Climate Variability and Forecasting Water (Supply) and Energy (Demand) Attributes

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Background

• Hydroclimate Variability – Seasonal to Interannual
  – Structured Interannual and Longer Variations
  – Climate Variability & Seasonal Forecasts Water and Energy Management
  – Water Quality Forecasts

• Hydroclimate Change – Long-term Planning
  – Increased CO\textsubscript{2} concentration and population growth; Non-stationary hydroclimatology
  – Near-term Climate Change & Uncertainty Reduction
  – System Design, Capacity Expansion, Water Use and Ecological Impacts
Large Scale Hydroclimatology & Water Management

Climatic Indices

Land Surface Indices

Understanding & Monitoring of Large Scale Hydroclimatic Systems

Hydrologic Fluxes Estimation
- Modeling
- Forecasting

Water Management
- System Design
- Impact/Assessment
- Allocation/Operation
Climate-Information based Water Management
Streamflow and Reservoir Storage Forecasts
Forecasting Seasonal Floods and Streamflow volumes – Two Approaches

General Circulation Model

“Downscaling” Regional Climate Model

Hydrologic Model

Exogenous Climate Predictors

Statistical Model

Forecasts of Reservoir Inflows and Flood Flows
Geographical Location of the Philippines
Hydroclimatology

Streamflow (in hm3)

Rainfall (mm)

JJAS – 30%
OND – 46%

3-months lag correlation

\( \rho(\text{Nino3.4}, Q_{\text{JJAS}}) = -0.20 \)
\( \rho(\text{Nino3.4}, Q_{\text{OND}}) = -0.51 \)
High OND Predictability
Critical Months for Water Management

Number of years of spills

Months

JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
Association with ENSO conditions
1997-98 ENSO Impacts

The Angat Reservoir during the 1997-98 El Nino (September 12, 1998 – RWL = 158.15 m AMSL)
Current Operation

ANGAT H.E. PLANT

ELEVATION (m)

IRI Forecast for OND 1998

Map A October - December 1998

Key
Percentage likelihood of:
A  Above-normal rainfall
N  Near-normal rainfall
B  Below-normal rainfall

produced October 1998
Retrospective AGCM Precipitation Forecasts

- **ECHAM 4.5**
  - Forced by Persisted SST
  - Provides 12 ensemble member
  - Forecast issued for 5 months every month
Forecast Precipitation Vs Streamflow

$\rho(P_F, Q_{obs}) : 0.51$

ONDJF
Empirical Orthogonal Function Analysis

$P(x,y,t) = \sum_{k=1}^{N} PC(t) \cdot EOF(x,y)$

$P(x,y,t)$ – Precipitation

$PC(t)$ – Principal Component time series

$EOF(x,y)$ – Orthogonal functions – accounting for temporal variations in $P(x,y,t)$
ONDJF Forecast - October

\[ \rho(Q_{\text{pred}}, Q_{\text{obs}}): 0.58 \]
Forecast – Issued October

Streamflow (MCM)

Year

October

December

November

February
Forecast Performance - October

Correlation vs Months

Oct, Nov, Dec, Jan, Feb
Forecasts – Updated Every Month
Performance - updated Forecasts

Use of Updated Forecasts

Correlation vs Months

- Oct
- Nov
- Dec
- Jan
- Feb
Ensemble Generation

\( X \) – October  \( Y \) – November

\( I \) = Forecast issuing month, October

\( \mu^i_X = \mathbb{E}^i(Q_t|PC_t); \)

\( \sigma^i_X = \sigma^i(Q_t|PC_t) \)

\( \mu^i_Y = \mathbb{E}^i(Q_{t+1}|PC_{t+1}); \)

\( \sigma^i_Y = \sigma^i(Q_{t+1}|PC_{t+1}) \)

\( \rho_1 \) = Climatology lag-1 correlation between October and November flows
Adaptive Water Allocation Model

- Reservoir Inflow Forecasts Ensembles
- Water Contracts Specification
- Water Allocation Model for Bulk Sector contracts
  - Simulation – Optimization Model
**Objective Function:**
Maximize the net value from contracts and surplus water provision

Subject to

- \( P(W_i \geq W_i^*) \leq p_{fi} \) - Contract Level Constraint
  For Industry, at a reliability \( (1-p_{fi}) = 90\% \), \( P(W_i \geq 500) \leq 0.10 \)

- \( P(S_T \leq S_T^*) \leq p_s \) - End of the Year Storage Constraint
  For \( S_T^* = 500 \text{ hm}^3 \) and \( (1-p_s) = 75\% \), \( P(S_T \leq S_T^*) \leq 0.25 \)

- \( P(RL_j) \leq p_{rj} \) - Reservoir Level Constraint
  For Restriction Level 1, \( P(RL_1) < 0.25 \); \( p_{r1} \) – Restriction level 1 prob.
  Similarly for level 2, \( P(RL_2) < 0.10 \); \( p_{r2} \) – Restriction level 2 prob.
Reservoir Simulation
(for each ensemble ‘k’)

• Inflow Forecast: \( q_{tk}; \ t=1\ldots,T; \ k=1\ldots,N \)

• Continuity Equation: \( t=1,2, \ldots, T \)

\[
S_t = S_{t-1} + q_t - E_t - \sum_{i=1}^{n} R_{ti}
\]

• \( SD_t = -S_t \ | \ S_t < 0 \) (Account the Deficit)

• \( R_{ti} = \beta_{ti} R_i \) (Target Release for each user)

• Evaporation \( E_t = \psi_t \delta_1 ((S_t + S_{t-1})/2)^{\delta_2} \)
Revisiting ONDJF Operation

- **Constraint 1**: Ensure that the net storage at the end of February will be equal to 568.7 hm³ (based on upper rule curve)
- **Goal 1**: Assume that the current priority in water allocation is honored: 1<sup>st</sup> MWSSB; 2<sup>nd</sup> Irrigation (NIA); 3<sup>rd</sup> Hydropower (NAPCOR)
- **Allow reservoir levels to go below upper and lower rule curves during ONDJF, but always above the upper rule curve in February.**
Retrospective Analyses – October Forecast

• Period considered for analyses: 1987-2001

• Use the ONDJF forecasts issued in October to setup water allocation for the season
  – Ensure current priority and February target storage by 99% reliability.

• Make ONDJF allocation for each use (90% reliability) based on October forecast
  – Perform simulation by ensuring current priority and February target storage
Retrospective Analyses – Updated Forecast

• Revisit reservoir operation every month based on the updated streamflow forecasts so that February target is maintained.
  – If updated forecasts suggests drier conditions than October forecast, reduce October allocation based on priority
  – Always ensure priority and February target storage reliability
  – Initial condition: Use the updated storage conditions by simulating the reservoir with the observed flow using the previous month updated allocation policy
  – Not using the actual observed storage in the beginning of the month
Retrospective Analyses – Forecast Validation

• **October Forecast Evaluation**
  – Combine it with the observed flow during October-February
  – Account shortfall, spill, evaporation, net release and hydropower generated for each month

• **Updated Forecast Evaluation**
  – Initial condition: Use the updated storage conditions by simulating the reservoir with the observed flow using October/updated allocation policy
  – Combine the above initial condition with the observed flow from the current month to February
  – Account shortfall, spill, evaporation, net release and hydropower generated for each month
Water Demand

• February Target: 568.7 hm³
• Municipal ONDJF demand – 567.5 hm³
  – Monthly: 113.5 from October – February
• Irrigation ONDJF demand – 385 hm³
  – Monthly: 154 hm³ (Oct); 77 hm³ (Nov-Feb)
• Hydropower ONDJF Demand – 2890 hm³
  – Monthly: 578 hm³
• Irrigation water goes through main turbine, Manila water goes through auxiliary turbine.
Decision Analyses

• Performance under October Forecast
• Comparison with the updated forecasts
  – In meeting target storage in February
  – Reservoir Performance
• Scenario I: Operation during surplus months
  – Maximizing hydropower generation
• Scenario II: Operation during drier years
  – Delay Irrigation practice by two months (December) if we cannot allocate water in October
Performance of October Forecast

The graph shows the performance of October forecast with the years ranging from 1987 to 2001. The x-axis represents the year, and the y-axis represents the October Allocation in hm3. The graph includes lines for Municipal, Irrigation, Hydropower, and Observed Inflow, as well as M&I target and Irrigation target. The Observed Flow is indicated by a blue line, and the Observed Inflow is shown at the top right corner.
Meeting February Target Storage

![Graph showing February storage target over years (1989, 1991, 1997) with forecast issued in October, November, December, January, and February.](Image)
Hydropower Allocation

Allocation for Hydropower (in hm³)

Year

October - Updated Forecast

November
December
January
February
Spill Volume Reduction

- **Actual**
- **Updated Forecast**
- **October Forecast**

<table>
<thead>
<tr>
<th>Years</th>
<th>Spill Volume (in hm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td></td>
</tr>
<tr>
<td>1989</td>
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<td>1999</td>
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<td>2001</td>
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</table>

Spill Volume (Max Hydro)

- **Actual**
- **Updated Forecast**
- **October Forecast**
- **Observed Inflow**

Spill Volume (in hm$^3$)

Years

Increased Hydropower

![Graph showing hydropower generation over years, with lines for actual, updated forecast, and October forecast, and points for observed values. The graph compares observed inflow and hydropower generated in GWH, with years from 1987 to 2001.]
Meeting Target Storage during Drought Conditions (100 cfs) and the Utility of Multimodel Forecasts (Golembesky et al., 2008)
Enforcing Restrictions based on the Estimates of $P(S_T < S^*_T)$

Risk  Restrictions
0.5 – 0.6  10%
0.6 – 0.7  20%
0.7 – 0.8  30%

Resampling – Missed Target in 2005
Regression – False Alarm in 2004
Multimodel suggests restrictions in BN years
Reduced model uncertainties
Improves confidence in using forecasts
Streamflow and Storage Forecasts Portal

http://www.nc-climate.ncsu.edu/water/map
Streamflow (HCDN basins) and Soil Moisture (Gridded) Forecasts for the Southeast

- Precipitation Forecasts (GCM)
  - 2.8° Spatial Scale
  - Monthly Temporal Scale

- Spatial Downscaling
  - Temporal Disaggregation

- Climatological Forcings (exceeding Precipitation)
  (e.g., Wind, Solar Radiation, Pressure, etc.)

- Updated NLDAS2 Conditions

- NASA LIS

- Monthly to Seasonal Streamflow Forecasts
Streamflow Forecasts for HCDN basins
Climate-Information based Power Demand Forecasts
TN and TX Power Systems

Cawthorne et al., (2015), ERL, in review
Growth, Development and Power Demand

\[ R^2 = 0.71 \]

\[ R^2 = 0.70 \]

\[ R^2 = 0.61 \]

\[ R^2 = 0.544 \]
Power Demand Residuals vs Temperature

Residuals of TN Baseload vs. Population (TWh)
- JFM Minimum Temperature (F)
  - $R^2 = 0.25$

Residuals of TN Baseload vs. Population (TWh)
- JAS Maximum Temperature (F)
  - $R^2 = 0.42$

Residuals of TX Baseload vs. Population (TWh)
- JFM Minimum Temperature (F)
  - $R^2 = 0.42$

Residuals of TX Baseload vs. Population (TWh)
- JAS Maximum Temperature (F)
  - $R^2 = 0.31$
Power Demand Residuals vs Forecasted Temperature

**Residuals of TN Baseload vs. Population (TWh)**

CFS Forecast JFM Average Temperature (F)

- $R^2 = 0.15$

**Residuals of TN Baseload vs. Population (TWh)**

CFS Forecast JAS Average Temperature (F)

- $R^2 = 0.61$

**Residuals of TX Baseload vs. Population (TWh)**

CFS Forecast JFM Average Temperature (F)

- $R^2 = 0.53$

**Residuals of TX Baseload vs. Population (TWh)**

CFS Forecast JAS Average Temperature (F)

- $R^2 = 0.42$
Table 1 - Correlation between observed average temperature and forecasted average temperature from two atmospheric GCM forecasts, CFS and ECHAM 4.5, for the winter and summer seasons.

<table>
<thead>
<tr>
<th>Season</th>
<th>Tennessee</th>
<th>Texas</th>
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<tr>
<td></td>
<td>CFS Forecast</td>
<td>ECHAM4.5 Forecast</td>
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<tr>
<td>JFM</td>
<td>0.587</td>
<td>0.566</td>
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<tr>
<td>JAS</td>
<td>0.865</td>
<td>0.821</td>
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Hydroclimate, Water and Energy Management (NSF-CyberSEES)

Streamflow Forecasts – Multi-reservoir
Power Demand Forecasts – Power System (TEMOA)
Combined Optimization

TVA System
Insights from Retrospective Analyses

• Analyses from six reservoir systems
  – Three from the US and Three international basins

• For seasonal forecasts to be useful
  – Initial storage should constrain the allocation
  – If not, 100% reliability; Most systems belong to this category, since reservoirs are designed to reduce the variability and ensure reliability of supply.

• Use end of season target storage constraint
  – If initial storage does not constrain allocation
  – If skill is good only during a particular season
  – To enforce restrictions for below normal conditions
  – To reduce spillage and increase allocation (primarily hydropower) for above normal conditions
Insights from Retrospective Analyses

• Perspectives from Forecasting
  – Update the forecasts within the season (very beneficial for hydropower systems)
  – Multimodel climate forecasts are better, since it reduces overconfidence of individual models

• Forecasts are more useful than climatology
  – Within year storage systems (typically humid basins) than over year (arid basins) systems
  – Reducing system losses (spill and evaporation)
  – Systems with low storage/annual demand ratio
  – Multiple uses constraining the allocation process