Georgia Water
Resources Institute

Aris Georgakakos

Climate Projections, Uncertainty, and Scenarios for Impact Assessments: Water Resources Planning and Mgt.

Aris Georgakakos

Georgia Water Resources Institute / Georgia Tech

"Those who will solve the global water problems deserve two Nobel Prizes:

One for science and one for peace."

John F. Kennedy

Case Studies: Southeastern US and East Africa

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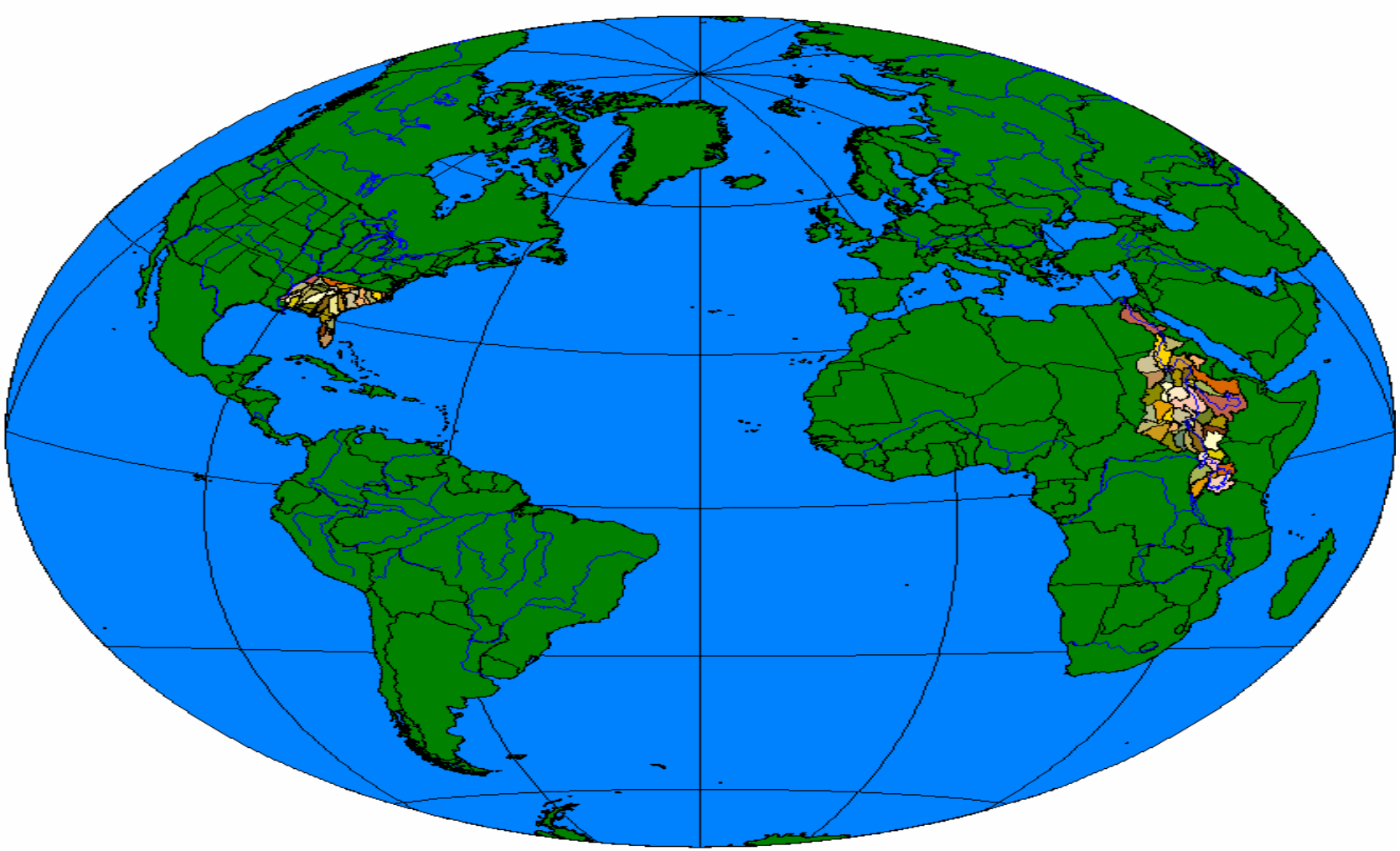
Climate
Projections,
Uncertainty, &
Scenarios
for Impact
Assessments



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Case Studies: Southeastern US and East Africa

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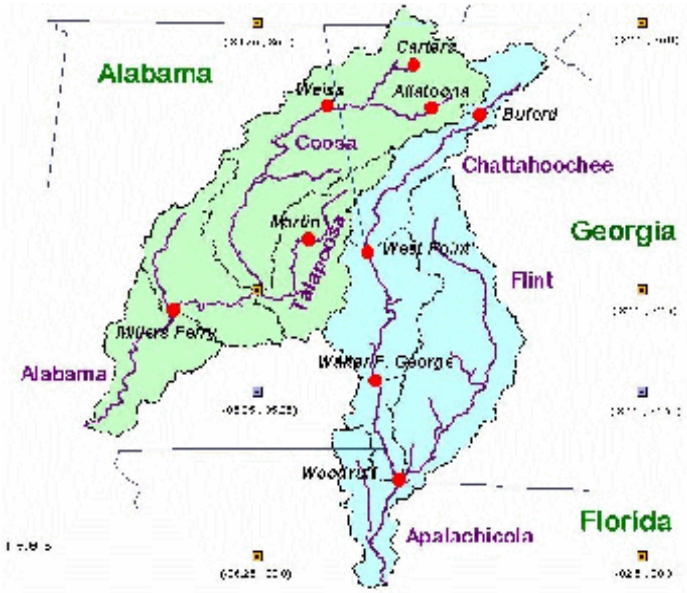
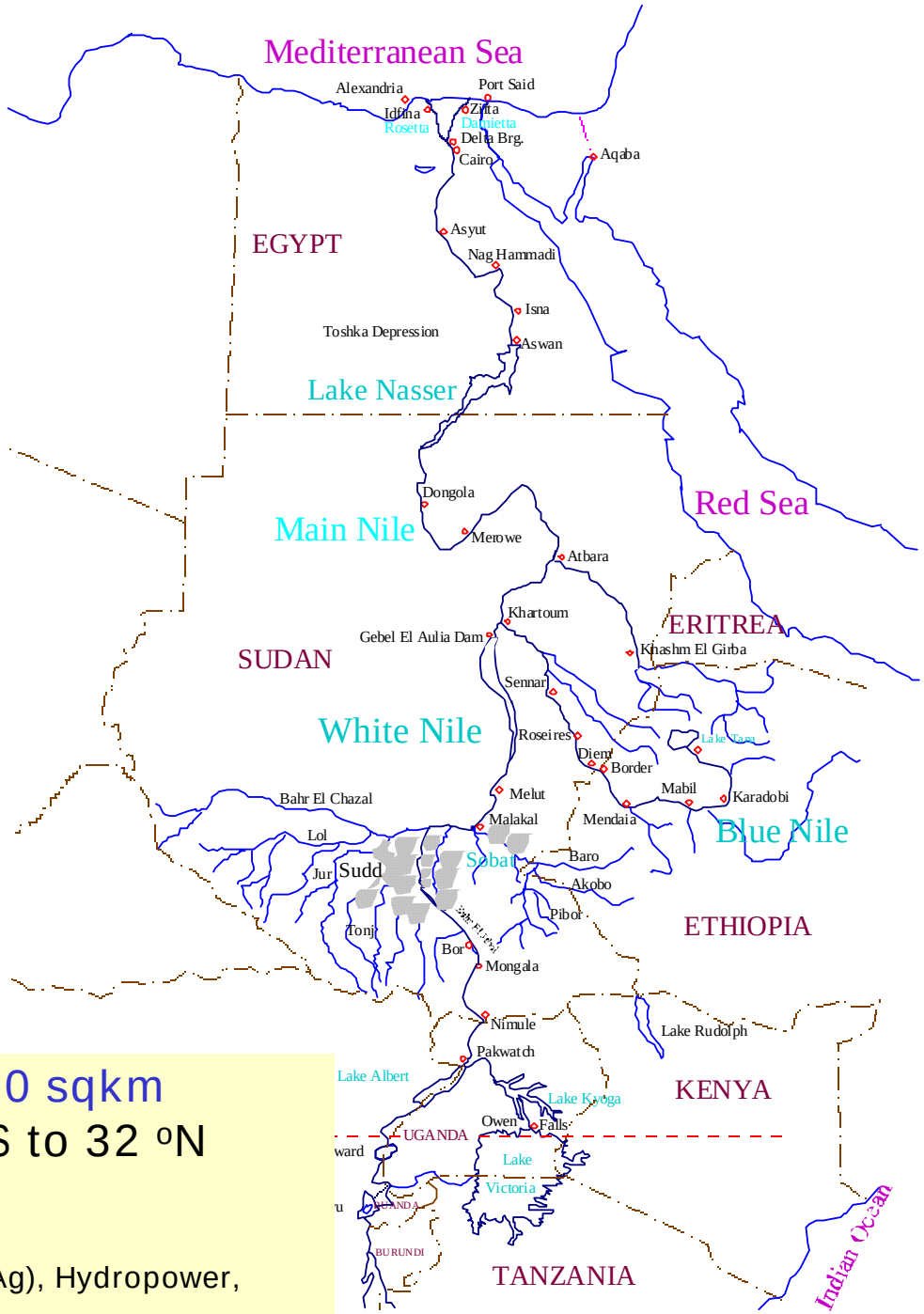


ACT: 58,263 sqkm;
ACF: 50,767 sqkm;
Latitude: ~ 30 to 35 ºN

3 States

Water Supply (Urban/Industry/Ag), Hydropower, Lake Recreation, Navigation, Environment

Ecosystems



Nile: 3,100,000 sqkm
Latitude: ~ 5 ºS to 32 ºN

10 Countries

Water Supply (Urban/Ag), Hydropower, Environment, Ecosystems

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Water Resources Assessments

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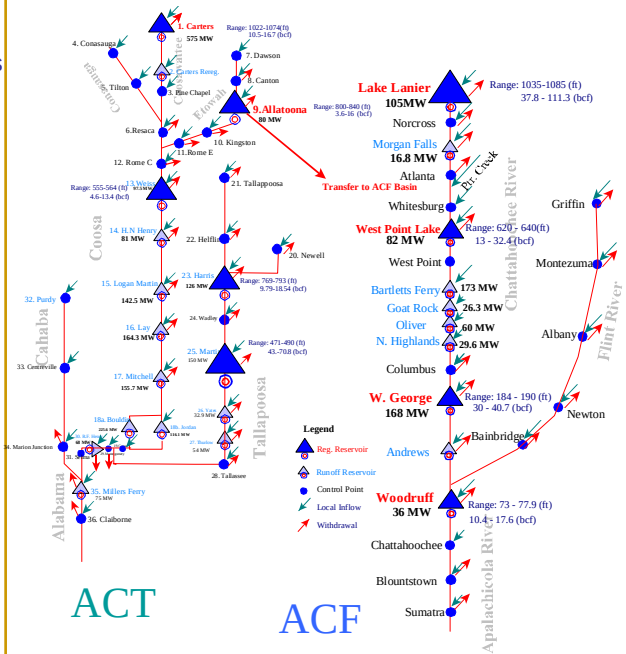
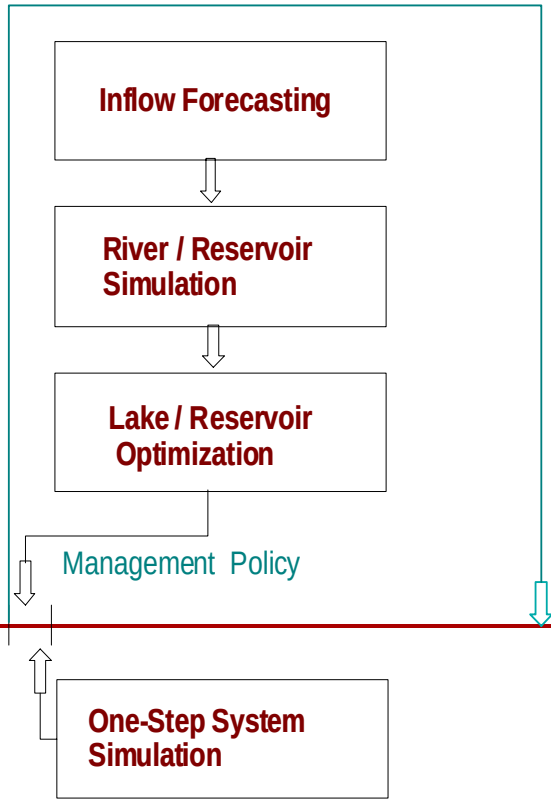
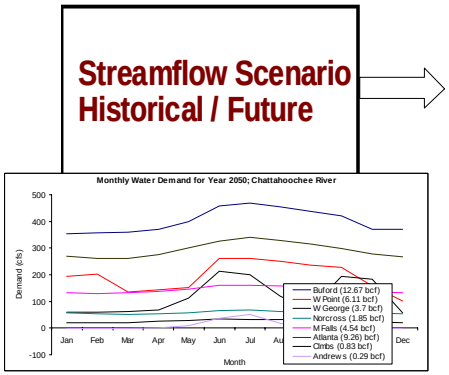


Forecast-Control Horizon



Assessment Criteria

- Water Supply Reliability
- Reservoir Levels/Spillage
- Energy Generation
- Instream Flow Changes
- Water Quality



(Daily to Monthly time steps)

Simulation Horizon (e.g., 1939 to 1993; 64 years)

Water Resources Assessments are Based on Historical Climates, Simple Simulation Methods, & Historical Demand Projections

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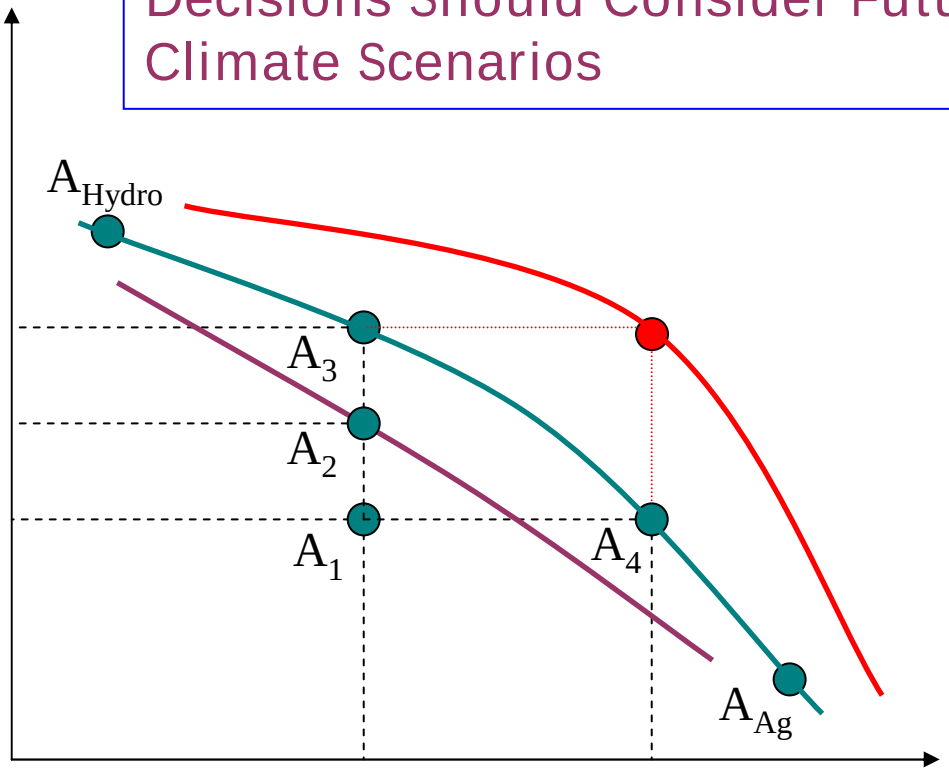
Relevance of Climate Scenarios to River Basin Planning

Water Sharing and Basin Development Decisions Should Consider Future Climate Scenarios



Everything should be made as simple as possible **...**
but not simpler.

Albert Einstein

Historical Climate Assessments: Lake Levels

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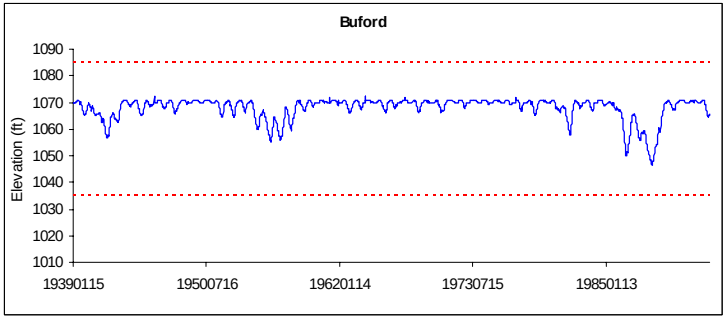

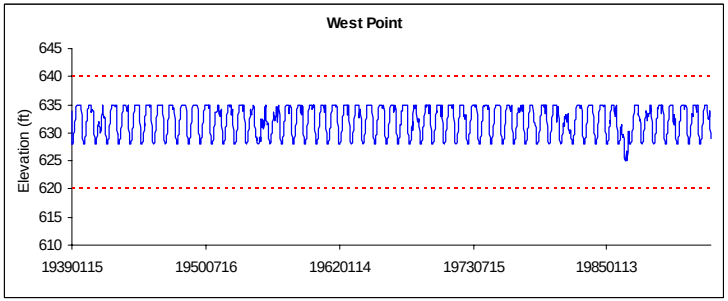

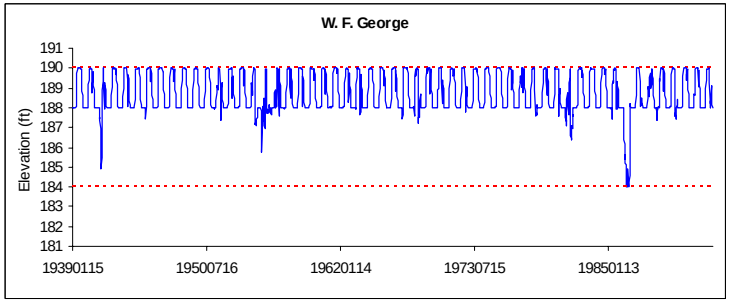

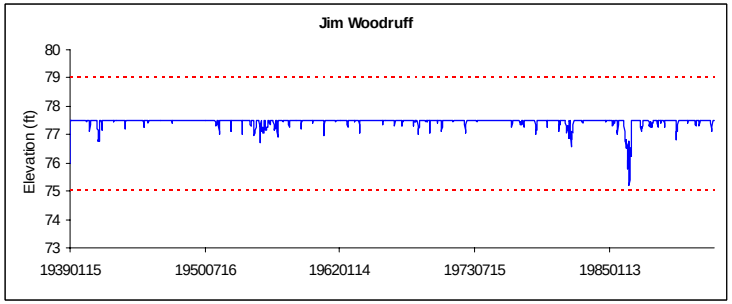

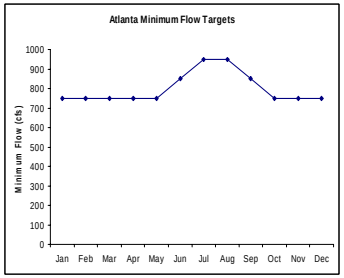

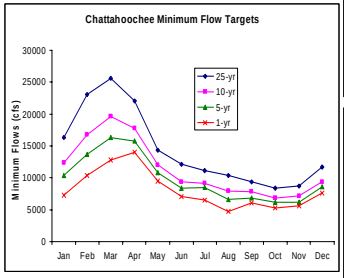

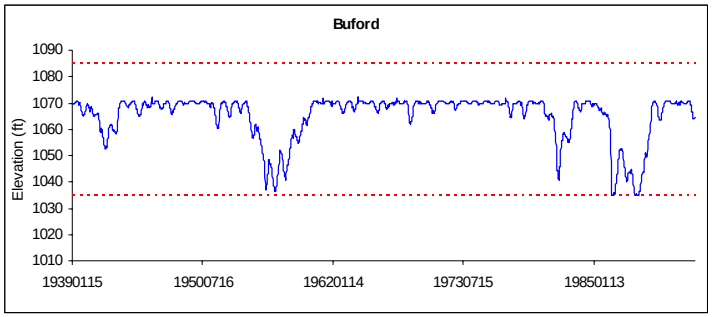

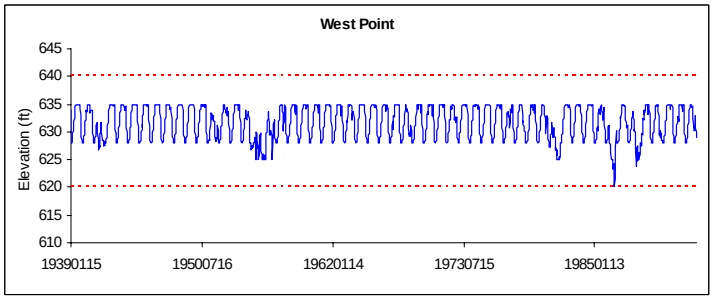

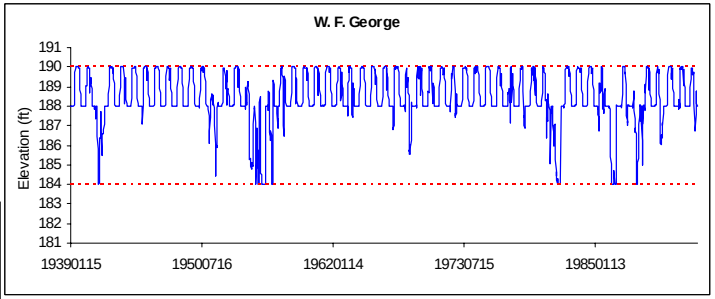

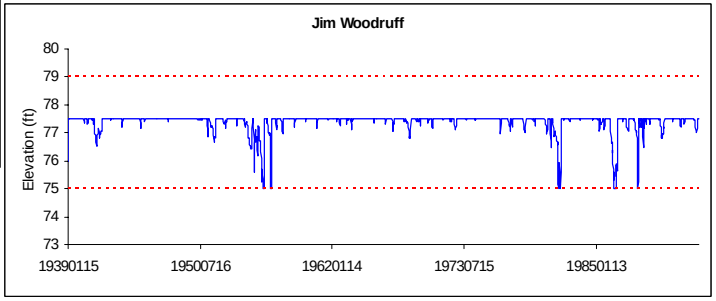

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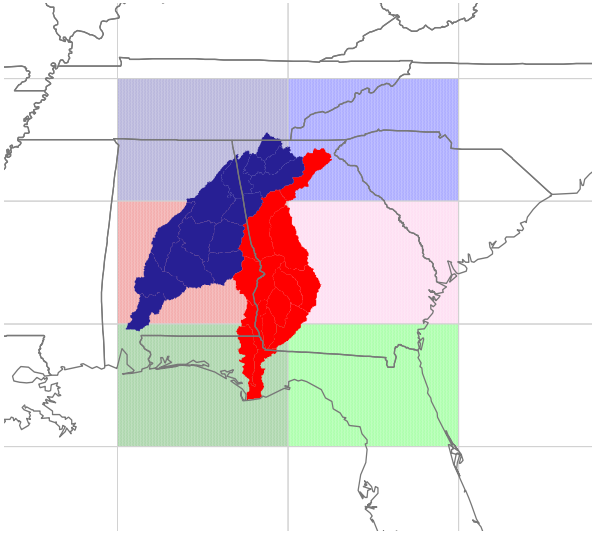
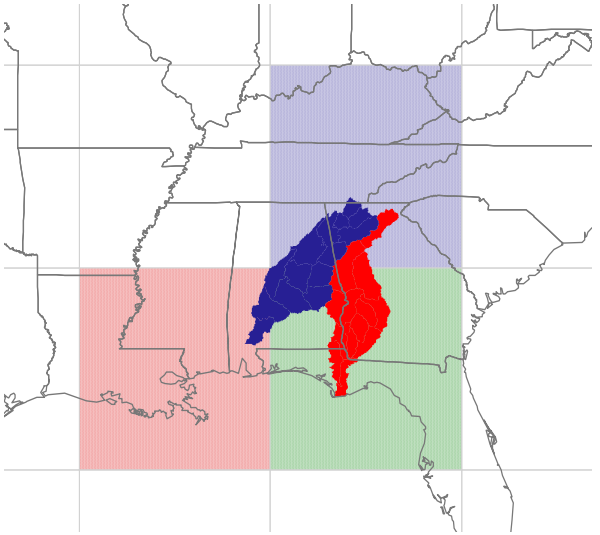
Climate Model Cells over the ACT and ACF Basins

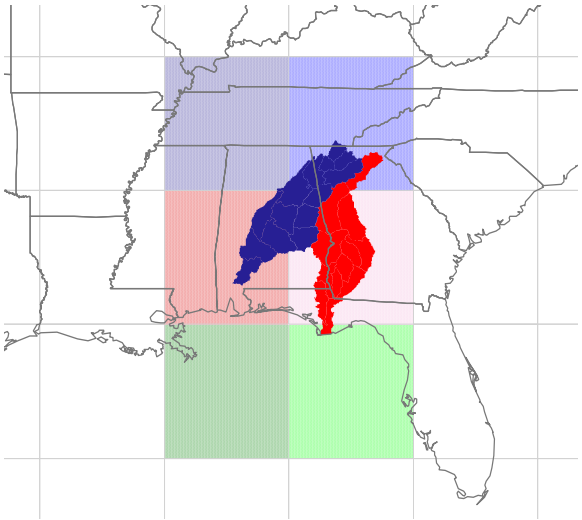
Hadley (HadCM2)



ECHAM3



Canadian (CGCM1)



Future Climate Assessment: Lake Levels; CGCM1

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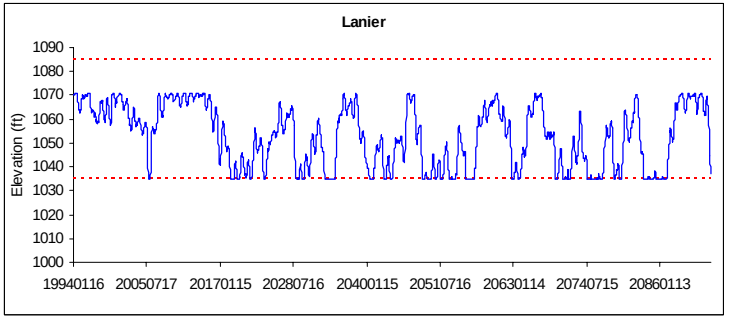

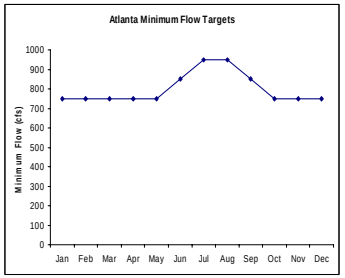

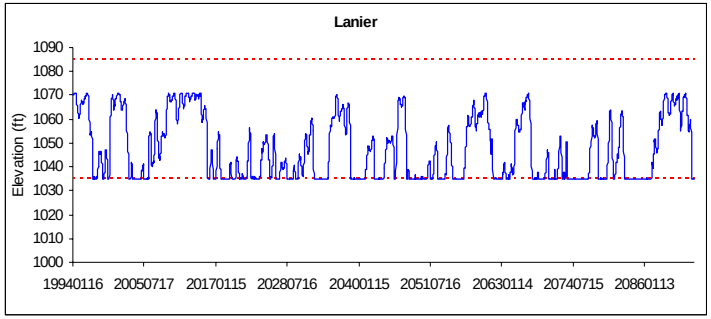

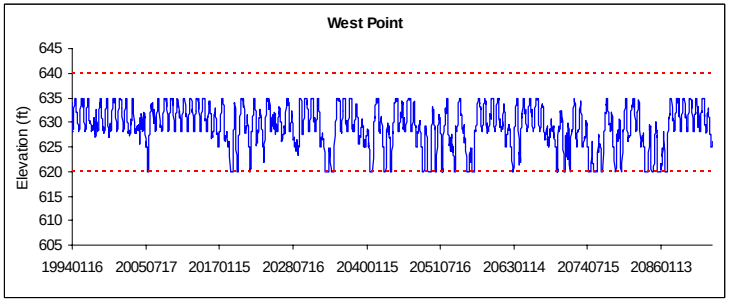

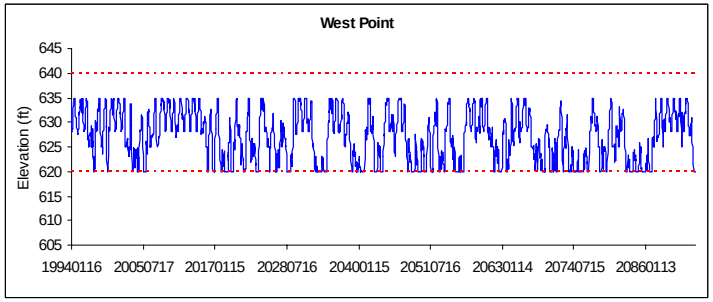

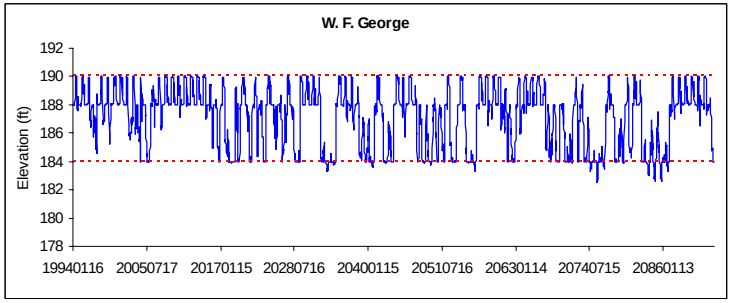

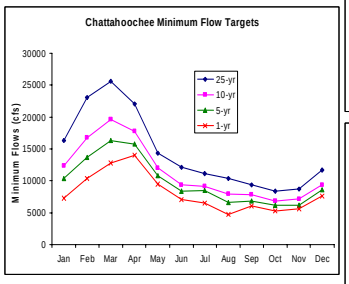

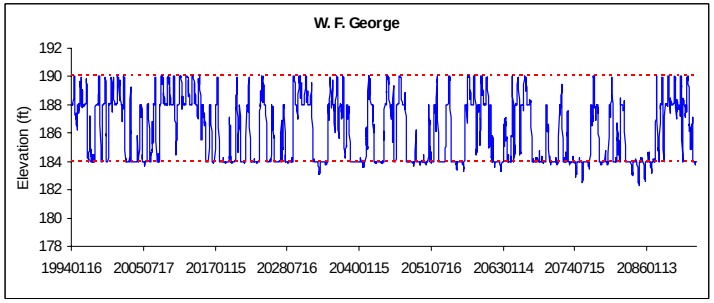

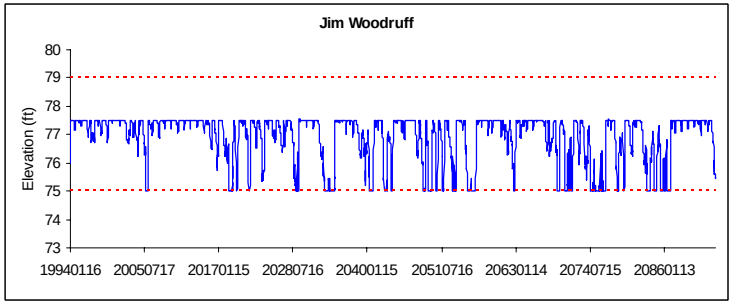

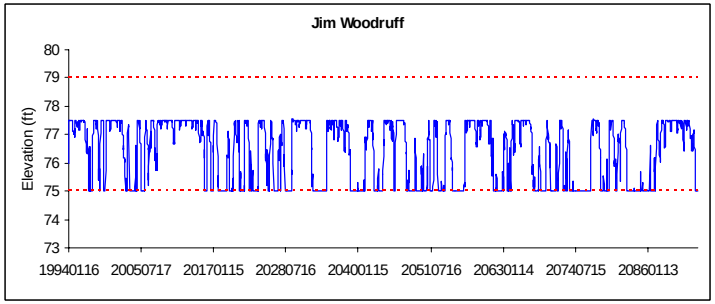

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Future Climate Assessment: Lake Levels; HadCM2

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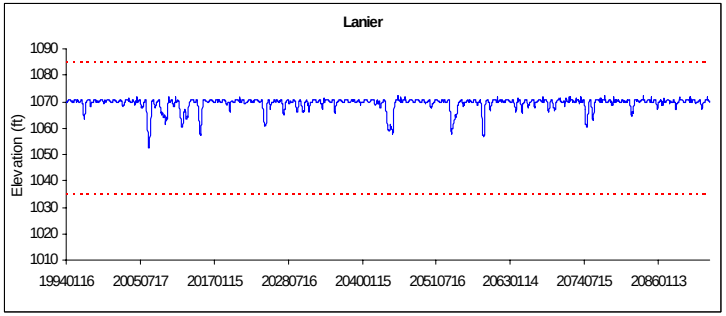

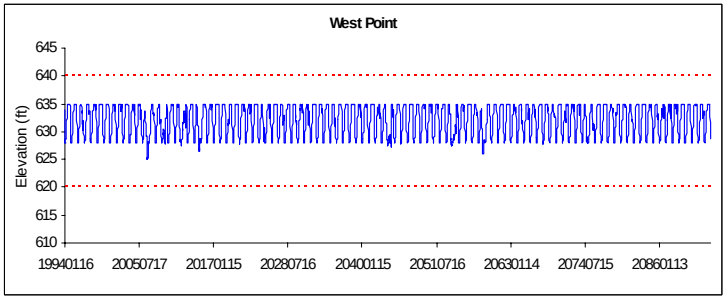

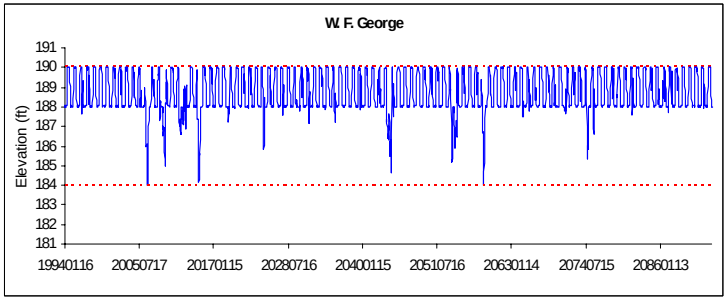

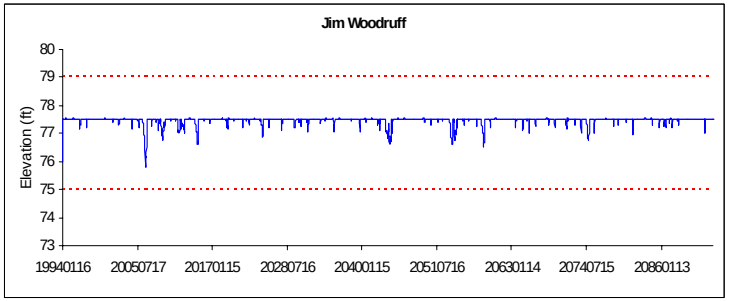

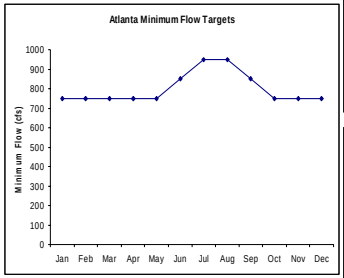

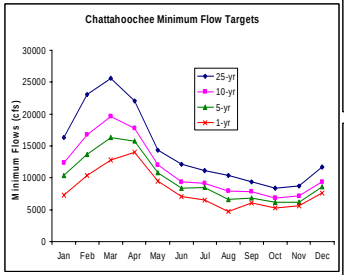

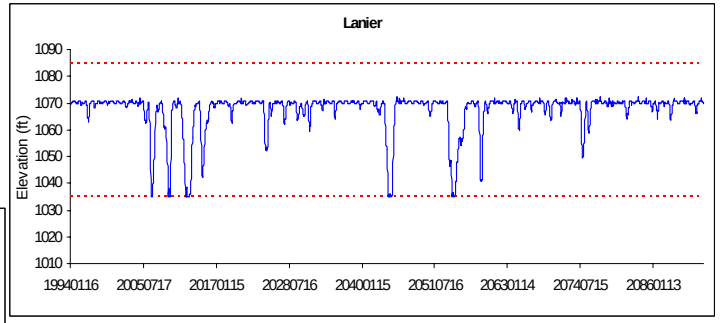

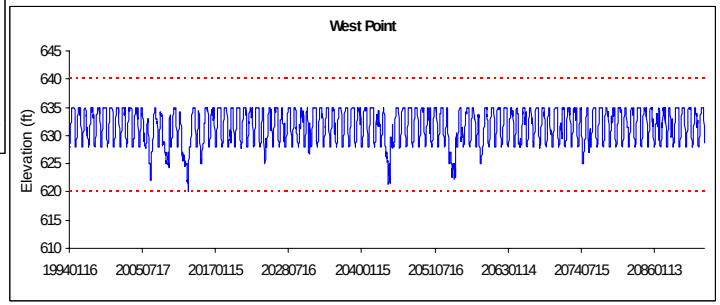

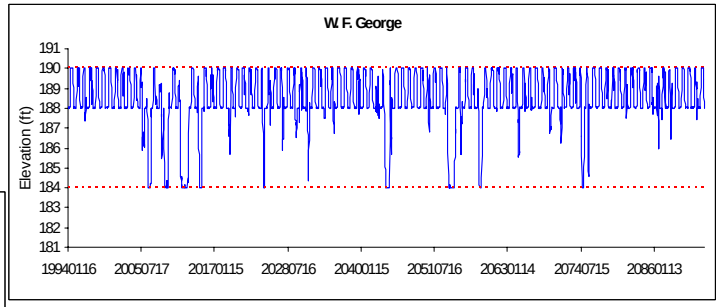

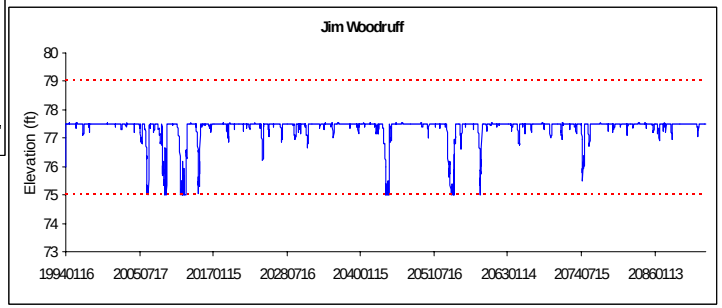

Historical & Future Climate Assessments: Water Supply

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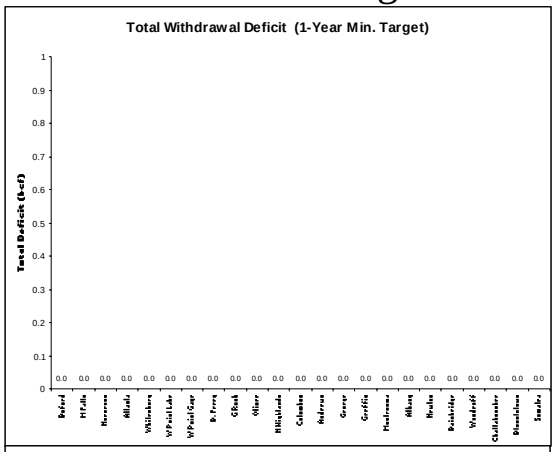
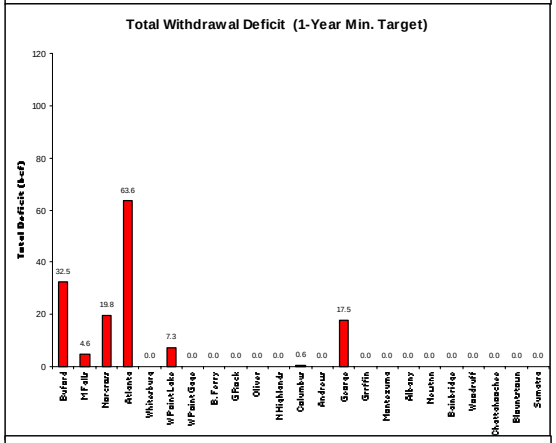
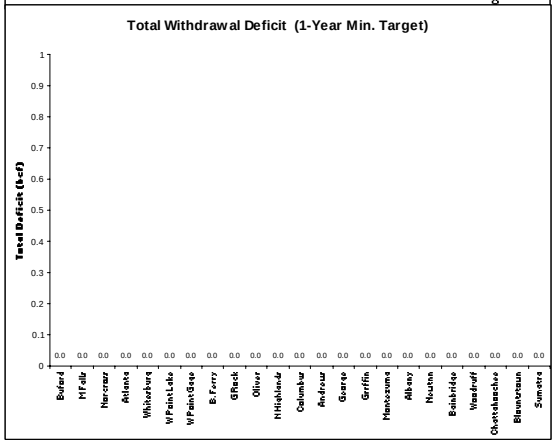
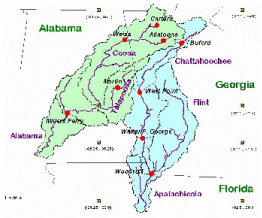
1-Yr Flow Target



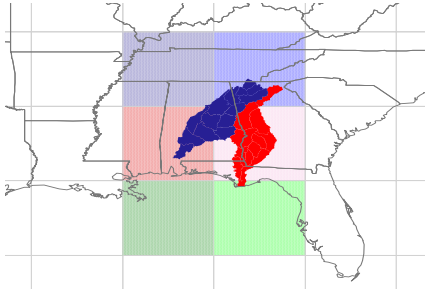




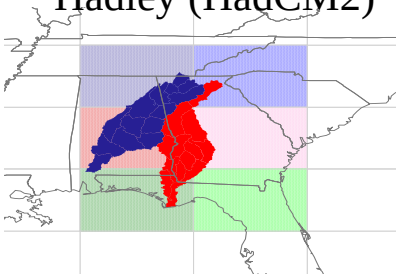
Historical



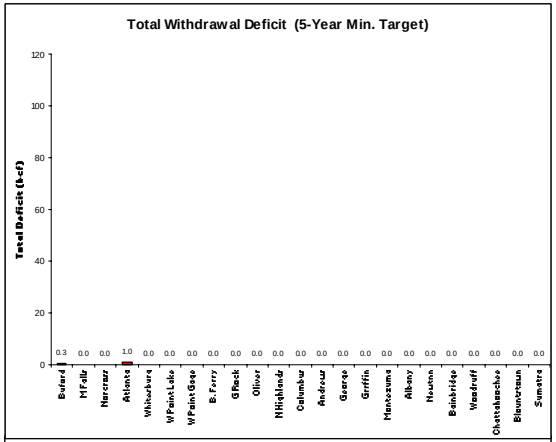
Canadian (CGCM1)

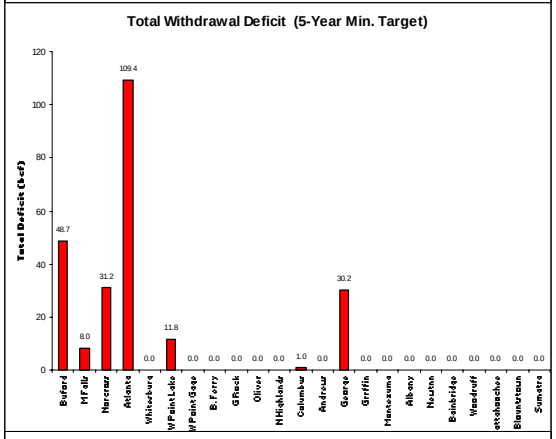


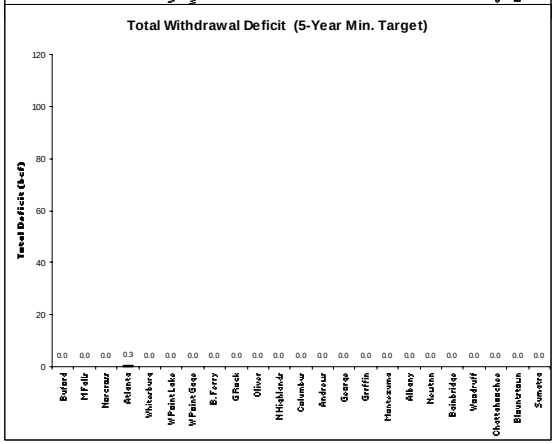
Hadley (HadCM2)



5-Yr Flow Target







Historical & Future Climate Assessments: Hydropower

Table 5.1a: Energy Generation Statistics; Historical Scenario; Federal Reservoirs

Min. Target	Energy (GWH)	Buford	West Point	George	Woodruff	System
1-Year	Primary	27.36	21.53	37.75	8.05	94.69
	Secondary	136.99	183.95	416.64	214.9	952.48
	Sum	164.35	205.48	454.39	222.95	1047.17
	Reliability (%)	100	100	100	100	100
5-Year	Primary	26.89	21.52	37.76	8.04	94.21
	Secondary	135.55	183.78	417.14	216.65	953.12
	Sum	162.44	205.3	454.9	224.69	1047.33
	Reliability (%)	99.86	100	100	100	99.86

Table 5.2a: Energy Generation Statistics; Canadian Scenario; Federal Reservoirs

Min. Target	Energy (GWH)	Buford	West Point	George	Woodruff	System
1-year	Primary	23	19.89	35.76	8.61	87.26
	Secondary	83.15	111.7	248.66	182.76	626.27
	Sum	106.15	131.59	284.42	191.37	713.53
	Reliability (%)	95.09	94.86	95.88	100	94.86
5-Year	Primary	19.63	18.27	33.87	8.41	80.18
	Secondary	82.79	111.08	249.91	181.7	625.48
	Sum	102.42	129.35	283.78	190.11	705.66
	Reliability (%)	92.16	90.14	92.27	100	90.14

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Climate Projections are Crucial in Many Regions

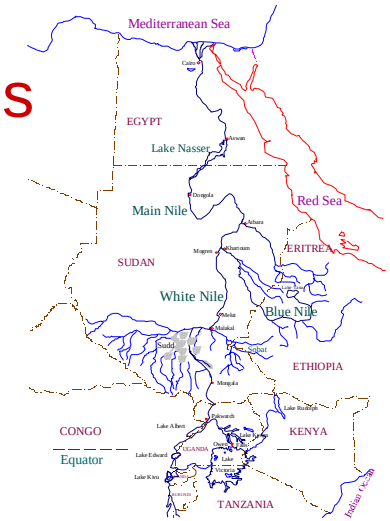

Table 1: Nile Basin Water Development and Management Scenarios System Configuration

	Current Condition	Full Development in Eastern Nile (Ethiopia/Sudan)	Full Development in Southern Nile (Wetland Projects + Eq. Lake Regulation)	Basinwide Cooperation
Scenario I	Yes			
Scenario II	Yes	Yes		
Scenario III	Yes		Yes	
Scenario IV	Yes	Yes	Yes	Yes

Note 1: Wetland Projects imply a 12 bcm annual increased yield, 4.75 bcm of which is attributed to the Machar Marshes and Ghazal projects, and the
Note 2: Full Development in Ethiopia includes projects at Lake Tana, Karadobi, Mabil, Mendaia, and Border.

Water Withdrawal Targets (Billion Cubic Meters per Year)

	Eq. Lake Region	Sudan	Ethiopia/Eritrea	Egypt
Current Condition	0	18.5	0	55.5
Low Demand Increase	2.5	21	10	58
High Demand Increase	5	23.5	20	60.5

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Climate Projections, Uncertainty, & Scenarios for Impact Assessments

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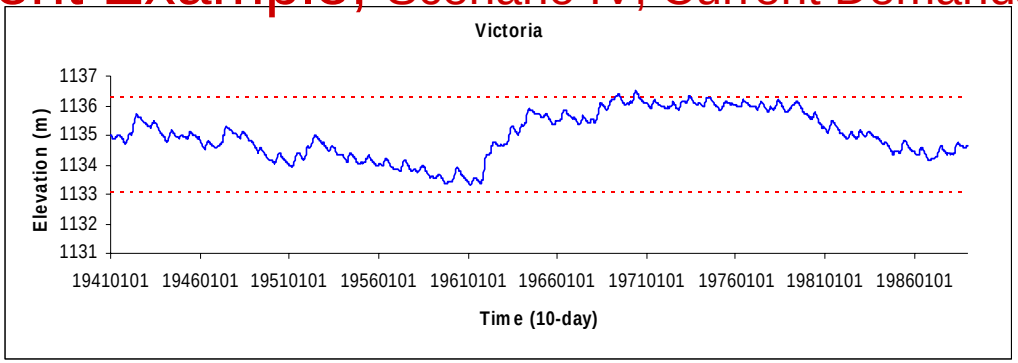
Nile-DST Assessment Example; Scenario IV; Current Demands

Lake Victoria



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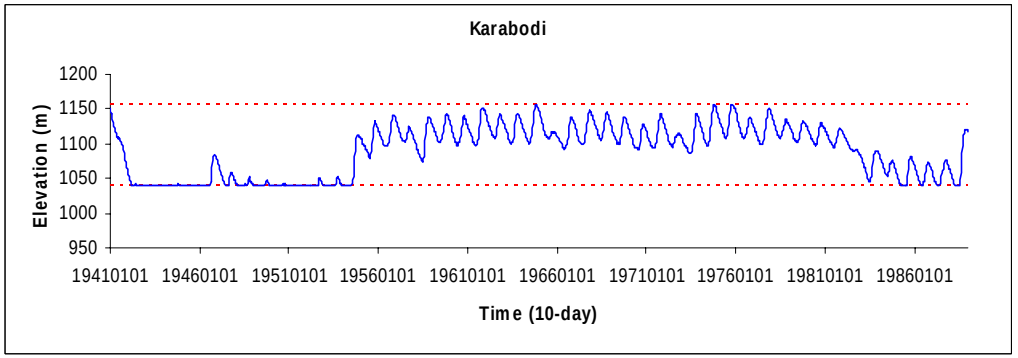
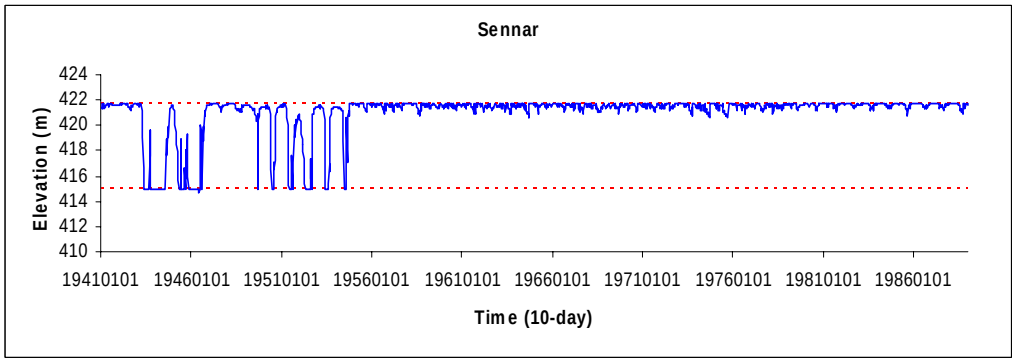
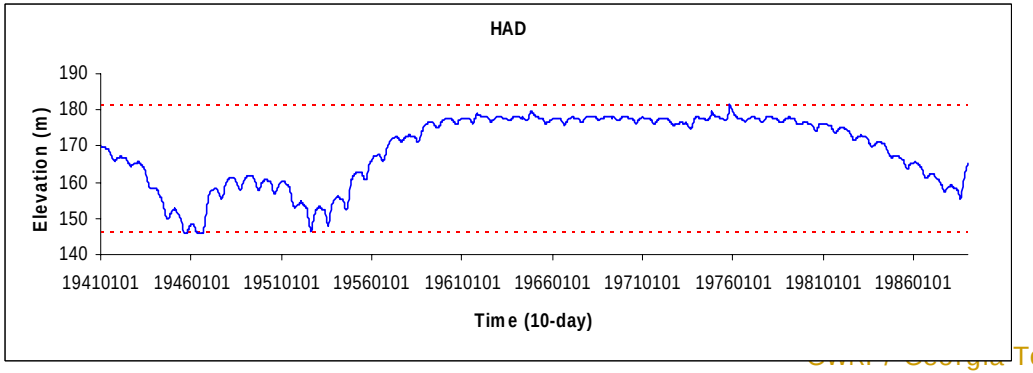


Sennar



HAD



Nile-DST Water Supply Deficits (Annual Average)

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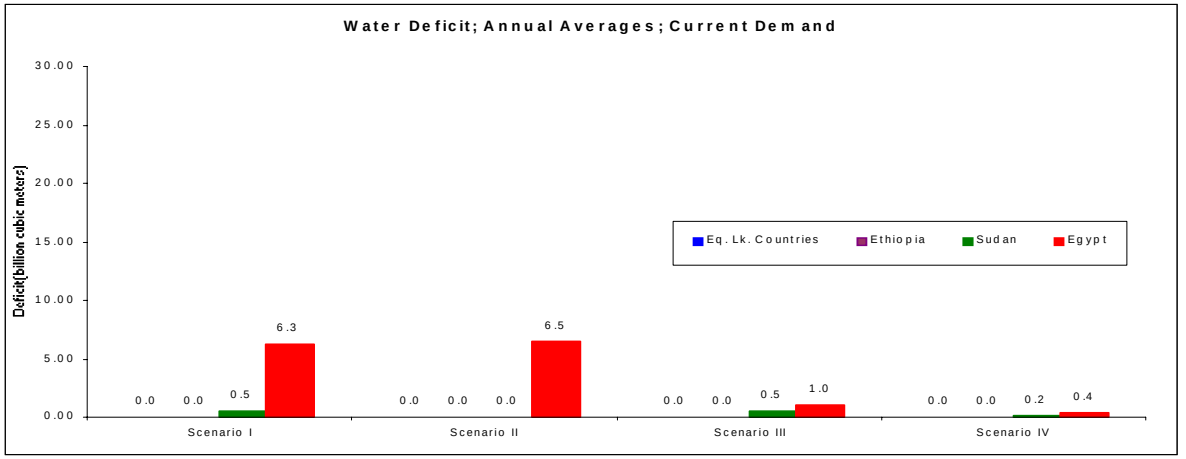

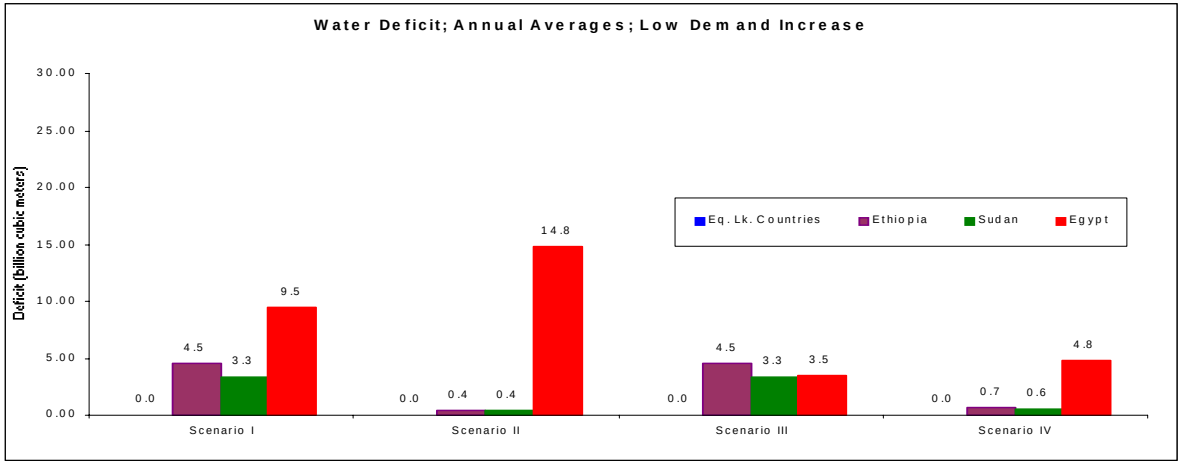

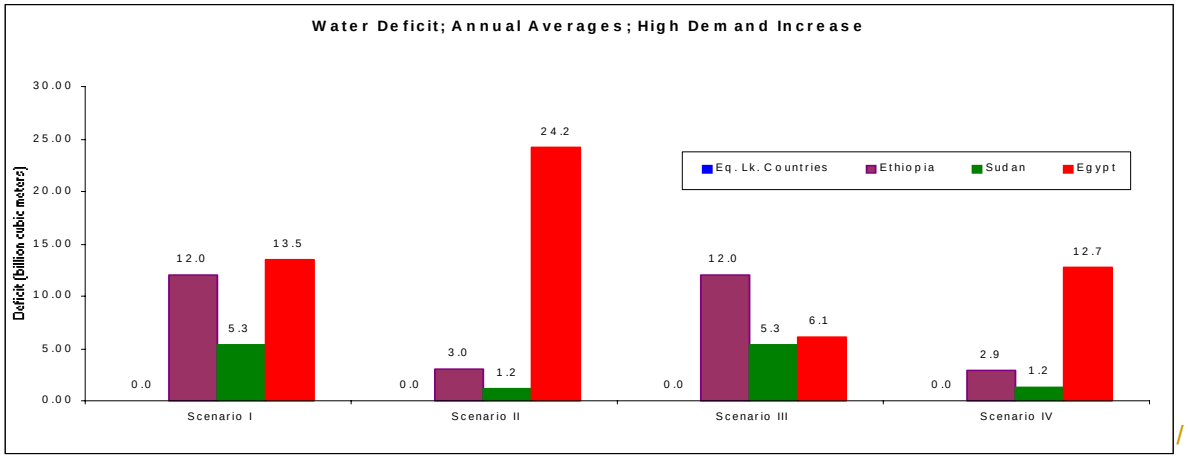

Nile-DST Assessment Example: Eq. Lake Energy Statistics

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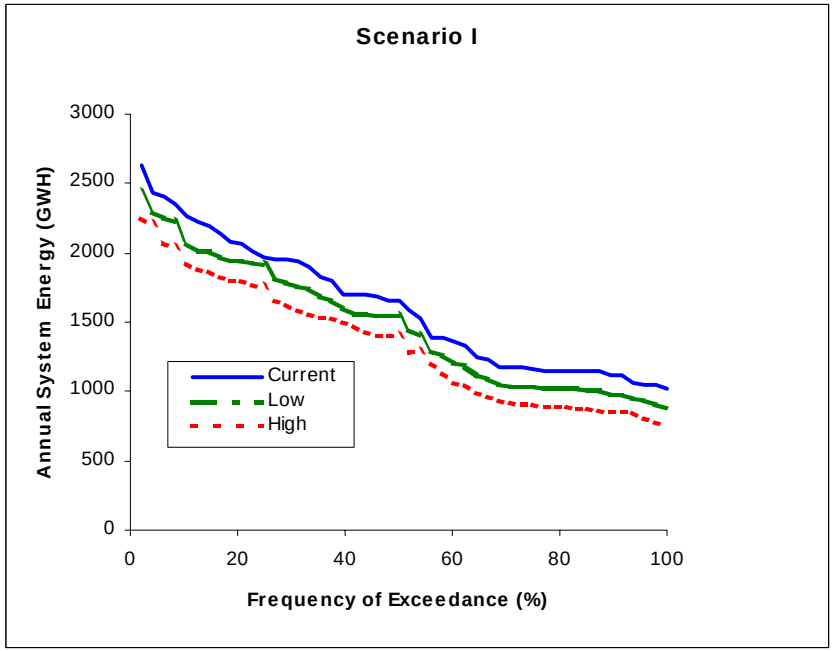

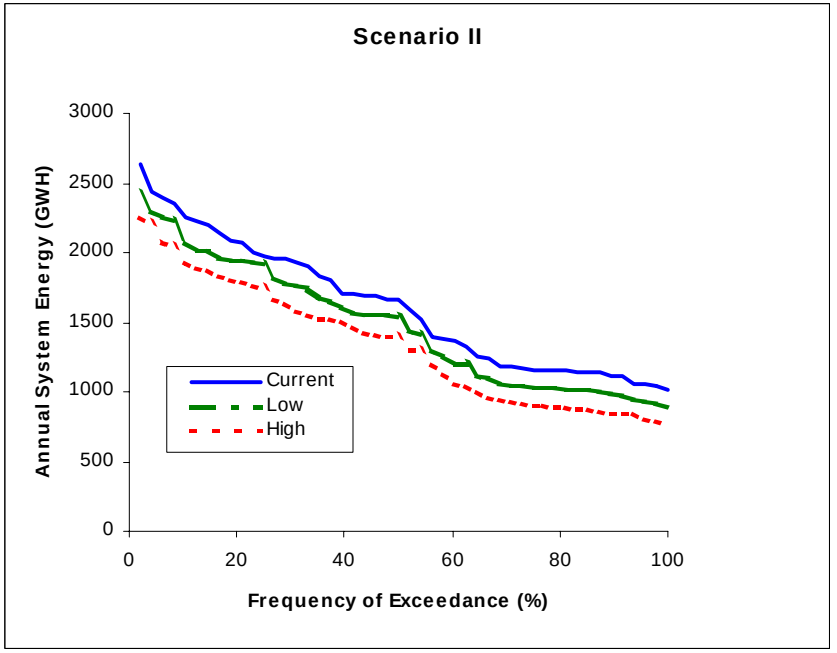

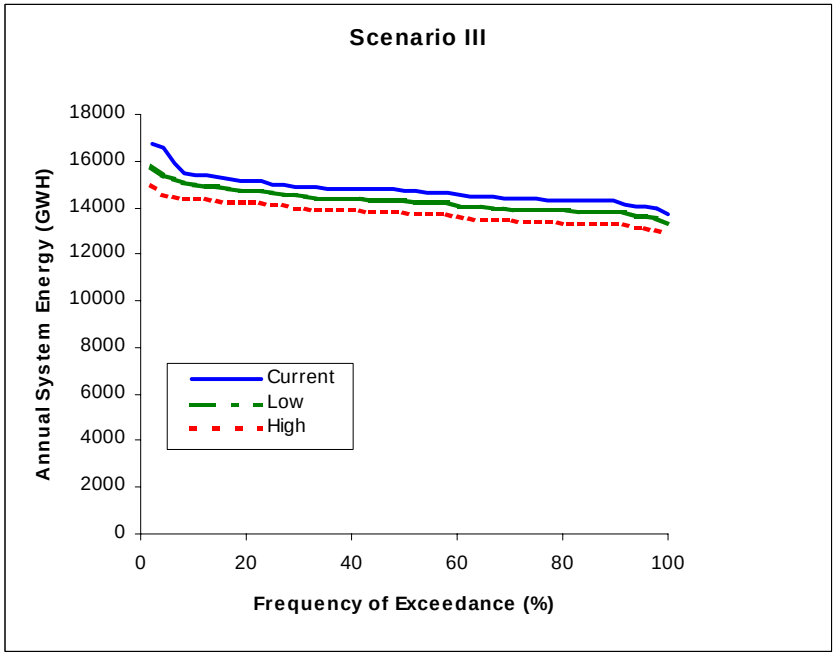

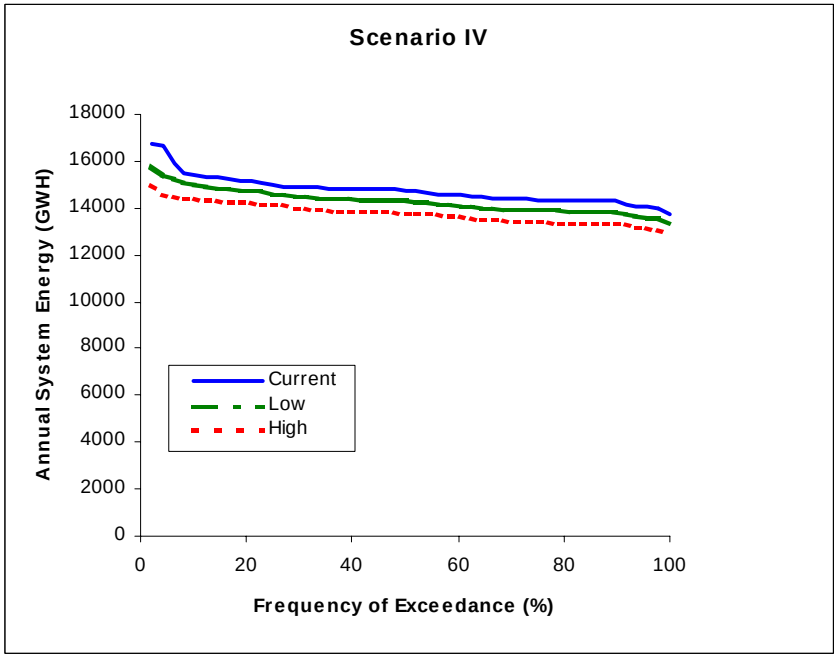

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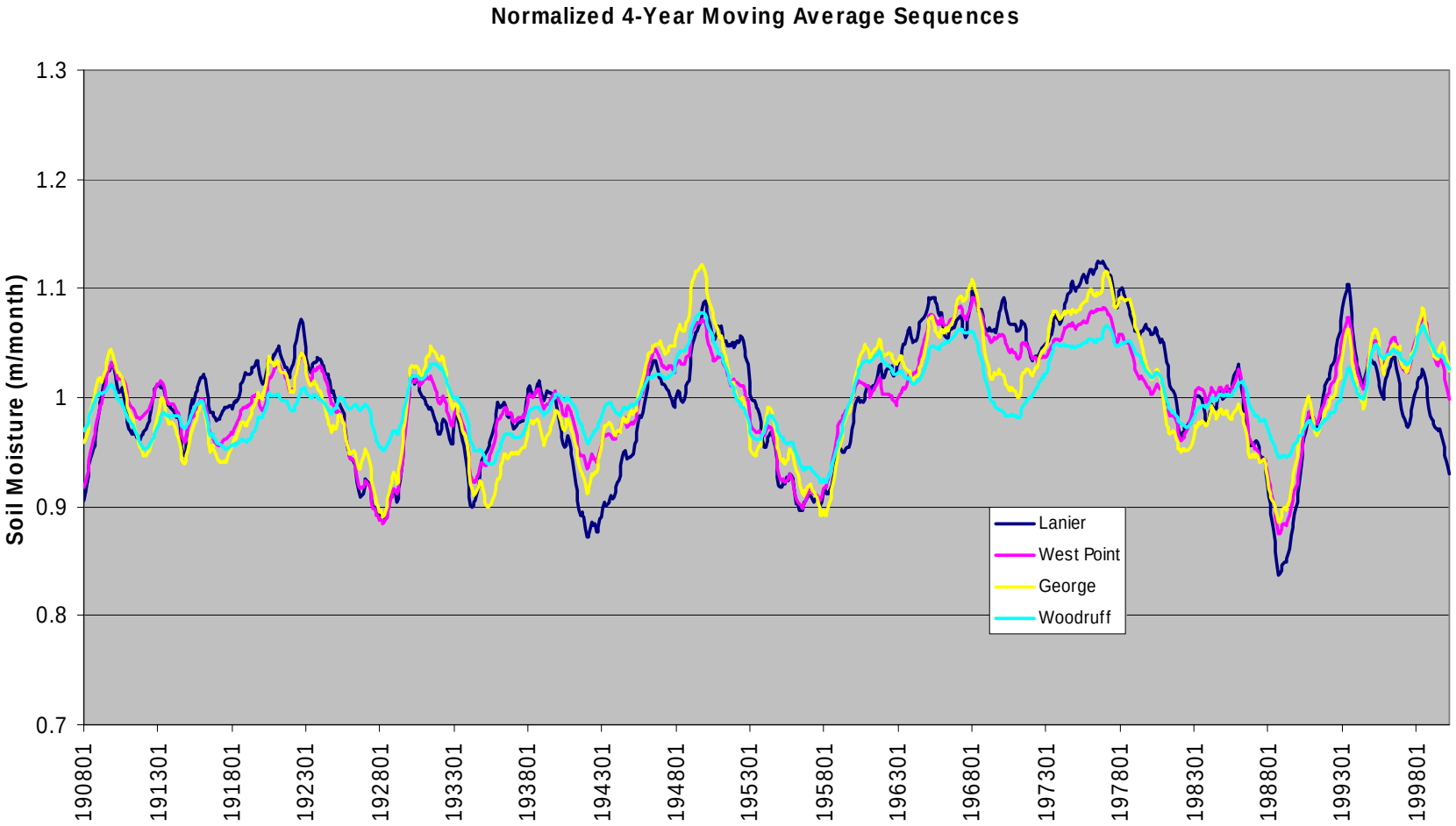
A Key Requirement of Climate Scenarios



In addition to seasonal and annual features, Climate Scenarios must be able to represent the *inter-annual* dry and wet cycles.

Soil Moisture Storage is a very good index of inter-annual climate variability.

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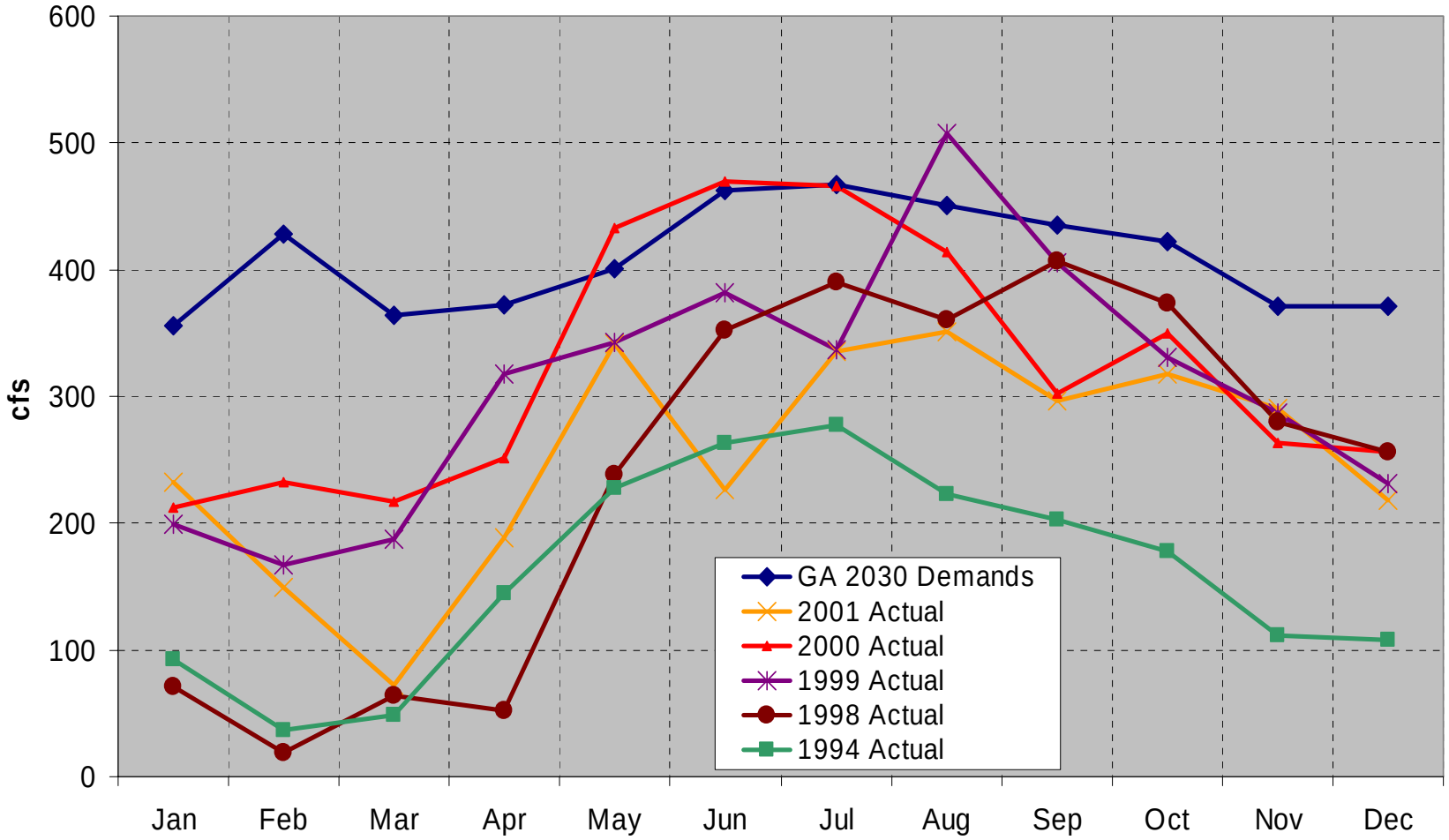
Municipal Water Demand Varies with Climate



Assessments must be based on municipal water use scenarios that are *consistent* with climate scenarios.

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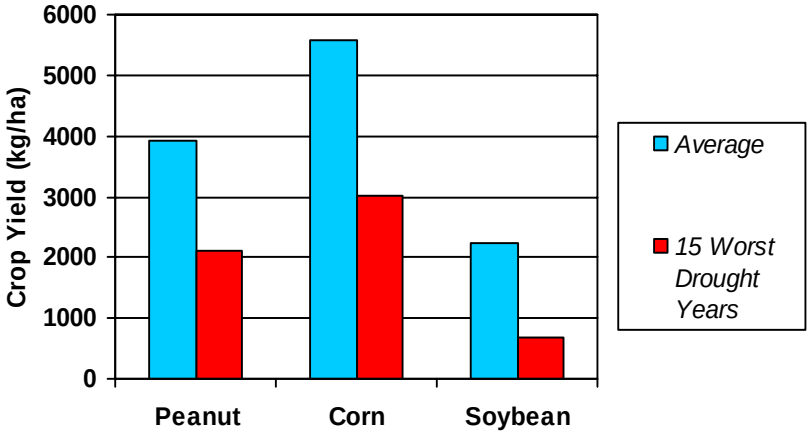
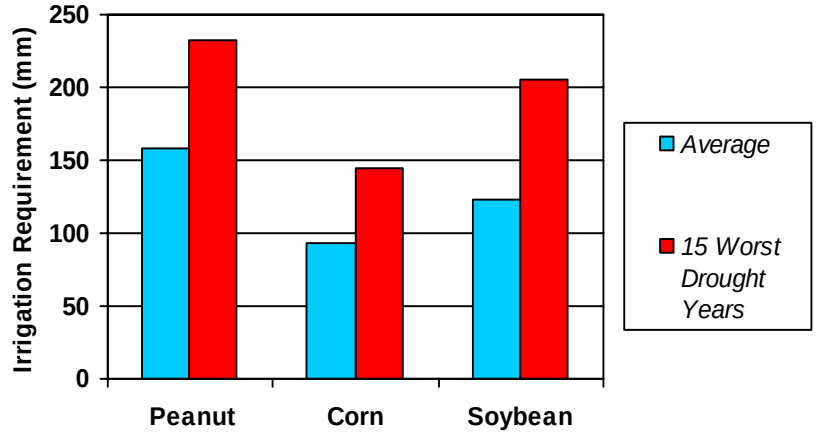
Agricultural Water Demand Varies with Climate

Reductions in Georgia Crop Yield during Droughts

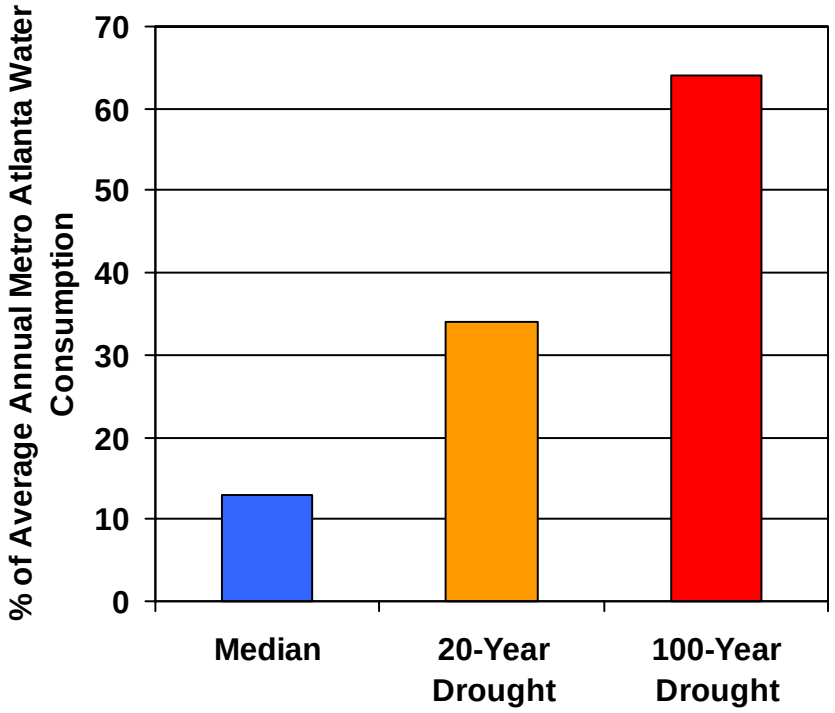


Increases in Georgia Irrigation Needs during Droughts



Source: J.E. Hook, UGA/NESPAL, Tifton, GA.

Comparison of Georgia Irrigation Requirements for Peanuts, Corn, and Wheat* (~36% of total acreage) versus Metro Atlanta Water Consumption



** Not included: Cotton, Watermelons, Orchard crops, Turf grass, and others*

Assessments must be based on agricultural water use scenarios that are *consistent* with climate scenarios.

Agricultural Climate Assessments: CGCM1

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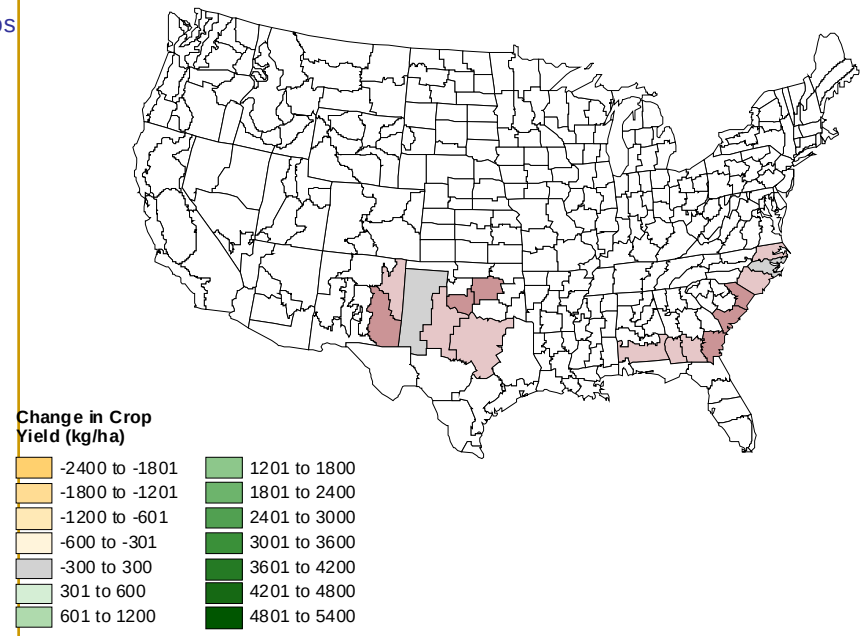
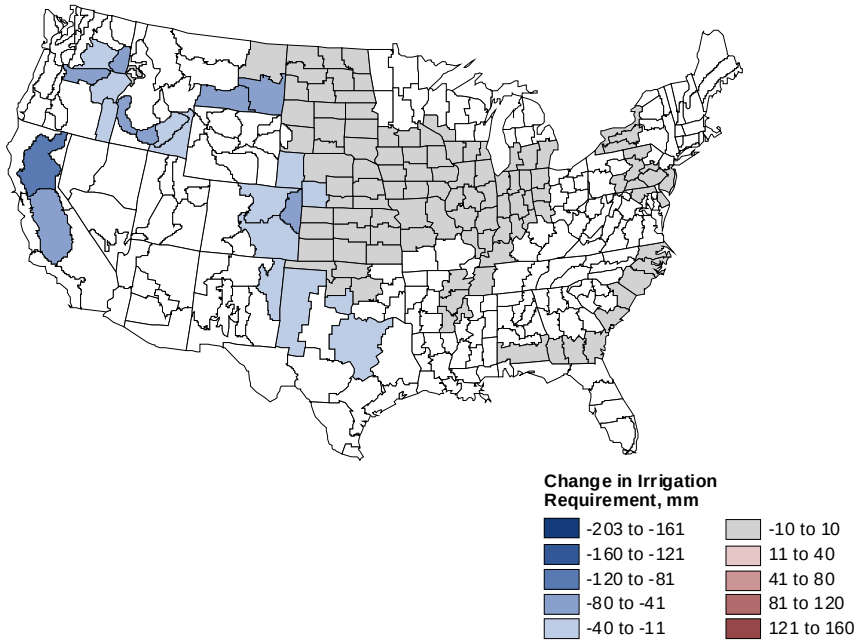
Change in Mean Irrigation Requirements for Peanuts



Change in Mean Irrigation Requirements for Corn



Change in Mean Crop Yield for Peanuts

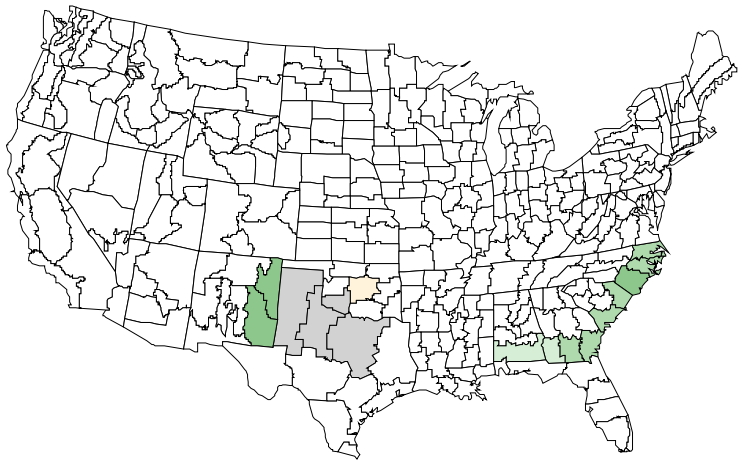


Figure GWRI-6a

Change in Mean Crop Yield for Corn

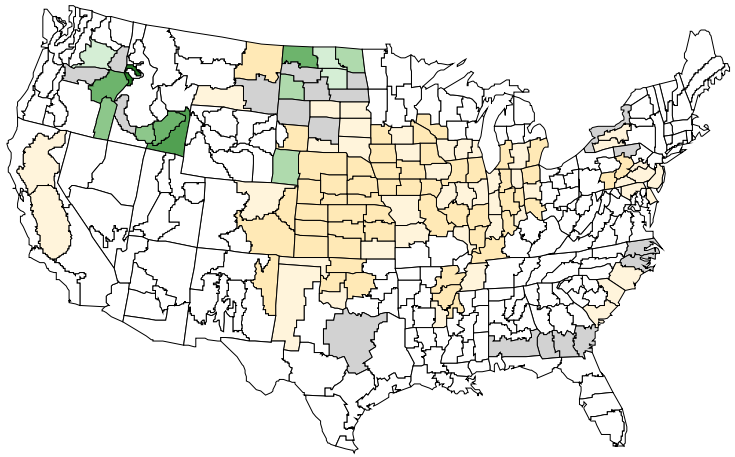


Figure GWRI-6e

(Source: Brumbelow and A. Georgakakos, 2000)

Agricultural Assessments: Lake Victoria

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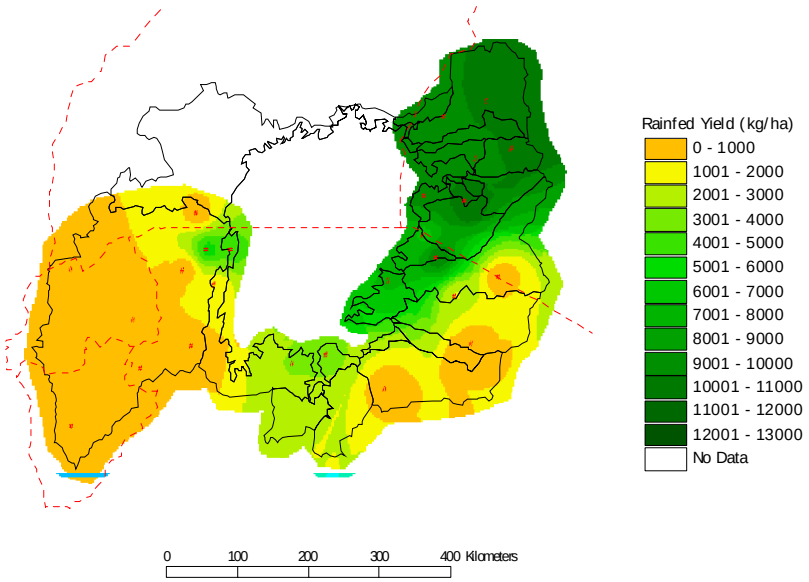
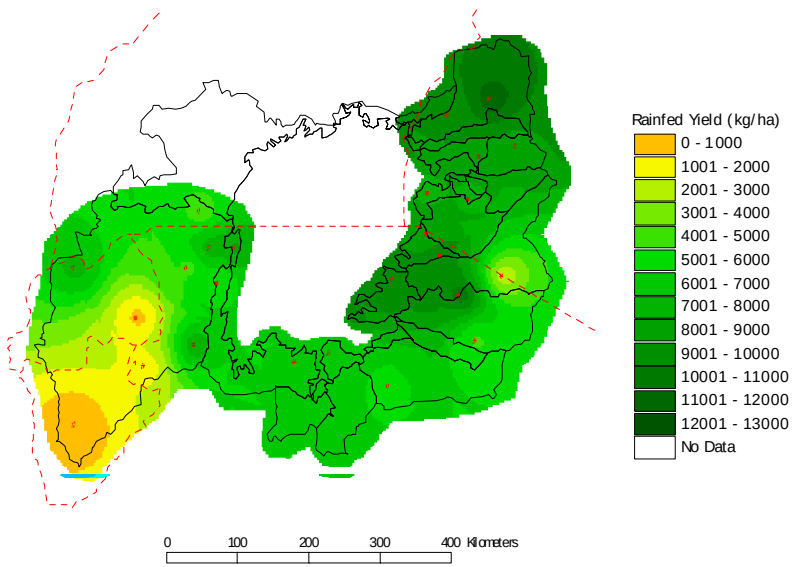
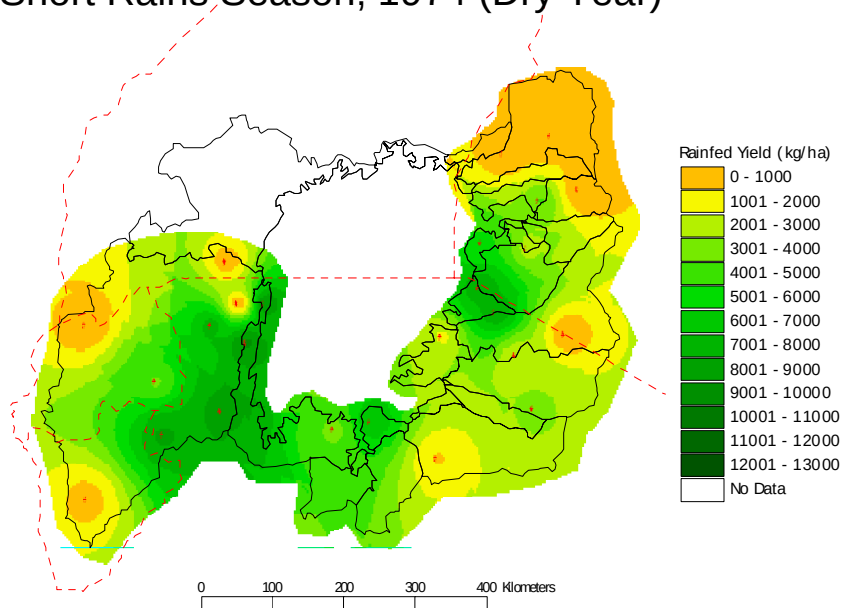
Long Rains Season; 1984 (Dry Year)



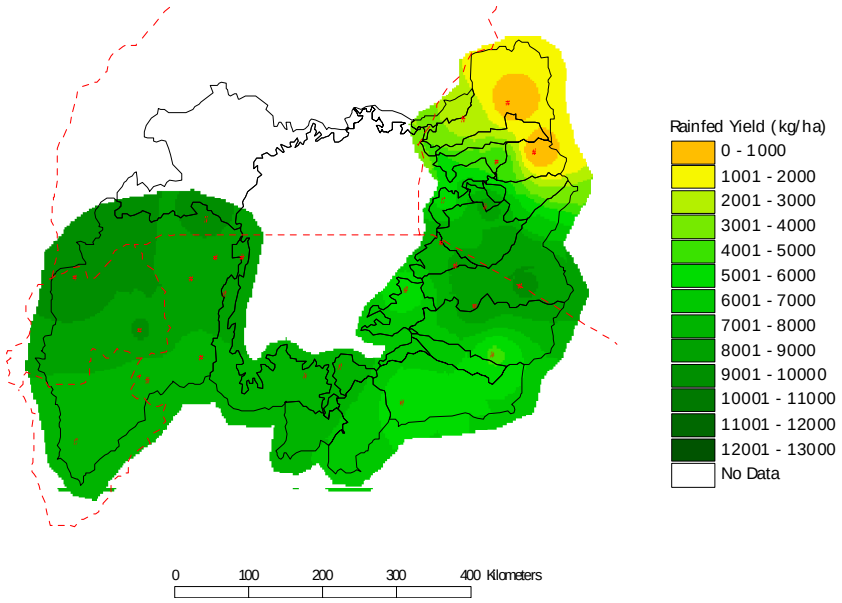
Long Rains Season; 1985 (Wet Year)



Short Rains Season; 1974 (Dry Year)



Short Rains Season; 1972 (Wet Year)



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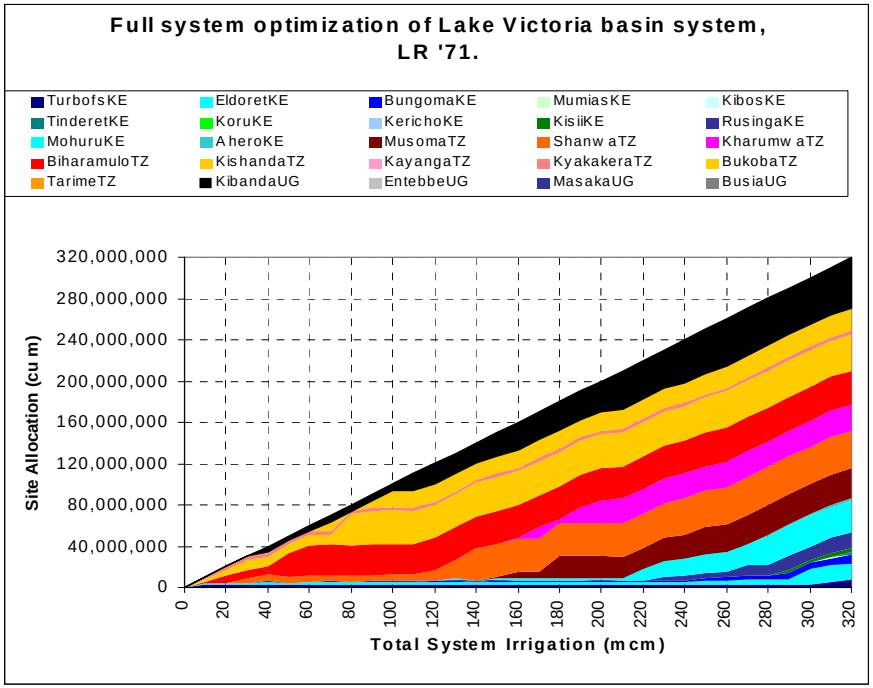
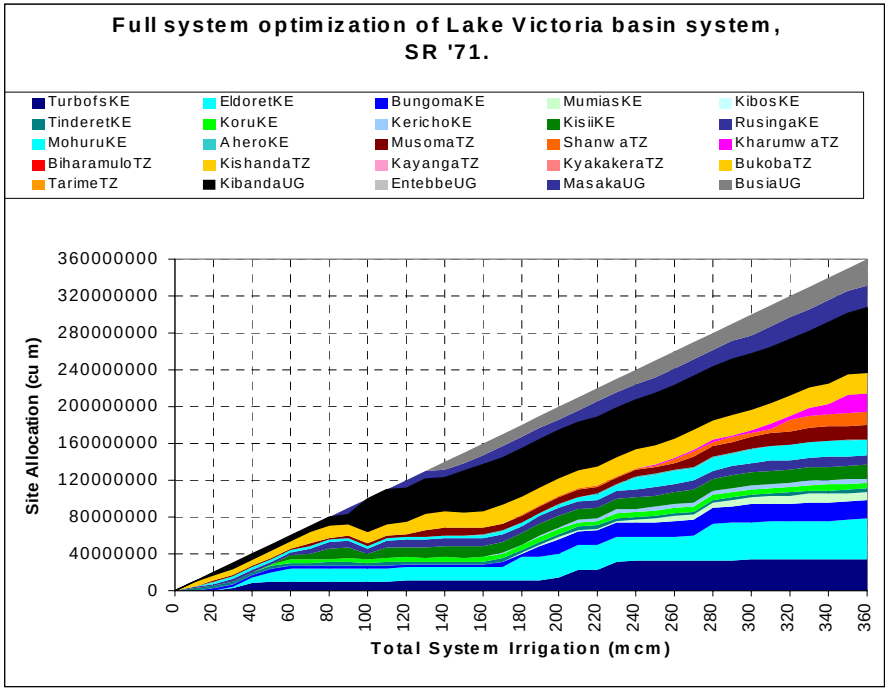
Agricultural Assessments – Water Sharing

Potential Water Sharing Strategies

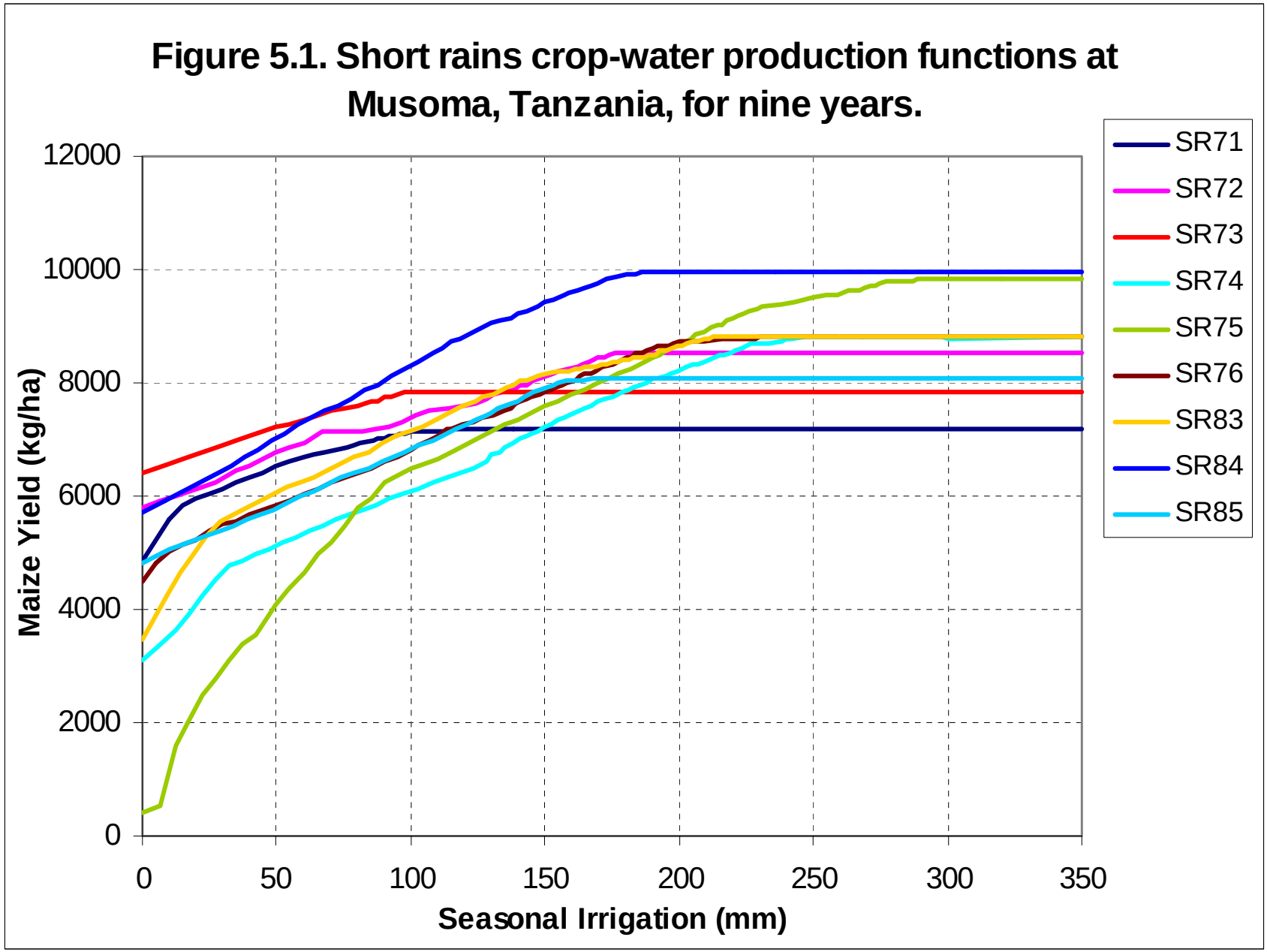
Full system optimization; Equal national water shares; Equal national irrigation benefits; Equal national crop production; Food supply security





Climate Scenarios must be downscaled so as to represent regional climatic features at scales finer than those of the GCMs.

Agricultural Assessments



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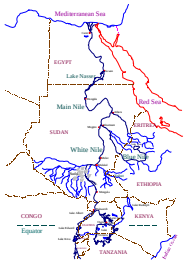
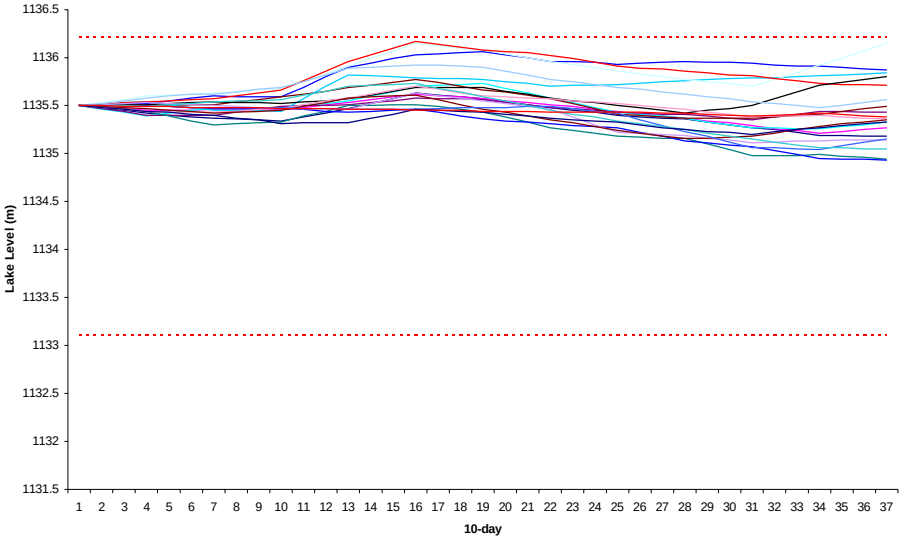
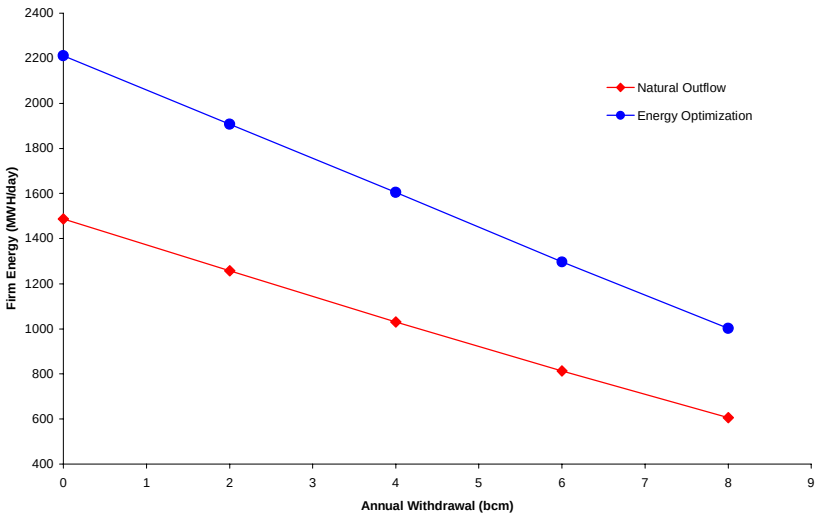
Hydropower vs. Irrigation Tradeoff







Climate Information is Useful for Agricultural Planning

Short Rains rainfed maize yield at Bungoma, Kenya:

Rank	Year	Rainfed Yield (kg/ha)	ENSO Condition
1	1984	7,085	EN + 1
2	1972	6,705	EN
3	1985	6,621	--
4	1973	5,966	EN + 1
5	1983	5,798	EN
6	1976	5,126	LN
7	1974	5,076	LN
8	1975	4,546	LN
9	1971	2,676	LN + 1

El Nino correlates with increased rainfall over Blue Nile basin during rainy season and increased rainfall over Lake Victoria basin in short rains. Opposite effect correlated with La Nina.

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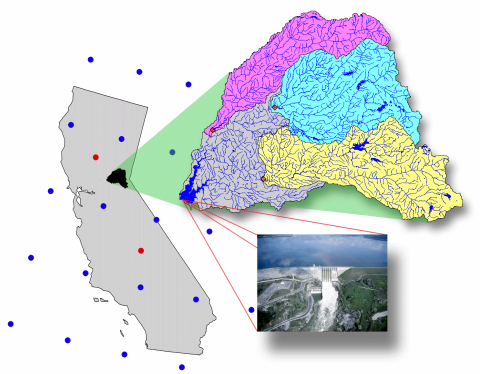
Rule-Based vs. Integrated Forecast-Control Management Forecast Uncertainty Characterization



Climate Projections, Uncertainty, & Scenarios for Impact Assessments

Assessments for Generated Future Climate (1% Annual CO_2 Increase)

Decision-Forecast Scheme		Reliability	Energy (GWH)	Energy Value (Million $)	Spillage (BCF)	Min. Flow Violations (Days)	Max. Flood Damage (Million $)
Rule Curve	**Ensemble Forecasts**	Deterministic	744.67	67.77	28.77	0	0
	Perfect Forecasts	Deterministic	746.22	67.90	28.53	0	0
DSS	**Ensemble Forecasts**	50%	780.99	70.93	30.06	0	4,275.20
		90%	846.23	76.68	16.83	0	0.00
	Perfect Forecasts	Deterministic	868.92	78.77	15.09	0	0.00

Integrated Forecast-Control approaches with uncertainty characterization can mitigate the adverse effects of climate variability and change more effectively than traditional rule-based methods.

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Climate Projections, Uncertainty, & Scenarios for Impact Assessments

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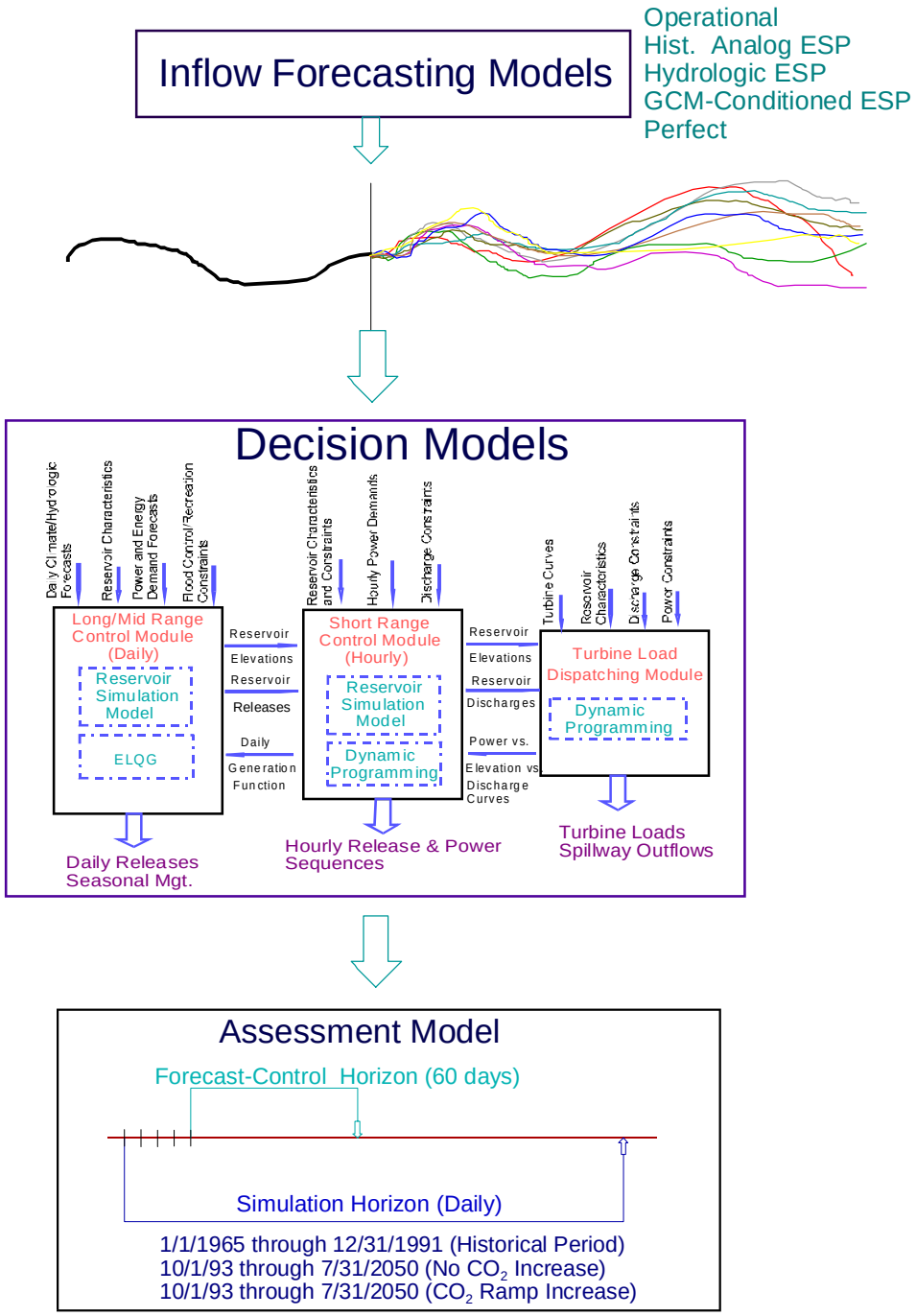
Integrated Forecast-Control Management Systems



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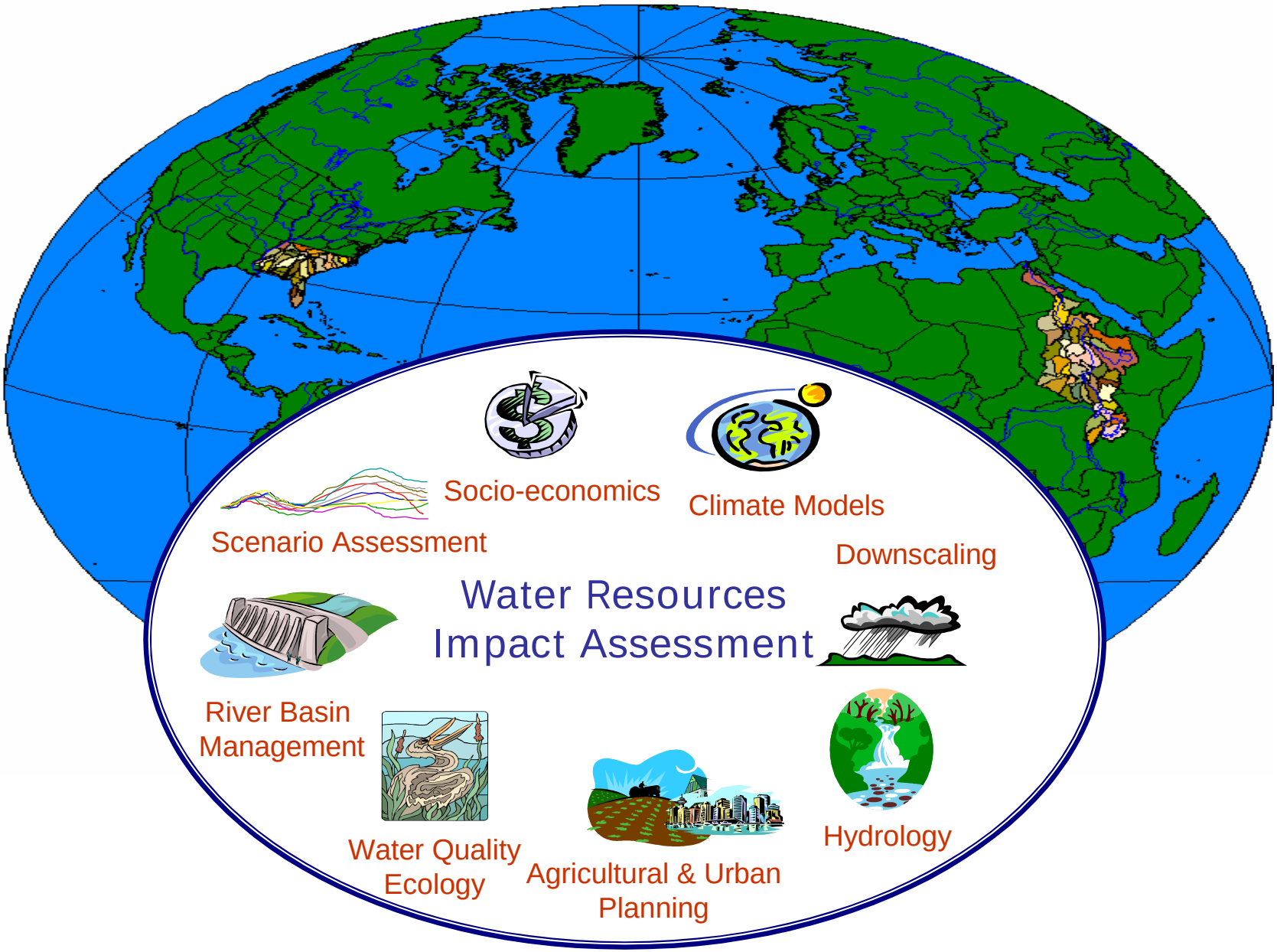
Integrated Impact Assessments

Climate
Projections,
Uncertainty, &
Scenarios
for Impact
Assessments



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Using Climate Information in Water Resources: Challenges and Opportunities

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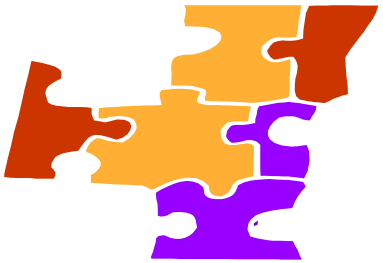

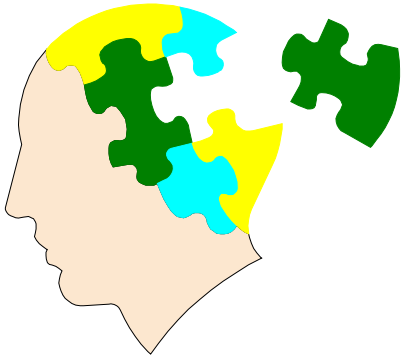

Technical

Understand the Ways in which Climate Influences Water Resources

Develop Integrated Impact Assessment & Decision Support Systems

Human Resources

Educate Scientists and Engineers (in Academia and Practice) in the Inter-disciplinary Aspects of Water Resources Assessments

Establish Demonstration Projects and Interdisciplinary Training & Education Programs

Institutional

Establish Shared-Vision Decision Processes

Facilitate Stakeholder Communication, Cooperation, and Access to Information