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

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“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
Case Studies: Southeastern US and East Africa

**Gulf Coast (AG):**
- **Area:** 58,263 sqkm
- **Area:** 50,767 sqkm
- **Latitude:** ~30 to 35°N
- **3 States**
- **Water Supply (Urban/Industry/Ag), Hydropower, Lake Recreation, Navigation, Environment, Ecosystems**

**Nile:**
- **Area:** 3,100,000 sqkm
- **Latitude:** ~5°S to 32°N
- **10 Countries**
- **Water Supply (Urban/Ag), Hydropower, Environment, Ecosystems**
Water Resources Assessments

Forecast-Control Horizon

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

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

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

Legend
- Lake / Reservoir
- Inflow Forecasting
- River / Reservoir Simulation
- Lake / Reservoir Optimization
- Management Policy
- One-Step System Simulation

Streamflow Scenario
- Historical / Future

Monthly Water Demand for Year 2050, Chattahoochee River

ACTACF

Water Resources Assessments are Based on Historical Climates, Simple Simulation Methods, & Historical Demand Projections
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
Climate Model Cells over the ACT and ACF Basins

Hadley (HadCM2)

ECHAM3

Canadian (CGCM1)
Future Climate Assessment: Lake Levels; CGCM1
Future Climate Assessment: Lake Levels; HadCM2

Climate Projections, Uncertainty, & Scenarios for Impact Assessments

Aris Georgakakos

17-19 July 2002
**Historical & Future Climate Assessments: Water Supply**

### 1-Yr Flow Target

- **Total Withdrawal Deficit (1-Year Min. Target)**

### 5-Yr Flow Target

- **Total Withdrawal Deficit (5-Year Min. Target)**

#### Historical

#### Canadian (CGCM1)

#### Hadley (HadCM2)
### Historical & Future Climate Assessments: Hydropower

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

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

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

<table>
<thead>
<tr>
<th>Min. Target</th>
<th>Energy (GWH)</th>
<th>Buford</th>
<th>West Point</th>
<th>George</th>
<th>Woodruff</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-year</td>
<td>Primary</td>
<td>23</td>
<td>19.89</td>
<td>35.76</td>
<td>8.61</td>
<td>87.26</td>
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<tr>
<td></td>
<td>Secondary</td>
<td>83.15</td>
<td>111.7</td>
<td>248.66</td>
<td>182.76</td>
<td>626.27</td>
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<tr>
<td></td>
<td>Sum</td>
<td>106.15</td>
<td>131.59</td>
<td>284.42</td>
<td>191.37</td>
<td>713.53</td>
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<tr>
<td></td>
<td>Reliability (%)</td>
<td>95.09</td>
<td>94.86</td>
<td>95.88</td>
<td>100</td>
<td>94.86</td>
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<tr>
<td>5-Year</td>
<td>Primary</td>
<td>19.63</td>
<td>18.27</td>
<td>33.87</td>
<td>8.41</td>
<td>80.18</td>
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<td>Secondary</td>
<td>82.79</td>
<td>111.08</td>
<td>249.91</td>
<td>181.7</td>
<td>625.48</td>
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<tr>
<td></td>
<td>Sum</td>
<td>102.42</td>
<td>129.35</td>
<td>283.78</td>
<td>190.11</td>
<td>705.66</td>
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<tr>
<td></td>
<td>Reliability (%)</td>
<td>92.16</td>
<td>90.14</td>
<td>92.27</td>
<td>100</td>
<td>90.14</td>
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</table>
### Table 1: Nile Basin Water Development and Management Scenarios

#### System Configuration

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Current Condition</th>
<th>Full Development in Eastern Nile (Ethiopia/Sudan)</th>
<th>Full Development in Southern Nile (Wetland Projects + Eq. Lake Regulation)</th>
<th>Basinwide Cooperation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario I</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario II</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario III</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Scenario IV</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**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)

<table>
<thead>
<tr>
<th></th>
<th>Eq. Lake Region</th>
<th>Sudan</th>
<th>Ethiopia/Eritrea</th>
<th>Egypt</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current Condition</strong></td>
<td>0</td>
<td>18.5</td>
<td>0</td>
<td>55.5</td>
</tr>
<tr>
<td><strong>Low Demand Increase</strong></td>
<td>2.5</td>
<td>21</td>
<td>10</td>
<td>58</td>
</tr>
<tr>
<td><strong>High Demand Increase</strong></td>
<td>5</td>
<td>23.5</td>
<td>20</td>
<td>60.5</td>
</tr>
</tbody>
</table>
Nile-DST Assessment Example; Scenario IV; Current Demands

Lake Victoria

Karadobi

Sennar

HAD
Nile-DST Water Supply Deficits (Annual Average)

1. Water Deficit; Annual Averages; Current Demand

2. Water Deficit; Annual Averages; Low Demand Increase

3. Water Deficit; Annual Averages; High Demand Increase
Nile-DST Assessment Example: Eq. Lake Energy Statistics

Scenario I

Scenario II

Scenario III

Scenario IV

Frequency of Exceedance (%)

Annual System Energy (GWH)

Current

Low

High

Frequency of Exceedance (%)

Annual System Energy (GWH)

Current

Low

High

Frequency of Exceedance (%)

Annual System Energy (GWH)

Current

Low

High

Frequency of Exceedance (%)

Annual System Energy (GWH)

Current

Low

High

Climate Projections, Uncertainty, & Scenarios for Impact Assessments

17-19 July 2002
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.
Assessments must be based on municipal water use scenarios that are *consistent* with climate scenarios.
Agricultural Water Demand Varies with Climate

Reductions in Georgia Crop Yield during Droughts

Increases in Georgia Irrigation Needs during Droughts

Comparison of Georgia Irrigation Requirements for Peanuts, Corn, and Wheat

(~36% of total acreage) versus Metro Atlanta Water Consumption

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

Source: J.E. Hook, UGA/NESPAL, Tifton, GA.
Agricultural Climate Assessments: CGCM1

Change in Mean Irrigation Requirements for Peanuts

Change in Mean Irrigation Requirements for Corn

Change in Mean Crop Yield for Peanuts

Change in Mean Crop Yield for Corn

Figure GWRI-6a

Figure GWRI-6e

(Source: Brumbelow and A. Georgakakos, 2000)
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

Figure 5.1. Short rains crop-water production functions at Musoma, Tanzania, for nine years.
Hydropower vs. Irrigation Tradeoff

Climate Projections, Uncertainty, & Scenarios for Impact Assessments

1131.5 1132 1132.5 1133 1133.5 1134 1134.5 1135 1135.5 1136 1136.5

Lake Level (m)

0 1 2 3 4 5 6 7 8 9

10-day

1136 1136.5 1137 1137.5 1138 1138.5

Firm Energy (MWH/day)

2000 2200 2400 2600 2800 3000 3200 3400 3600 3800 4000 4200 4400

0 1 2 3 4 5 6 7 8 9

Annual Withdrawal (BCM)

Natural Outflow

Energy Optimization

Hydropower vs. Irrigation Tradeoff

Climate Projections, Uncertainty, & Scenarios for Impact Assessments
Climate Information is Useful for Agricultural Planning

Short Rains rainfed maize yield at Bungoma, Kenya:

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

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.
Rule-Based vs. Integrated Forecast-Control Management

Forecast Uncertainty Characterization

Assessments for Generated Future Climate (1% Annual CO₂ Increase)

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

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

Inflow Forecasting Models

Operational
Hist. Analog ESP
Hydrologic ESP
GCM-Conditioned ESP
Perfect

Decision Models

Long/Mid Range
Control Module (Daily)
Reservoir Simulation
Model
ELOG

Short Range
Control Module (Hourly)
Reservoir Simulation
Model
Dynamic Programming

Turbine Load
Dispatching Module

Assessment Model
Forecast-Control Horizon (60 days)
Simulation Horizon (Daily)
1/1/1965 through 12/31/1991 (Historical Period)
10/1/93 through 7/31/2050 (No CO₂ Increase)
10/1/93 through 7/31/2050 (CO₂ Ramp Increase)
Integrated Impact Assessments

Water Resources Impact Assessment

- Scenario Assessment
- Socio-economics
- River Basin Management
- Water Quality Ecology
- Agricultural & Urban Planning
- Hydrology
- Climate Models
- Downscaling
Using Climate Information in Water Resources: Challenges and Opportunities

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 Interdisciplinary 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