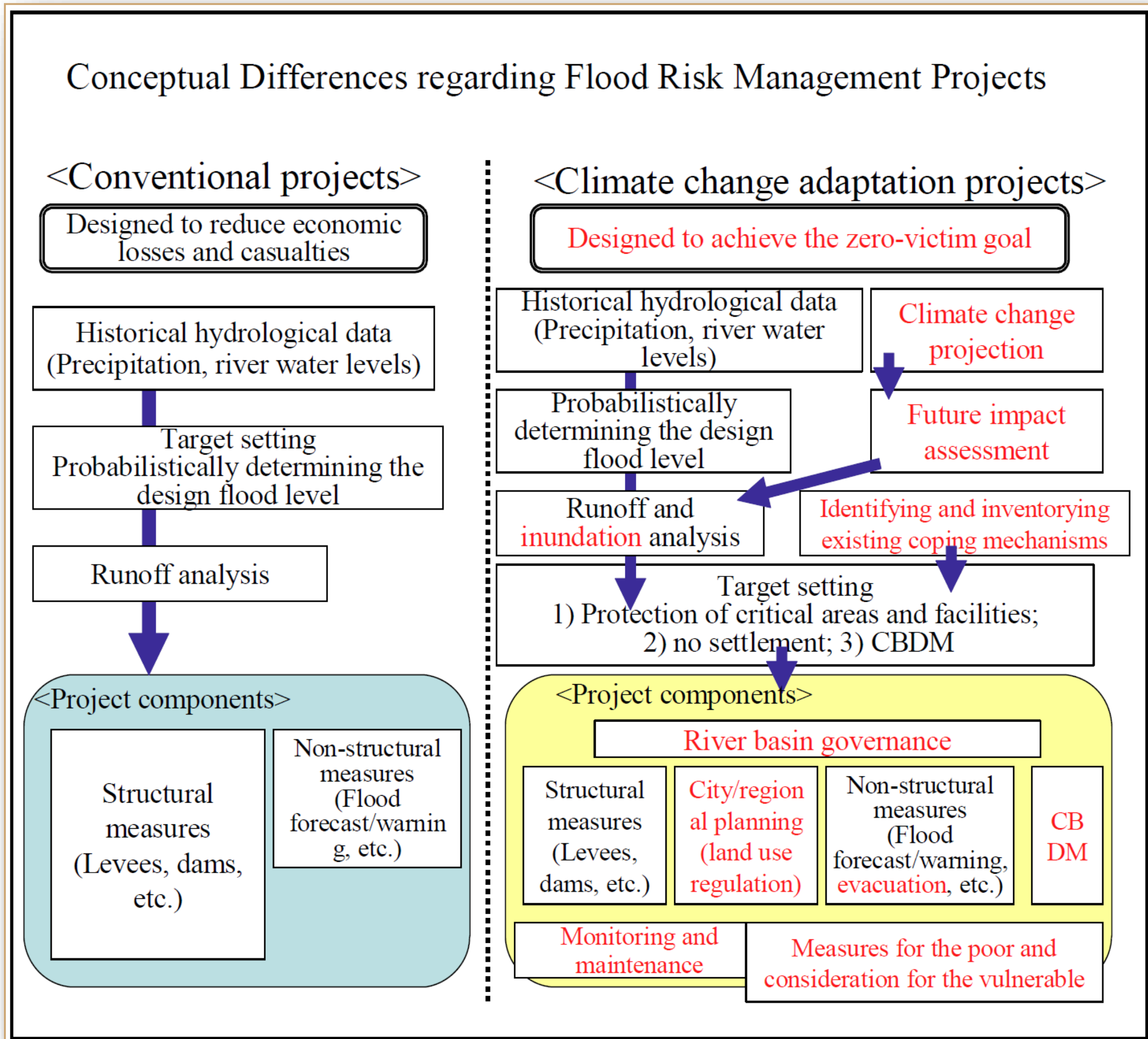
Outline

- ❑ Vulnerability and adaptation with respect to water resources
- ❑ Hydrologic implications of climate change for water resources
- ❑ Integrated Water Resources Management as an integrating framework
- ❑ Methods, tools and data requirements to assess vulnerability in water resources
- ❑ Adaptation responses by systems and sectors
- ❑ WEAP model presentation

Climate Change Adaptation Options – Water Sector

- Non-Structural or “soft interventions”
  - Deal with the development of institutions and human resources aiming to build capacity to address the climate change impacts
  - Examples:
    - Flood warning systems and emergency preparedness
    - Rainwater harvesting
    - Irrigation water use efficiency
    - Ground water legislation
- Structural or “hard interventions”
  - Include infrastructural elements such as dams, flood walls and dikes
  - Most significant form of intervention since controlling and managing water has been the priority for most part of developmental history
  - Mainly, supply-side interventions
    - Can be intended for improving access, distribution, and application
  - Challenging because of maintenance and benefit sharing
  - Financial situation of the nation will influence the choices and balances between “soft” and “hard” interventions

Climate Change Adaptation – Water Sector - Example



- Effective combination of structural with non-structural measures, including community-based disaster management
- Conventional measures are increasingly found to be inadequate and less open to modification
- Integrating Water resources management, water environments, sediment, and coasts are better options
    - Critical Area – Structural
    - Other areas - No settlement
    - Unavoidable inundation - Community-based disaster management and crisis management:

http://www.jica.go.jp/english/our_work/thematic_issues/water/pdf/guideline_02.pdf

Examples of Adaptation – Water Supply

- Construction/modification of physical **infrastructure**: (Hard adaptation)
  - Canal linings
  - Closed conduits instead of open channels
  - Integrating separate reservoirs into a single system
  - Reservoirs/hydroplants/delivery systems
  - Raising dam wall height
  - Increasing canal size
  - Removing sediment from reservoirs for more storage
  - Inter-basin water transfers
- Adaptive **management** of existing water supply systems: (Soft adaptation)
  - Change operating rules
  - Use conjunctive surface/groundwater supply
  - Physically integrate reservoir operation system
  - Co-ordinate supply/demand

Examples of Adaptation – Water Demand

- Policy, conservation, efficiency, and technology:
  - Domestic:
    - Municipal and in-home re-use
    - Leak repair
    - Rainwater collection for non-potable uses
    - Low flow appliances
    - Dual supply systems (potable and non-potable)
    - Conservation programs
  - Agricultural:
    - Irrigation timing and efficiency
    - Lining of canals, closed conduits
    - Drainage re-use, use of wastewater effluent
    - High value/low water use crops
    - Drip, micro-spray, low-energy, precision application irrigation systems
    - Salt-tolerant crops that can use drain water

Examples of Adaptation – Water Demand (continued)

- Policy, conservation, efficiency, and technology:
  - Industrial:
    - Water re-use and recycling
    - Closed cycle and/or air cooling
    - More efficient hydropower turbines
    - Cooling ponds, wet towers and dry towers
  - Energy (hydropower):
    - Reservoir re-operation
    - Cogeneration (beneficial use of waste heat)
    - Additional reservoirs and hydropower stations
    - Low head run of the river hydropower
    - Market/price-driven transfers to other activities
    - Using water price to shift water use between sectors

Outline

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- ❑ WEAP model presentation

WEAP Model Presentation

WEAP and Planning

- Provides a common framework for transparently organizing water resource data at any scale desired
  - Local watershed, regional or transboundary river basin
- Scenarios can be easily developed to explore possible water futures
- Implications of various policies can be evaluated

Uses of WEAP

- Policy Research
  - Alternative Allocations
  - Climate Change
  - Land Use Change
  - Infrastructure Planning
- Capacity Building
- Negotiation
- Stakeholder Engagement

WEAP - Can Do

- High level planning at local and regional scales
- Demand management
- Water allocation
- Infrastructure evaluation

WEAP - Cannot Do

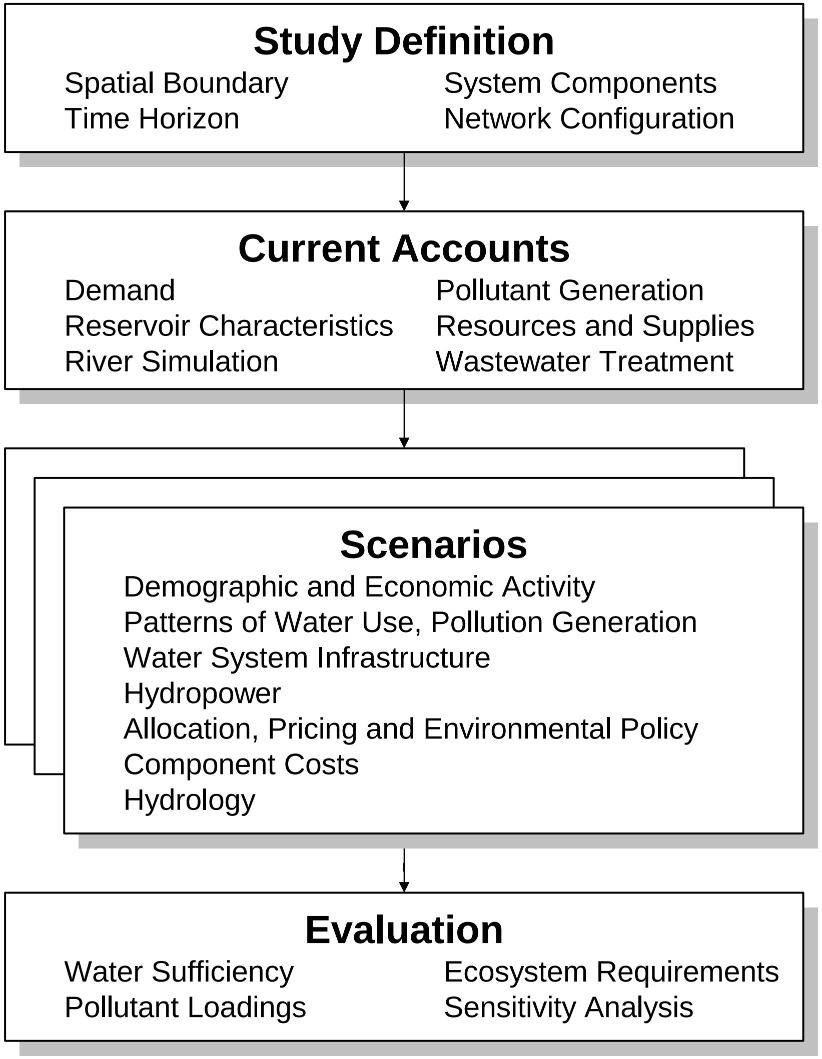
- Sub-daily operations
- Optimization of supply and demand (e.g., cost minimizations or social welfare maximization)

WEAP Advantages

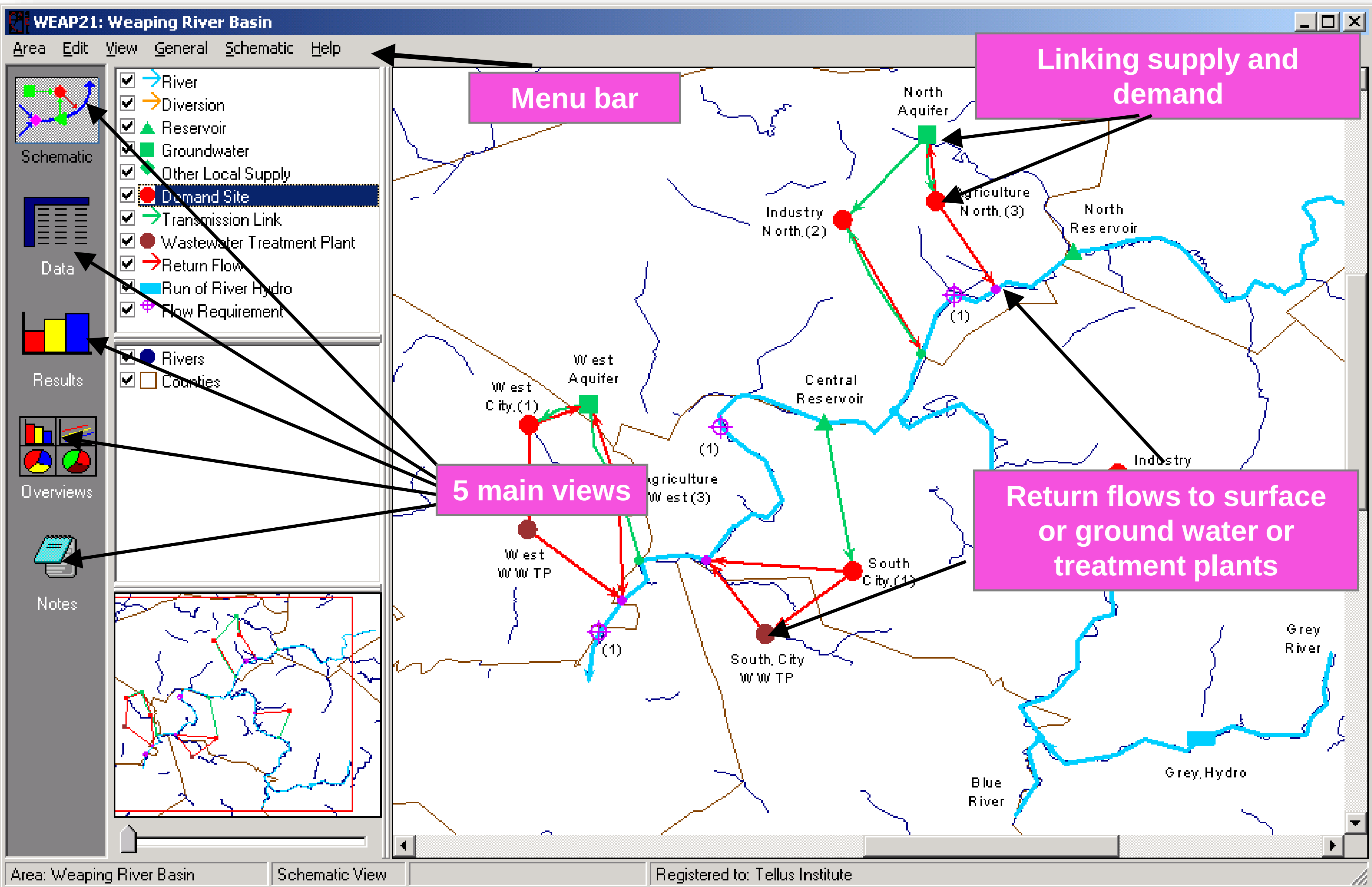
- Graphical interface facilitates learning, data input and scenario development
- Water allocation problem is solved based on demand priorities and supply preferences
- Input can be from files or user specified functions
- Multiple scenarios can be run and displayed graphically at one time
- Use of notes allows for internal documentation of scenarios
- Hydrology may be climate driven or from gage data, facilitating the exploration of alternative future climate projections
- Several internal modules to choose from (e.g., hydropower generation, financial analysis, water quality)
- Time steps are as short as one day or longer
- Dynamically links to other models

WEAP as a V&A Mod and Steps

- WEAP for Vulnerability
  - Alternative **baseline** scenarios can examine vulnerability of water supplies to different demographic, technological & climatological/hydrological futures
- WEAP for Adaptation
  - Alternative **policy** scenarios can explore demand and supply management options for adapting to future vulnerability.
  - Implications for the multiple and competing demands on water systems.
  - Implications of policies can be evaluated (ability to meet water needs, hydropower availability, pollution loadings, costs, etc.)

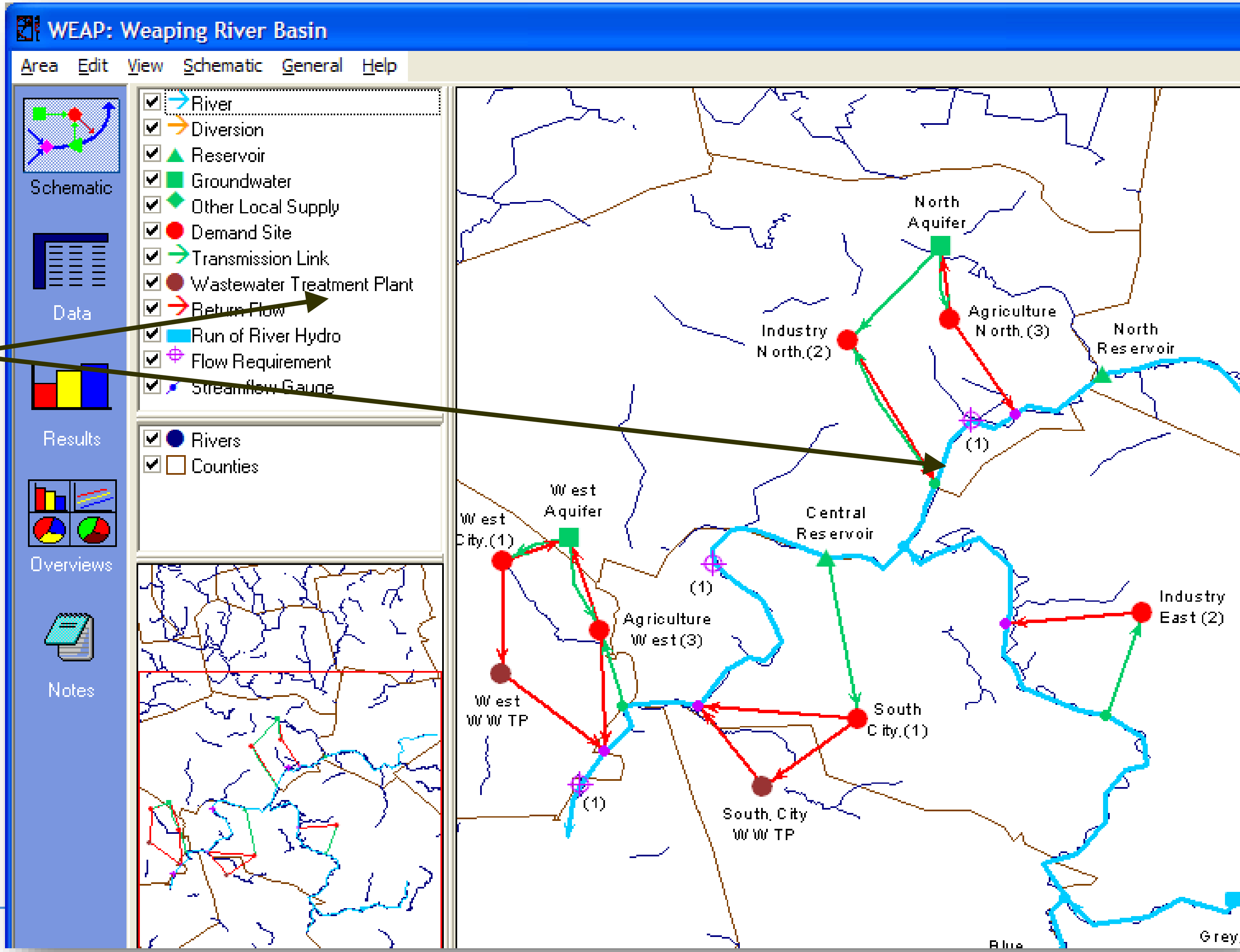


WEAP Graphical User Interface



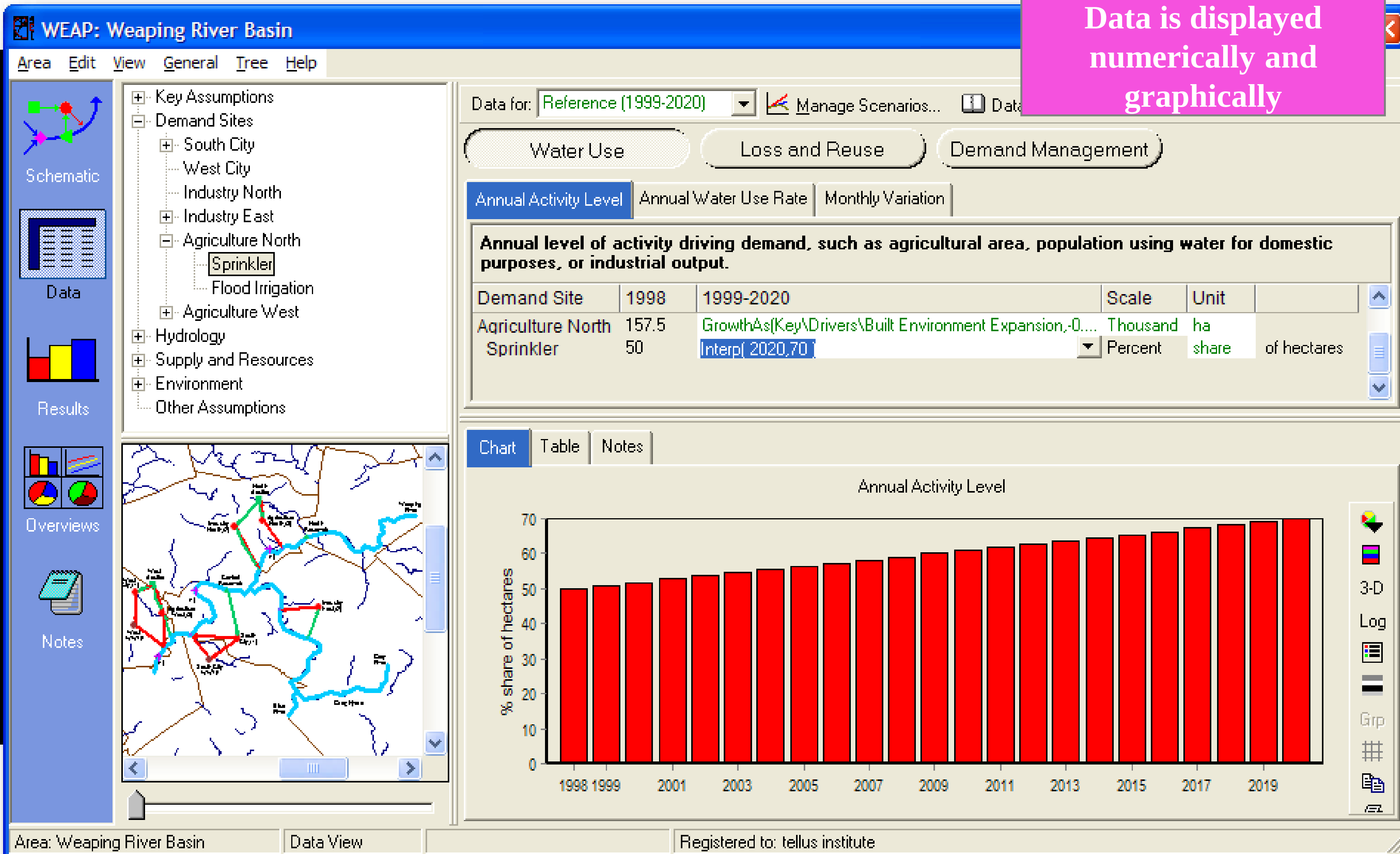
WEAP Schematic View

Click and drag to create a new demand

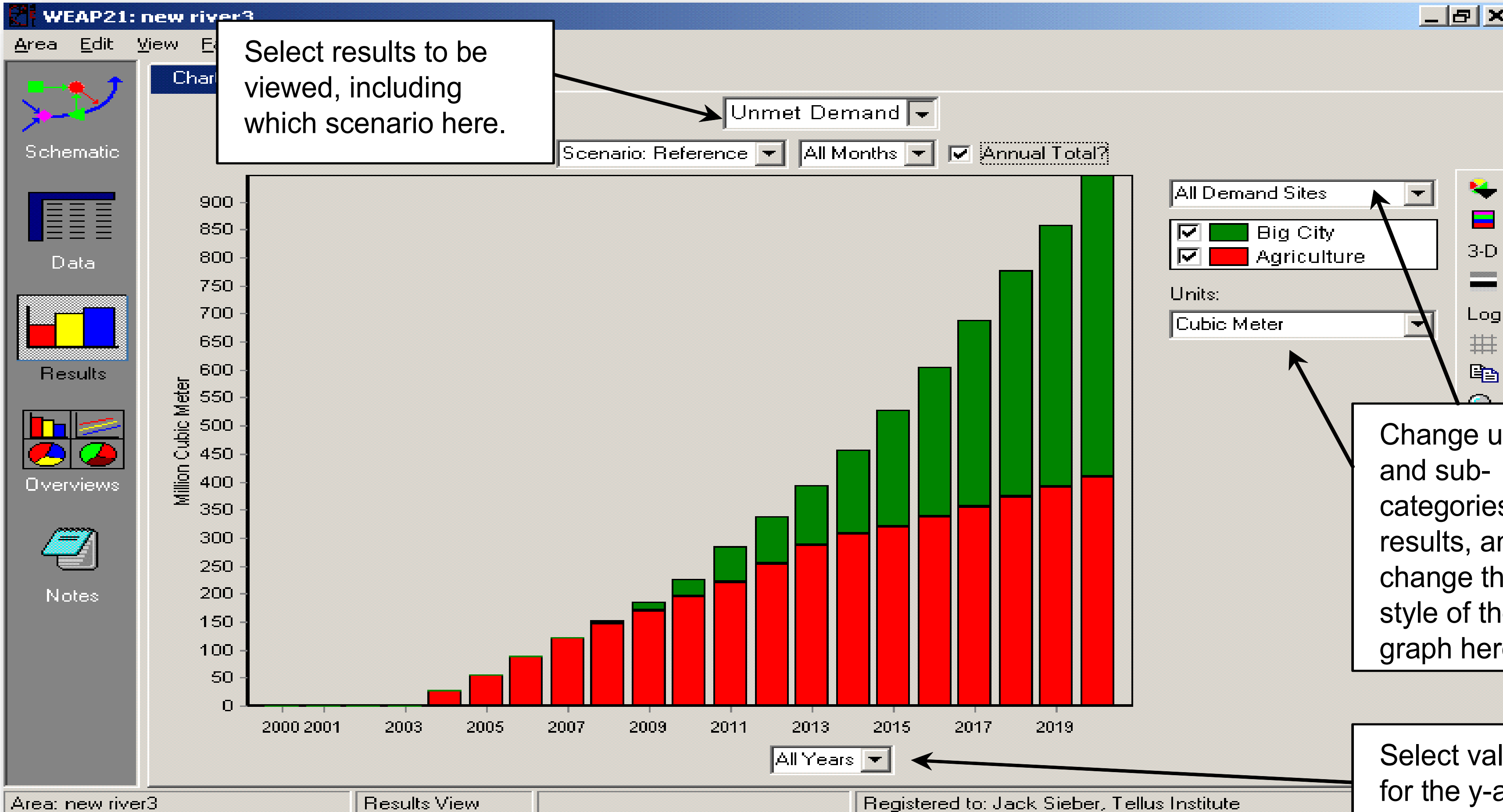


WEAP Data View

Data is displayed numerically and graphically



WEAP Results View

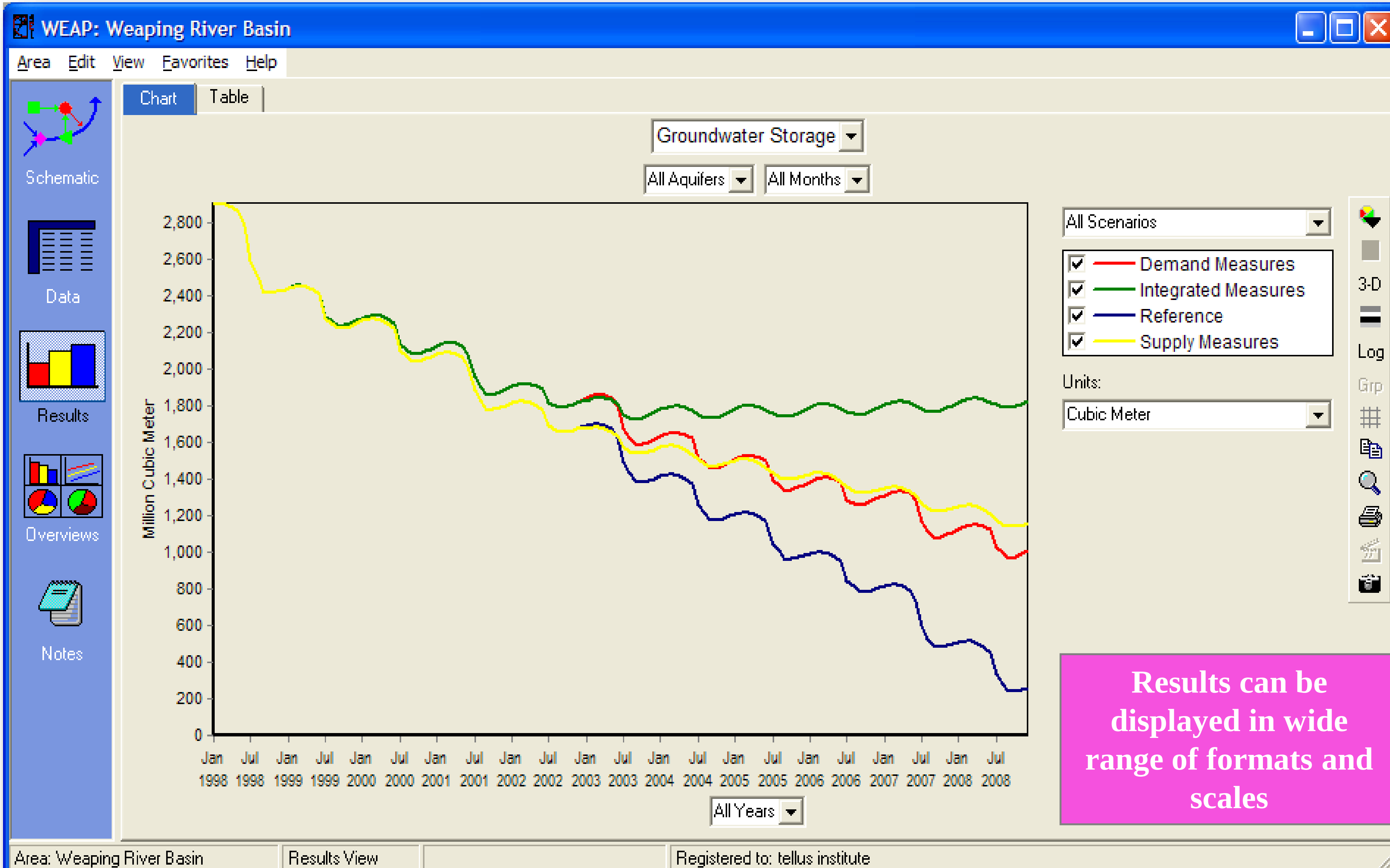


Select results to be viewed, including which scenario here.

Change units and sub-categories of results, and change the style of the graph here.

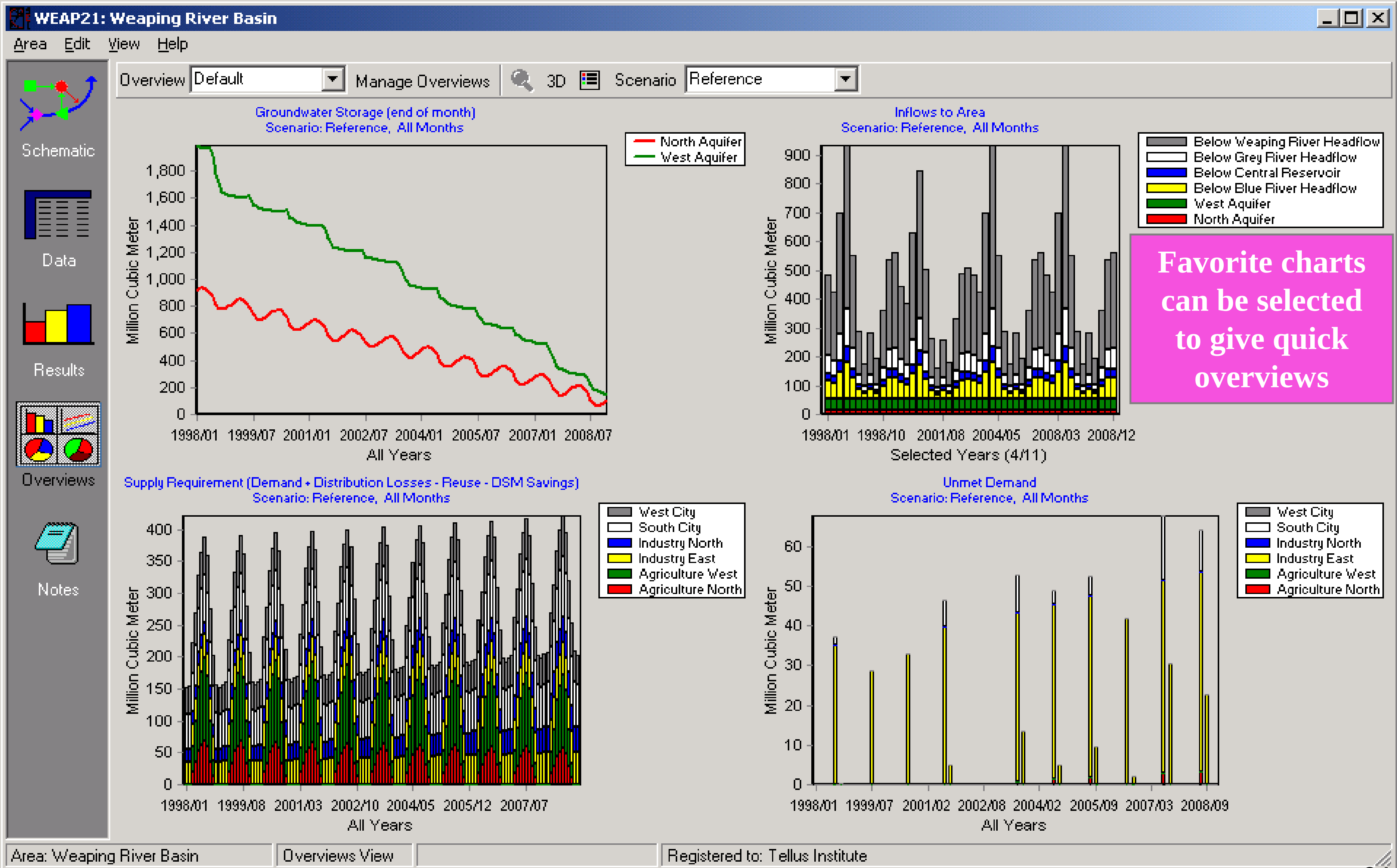
Select values for the y-axis here.

WEAP Results View (continued)



Results can be displayed in wide range of formats and scales

WEAP Overviews View

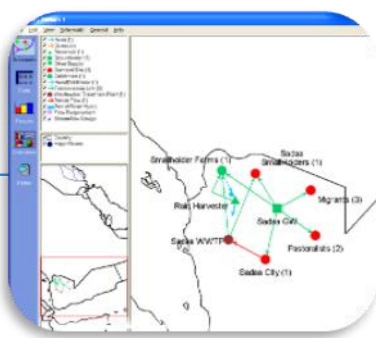


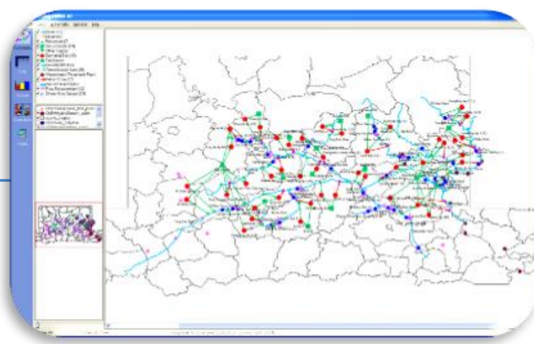
Favorite charts can be selected to give quick overviews

WEAP Data Requirements

- ❑ WEAP allows the user to determine the level of complexity desired
  - According to the questions that need to be addressed
  - The availability of data
- ❑ Data Requirements: Supply
  - User-prescribed supply (river flow given as fixed time series)
    - Time series data of river flows
    - River network (connectivity)
  - Alternative supply via physical hydrology (let the watershed generate river flow)
    - Watershed attributes
      - Area, land cover . . .
    - Climate
      - Precipitation, temperature, wind speed, and relative humidity

SIMPLE

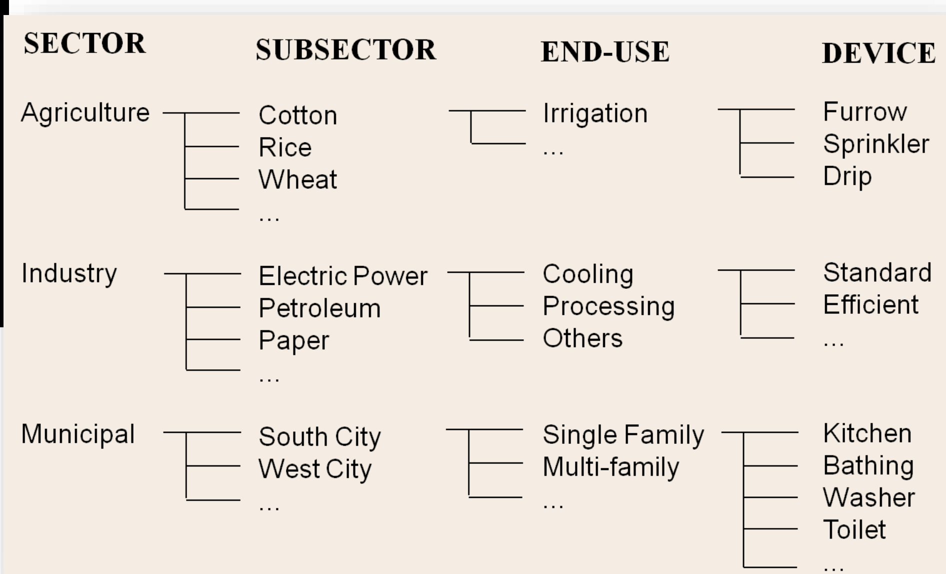


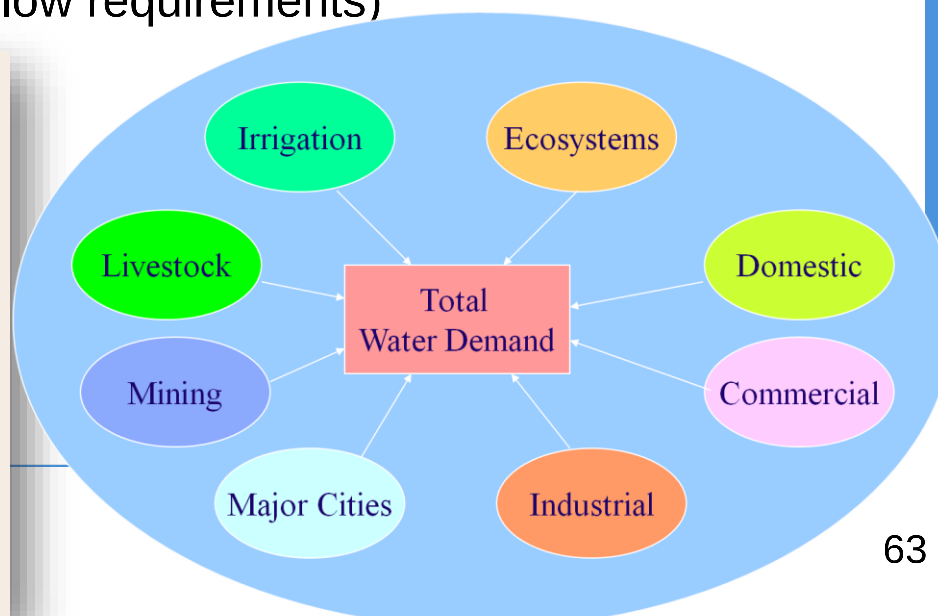


COMPLEX

WEAP Data Requirements (continued)

- Data Requirements: Demand
  - Water demand data: multi-sectoral
    - Municipal and industrial demand
      - Aggregated by sector (manufacturing, tourism, etc.)
      - Disaggregated by population (e.g., use/capita, use/socioeconomic group)
  - Agricultural demands
    - Aggregated by area (# hectares, annual water-use/hectare)
    - Disaggregated by crop water requirements
  - Ecosystem demands (in-stream flow requirements)

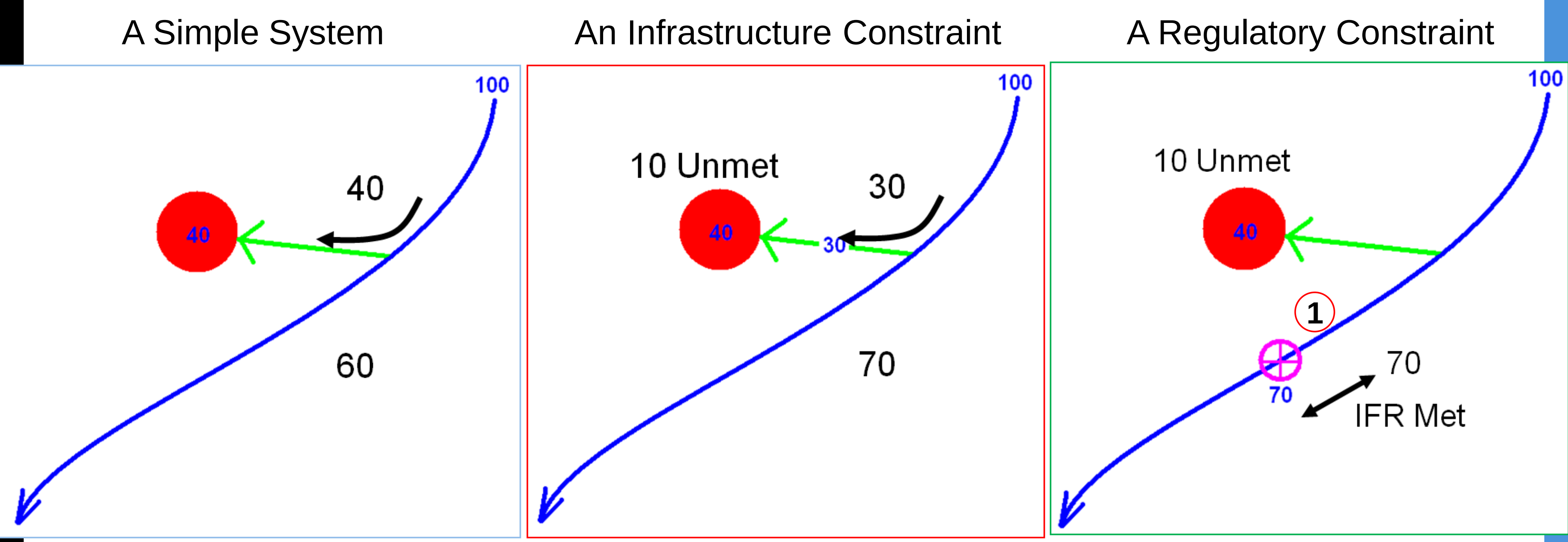




WEAP System Requirements and Availability

- System Requirements
  - Windows 95 or later
  - 32 MB of RAM (64 MB suggested)
  - Imports from/exports to Excel and Word (not required).
  - Uses standard ArcView GIS “shape” files. ArcView is not required
- Availability
  - Go to www.weap21.org and register for a new license (free for government, university, and non-profit organizations in developing countries)
  - Evaluation version available at no charge (CDs available here) or download from www.weap21.org
  - Full version requires license, available from SEI
  - Email weap@tellus.org
  - Training is needed for majority of users

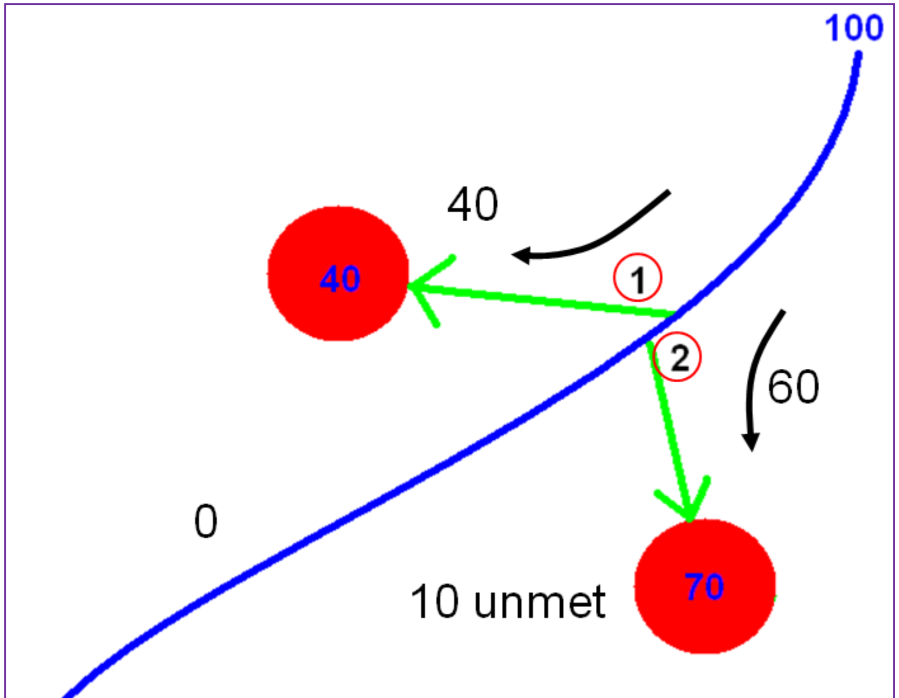
WEAP Illustration



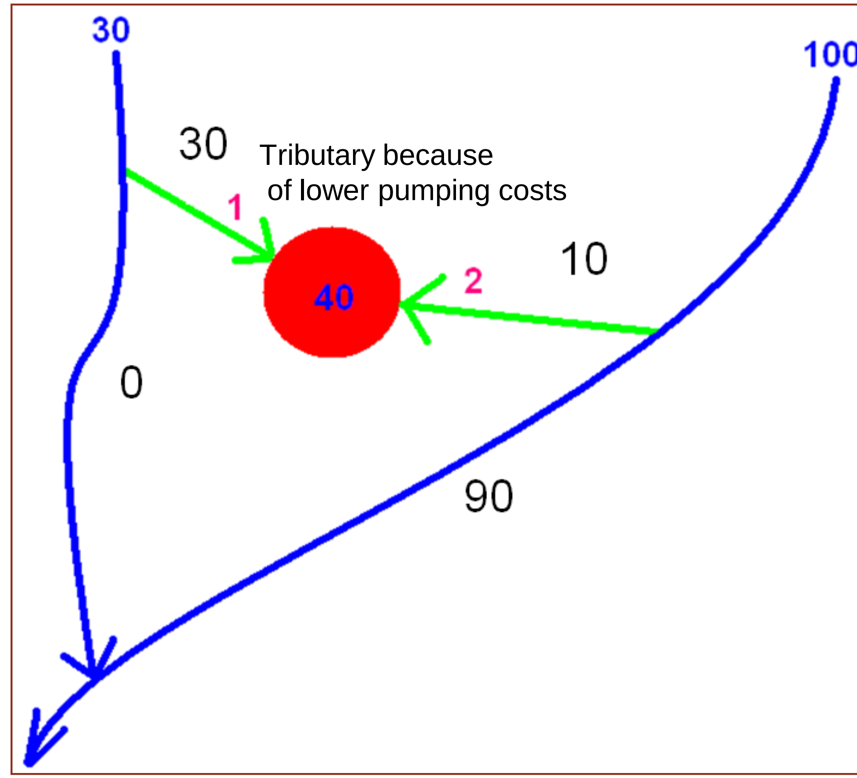
Legend:
Red Circle = Demand Site
Pink Circle with cross = In-stream flow requirement IFR
No with red circle = Priority
Blue Line = River (with flow direction)
Green Line = Transmission Link (brings water from supply to demand)
Black Line = Represents where the water is flowing and how much

WEAP Illustration (continued)

Different Priorities



Different Preferences



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Pink No = Preference
Blue Line = River (with flow direction)
Green Line = Transmission Link (brings water from supply to demand)
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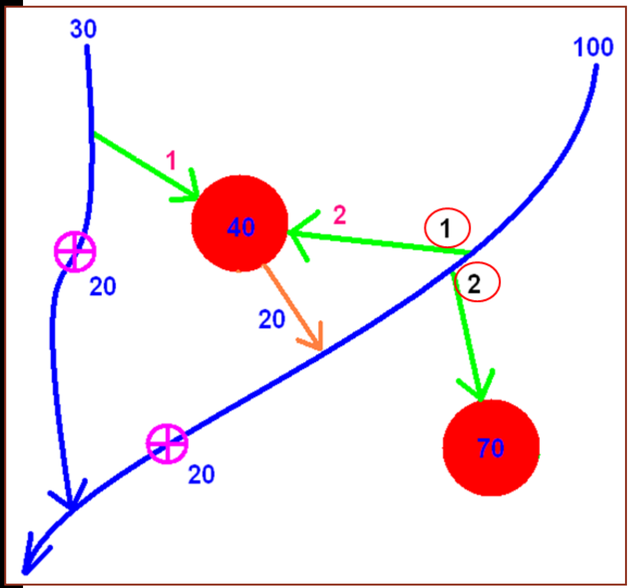
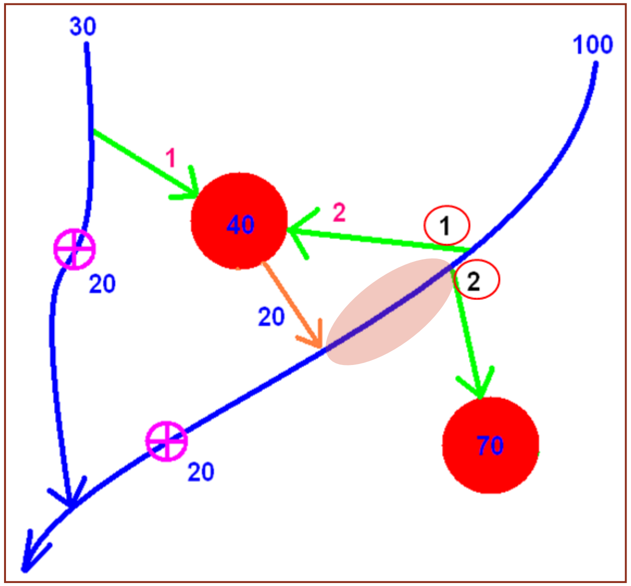
WEAP Examples

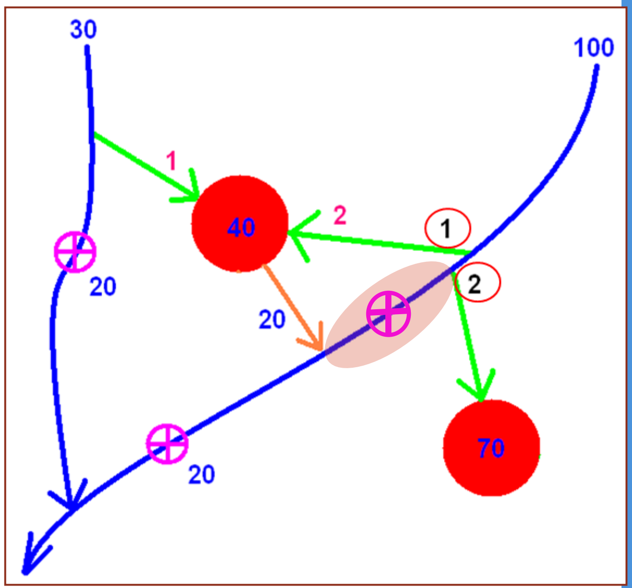
How much water will the site with 70 units of demand receive?



How much water will flow in reach between Priority 2 diversion & Priority 1 return flow?



What could we do to ensure that this reach does not go dry?



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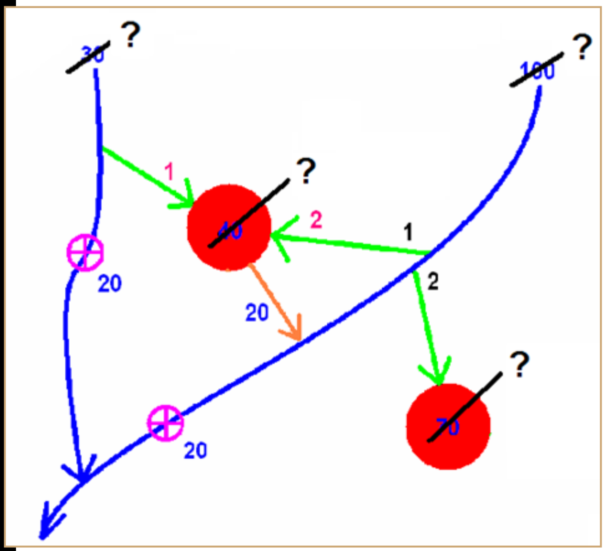
Black Line = Represents where the water is flowing and how much
Orange Line: Return flow

What are we Assuming?

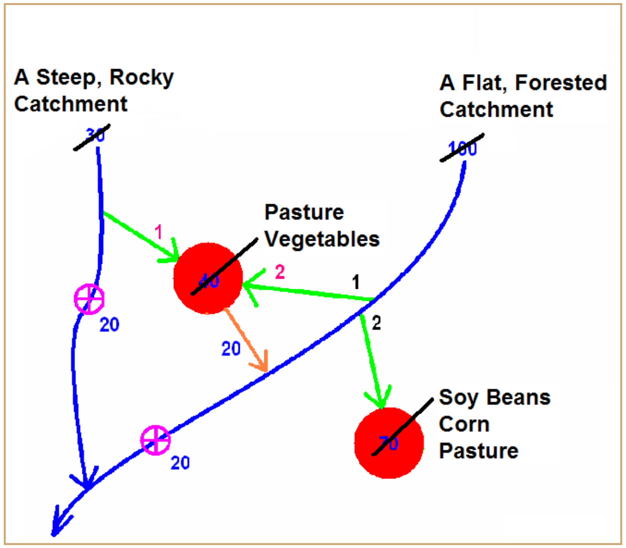
- That we know how much water is flowing at the top of each river
- That no water is naturally flowing into or out of the river as it moves downstream
- That we know what the water demands are with certainty
- Basically, that this system has been removed from its HYDROLOGIC context

WEAP Hydrology Examples

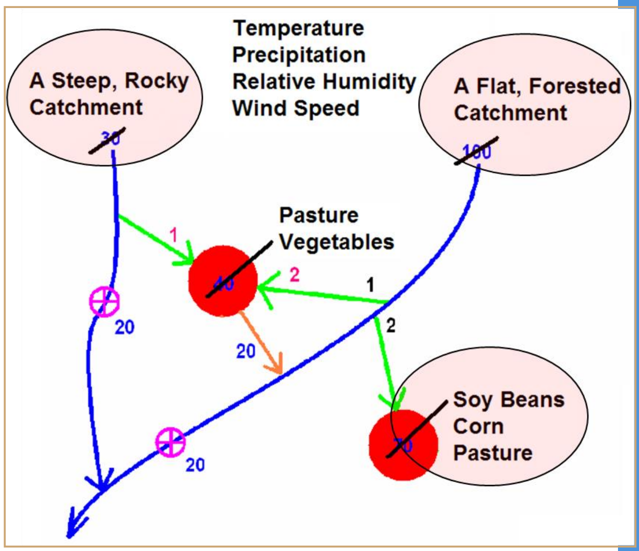
Unknown Head flow of river , unknown exact amount of demand



Using data calculate head flow in WEAP HYDROLOGY



Add Climate Interface to Hydrology



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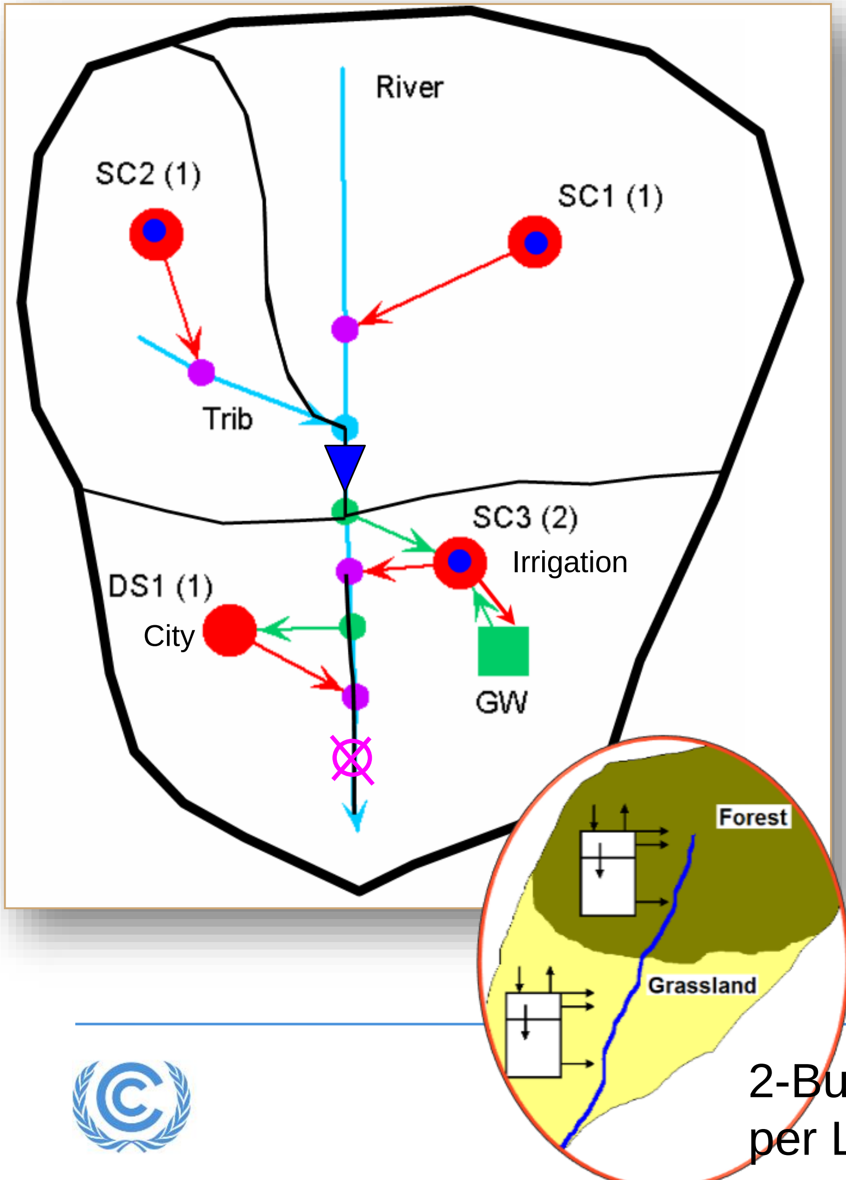
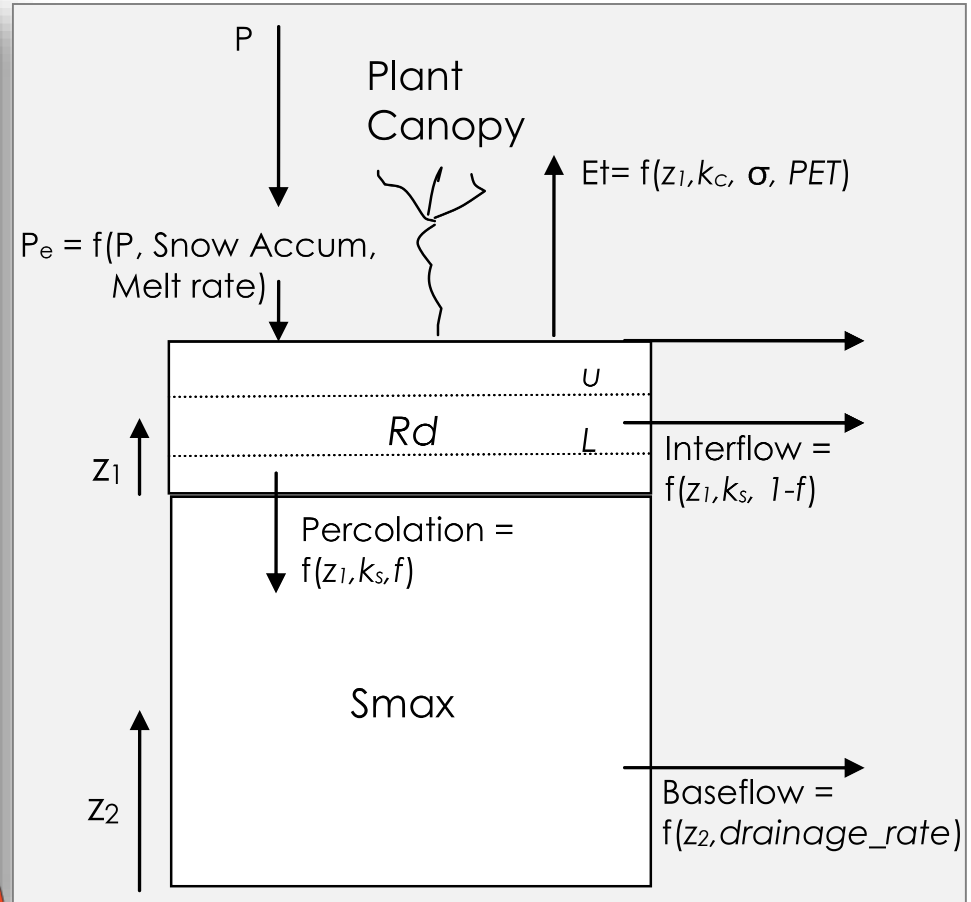
Integrated Hydrology/Water Management Analytical Framework in WEAP

Hydrology Framework



2-Bucket Model
per Landuse Class

2-Bucket Hydrology Module



Multiple methods to facilitate future climate projections

Simplified water-year method

- Describe a series of water year types from very dry to very wet
- Enter the water year sequence

Read-from-file method

- Historical or synthetic data
- Import from ASCII files

Rainfall-runoff

- Lumped parameter
- Semi-distributed
- Sub-watershed specific
- Climate input

Plant growth method

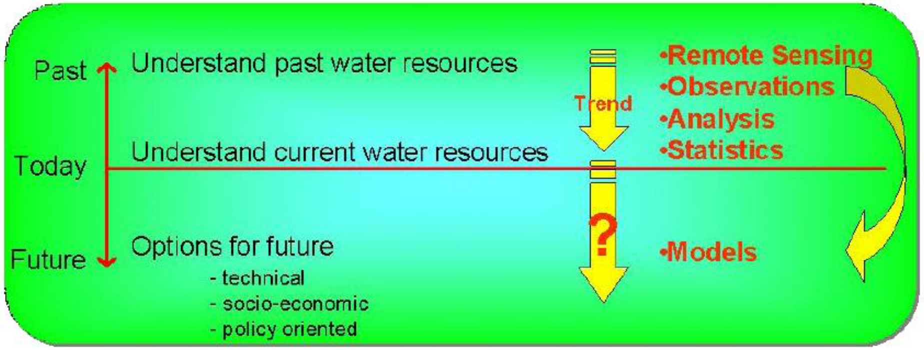
- Daily plant growth
- 13-layer soil moisture
- Atmospheric CO_2/temp

Some useful data sources

Source	Description	Link
World Bank water data and research	Provides country level statistics and data about water sector and a broad range of other indicators	http://water.worldbank.org/water
UNEP Environmental Data Explorer	Provides access to the data sets used by the United Nations Environment Programme and its partners in its integrated environmental assessments	http://geodata.grid.unep.ch/
Global Runoff Data Centre	Collects and disseminates river discharge data on a global, regional or catchment scale under the auspices of the WMO	http://www.bafg.de/GRDC
International Groundwater Resources Assessment Centre	Disseminates groundwater information and knowledge with the development of a global groundwater information system	http://www.un-igrac.org/
Climate Research Unit (CRU)	CRU at the University East Anglia provides global, high resolution historical climate datasets	http://www.cru.uea.ac.uk
Terrestrial Hydrology Group (Princeton University)	Climate model output and related studies, including Global Meteorological Forcing Dataset for land surface modelling	http://hydrology.princeton.edu

Case Studies 1 - Climate resilient development goals; assessing climate change adaptation costs in the Kenyan water sector

- Case study with multiple evidence lines for assessing indicative costs of climate adaptation in Kenya’s water sector
  - Three primary methods used to explore the costs of adaptation to climatic risks for the Kenyan water sector
    - Partial investment flows and financial flows (IF&FF, UNDP) analysis
    - Adaptation signatures (SEI)
    - Illustrative basin-level case study for costing integrated adaptation strategies (WEAP, SEI)
  - The geographical focus of the study
    - The Lake Victoria, Rift Valley, Athi River, Tana River and Ewaso Ngiro North basins
  - WEAP - computer tool for integrated water resources planning



https://www.weadapt.org/sites/weadapt.org/files/legacy-new/knowledge-base/files/4e25a6035cad51D-Final_Kenya_Water_Sector_Report.pdf
2009

Case Studies 1 – Inputs and Indicators

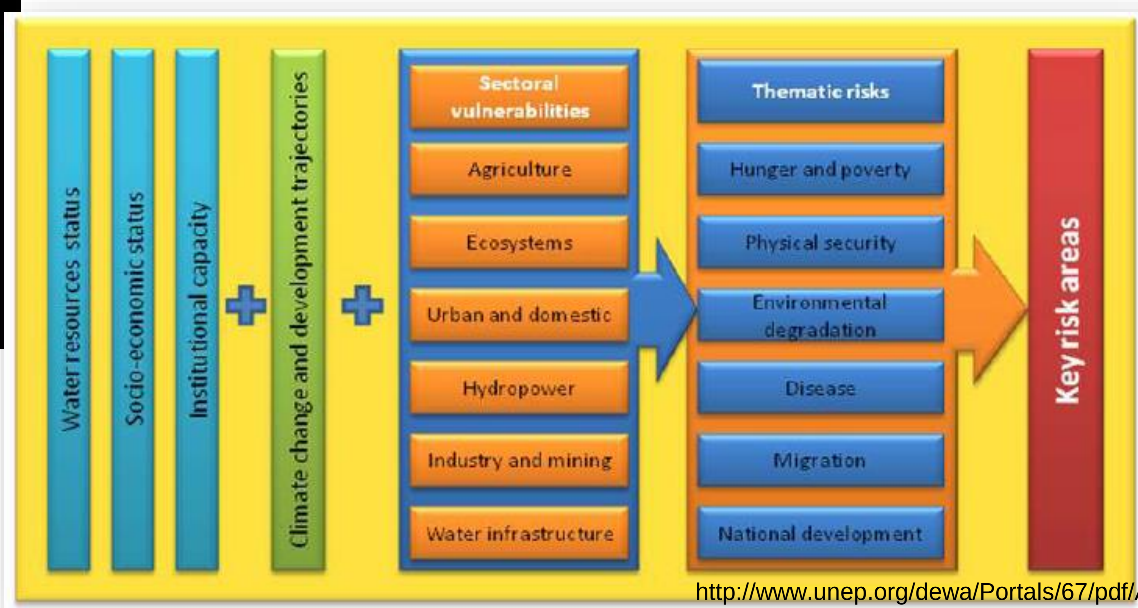
- Input Scenarios:
  - Climate Change Scenarios, Low projection, High projection
  - Increase in population by 20% by 2050
  - Reduction of reservoir capacity by 30% due to siltation
- Adaptation strategies; A coherent set of four adaptation strategies:
  - Demand-side management: e.g., improved irrigation and other end-use efficiency improvements across demand nodes
  - Supply-side management: e.g., application of water harvesting technologies to mitigate over-abstraction, or perhaps "harder" options such as reservoir construction.
  - Ecosystem protection: e.g., sustainable land management (SLM) interventions in upstream agriculture to reduce soil erosion and dam siltation, improve electricity production efficiency, etc.
  - "Full sectoral protection": Implementing all of the above activities in the basin
- To evaluate the impact of these projections and adaptation measures a set of indicators have been defined:
  - Hydropower generation
  - Irrigation water shortage
  - Rainfed agriculture shortage
  - Urban water shortage

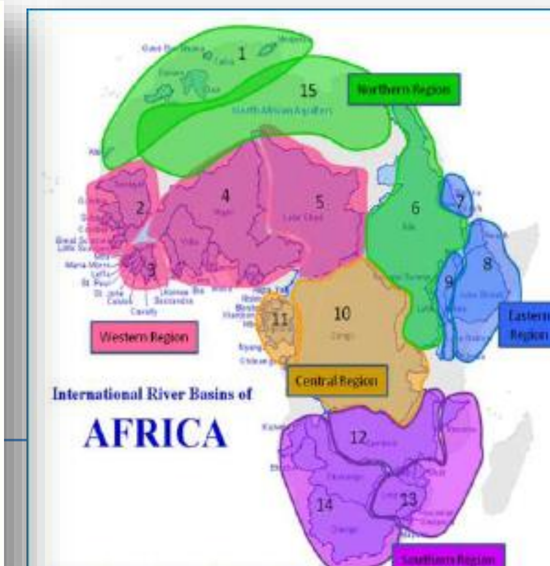
Case Studies 1 – Outputs

- Analysis shows that the impact of climate change without any adaptation strategies:
  - Ranges from a positive US$ 2 million to a cost of US$ 66 million for the hydropower, irrigation and drinking water sector
- Taking into account the costs and benefits of adaptation strategies, the so-called “demand-side” measures:
  - Always positive ranging from US$ 11 million to US$ 29 million for the low and high climate projection, respectively
  - Supply-side and ecosystem adaptations are only profitable if the climate will evolve in the direction of the high projection
- Refinement in the model itself can be considered
  - Inclusion of groundwater
  - Profits from rain-fed agriculture
  - Profits from grasslands and forests
  - Inclusion of livestock water requirements
  - Policy scenarios simulating managed flood events for downstream water users

Case Studies 2- Assessment of transboundary freshwater vulnerability in Africa to climate change

- UNEP Study gives an overview to identify some of the most vulnerable areas in Africa
- Some approaches have been suggested that may help to ameliorate the impacts of climate change
  - The challenge remains of sharing transboundary waters in the context of increasing stress and high levels of political instability and conflict
  - Key message
    - Ability to learn from one another
    - Share information and experiences
    - Develop a body of African experience
    - Knowledge about managing the impacts of climate change





http://www.unep.org/dewa/Portals/67/pdf/Assessment_of_Transboundary_Freshwater_Vulnerability_revised.pdf

Case Studies 2- Indicators

- Critical/very poor status/severe impacts/high risk
- Poor status/moderate impacts/moderate risk
- Good status/minor impacts/low risk
- Insufficient/uncertain information

- ❑ Summary of the assessment of the four key factors used in the risk assessment for each of the 15 identified clusters
- ❑ A qualitative assessment of these four parameters:
  - ▪ The water resources status is assessed on the basis
    - Of per capita water availability
    - General water quality and the level of water stress
  - ▪ The socio-economic status reflects
    - Average per capita income
    - The development status of the country, largely as reflected in the UN human development indices
  - ▪ The institutional capacity broadly reflects
    - The existence and capacity of transboundary water management institutions
  - ▪ The level of infrastructure development
  - ▪ The national water resources management capacity, including the existence of appropriate policy and legislation
  - ▪ The financial and human resources capacity to implement the policy and legislation
    - The climate change reflects
  - ▪ The predicted severity of climate change impacts in terms of rainfall and temperature changes
    - Their impact on the hydrology of the region

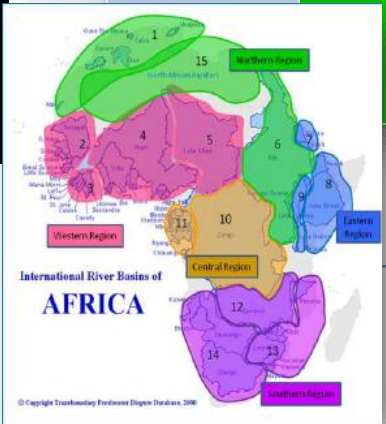
https://wedocs.unep.org/bitstream/handle/20.500.11822/7835/-Assessment%20of%20transboundary%20Freshwater%20Vulnerability%20in%20Africa%20to%20Climate%20ChangeAssessment_of_Transboundary_Freshwater_Vulnerability_revised.pdf?sequence=2&isAllowed=y

Case Studies 2- Outputs

- Critical/very poor status/severe impacts/high risk (red)
- Poor status/moderate impacts/moderate risk (orange)
- Good status/minor impacts/low risk (green)
- Insufficient/uncertain information (blue)

	Water resources status	Socio-economic status	Institutional capacity	Climate change impacts	Risk
Northern Region					
Cluster 6 The Nile River Basin	Hyper-arid in the north to sub-tropical in the south with the majority of water resources being generated the southern basin.	Very mixed socio-economic settings across very large basin. Large urban developments and many marginalized, rural, poor communities. Agriculture a key element of the socio-economic fabric of the basin.	Some policy reforms have taken place. Nile Basin Initiative and Nile Basin Discourse in place, but often fragmented.	Warmer and drier to the north whilst warmer and wetter to the south.	Impacts on agriculture is places vulnerability on national food security in a number of states. Rural communities are especially vulnerable across the basin. Impacts upon assurance of supply makes further hydropower developments and national development trajectories vulnerable.

Central Region	Water resources status	Socio-economic status	Institutional capacity	Climate change impacts	Risk
Cluster 10 The Congo River Basin	High rainfall, humid tropical climate, ITCZ, abundant water resources, no water stress	Despite rich natural resources, levels of poverty very high and low HDI (informal urban and rural communities)	Very weak institutions, poor penetration of services into the basin, limited and collapsing infrastructure	Limited agreement, although climate impacts are not anticipated to result in significant water resource impacts. Local effects may be important	Flooding in urban and peri-urban environments (local and river flooding) Alien species invasions (water hyacinth) with effects on hydropower and ecosystems Lake Tanganyika fisheries at risk through temperature increases



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Thank You