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

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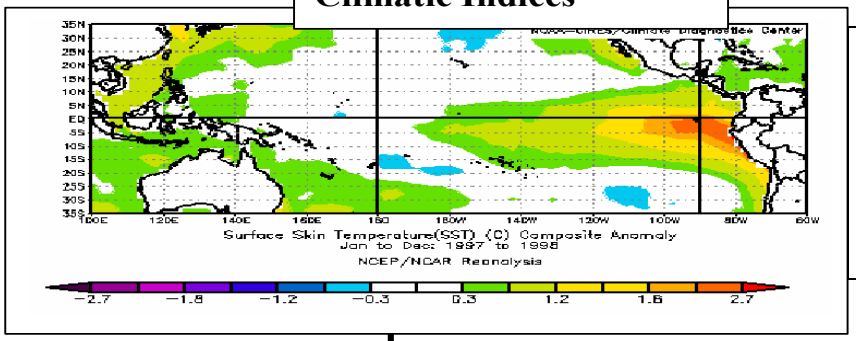
Background

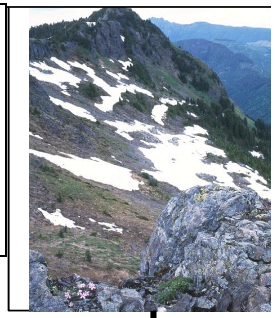
- **Hydroclimate Variability – Seasonal to Interannual**
  - Structured Interannual and Longer Variations
  - Climate Variability & Seasonal Forecasts Water and Energy Management
  - Water Quality Forecasts
- **Hydroclimate Change – Long-term Planning**
  - Increased CO_2 concentration and population 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

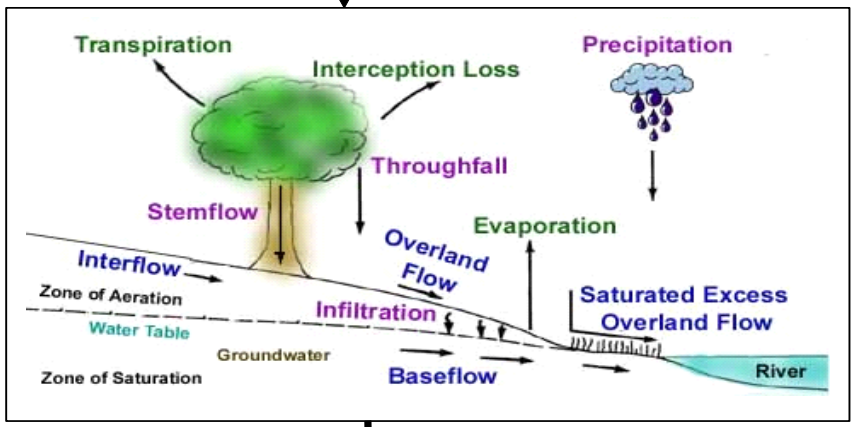


Land Surface Indices



Understanding & Monitoring of Large Scale Hydroclimatic Systems

Hydrologic Fluxes Estimation
- **Modeling**
- **Forecasting**

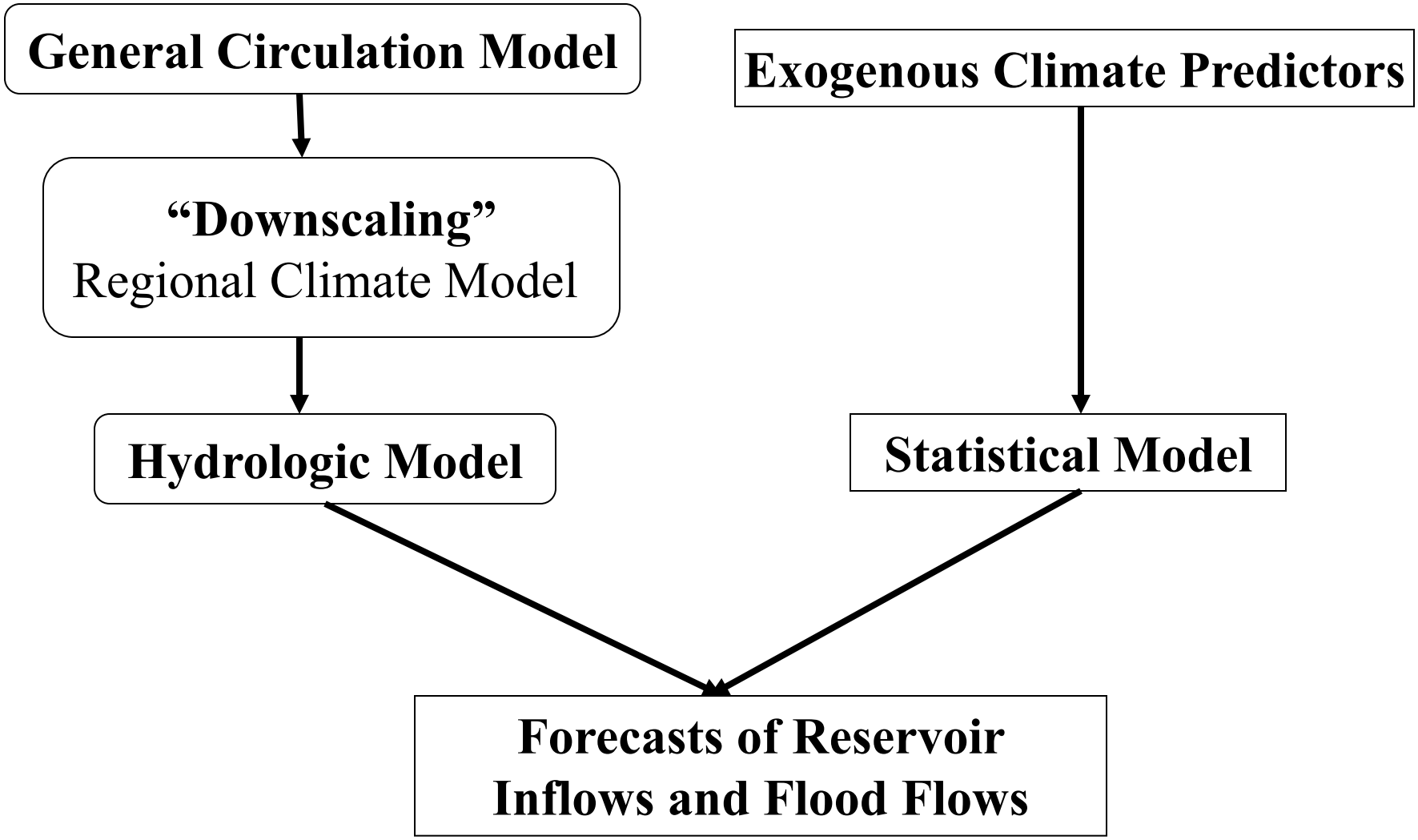


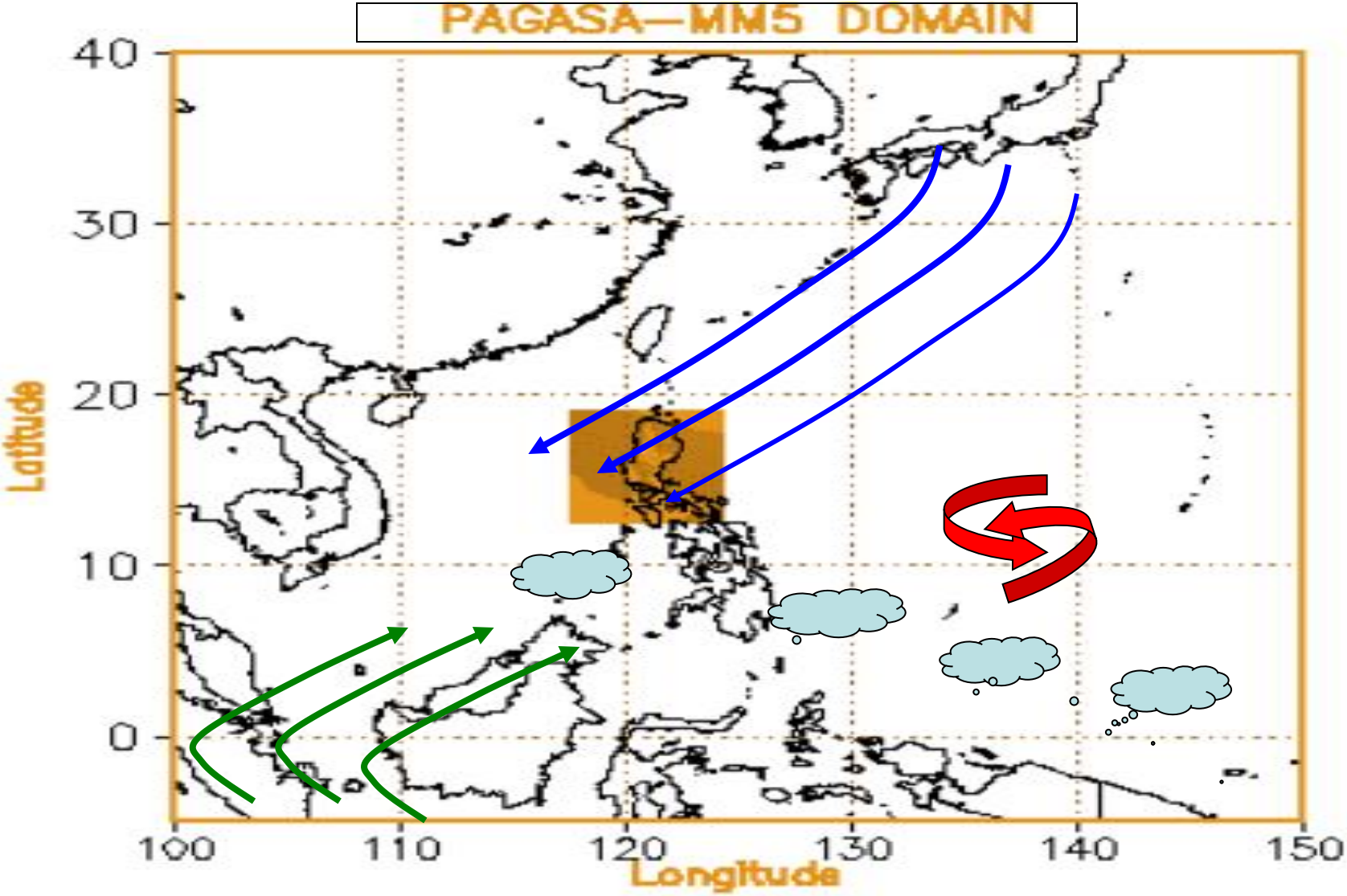
Water Management
- **System Design**
- **Impact/Assessment**
- **Allocation/Operation**

Climate-Information based Water Management

Streamflow and Reservoir Storage Forecasts

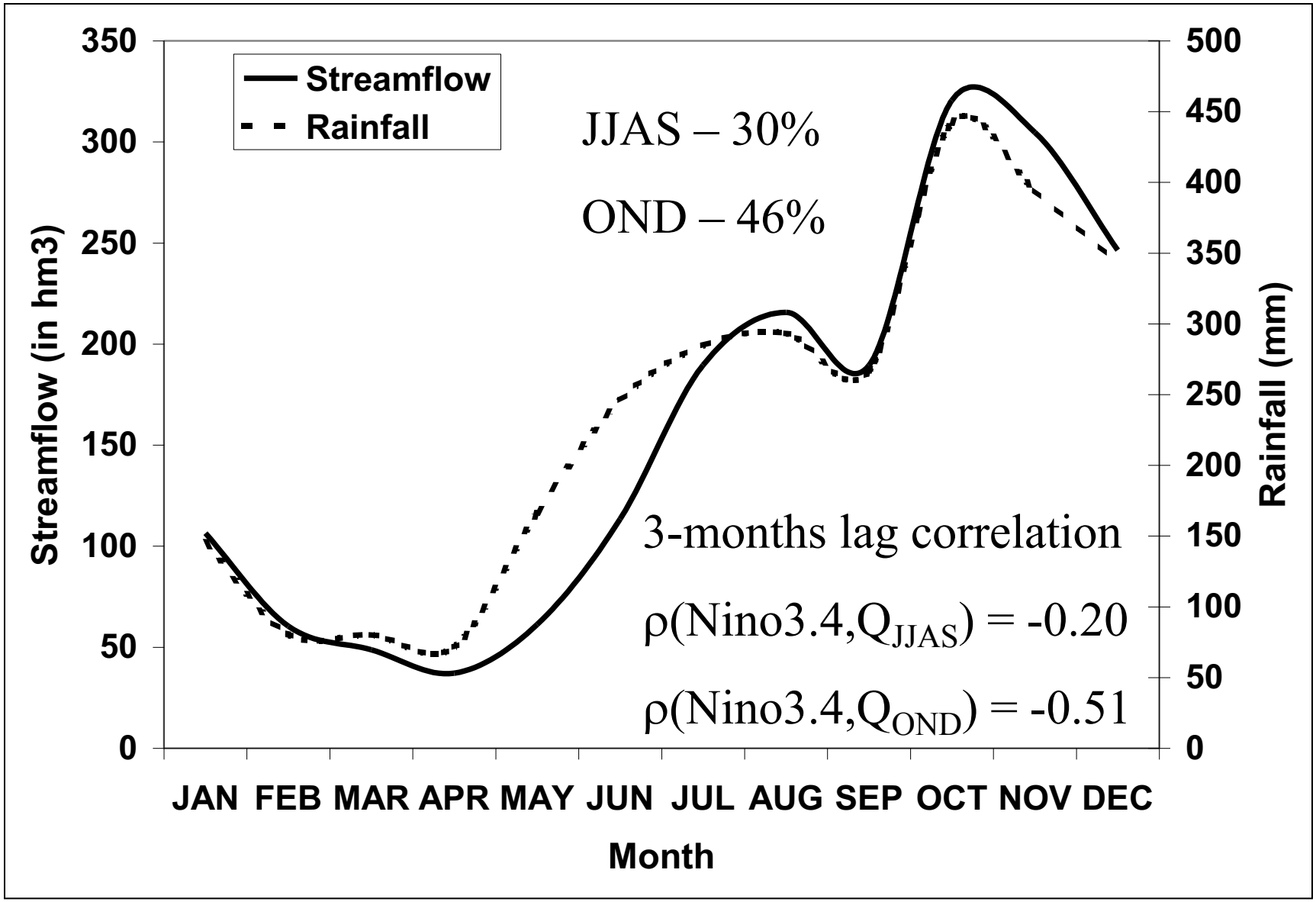
Forecasting Seasonal Floods and Streamflow volumes – Two Approaches



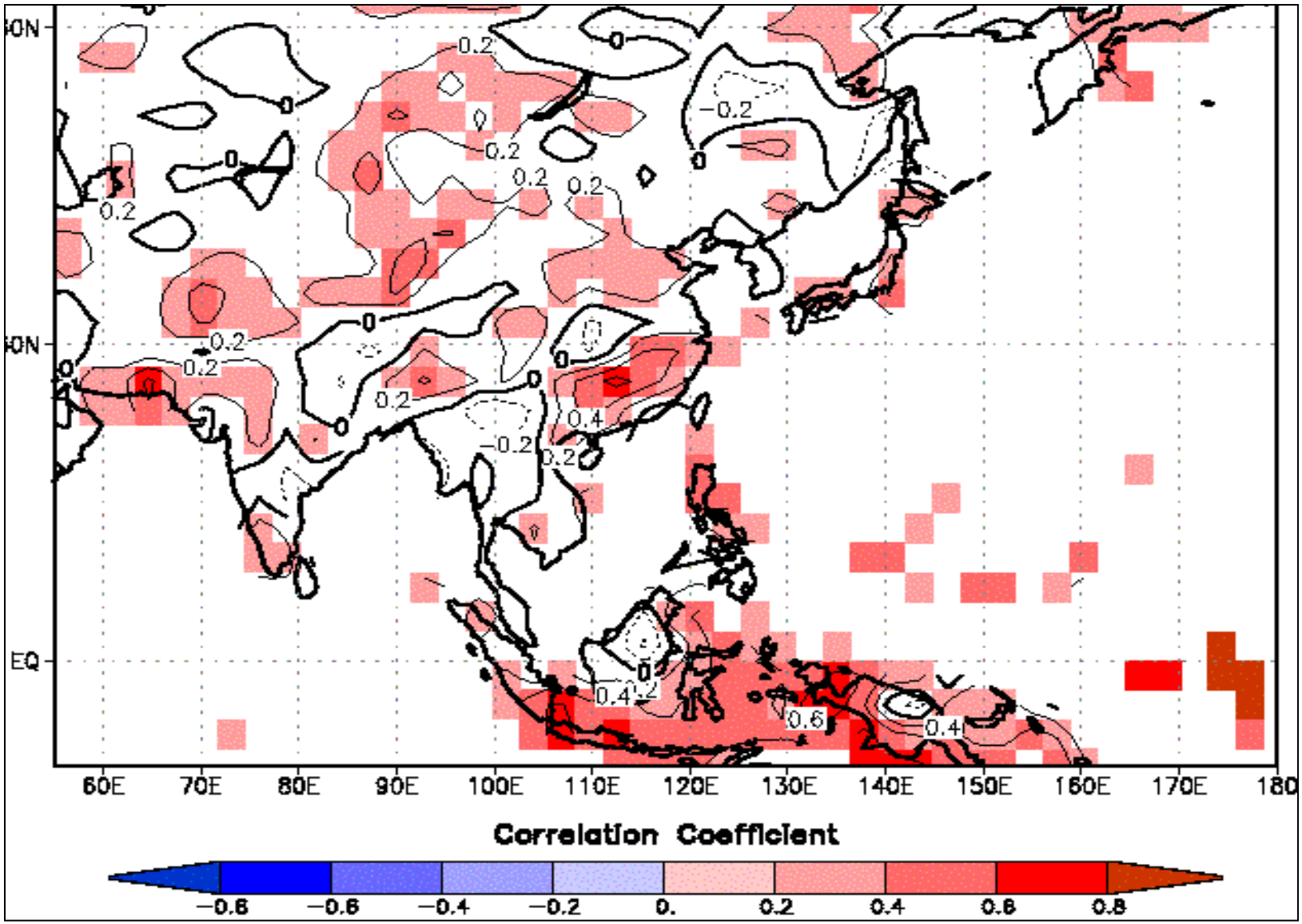


Geographical Location of the Philippines

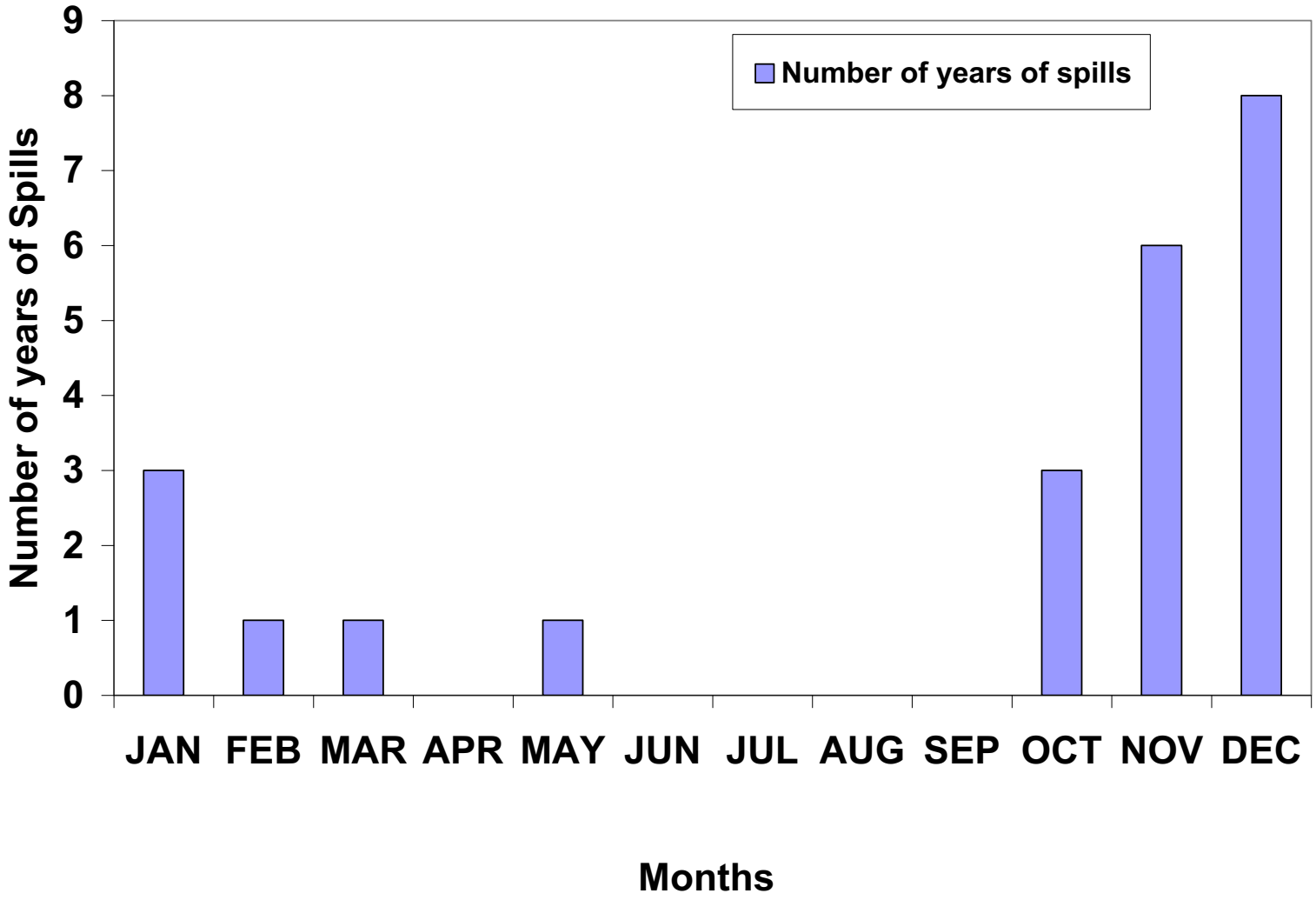
Hydroclimatology



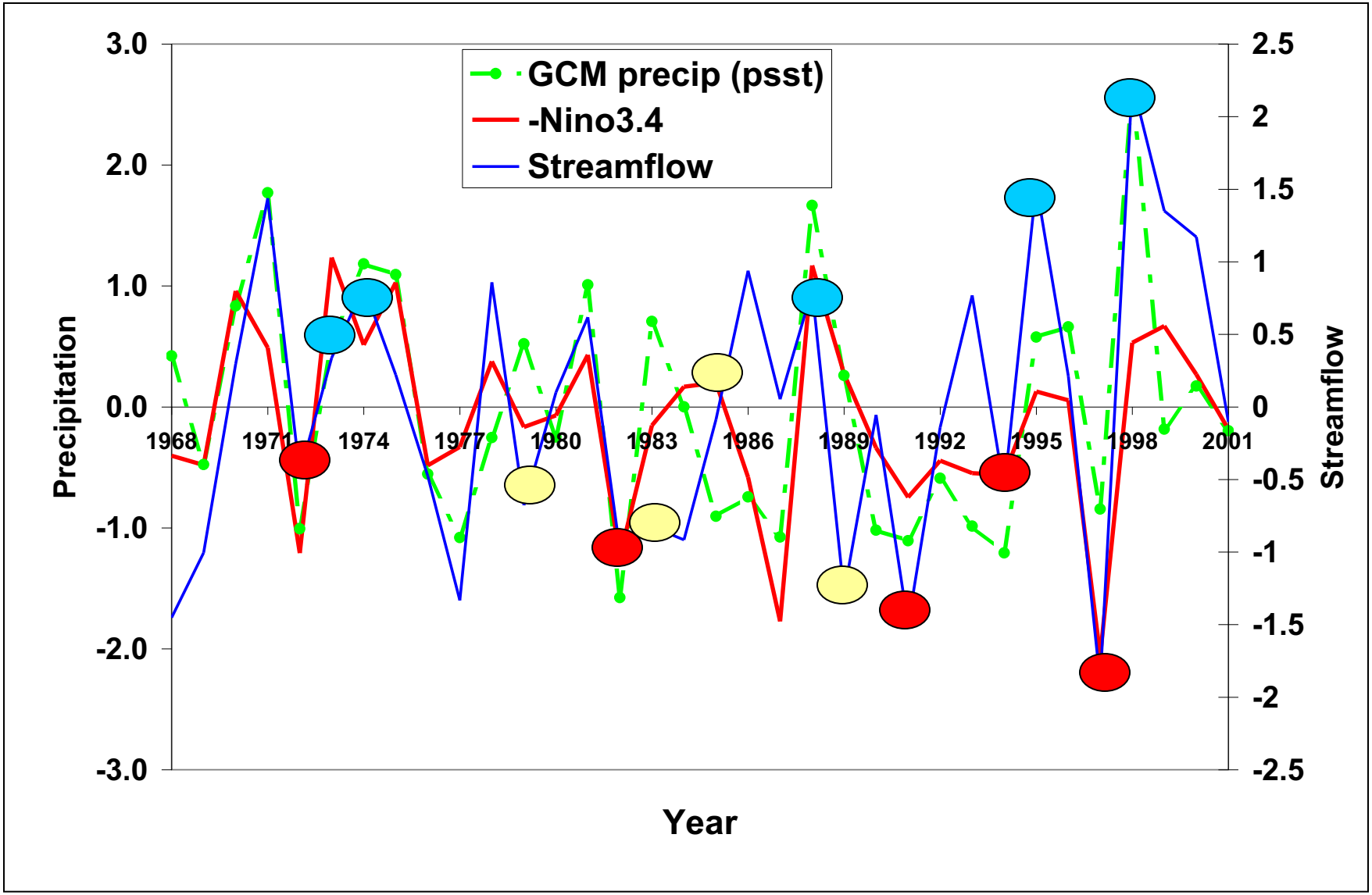
High OND Predictability



Critical Months for Water Management



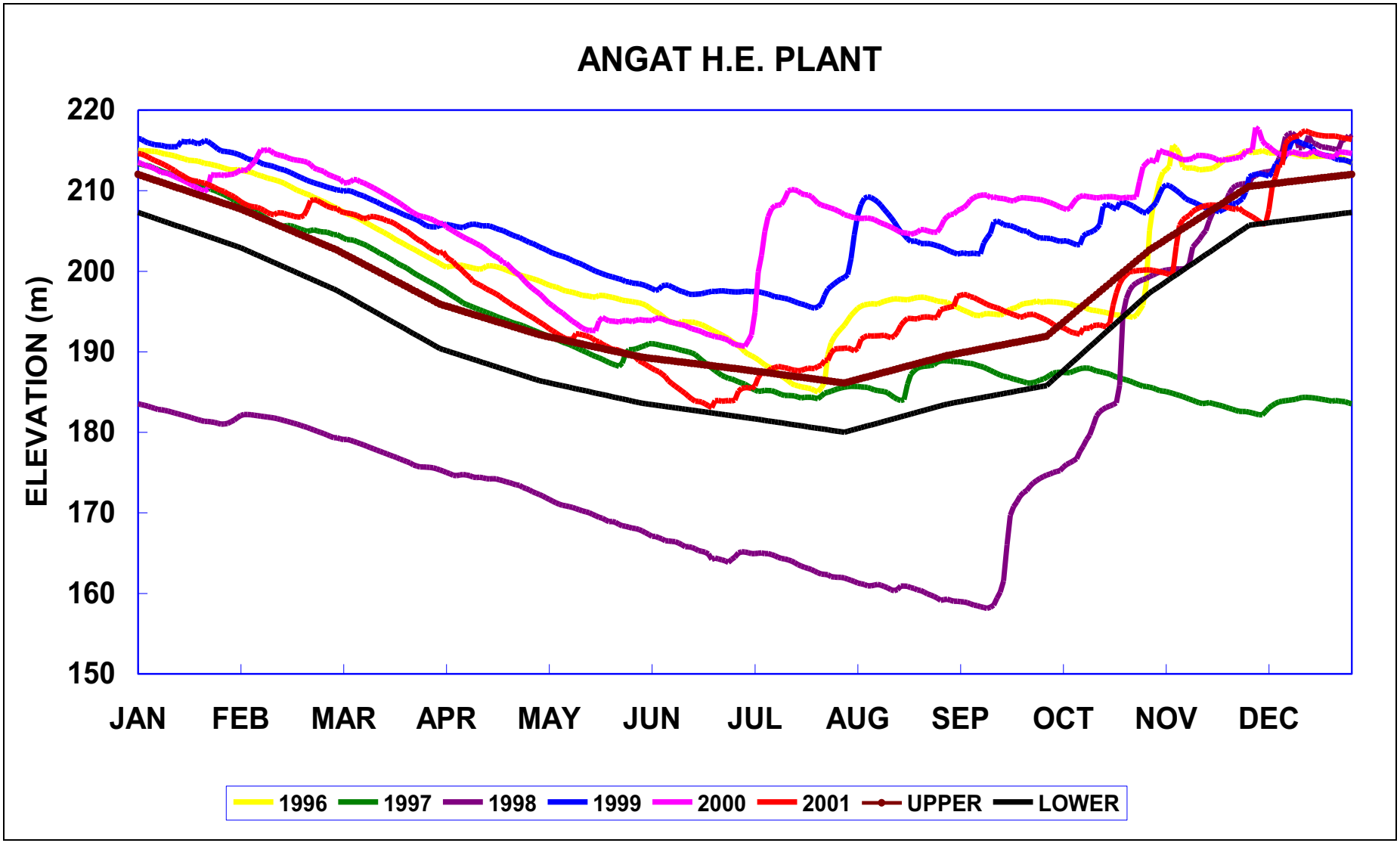
Association with ENSO conditions



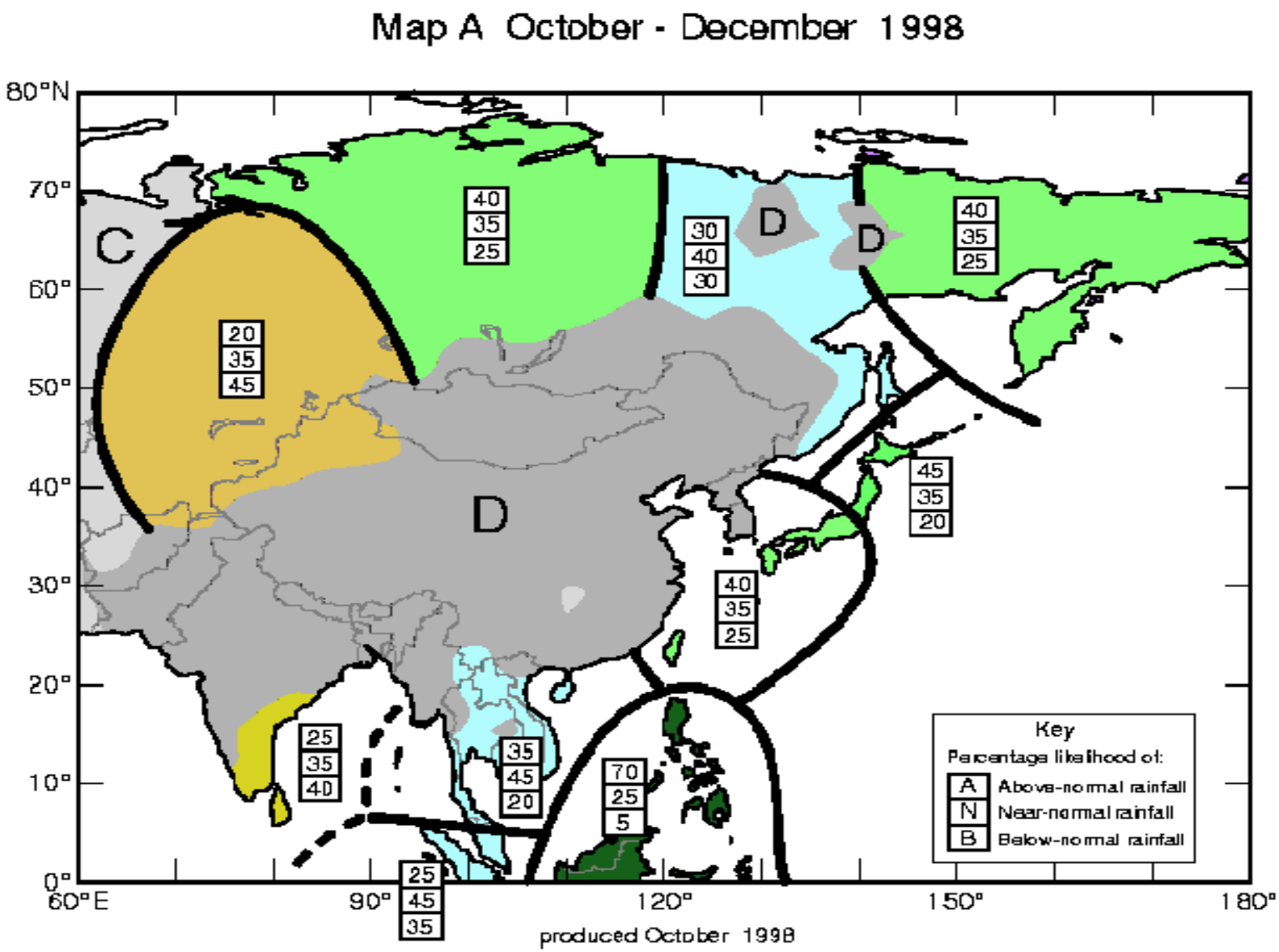
1997-98 ENSO Impacts

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

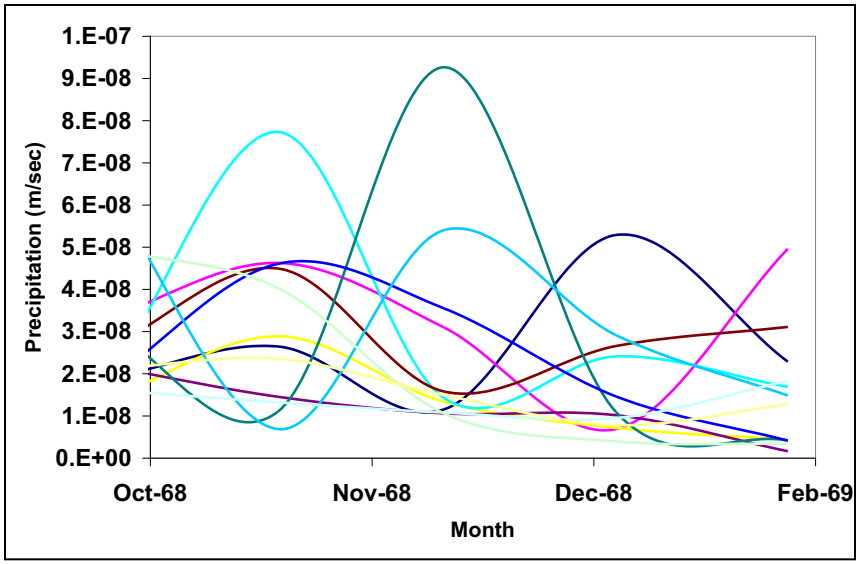
Current Operation



IRI Forecast for OND 1998

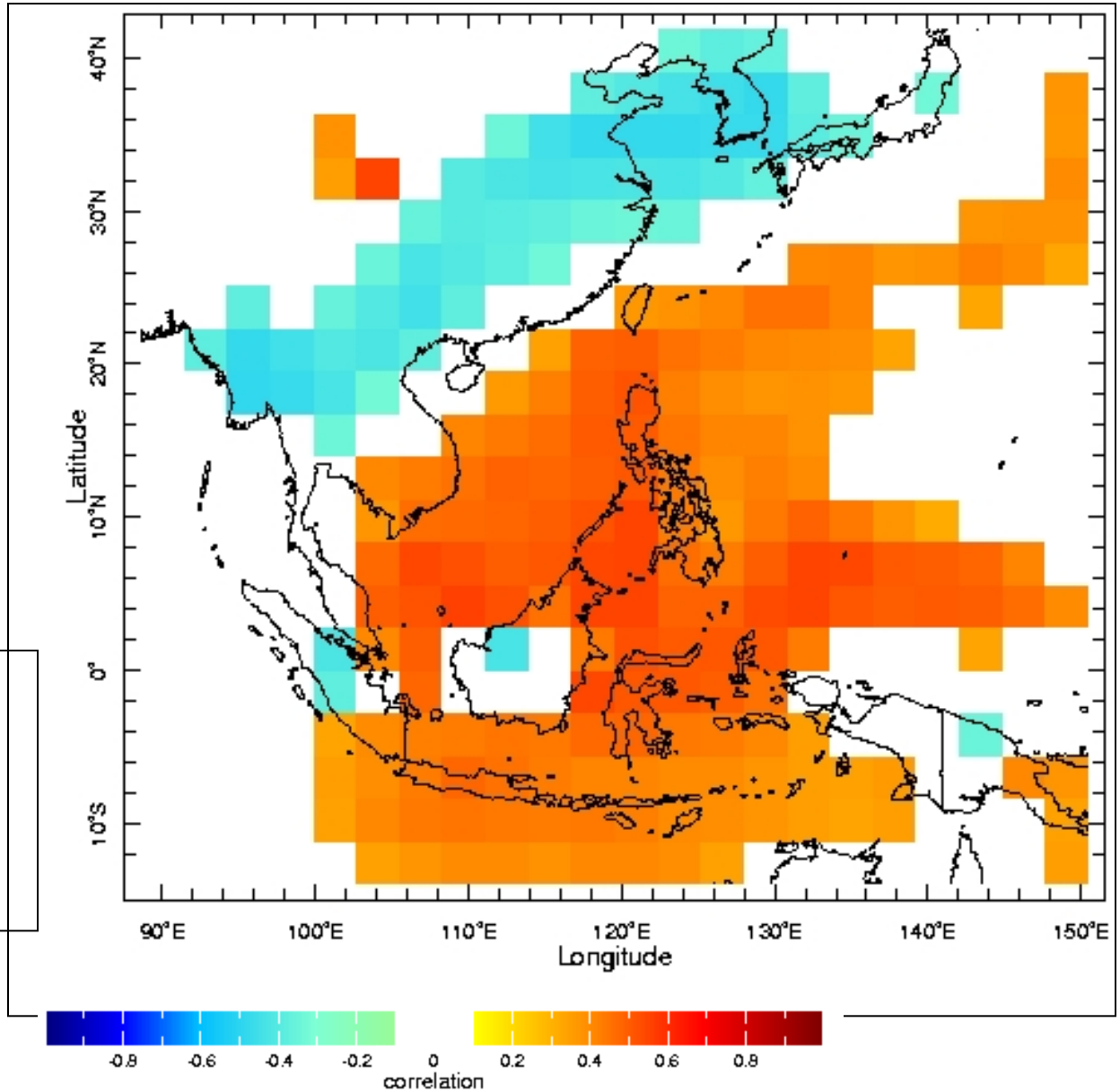


Retrospective AGCM Precipitation Forecasts



- **ECHAM 4.5**
  - Forced by Persisted SST
  - Provides 12 ensemble member
  - Forecast issued for 5 months every month
  - Retrospective Forecasts available from January 1968 to June 2003.

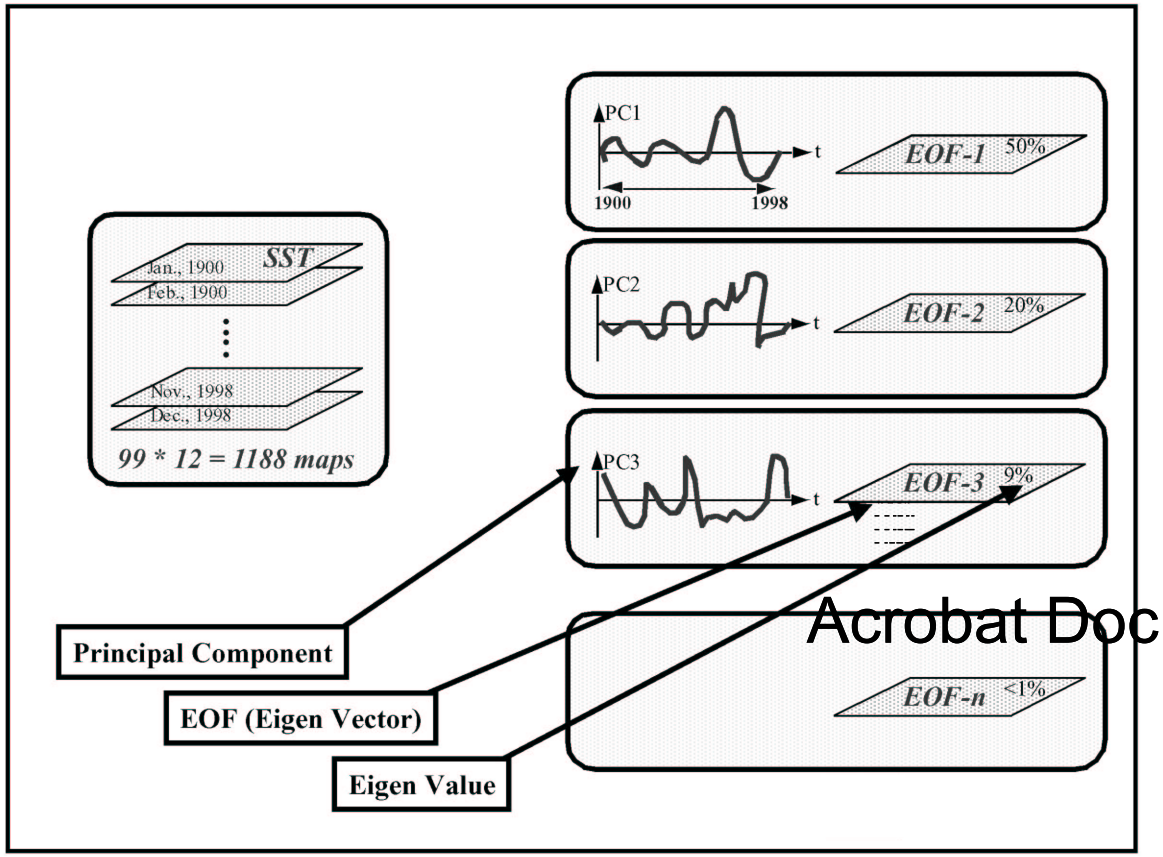
Forecast Precipitation Vs Streamflow



ONDJF

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

Empirical Orthogonal Function Analysis



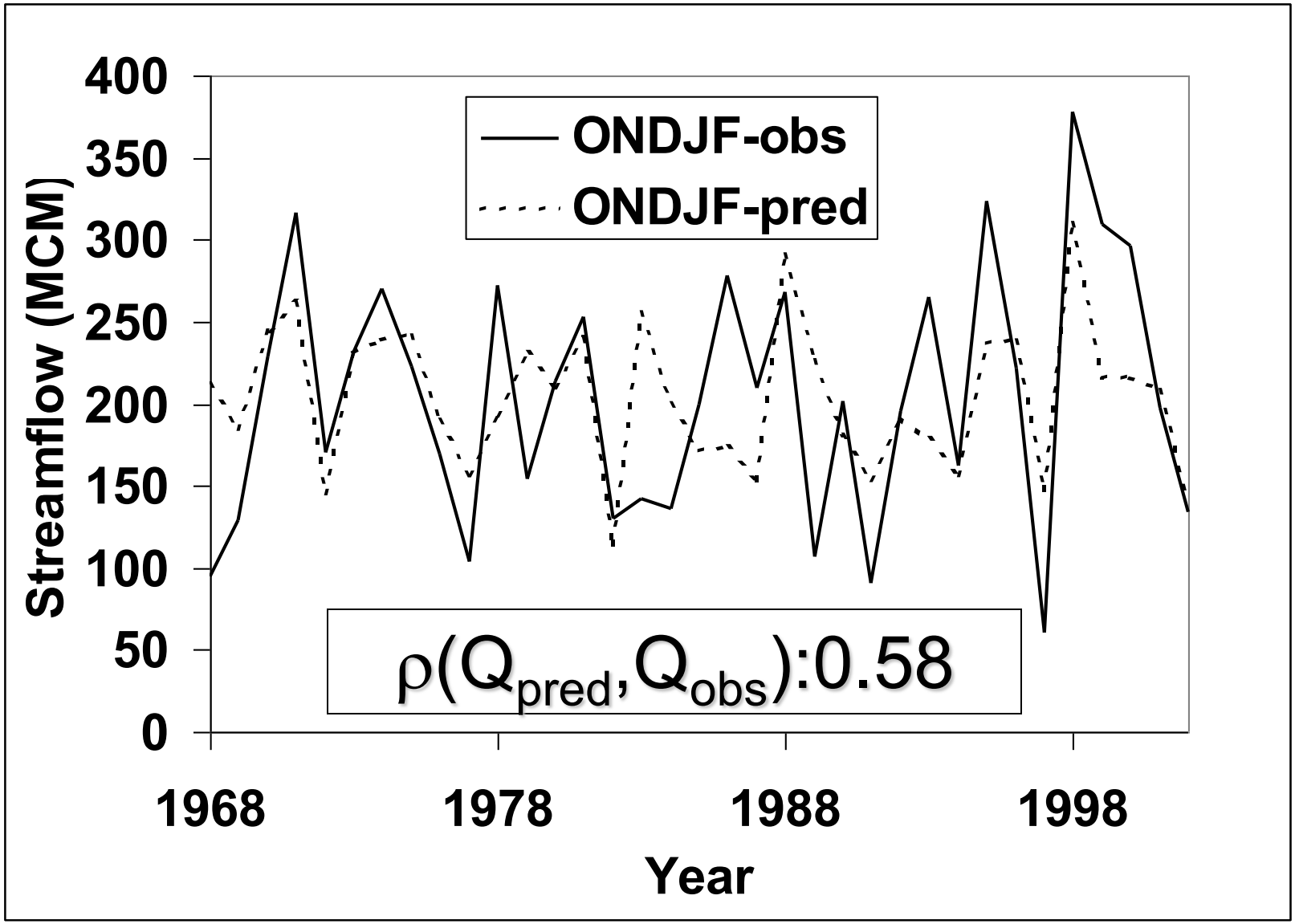
P(x,y,t) – Precipitation

PC(t) – Principal Component time series

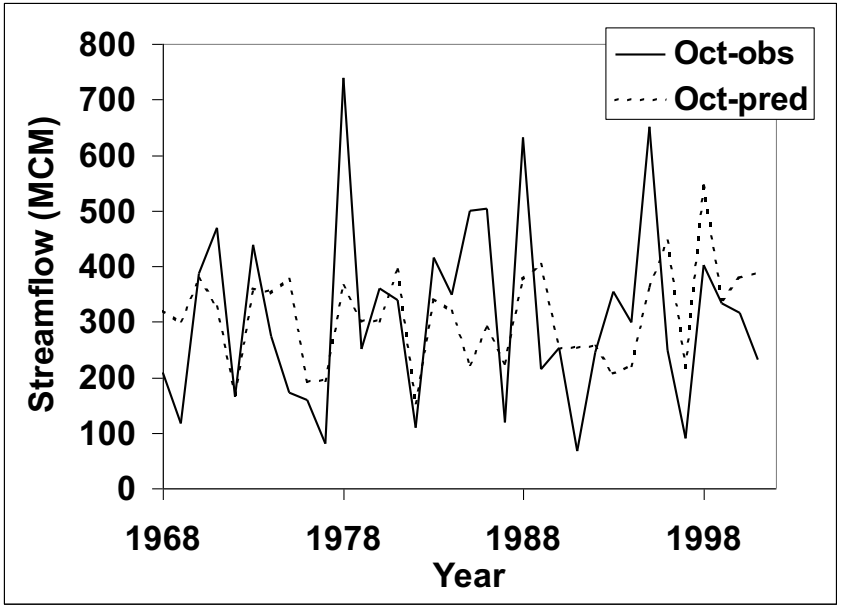
EOF(x,y) – Orthogonal functions – accounting for temporal variations in P(x,y,t)

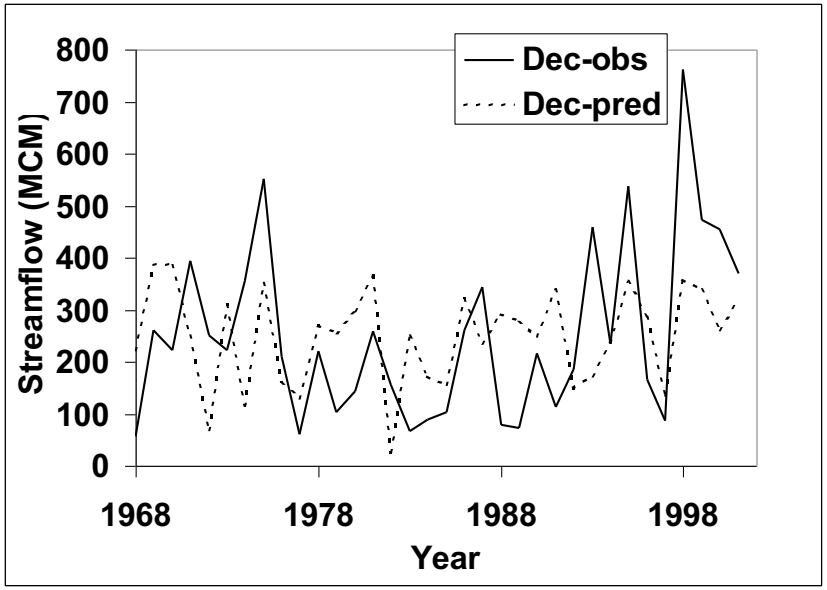
$$P(x,y,t) = \sum_{k=1}^{N} PC(t) \cdot EOF(x,y)$$

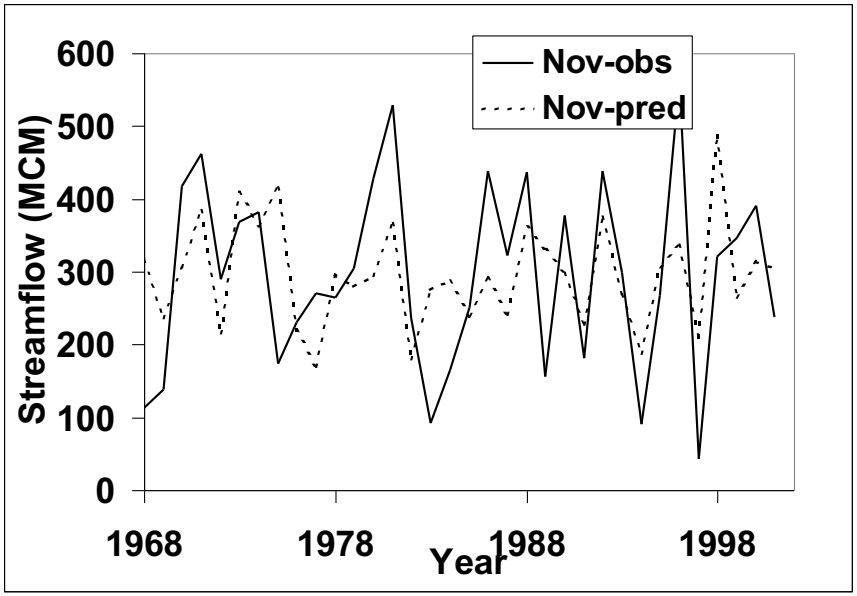
ONDJF Forecast - October

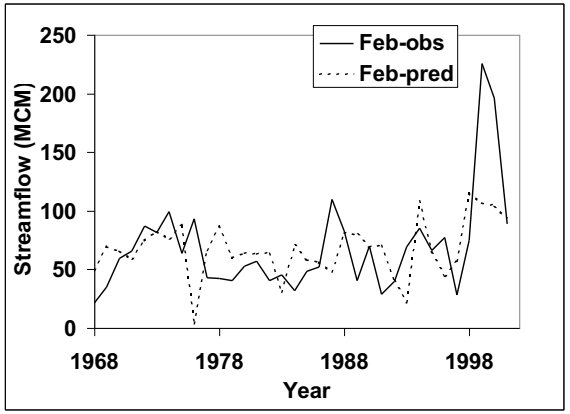


Forecast – Issued October

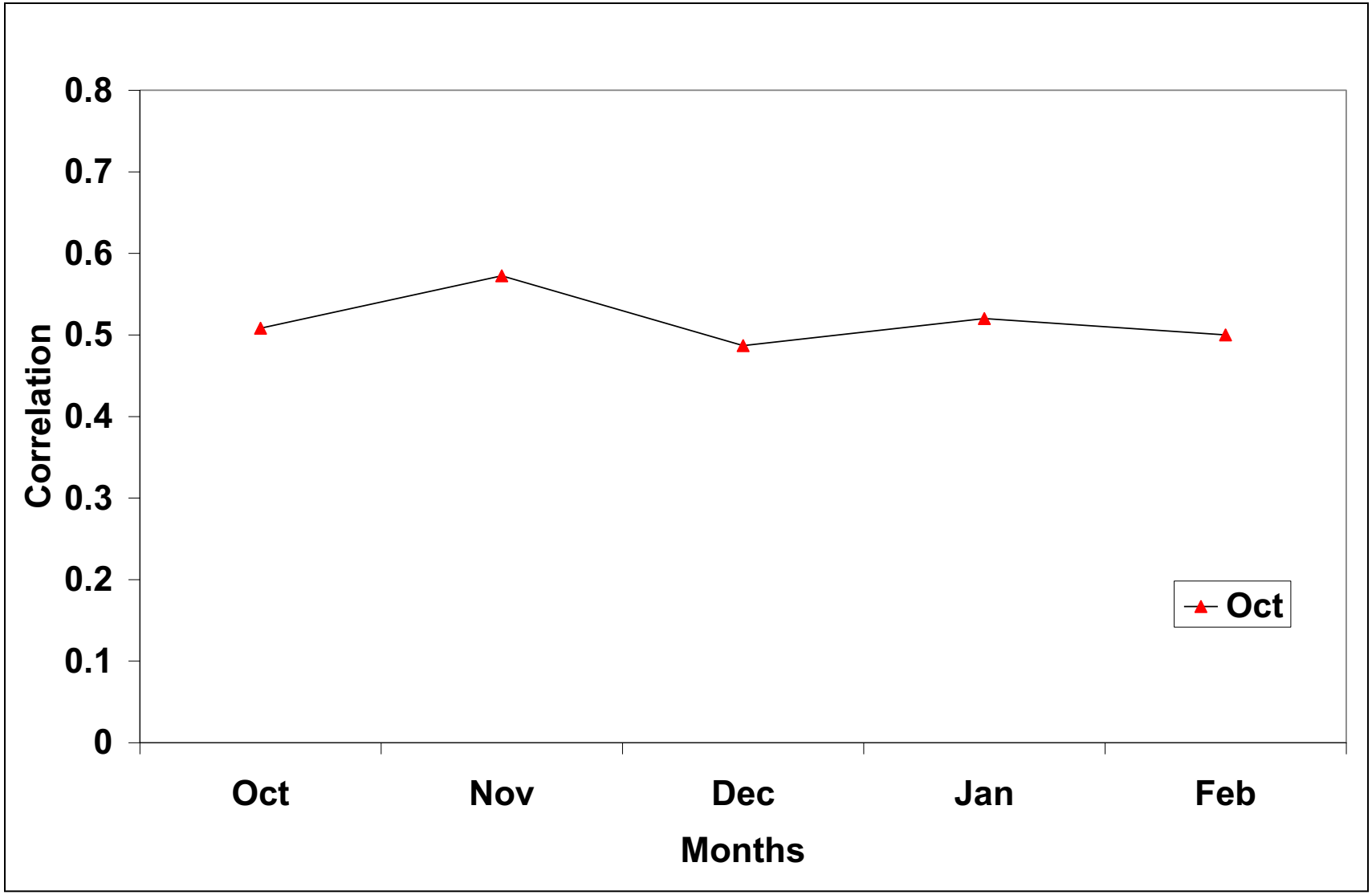




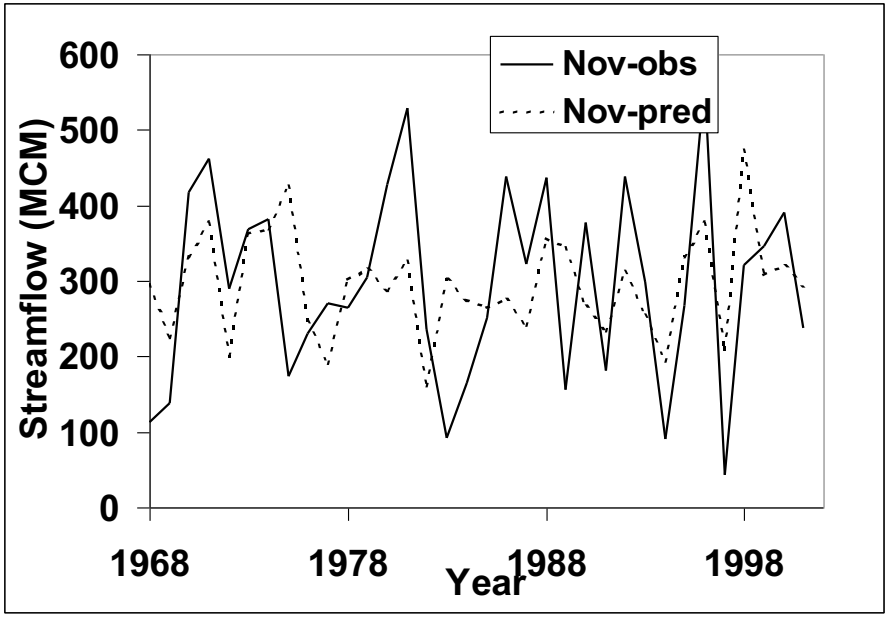


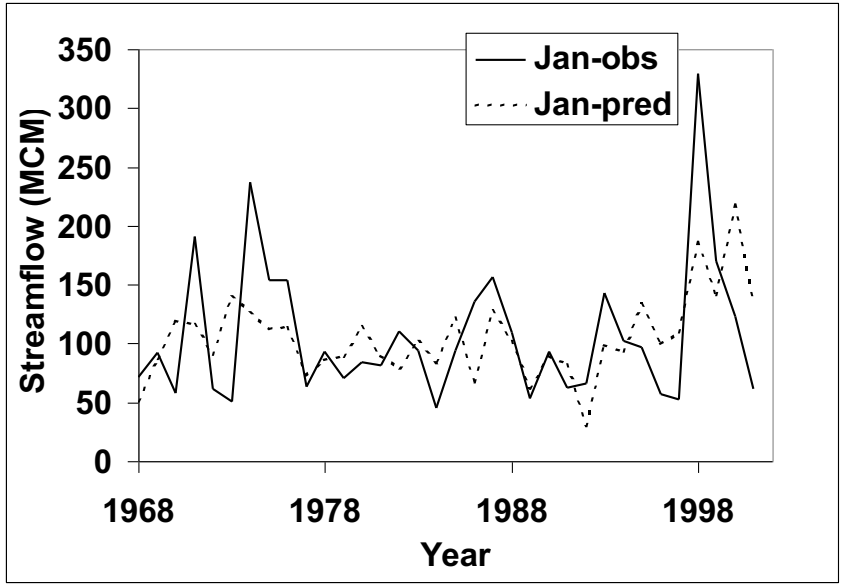


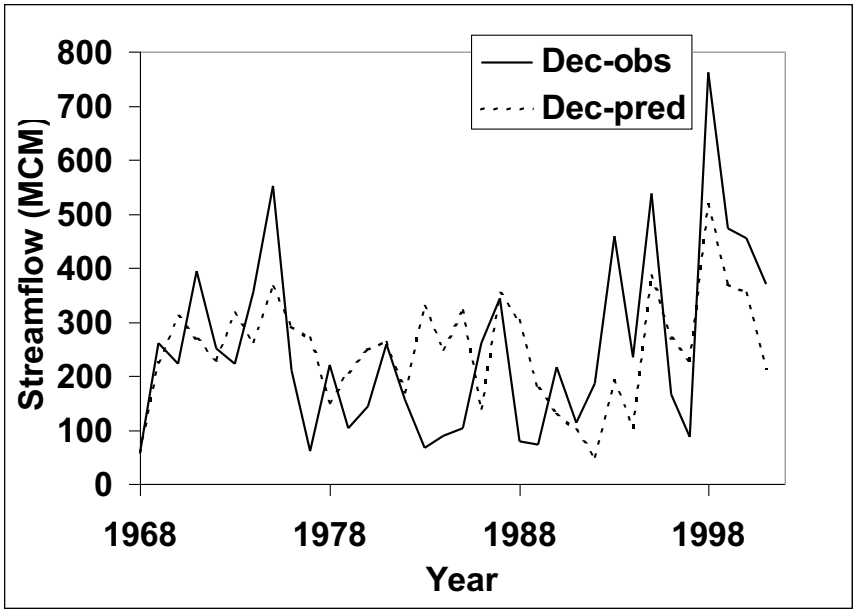
Forecast Performance - October

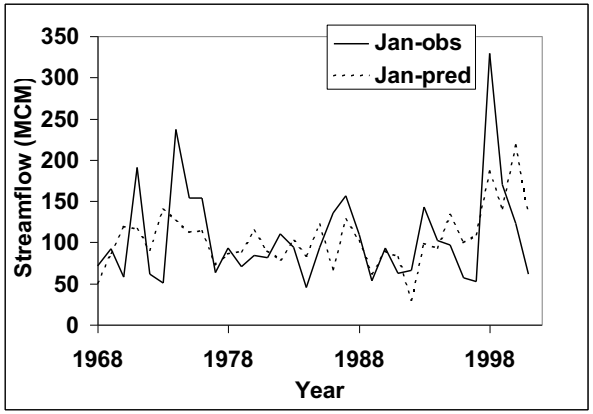


Forecasts – Updated Every month

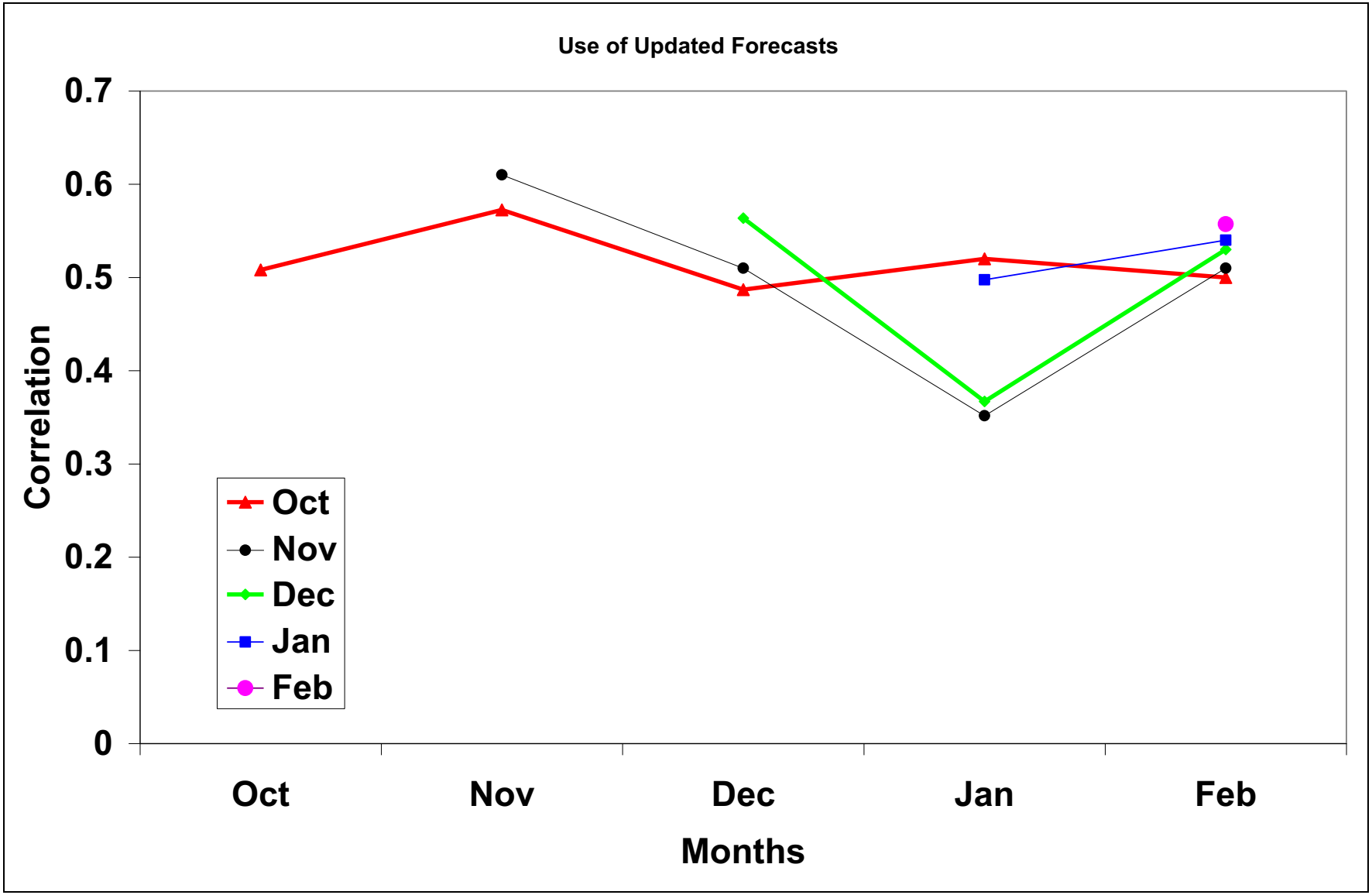




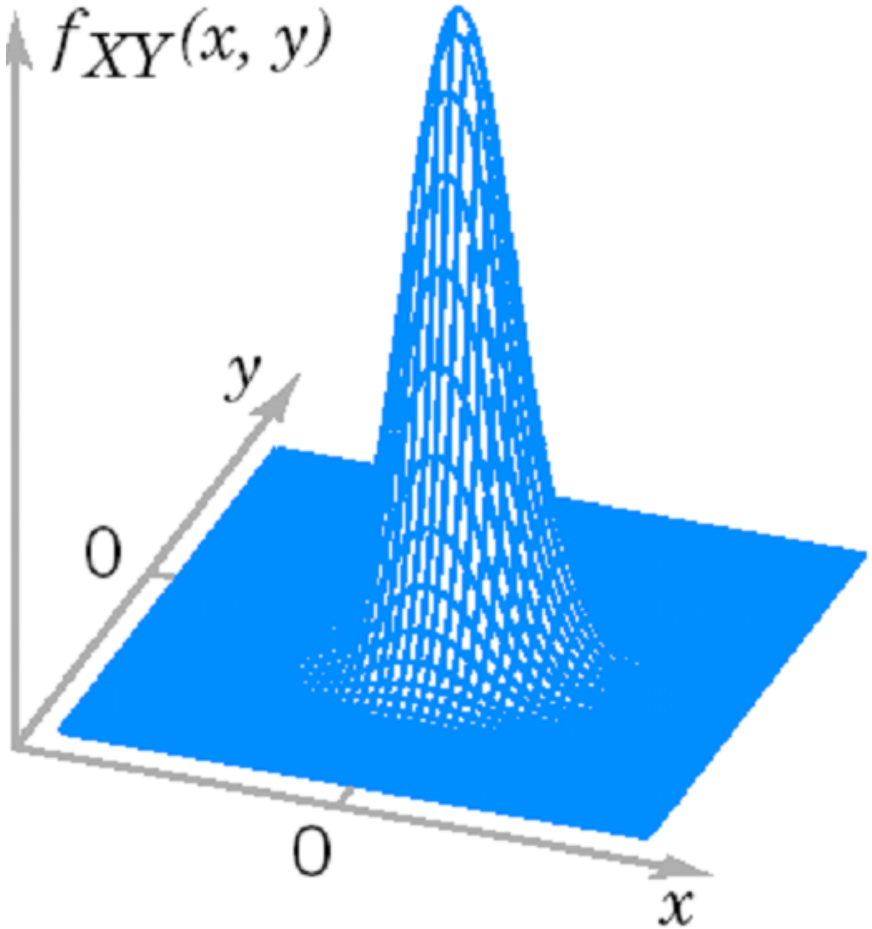




Performance - updated Forecasts



Ensemble Generation



X – October Y – November

I = Forecast issuing month, October

$\mu_X^i = E^i(Q_t|PC_t)$;

$\sigma_X^i = \sigma^i (Q_t|PC_t)$

$\mu_Y^i = E^i(Q_{t+1}|PC_{t+1})$;

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

ρ_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 $S_{T*} = 500$ hm3 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.

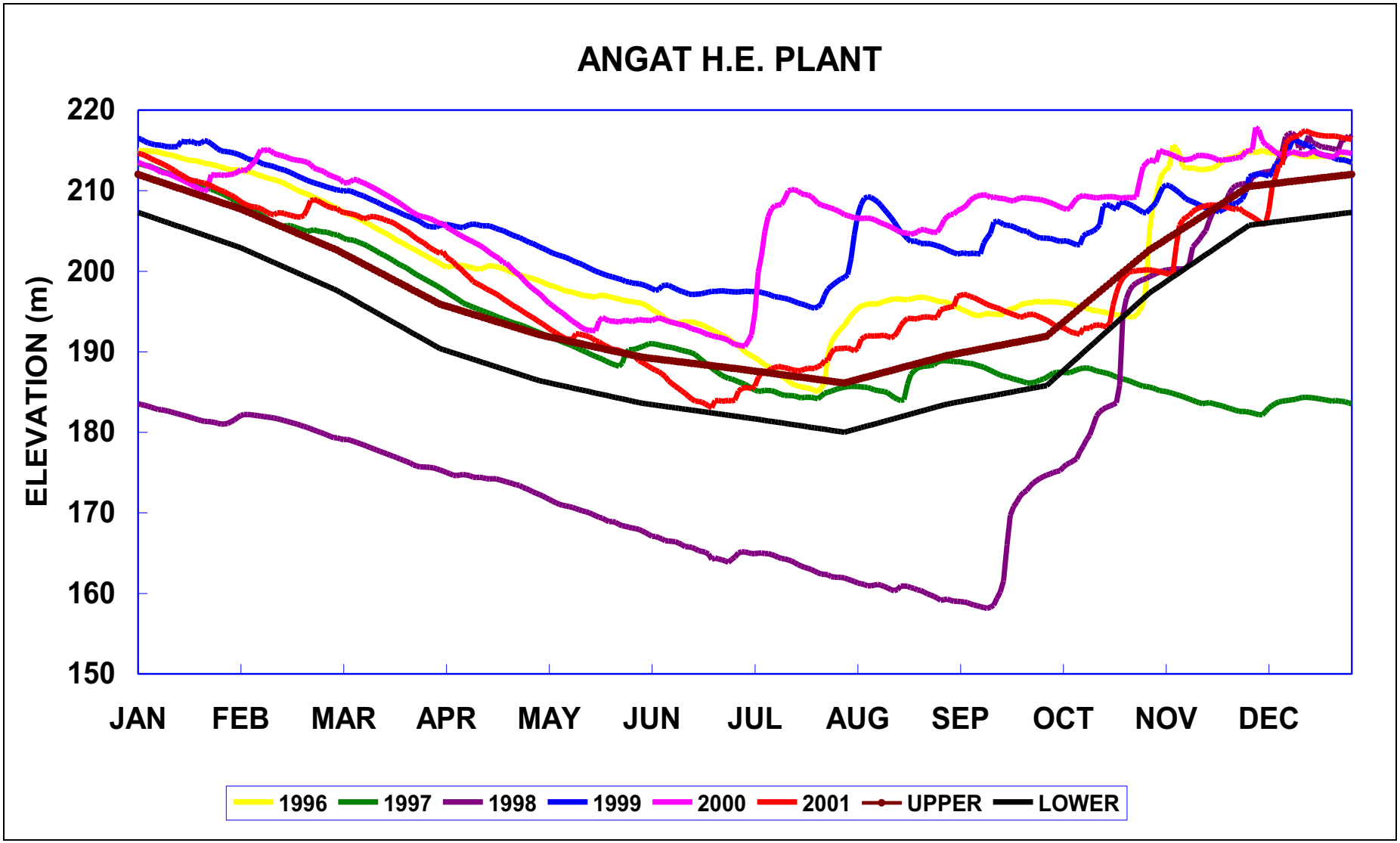
Reservoir Simulation (for each ensemble 'k')

- Inflow Forecast : q_{tk}; t=1…,T; k=1,…,N
- Continuity Equation: t=1,2, …, T

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

- $SD_t = -S_t \mid S_t < 0$ (Account the Deficit)
- $R_{ti}=\beta_{ti}R_i$ (Target Release for each user)
- Evaporation $E_t = \psi_t \delta_1((S_t + S_{t-1})/2)^{\delta_2}$

Current Operation



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: 1st MWSSB; 2nd Irrigation (NIA); 3rd 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**
  - **Initial storage conditions on October 1st from 1987-2001.**
  - 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

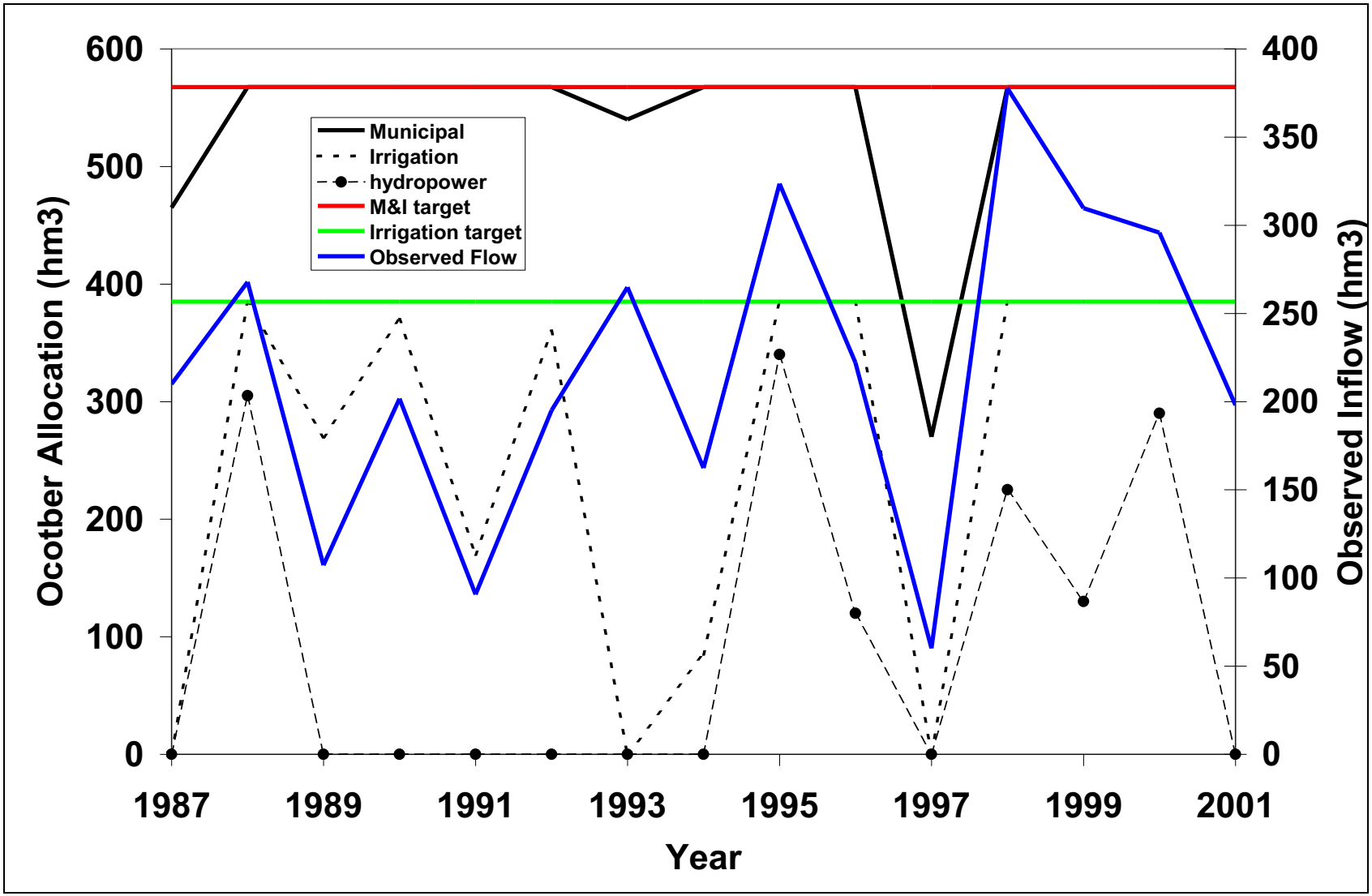
Water Demand

- **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.**

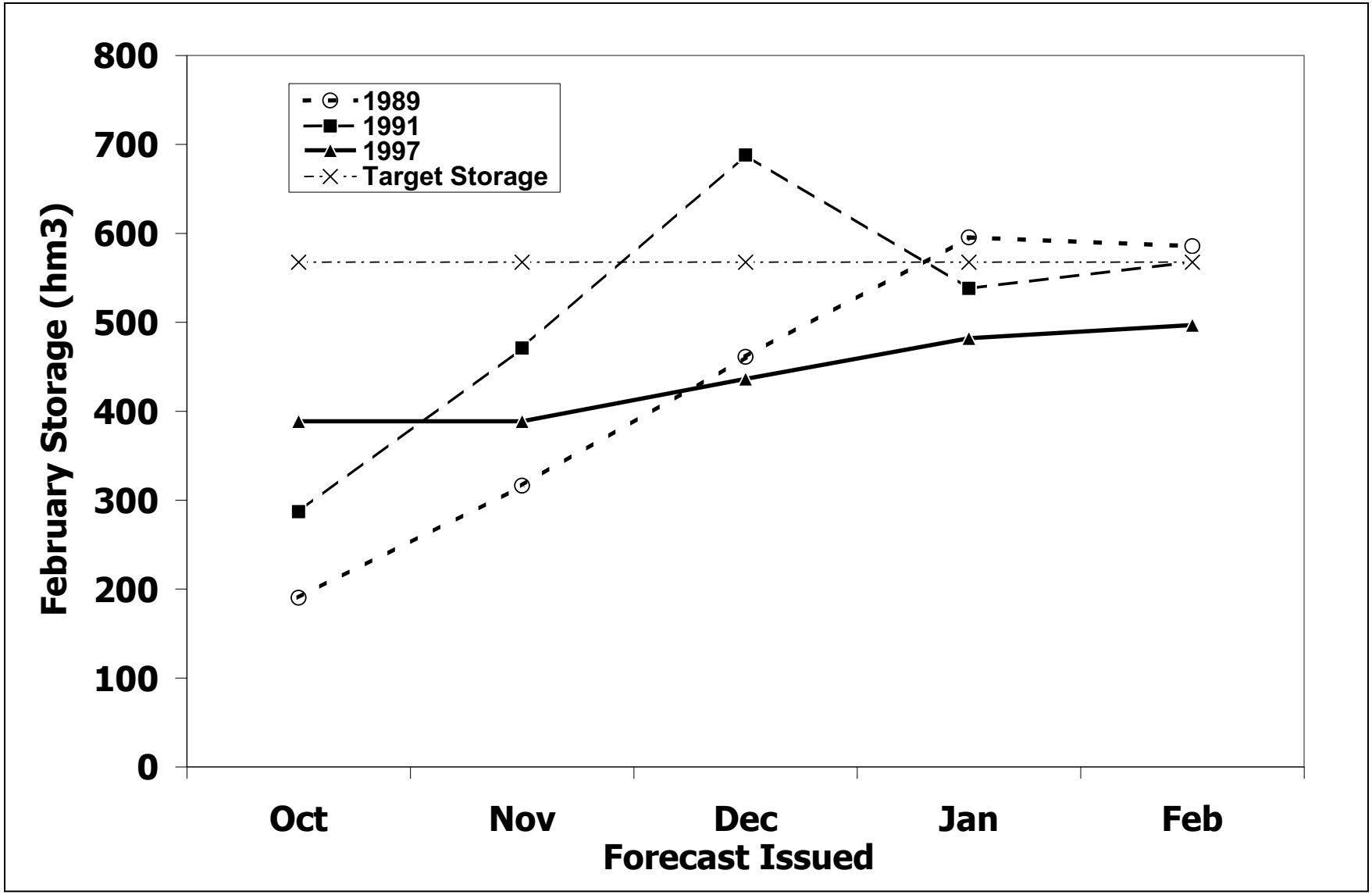
Decision Analyses

- **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

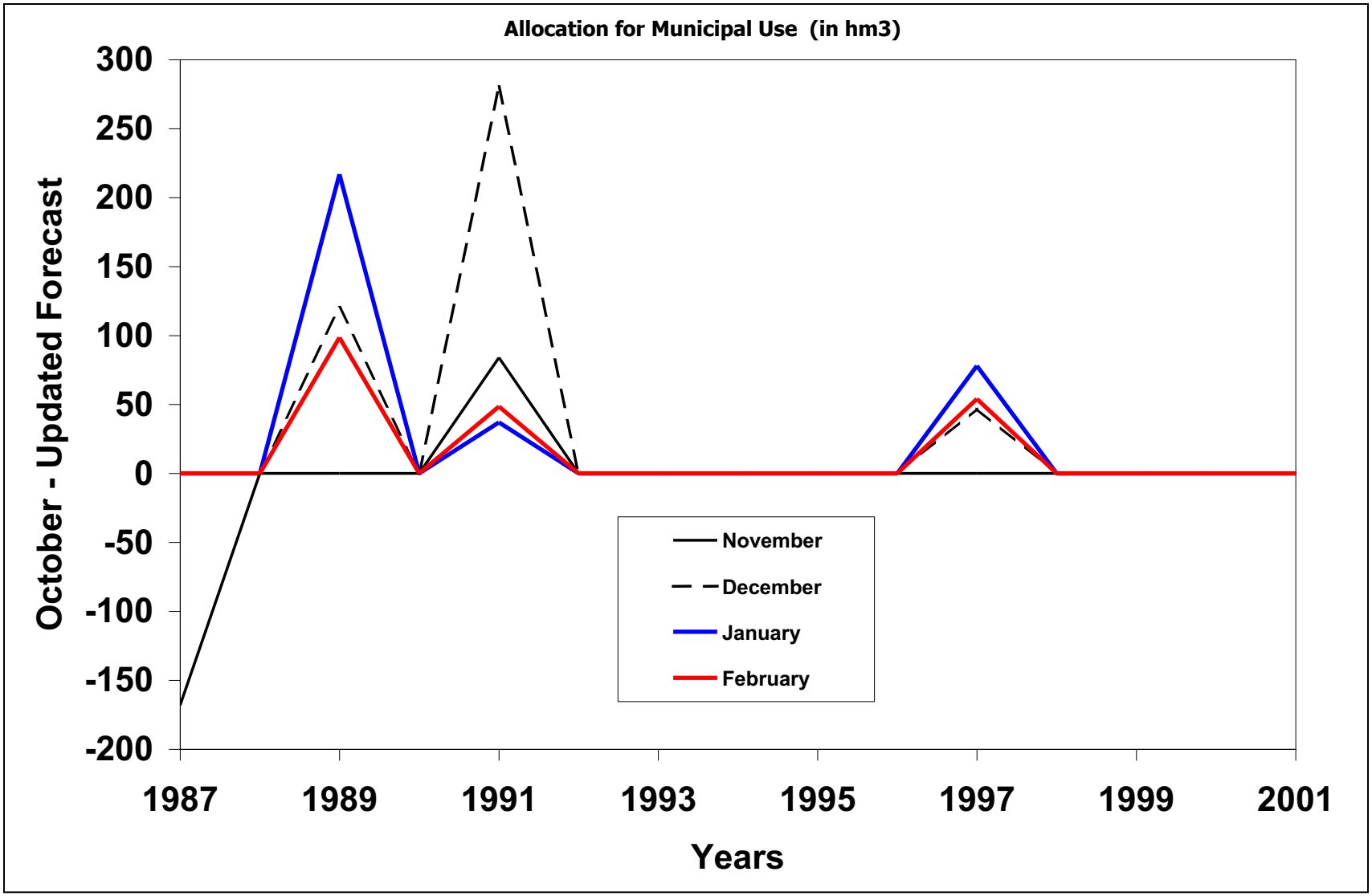
Performance of October Forecast



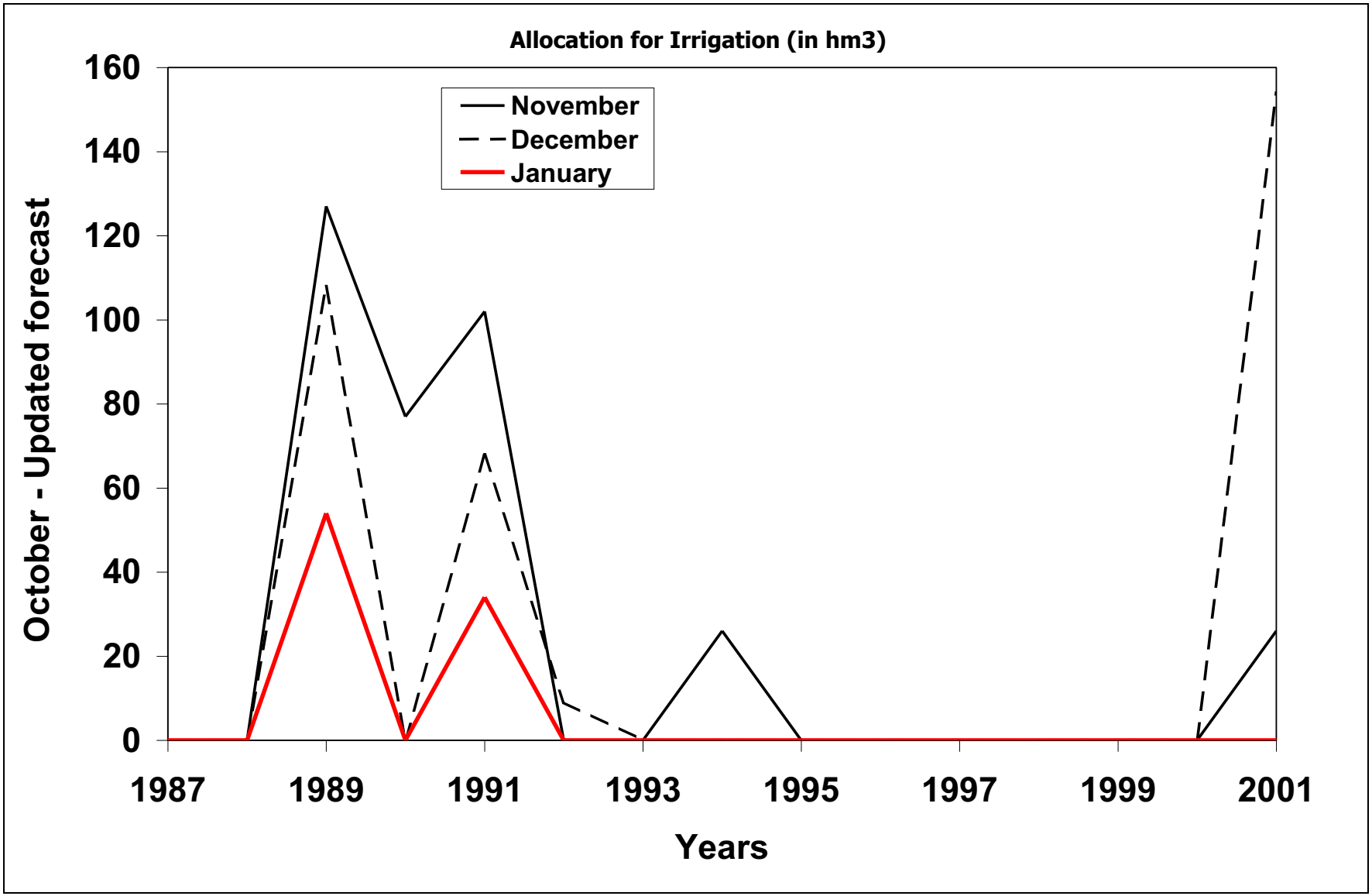
Meeting February Target Storage



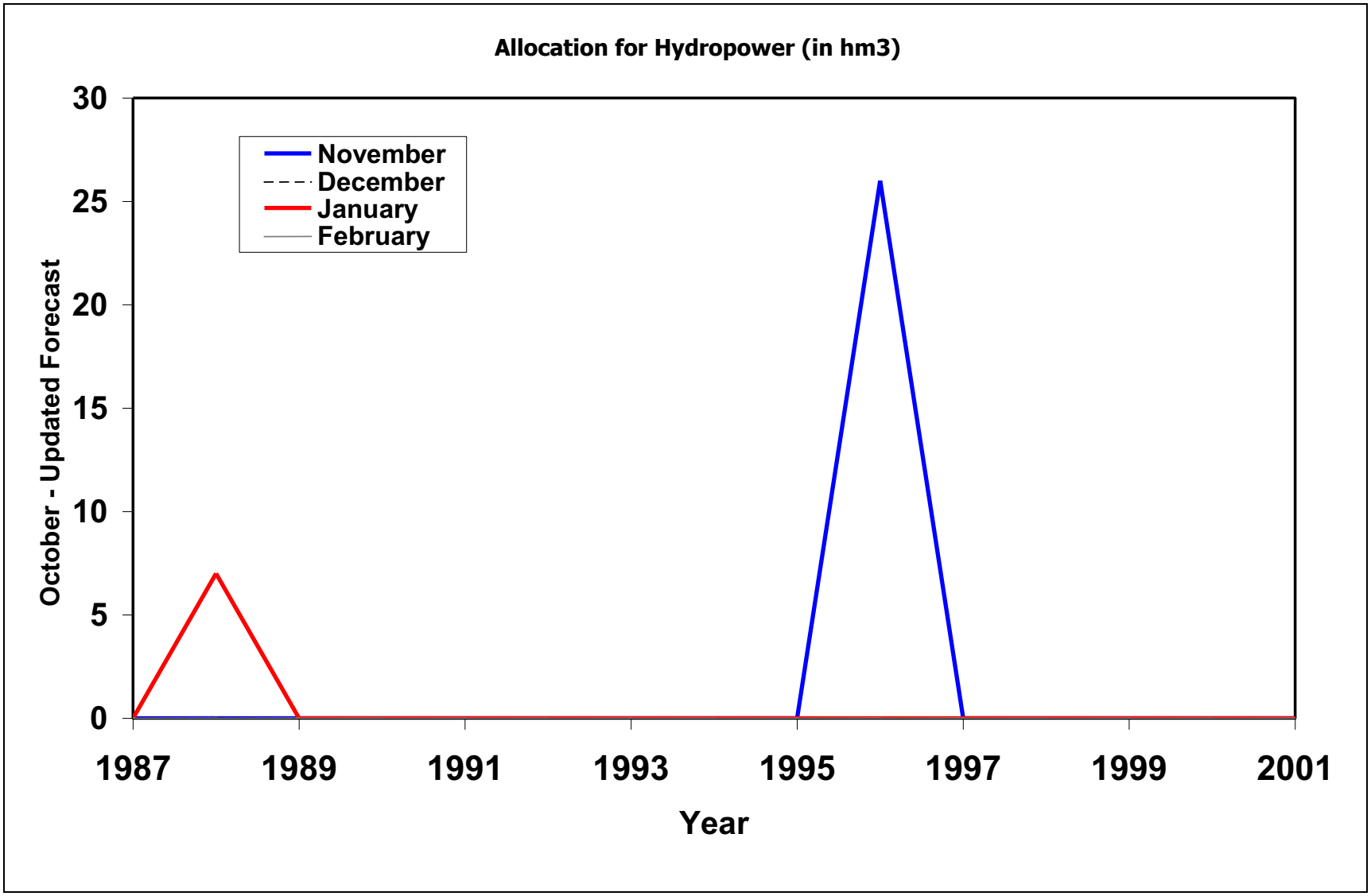
Municipal Allocation



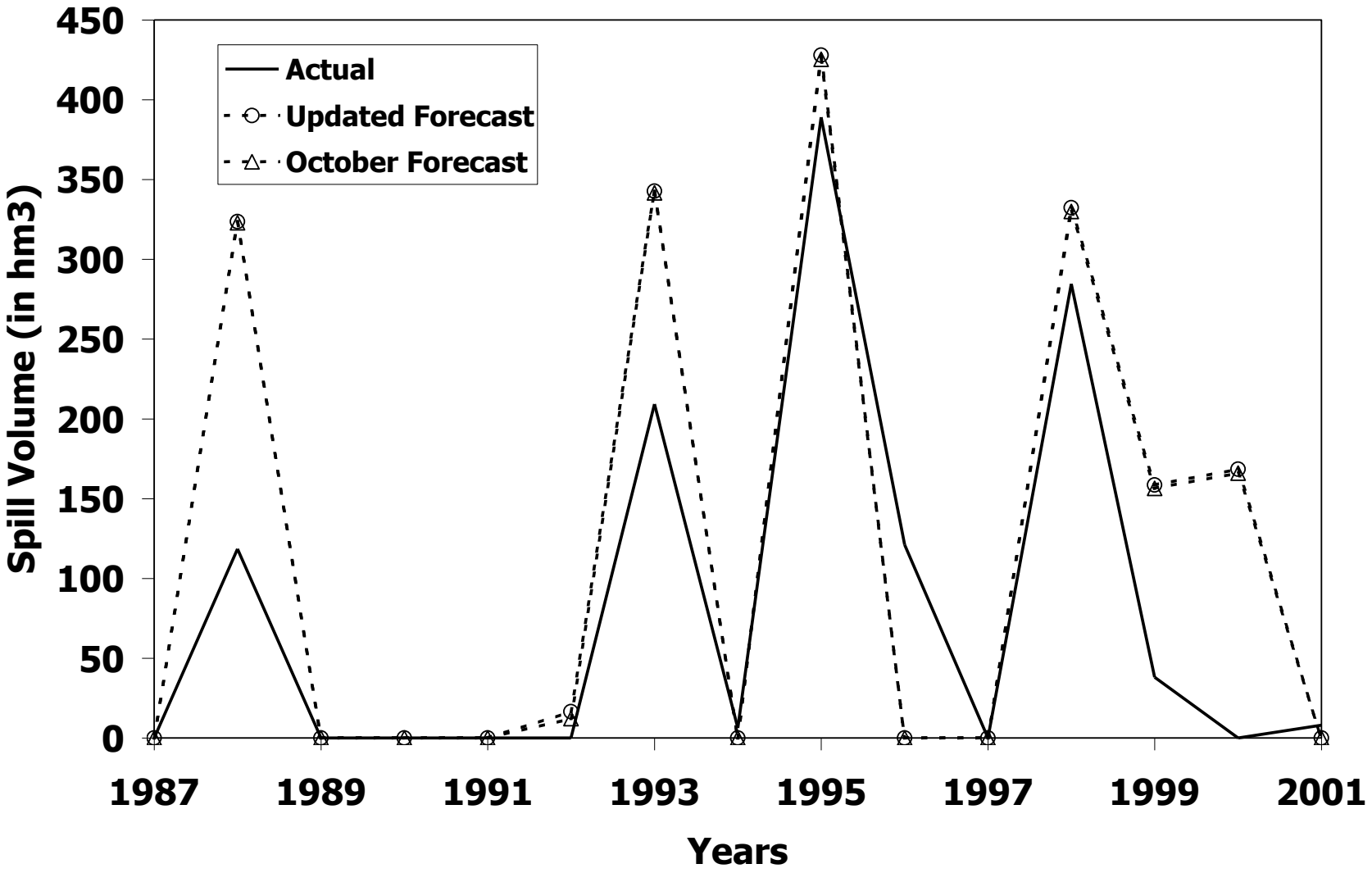
Irrigation Allocation



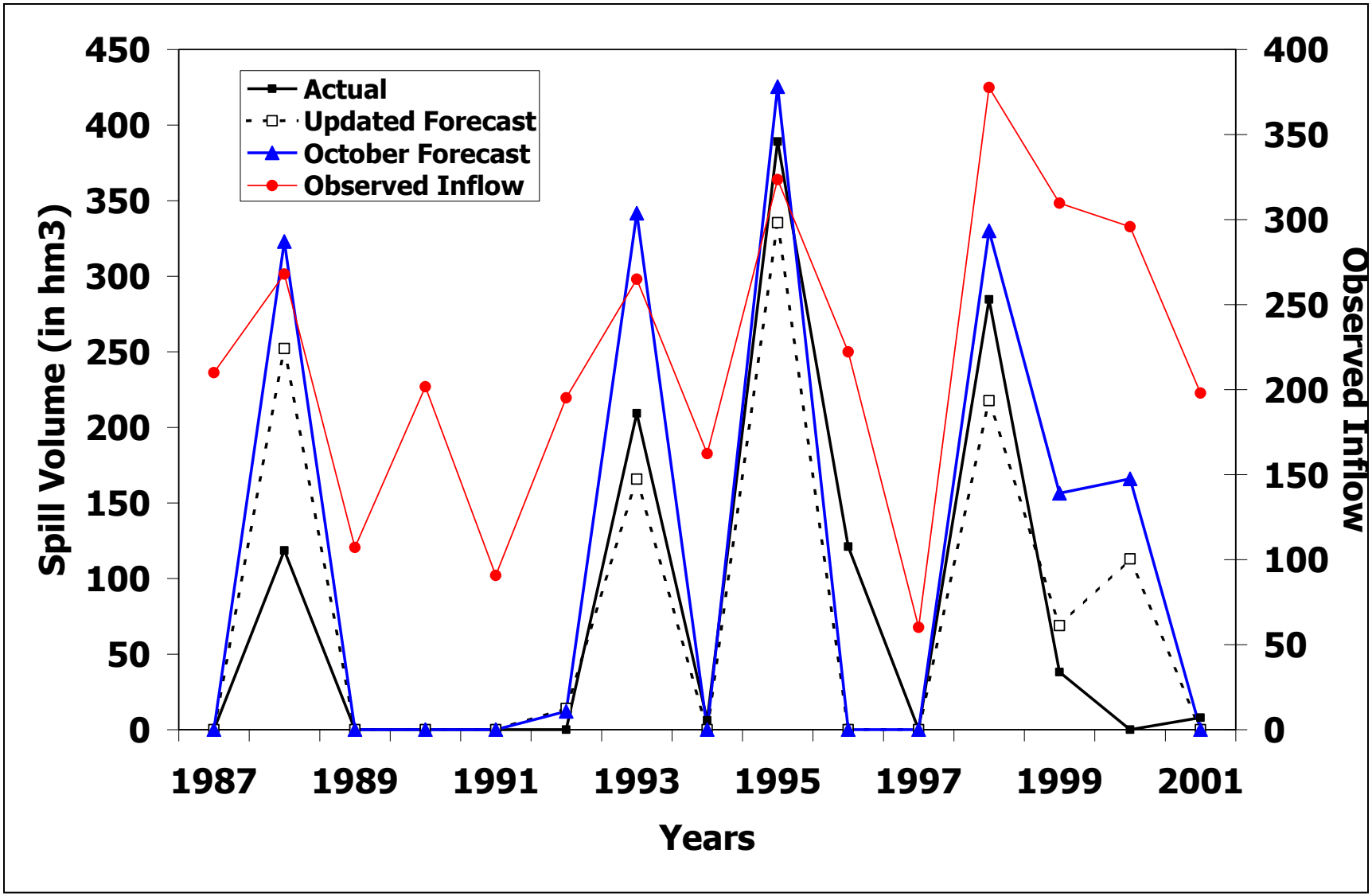
Hydropower Allocation



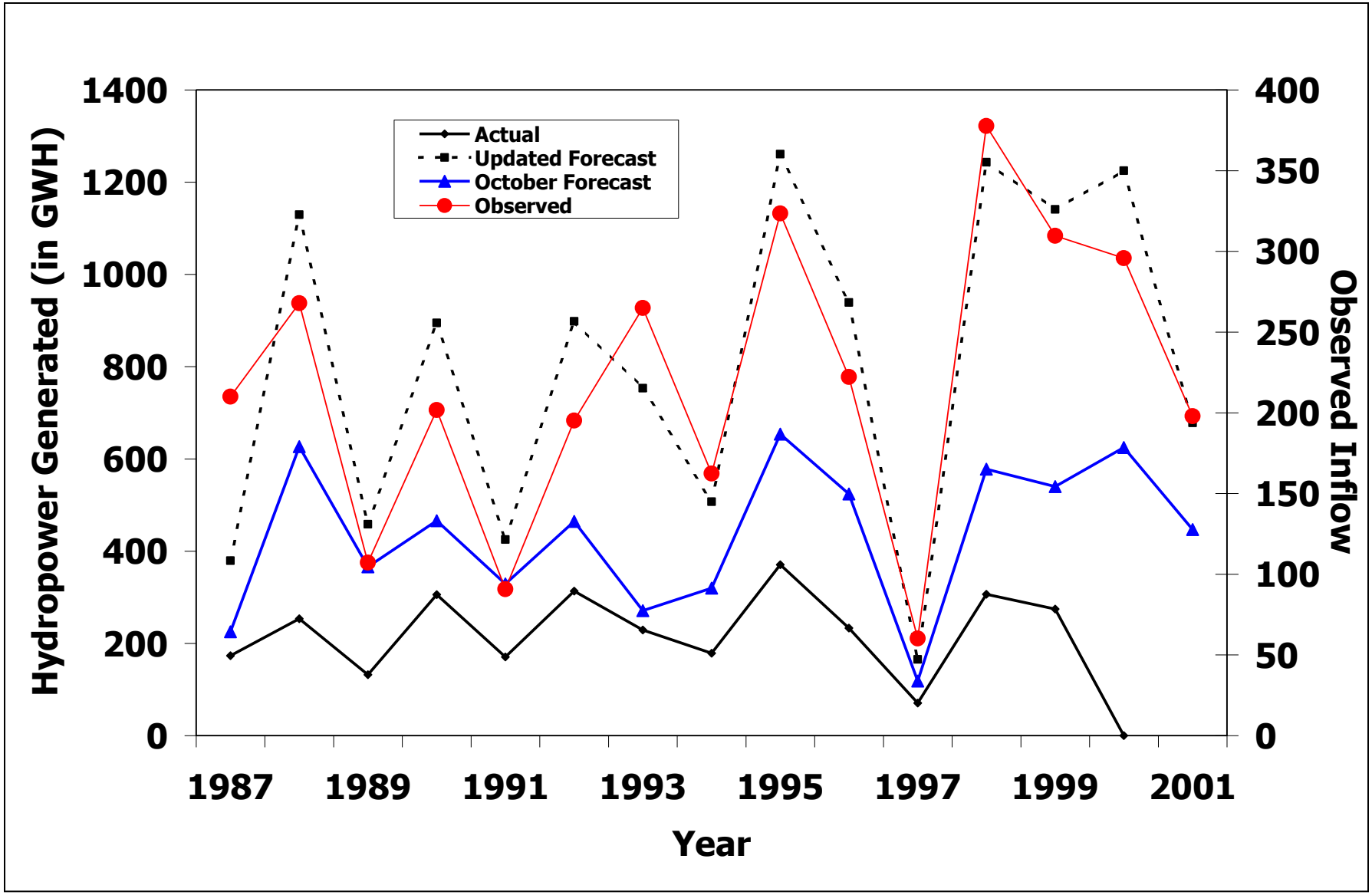
Spill Volume Reduction



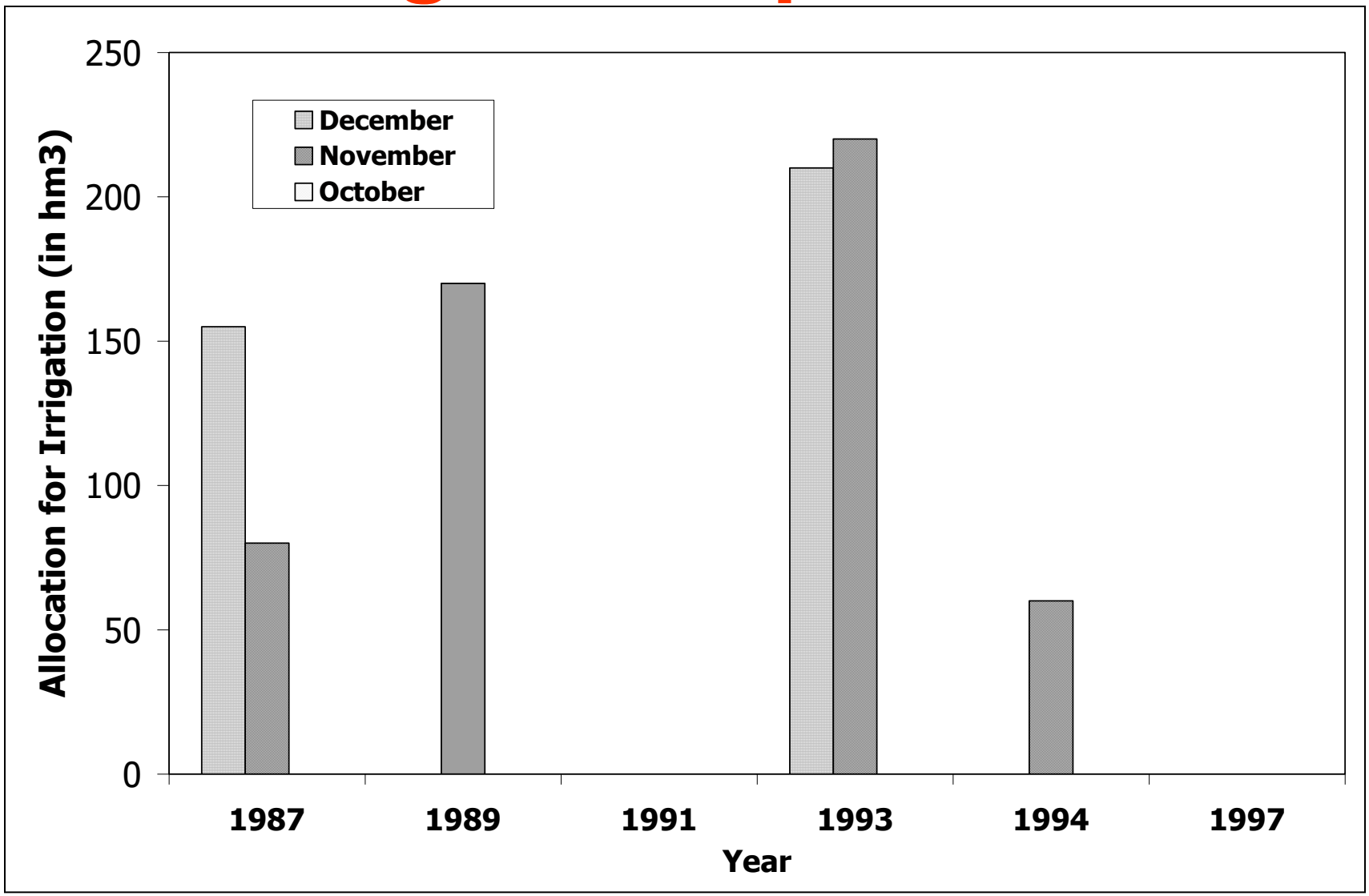
Spill Volume (Max Hydro)



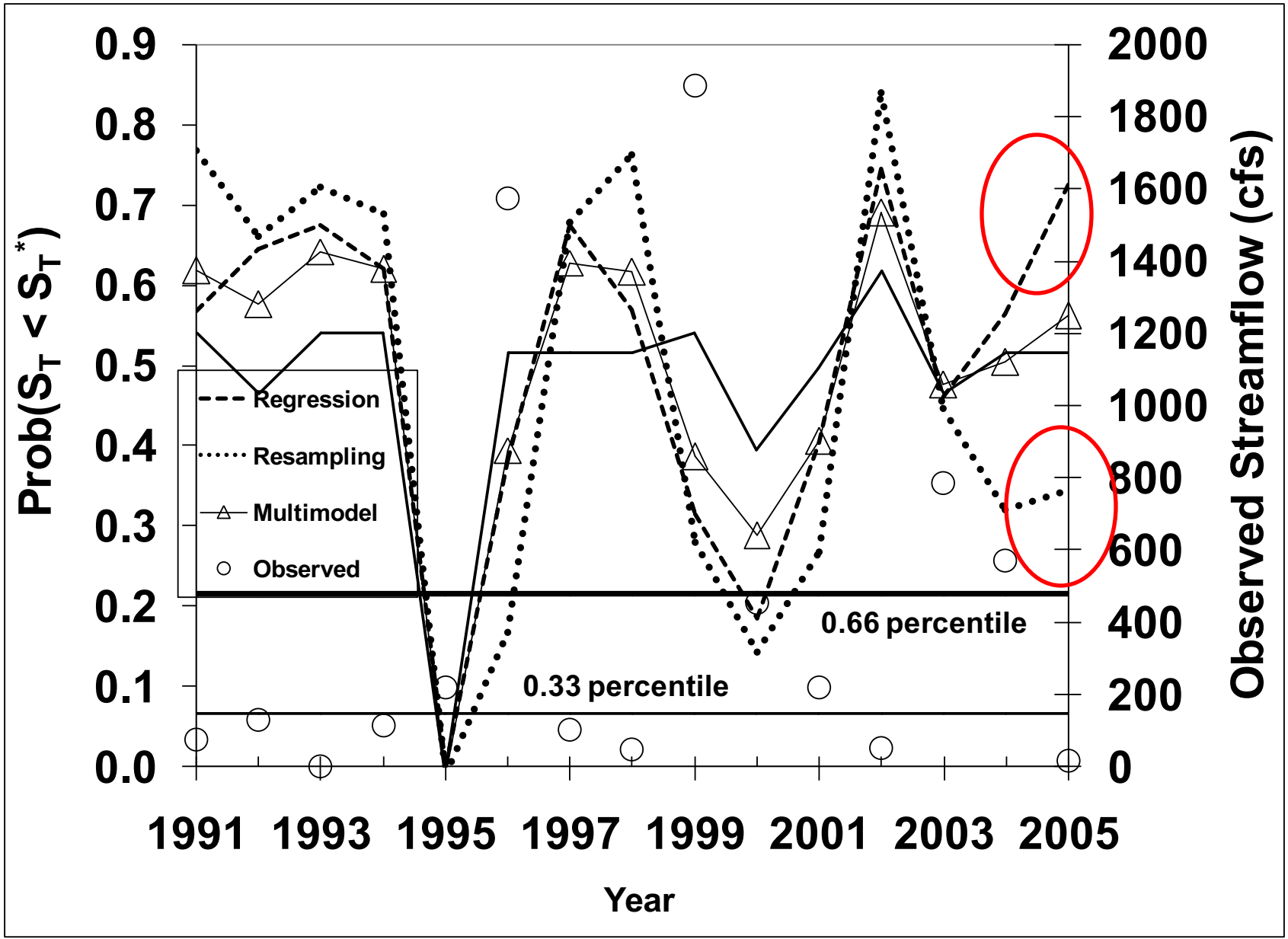
Increased Hydropower



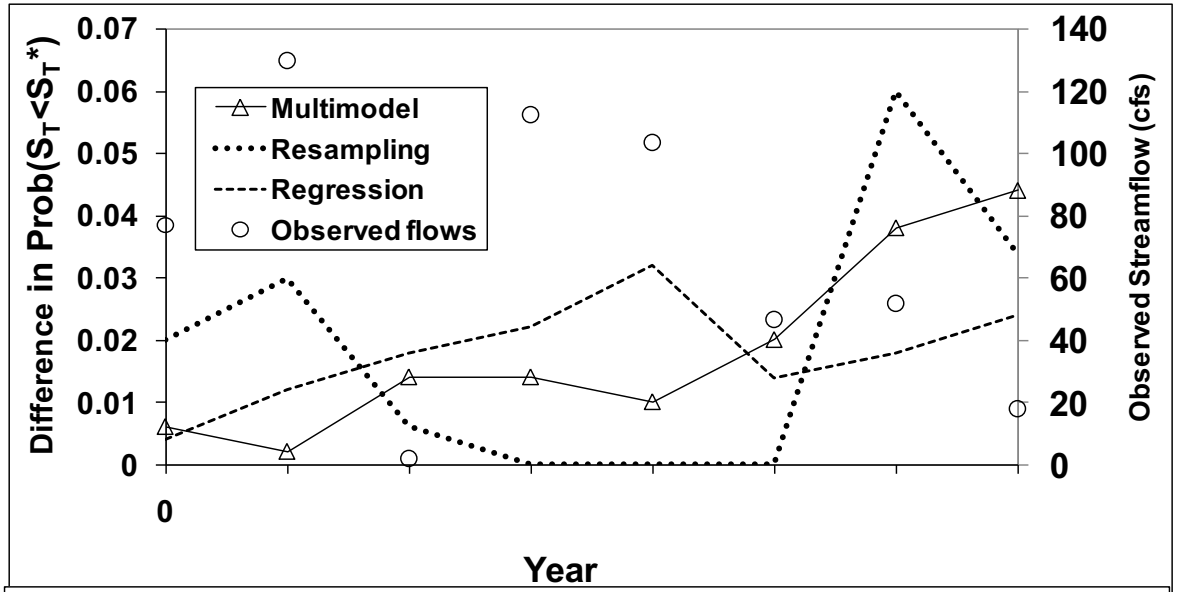
Irrigation Update

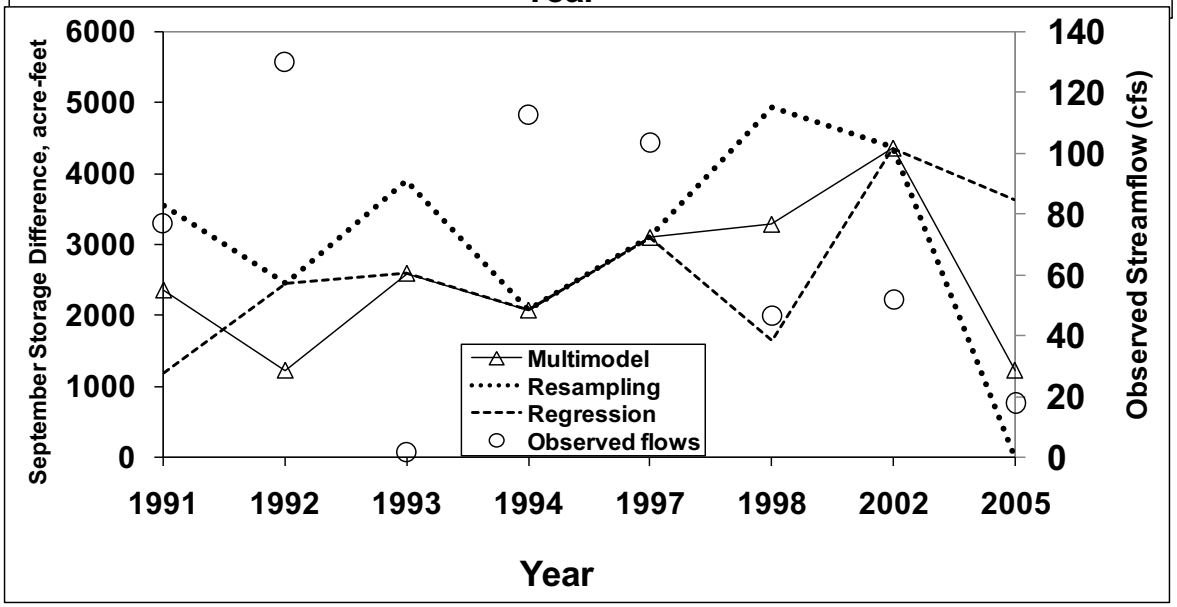


Meeting Target Storage during Drought Conditions (100cfs) and the Utility of Multimodel Forecasts (Golembesky et al., 2008)



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

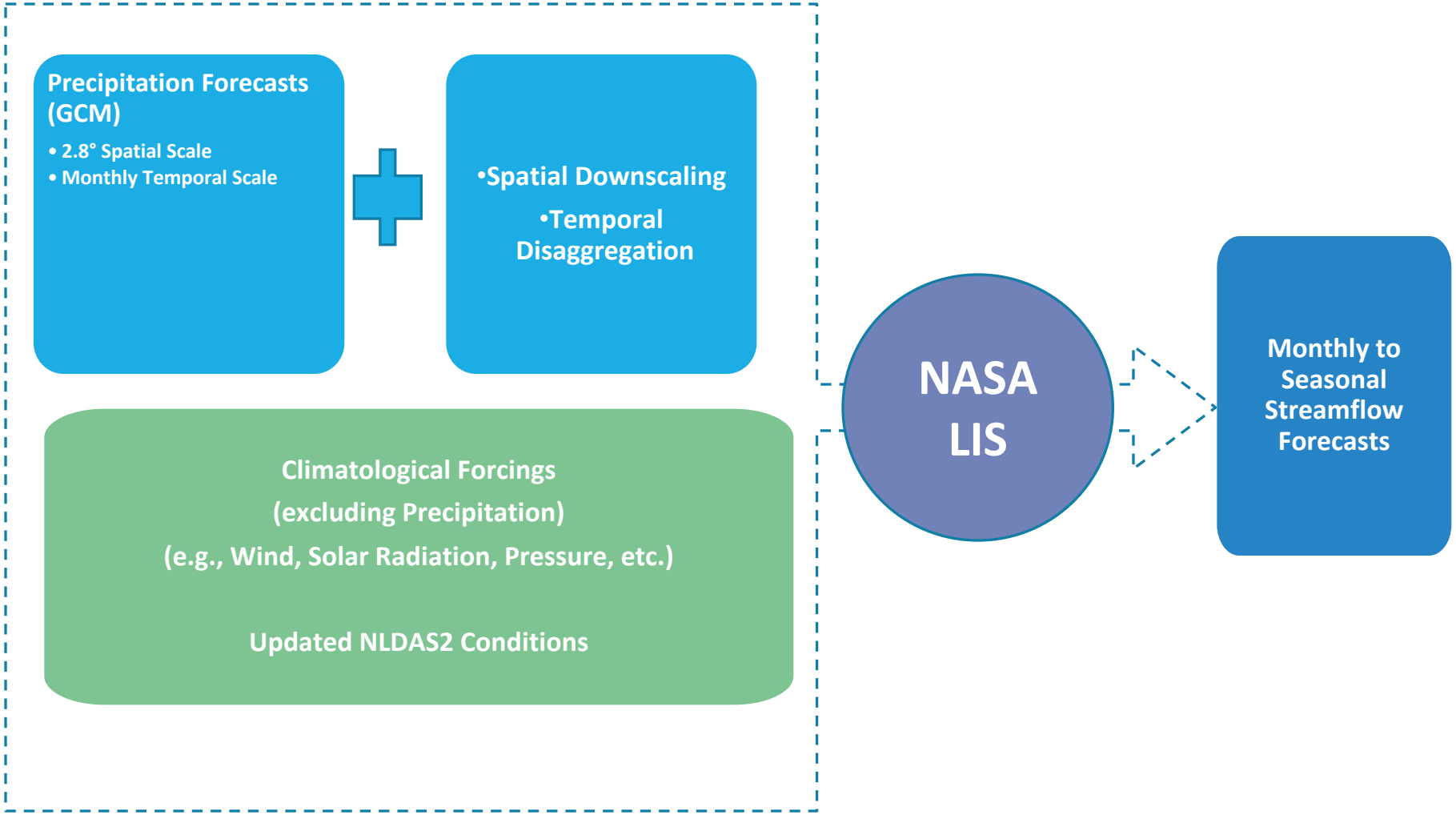
Reduced model uncertainties

Improves confidence in using forecasts

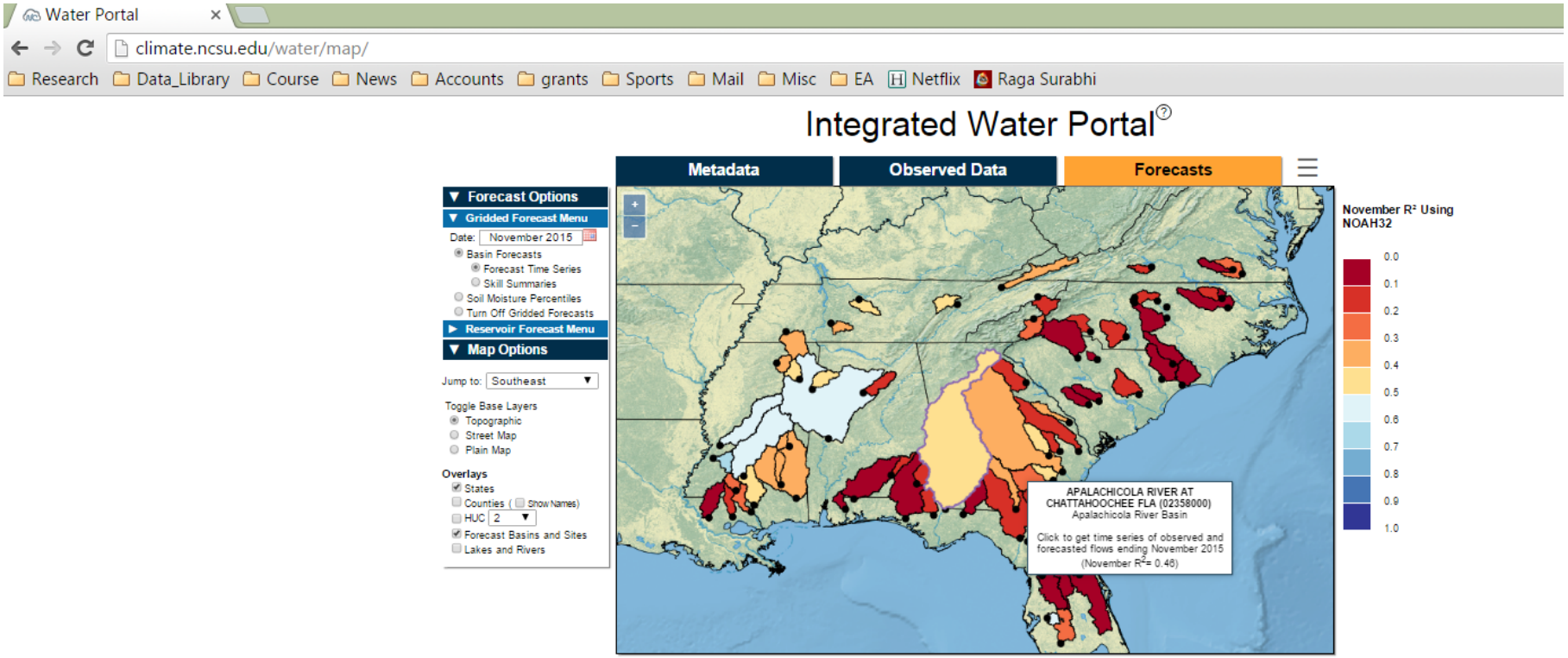
Streamflow and Storage Forecasts Portal

http://www.nc-climate.ncsu.edu/water/map

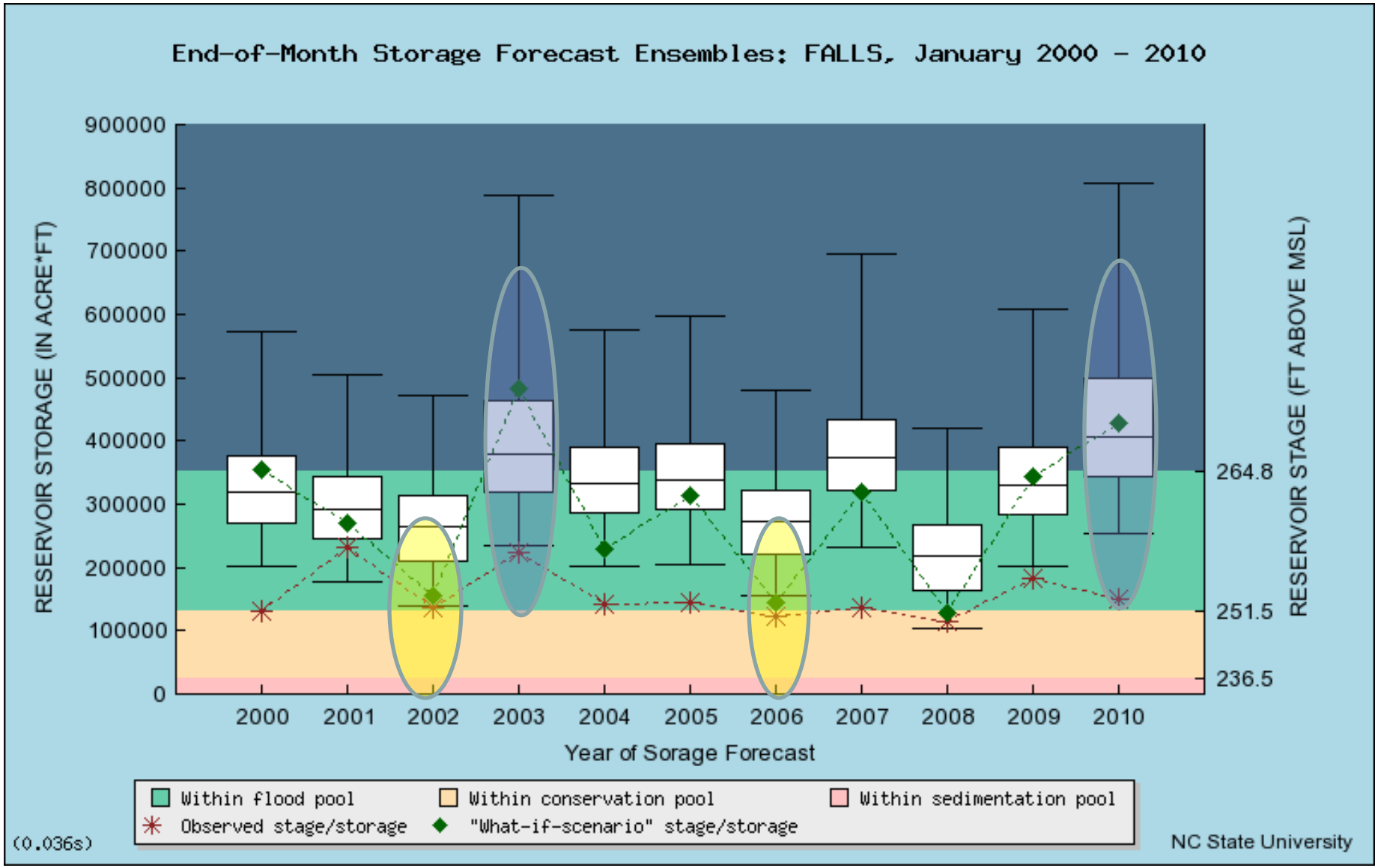
Streamflow (HCDN basins) and Soil Moisture (Gridded) Forecasts for the Southeast



Streamflow Forecasts for HCDN basins

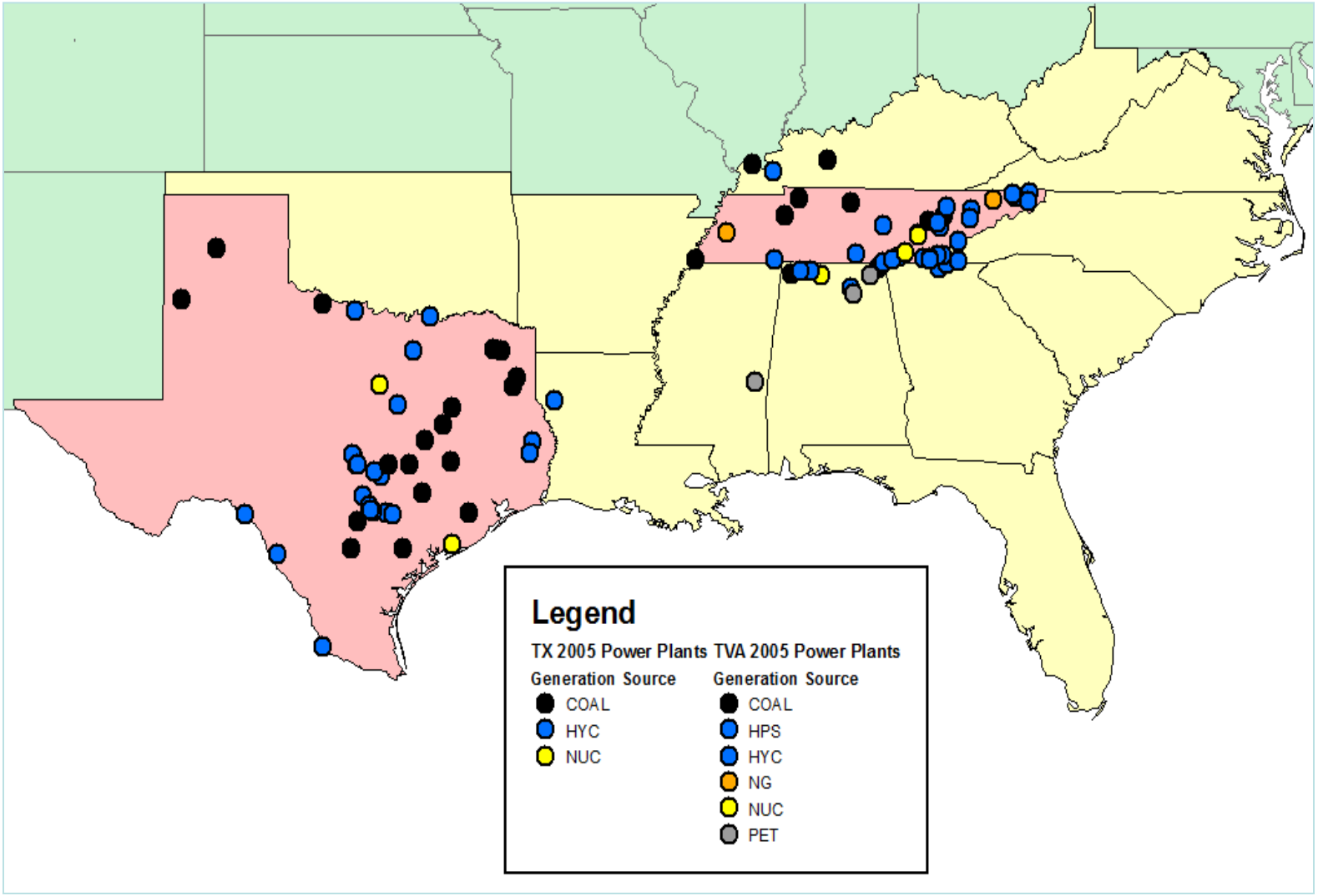


Storage Forecasts for Falls and Jordan Lake



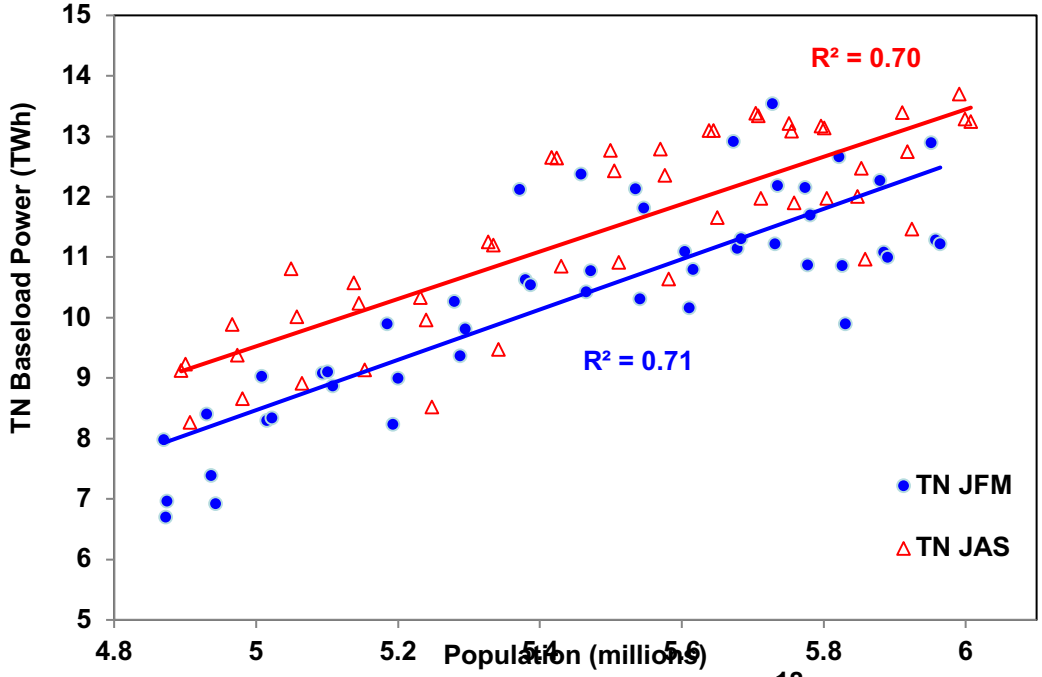
Climate-Information based Power Demand Forecasts

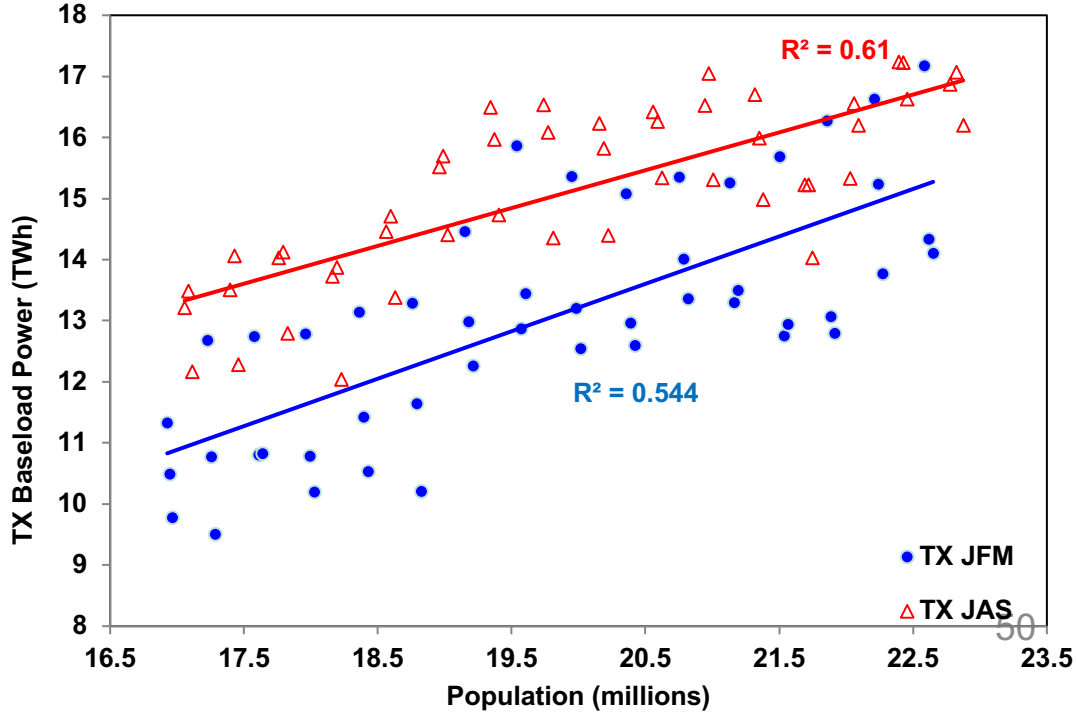
TN and TX Power Systems



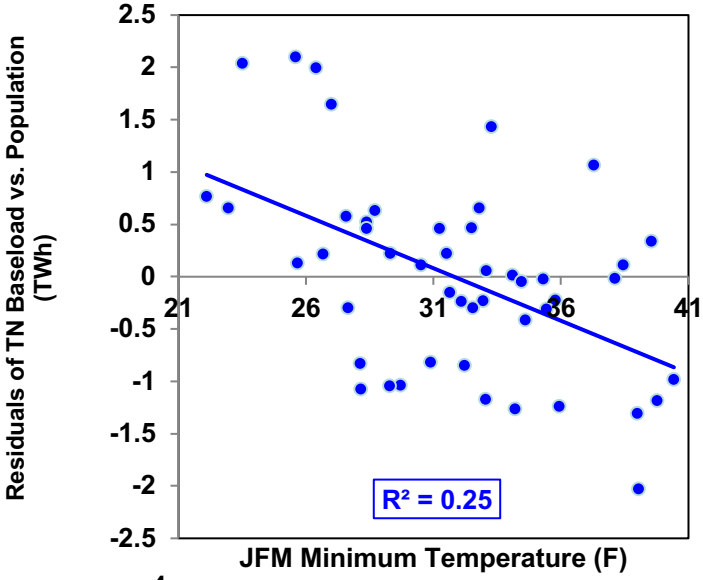
Cawthorne et al., (2015), ERL, in review

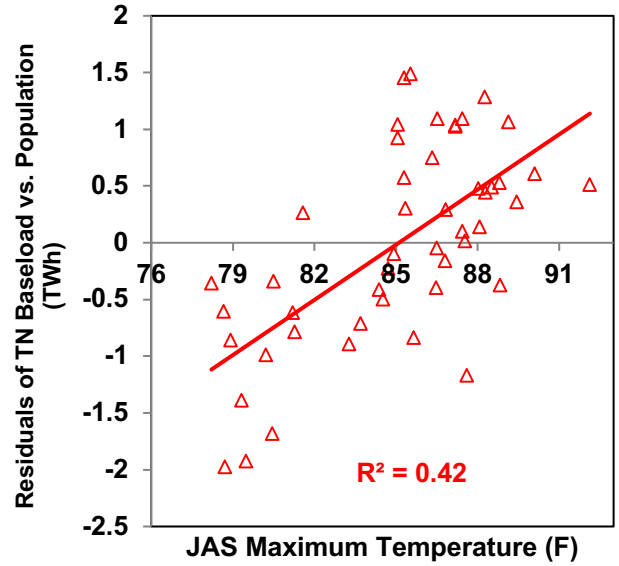
Growth, Development and Power Demand

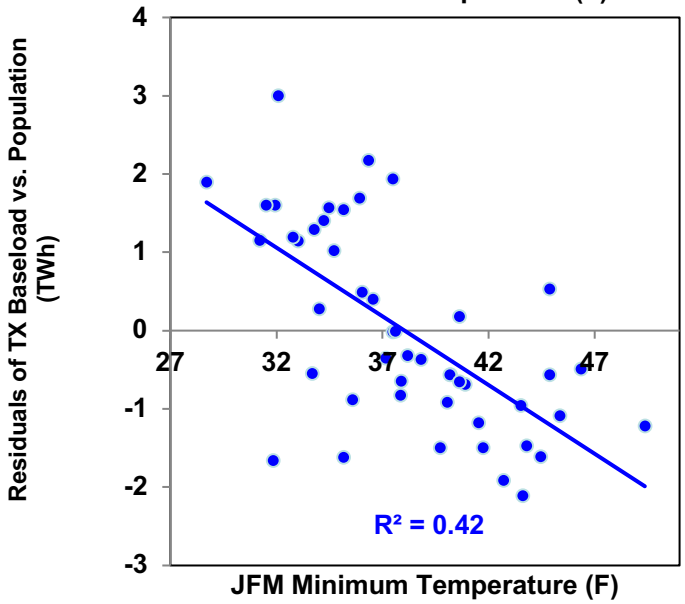


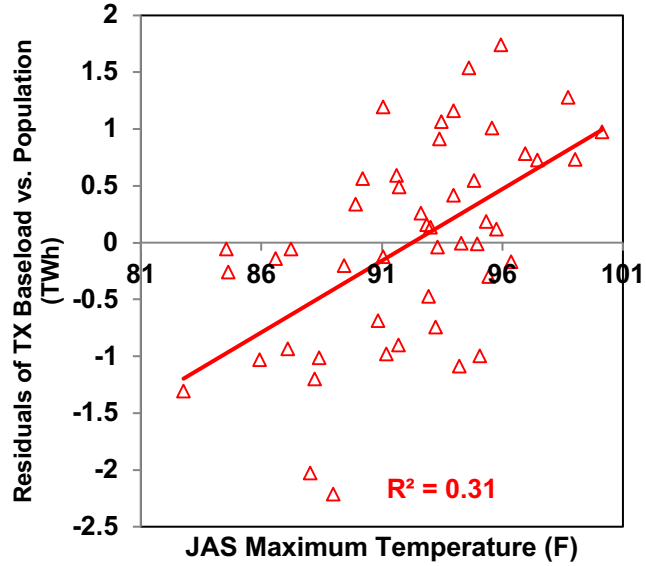


Power Demand Residuals vs Temperature

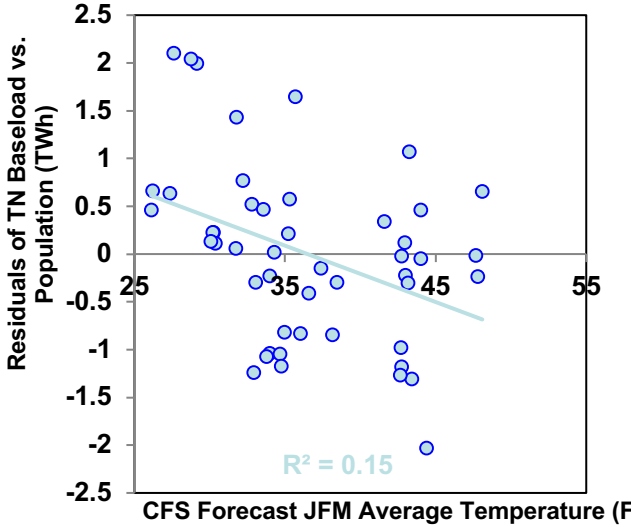


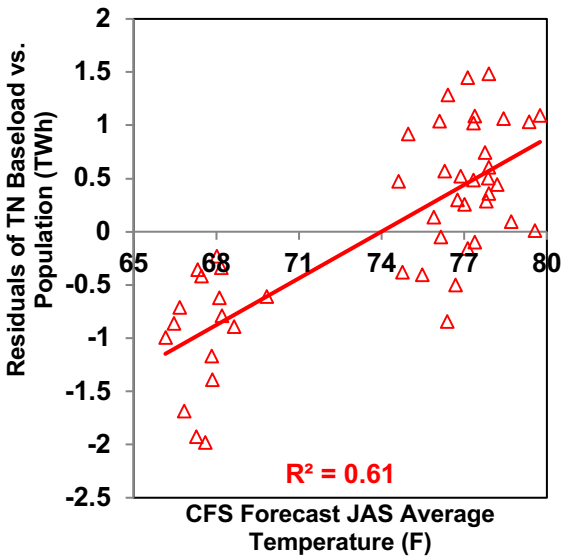


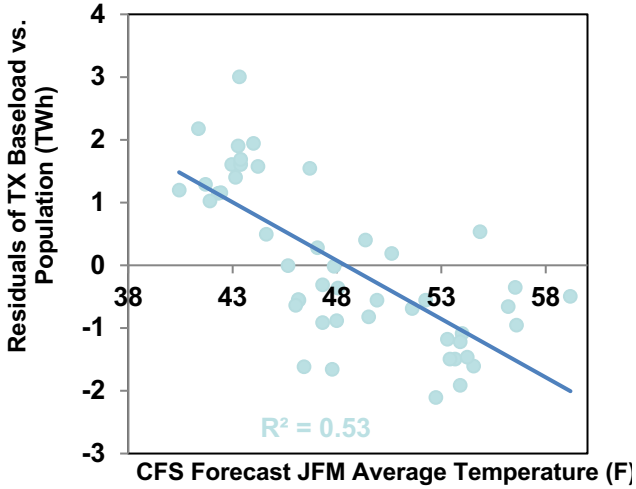




Power Demand Residuals vs Forecasted Temperature







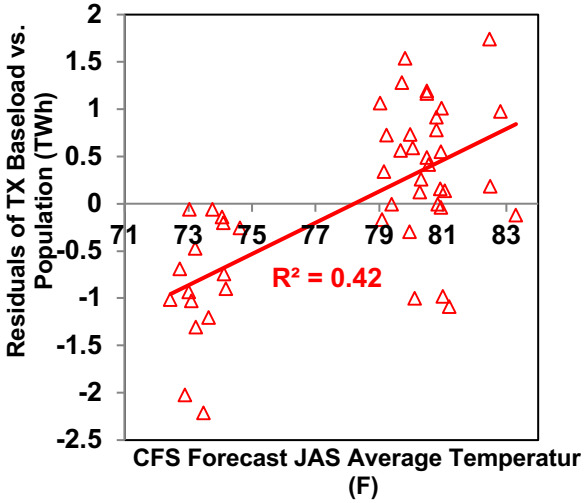
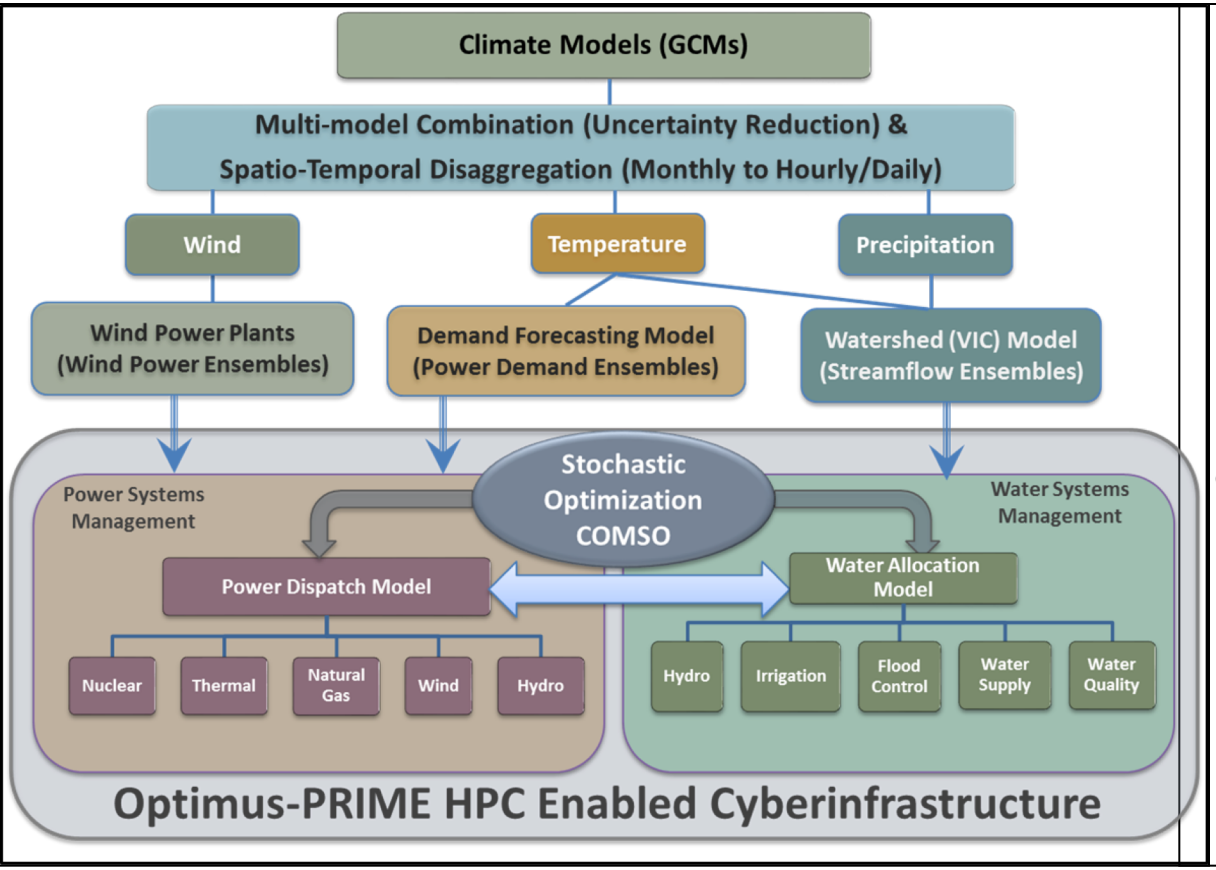
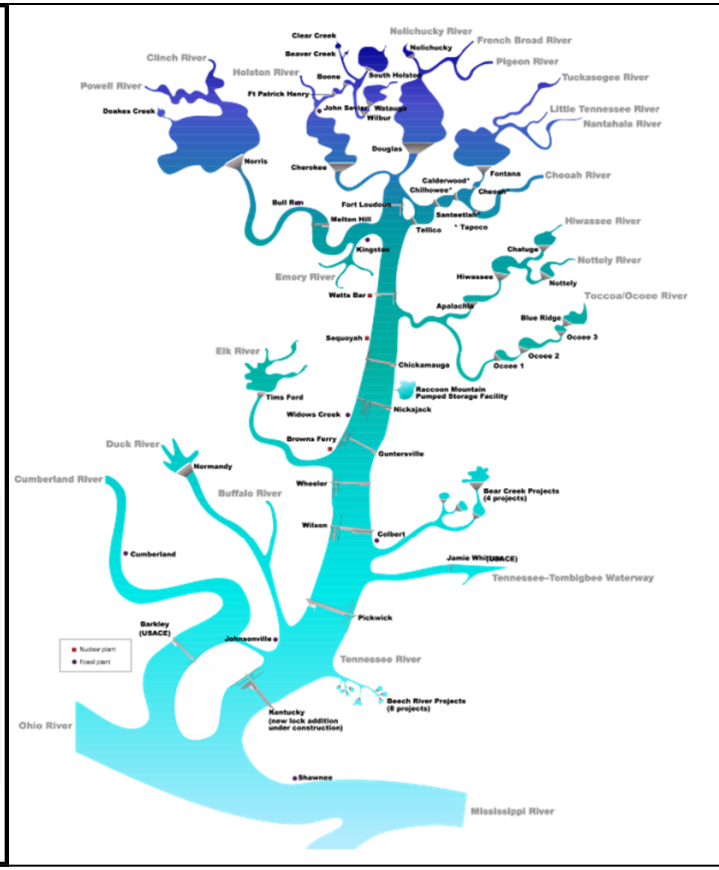


Table 1 - Correlation between observed average temperature and forecasted average temperature from two atmospheric GCM forecasts, CFS and ECHAM 4.5, for the winter and summer seasons.

	Tennessee		Texas	
Season	CFS Forecast	ECHAM4.5 Forecast	CFS Forecast	ECHAM4.5 Forecast
JFM	0.587	0.566	0.615	0.615
JAS	0.865	0.821	0.767	0.780

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