MODELING STREAMFLOW IN GLACIER DOMINATED BASINS

Presented by: Fernando R. Salas

Time Series Analysis, Modeling and Control

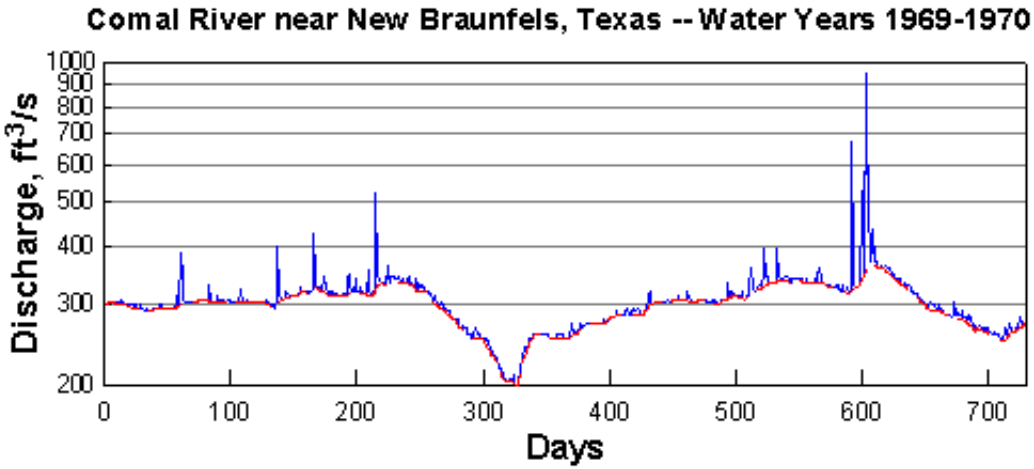
May 10, 2011

Outline

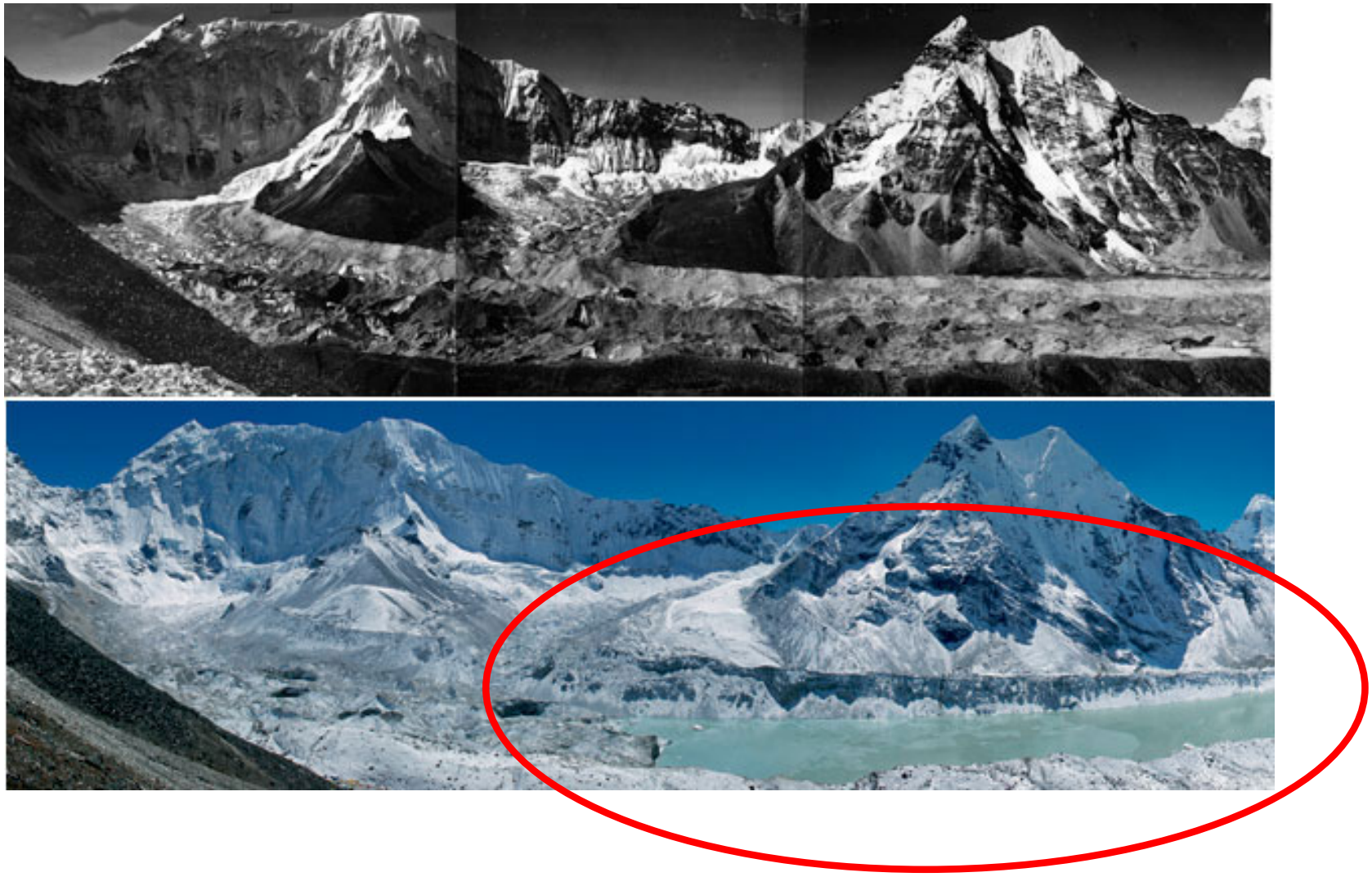
- Motivation for modeling glacier fed water systems
- Case Studies
  - Inflow to Toktogul Reservoir in the Himalayas
  - Inflow to Canon de Pato Dam in the Andes
- Models and Results
  - Are system dynamics in the Himalayas similar to the Andes?
  - Do monthly models translate to an annual scale?
- Where do we go from here?
  - Stochastic models vs. physical models

Modeling Glacier Fed Water Systems

- Annual prediction and planning
  - Mass balance at both monthly and annual time scales
- Constituents
  - Inputs
    - Precipitation, Groundwater and Glacial Melt
  - Outputs
    - Evaporation, Streamflow



Climate Change



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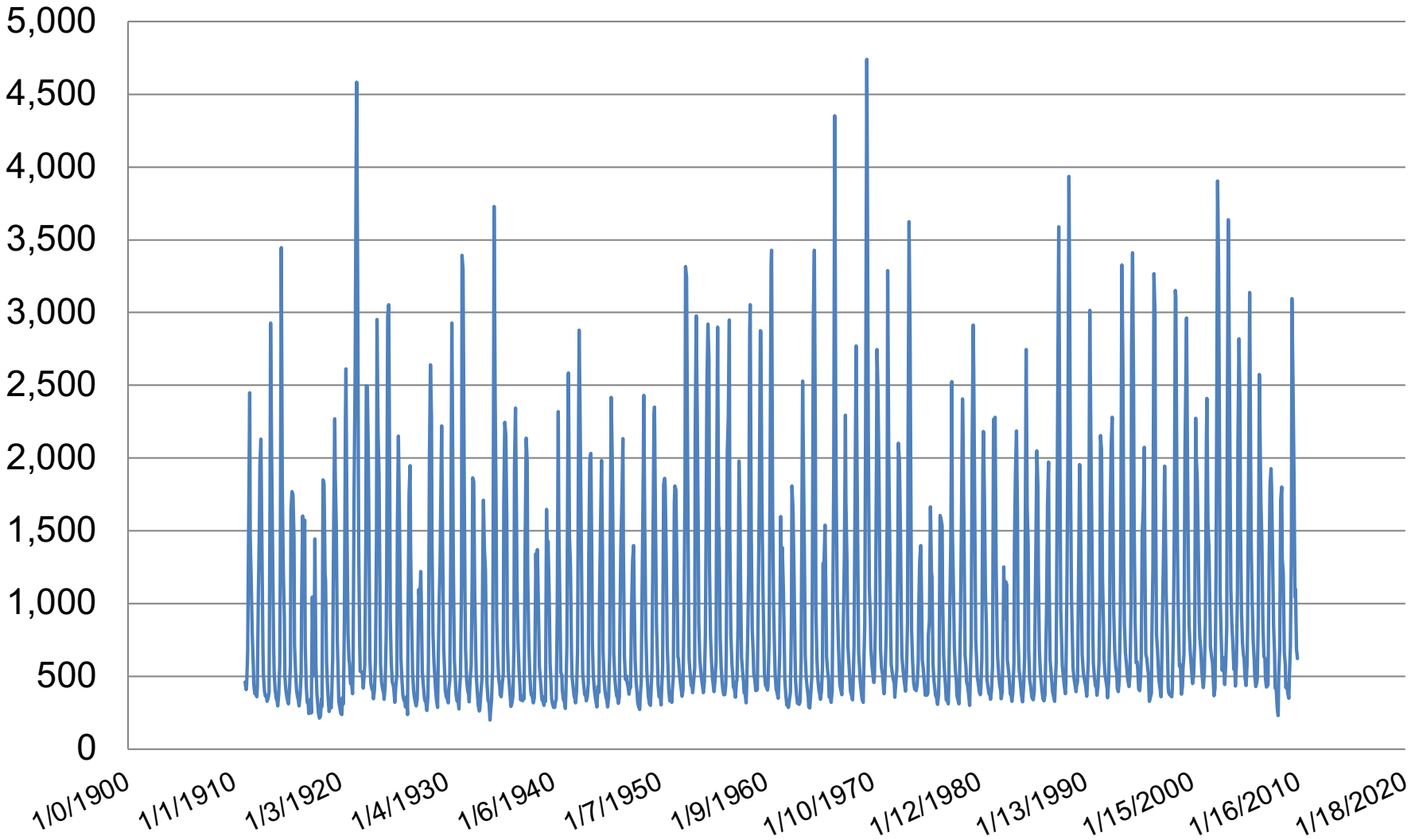
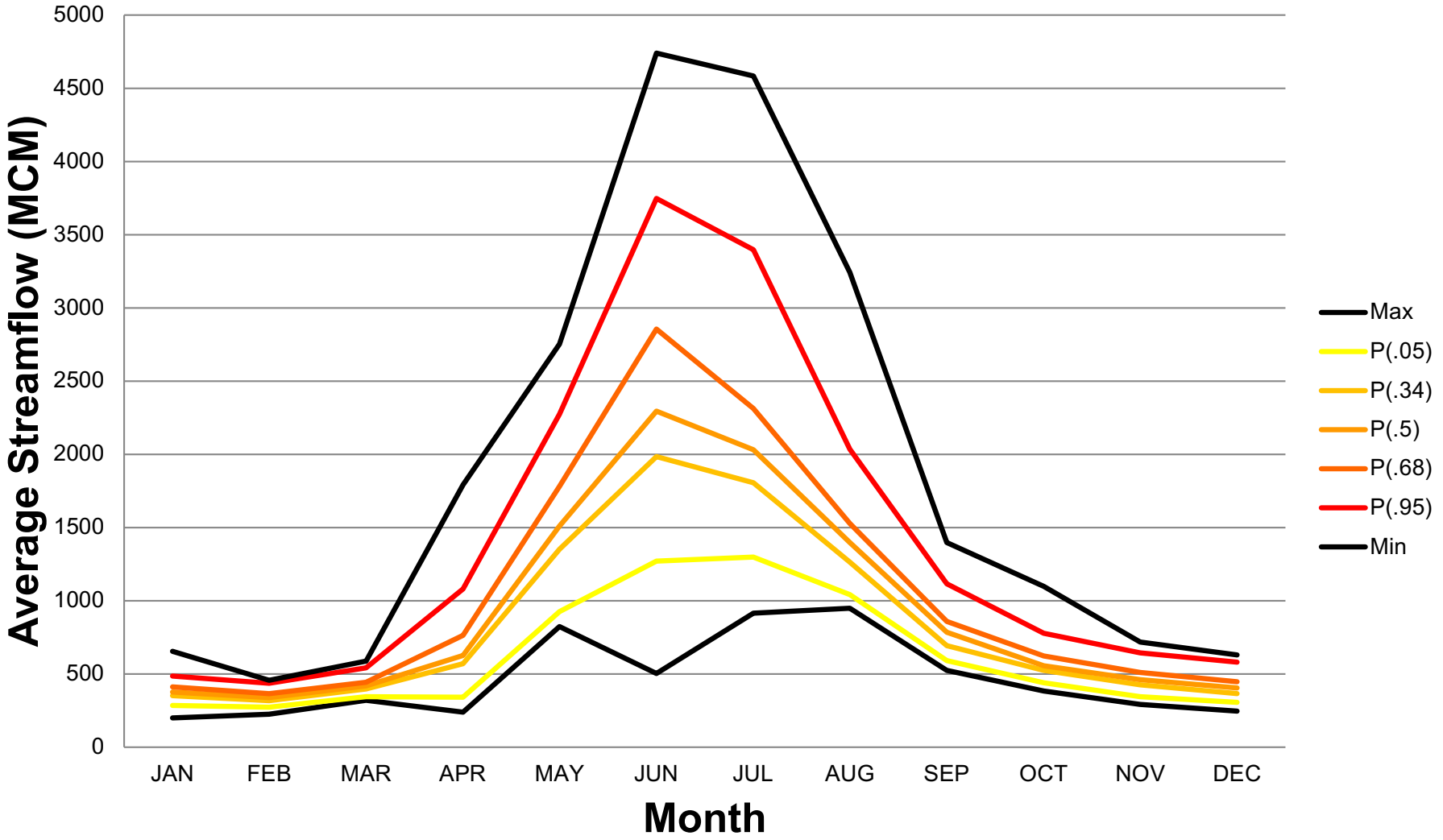
Toktogul Reservoir

- Located in Kyrgyzstan on the Naryn River
- Naryn River is glacially fed by the Himalayas
  - Average annual streamflow is 650 m^3/sec
- Hydroelectric station
  - Largest power plant in the country (1.2 GW)

Toktogul Monthly Streamflow (MCM)



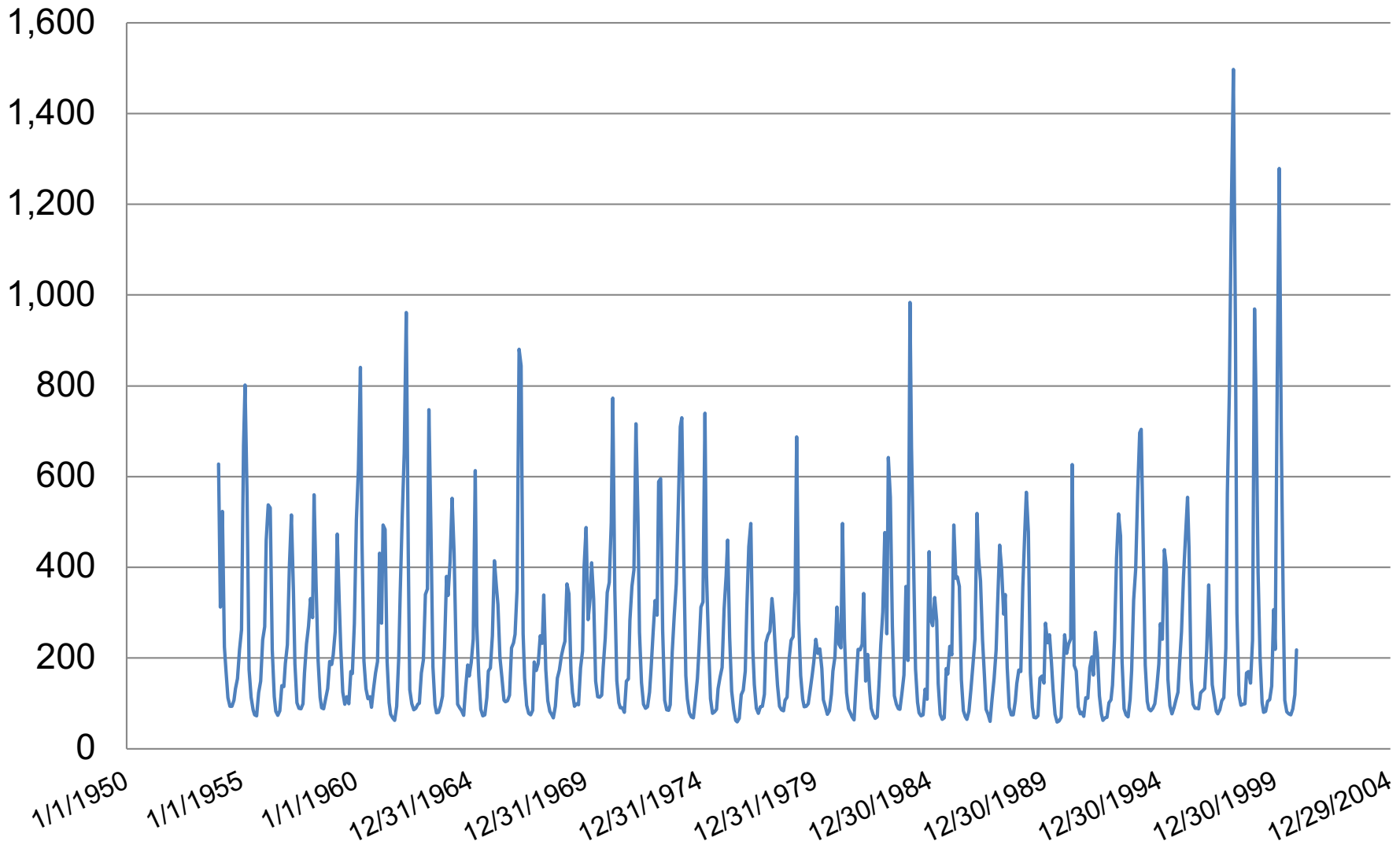
Toktogul Monthly Flow Regime



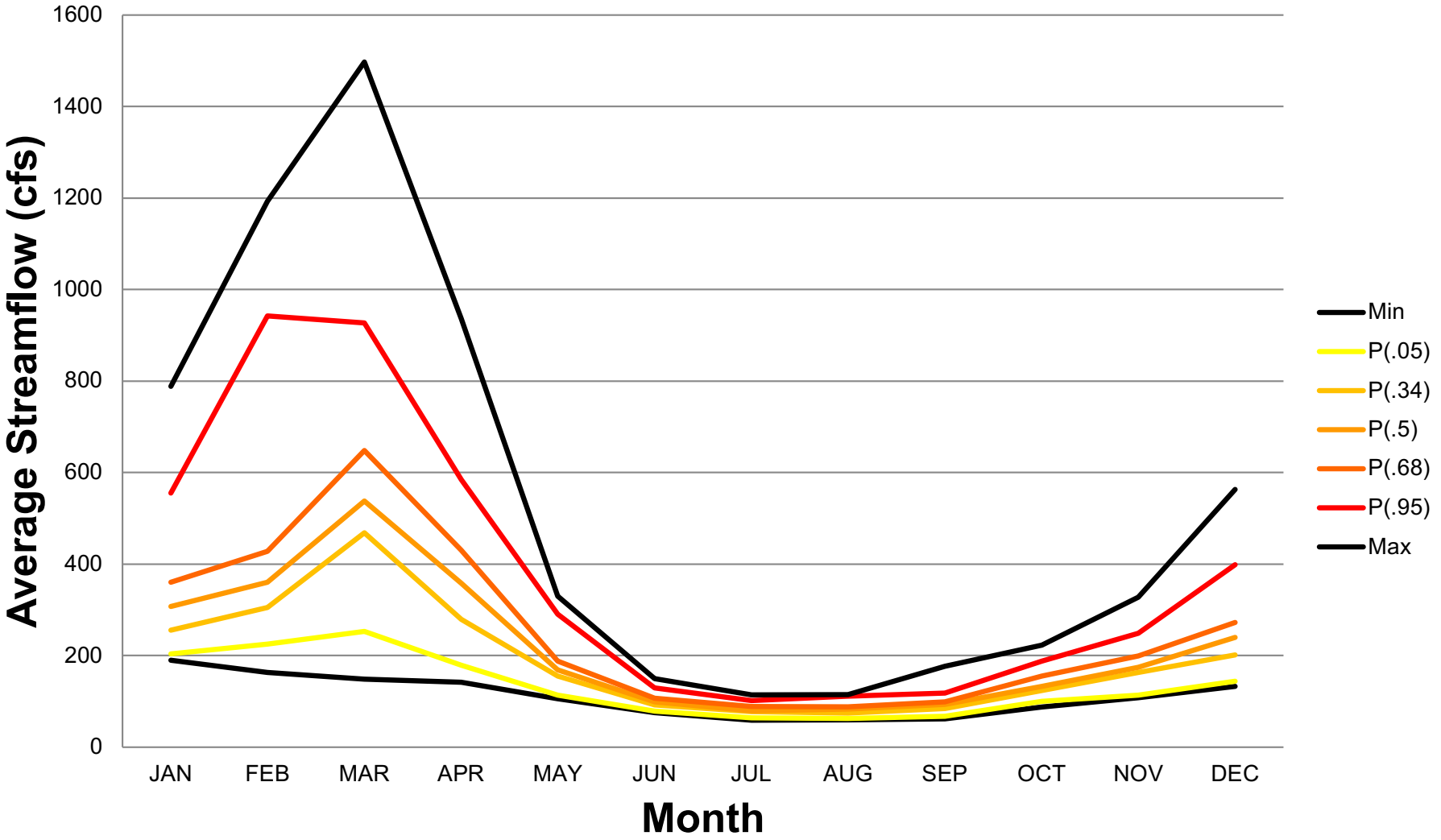
Canon del Pato Dam

- Located in the Ancash region of Peru on the Santa River
- Santa River is glacially fed by the Andes
  - One of the most susceptible areas in the world to climate change
- Hydroelectric station powers capital (Lima)

Canon del Pato Monthly Streamflow (MCM)



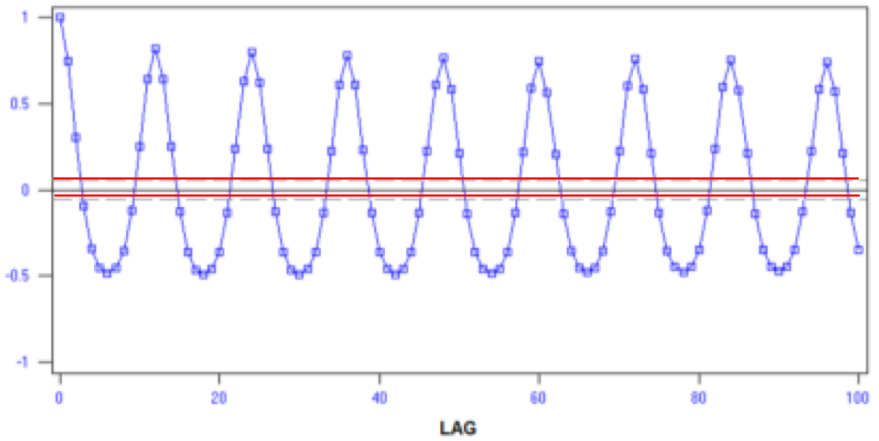
Canon del Pato Monthly Flow Regime



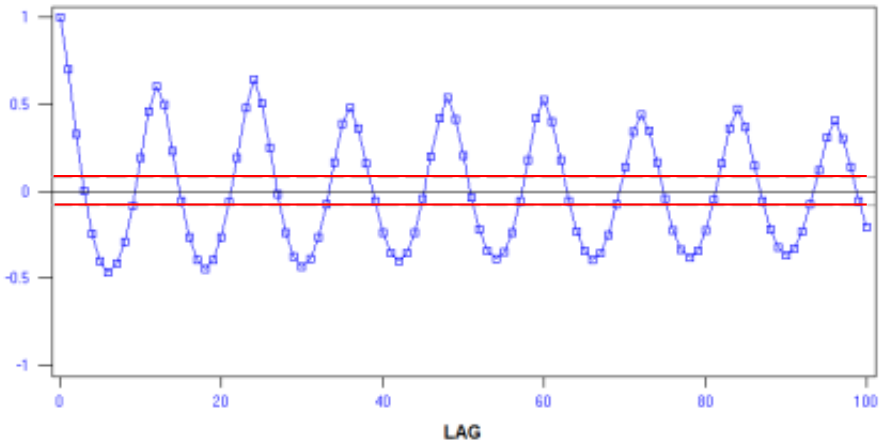
Autocorrelation Functions

- Both water systems demonstrate:
  - Strong correlations with past values
  - Slow decay (> 100 lag)
  - Cyclical patterns
- Resonance Time
  - Toktogul resonance time bigger than Canon del Pato

Toktogul Autocorrelation Function



Pato Autocorrelation Function



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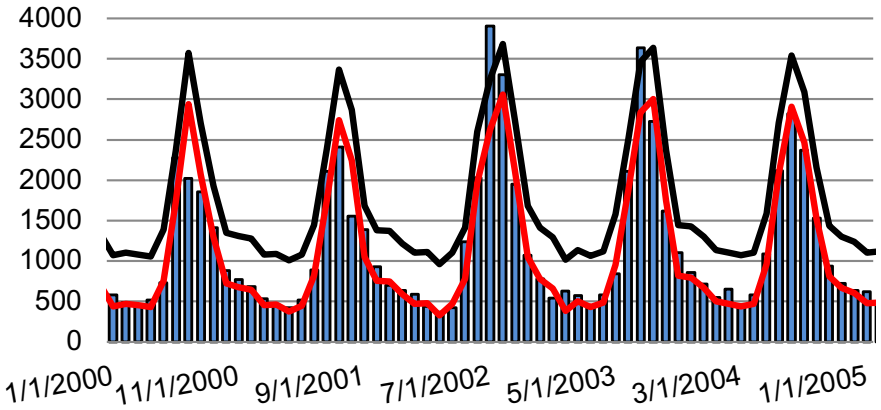
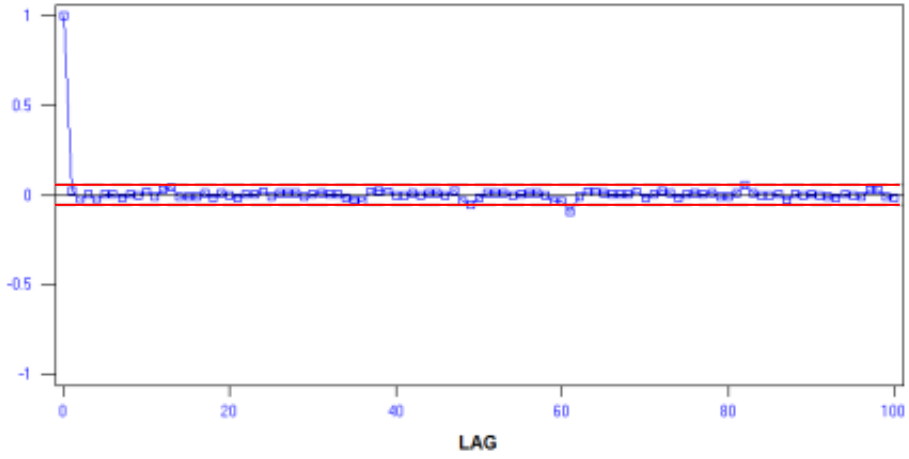
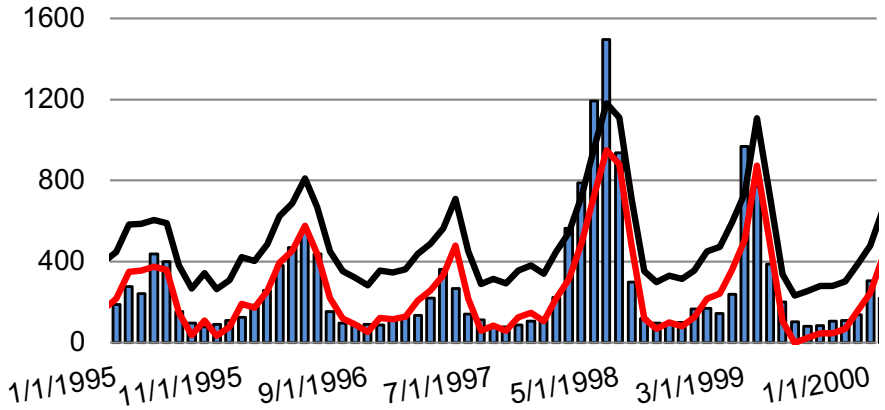
ARMA(n,m) Monthly Models

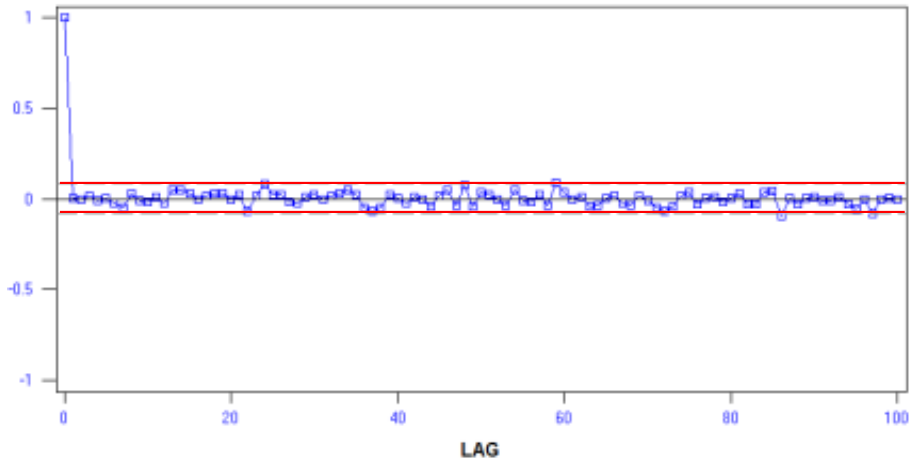
Toktogul – ARMA(14,13)





Canon del Pato – ARMA(16,15)

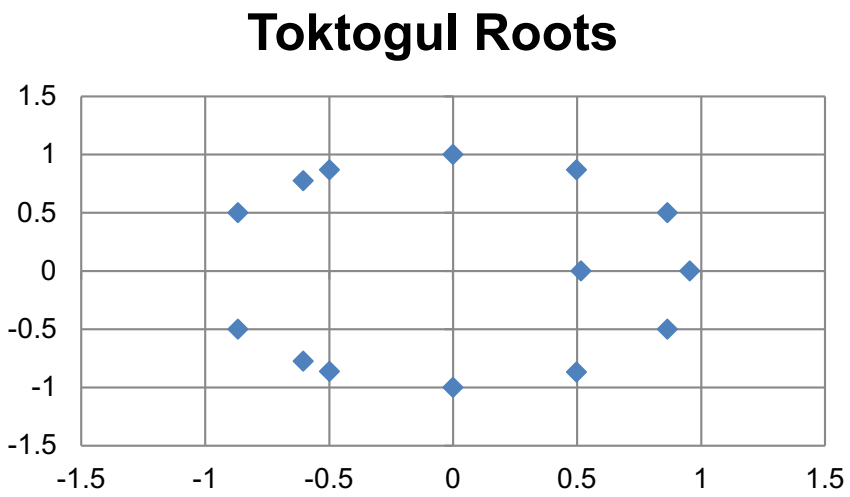




Monthly Model Trends

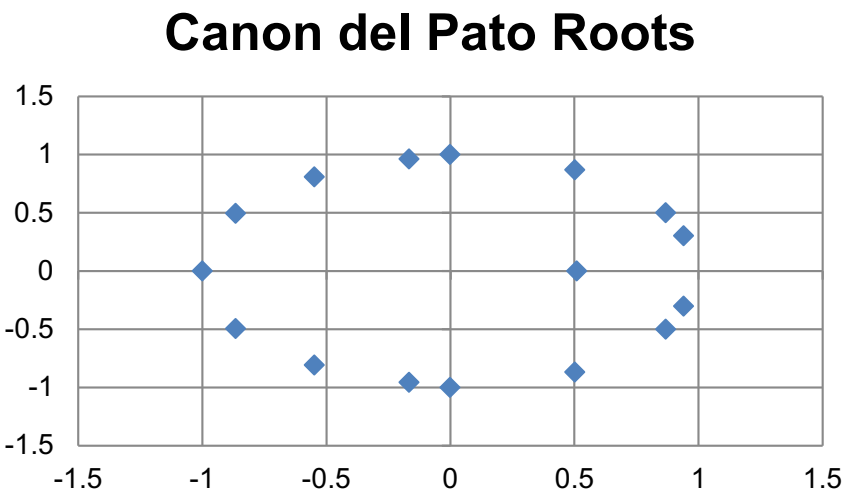
Toktogul – ARMA(14,13)

- Seasonality
  - 12, 6, 4, and 3 month
- Green's Function peak at lag 12

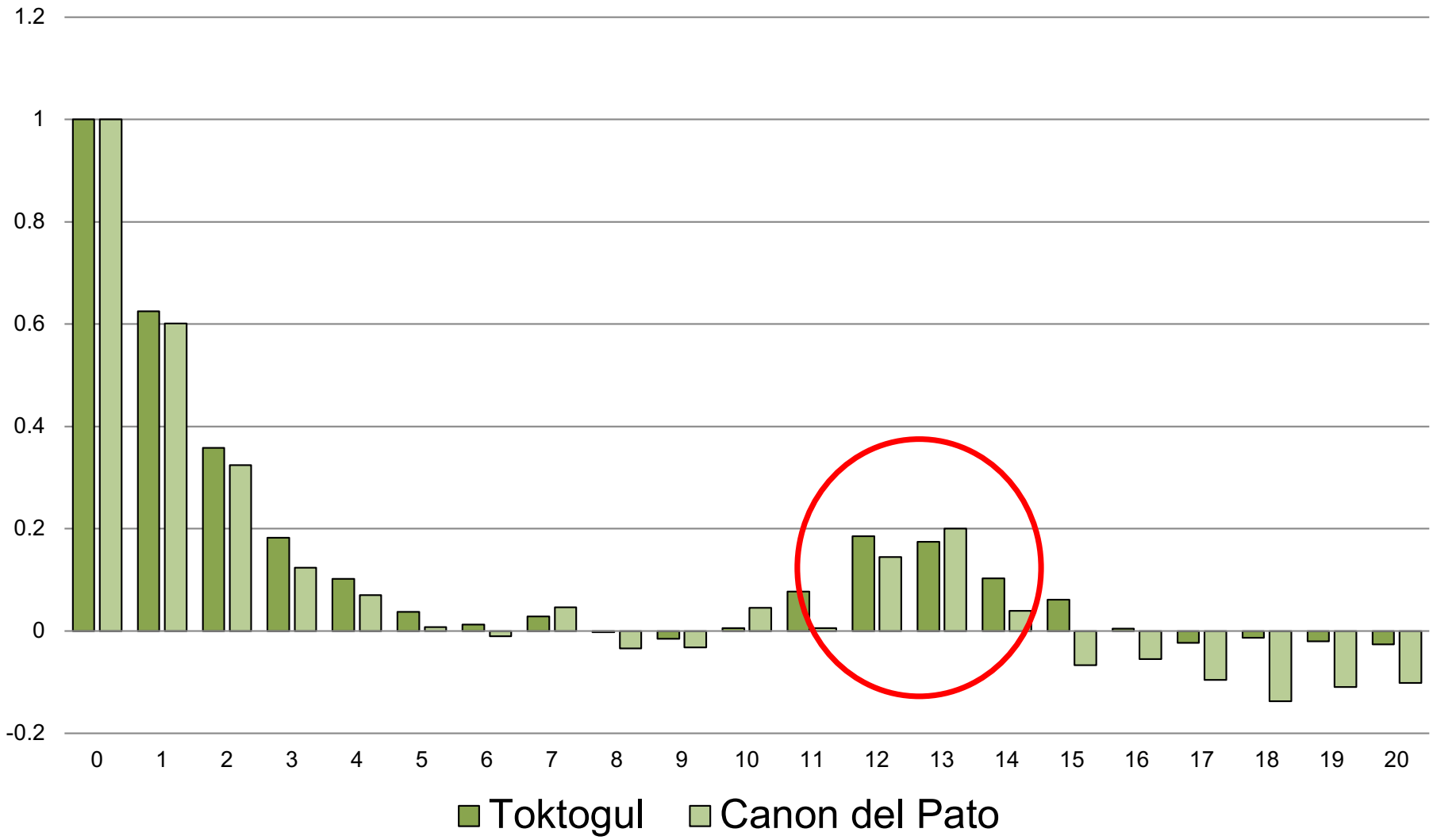


Canon del Pato – ARMA(16,15)

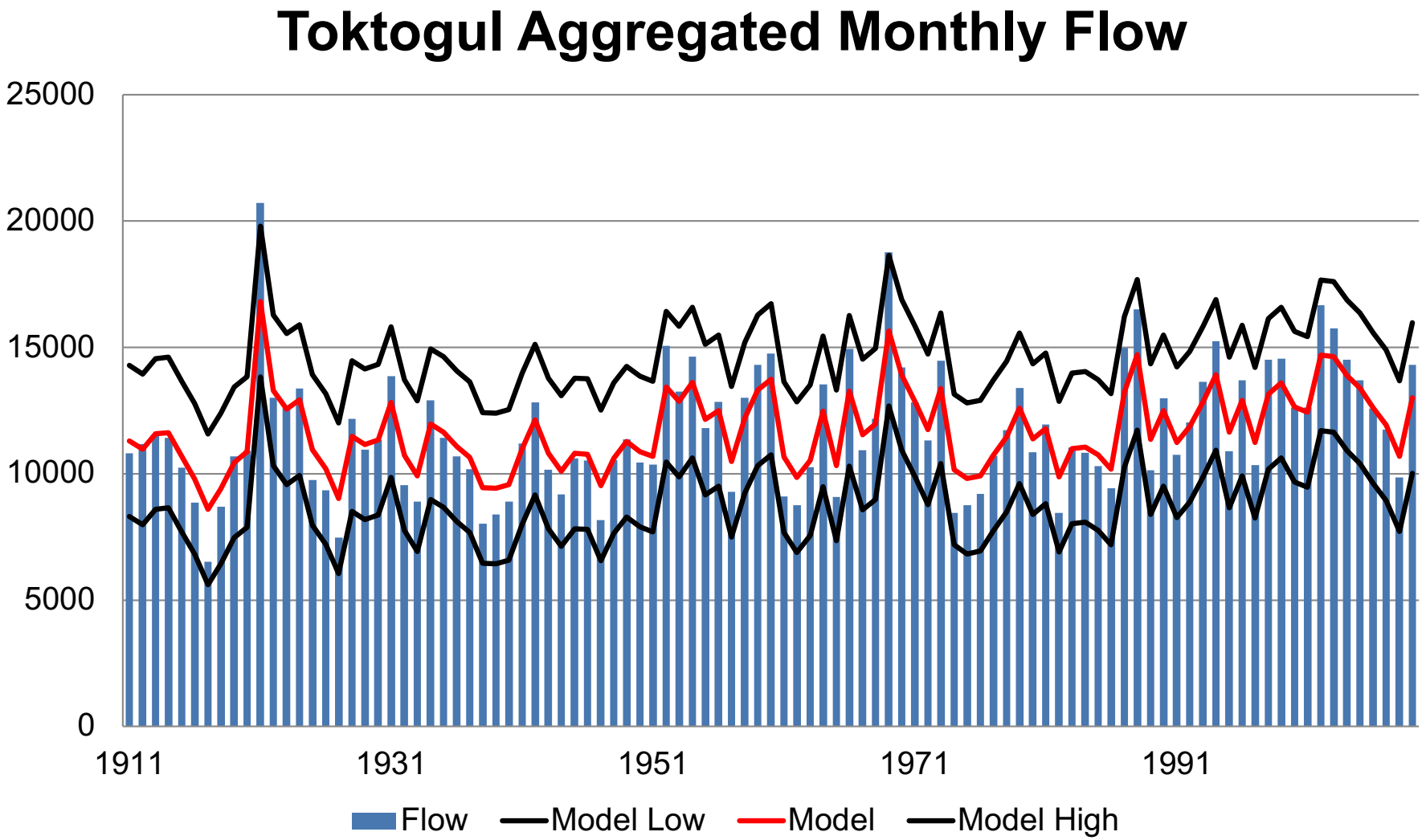
- Seasonality
  - 12, 6, 4, 3 and 2 month
- Green's Function peak at lag 12



Green's Function

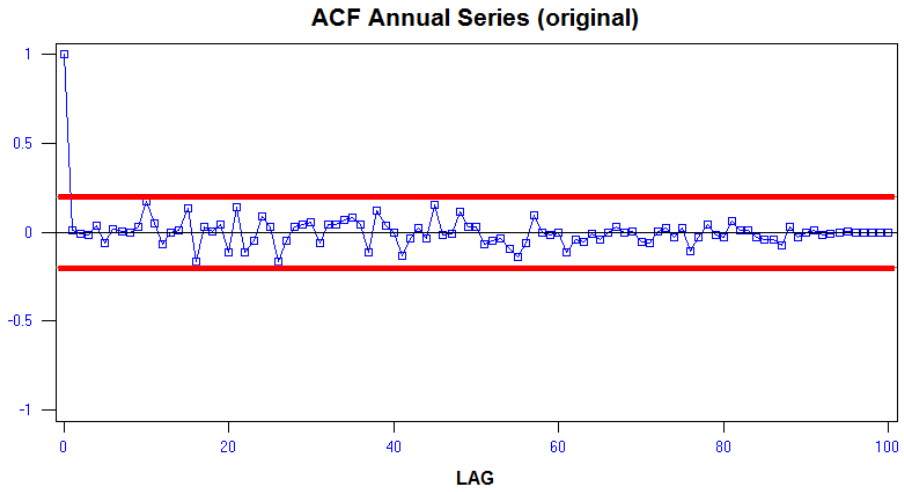


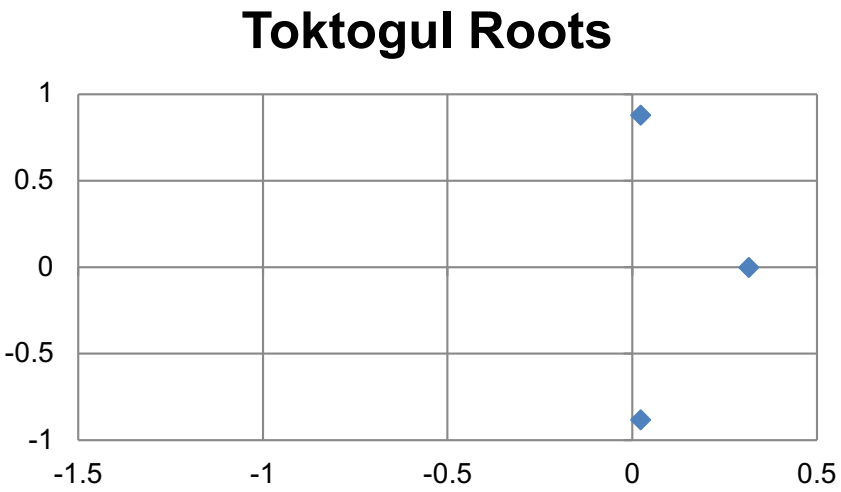
What About Annual Time Scales?

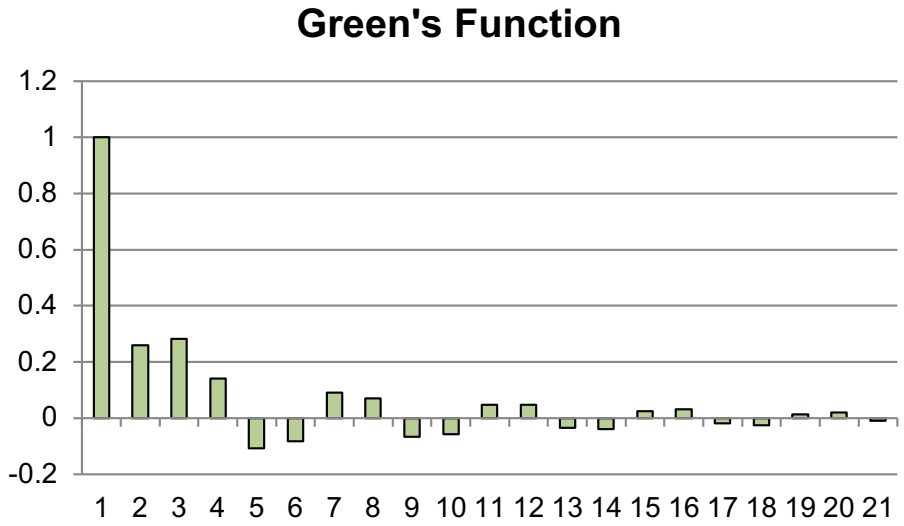


Toktogul Annual Model

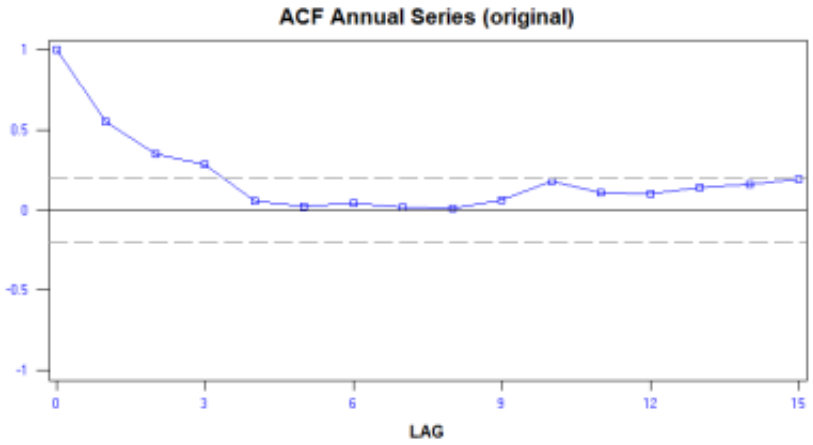
- ARMA(3,2)
- No significant trends
- No seasonality

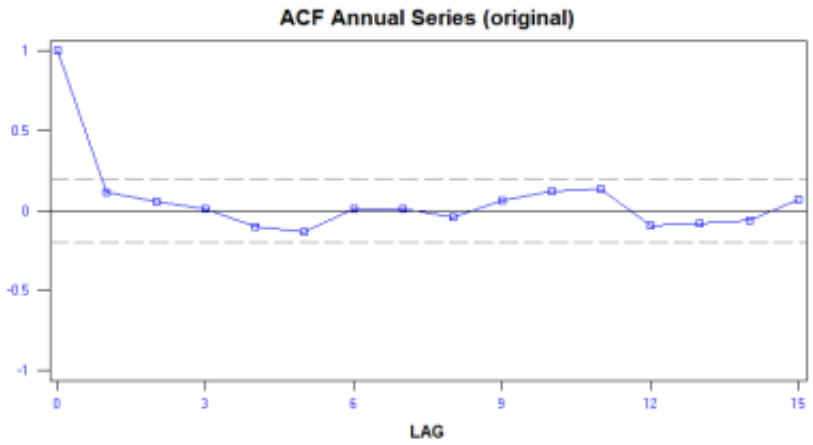


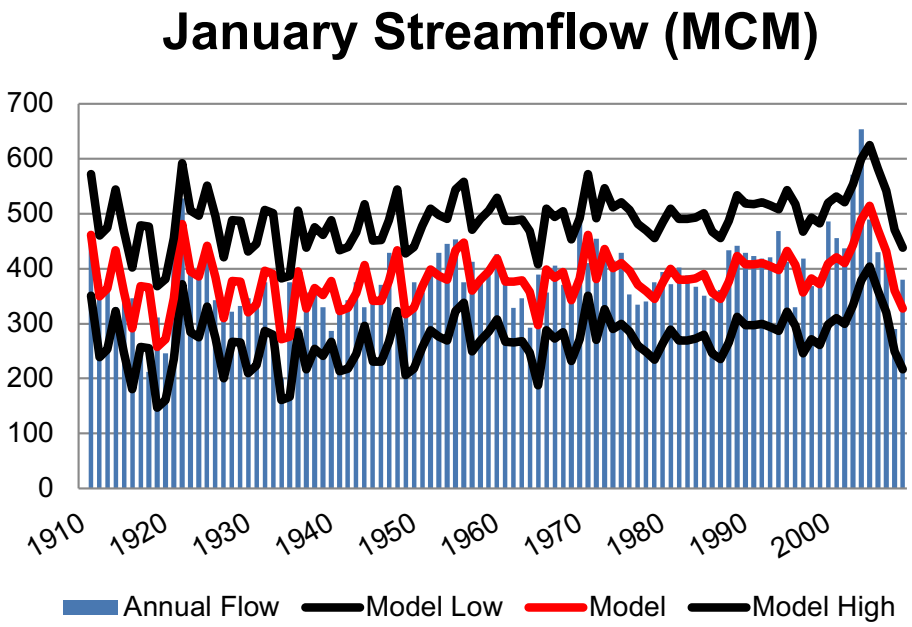


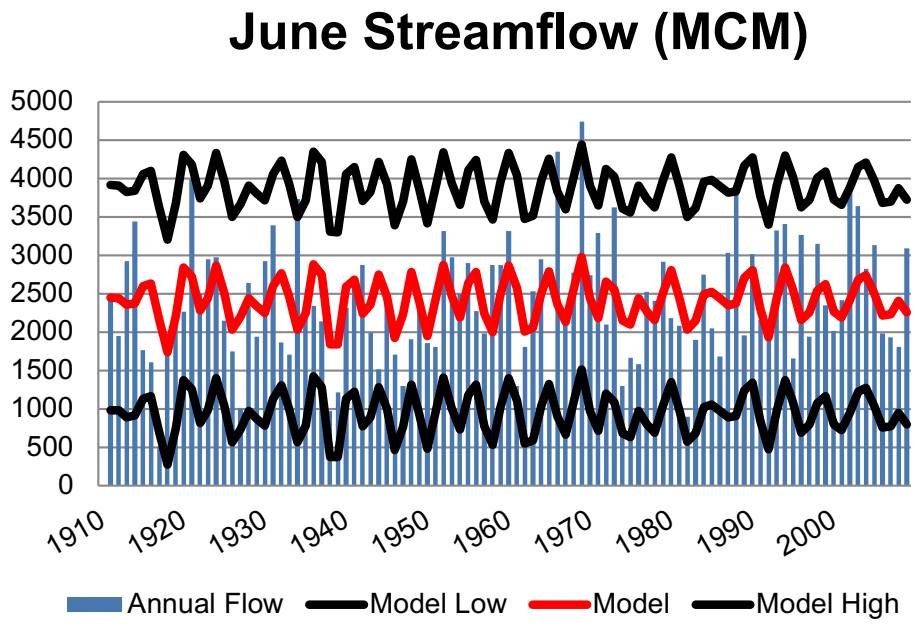


Toktogul Seasonal Model?

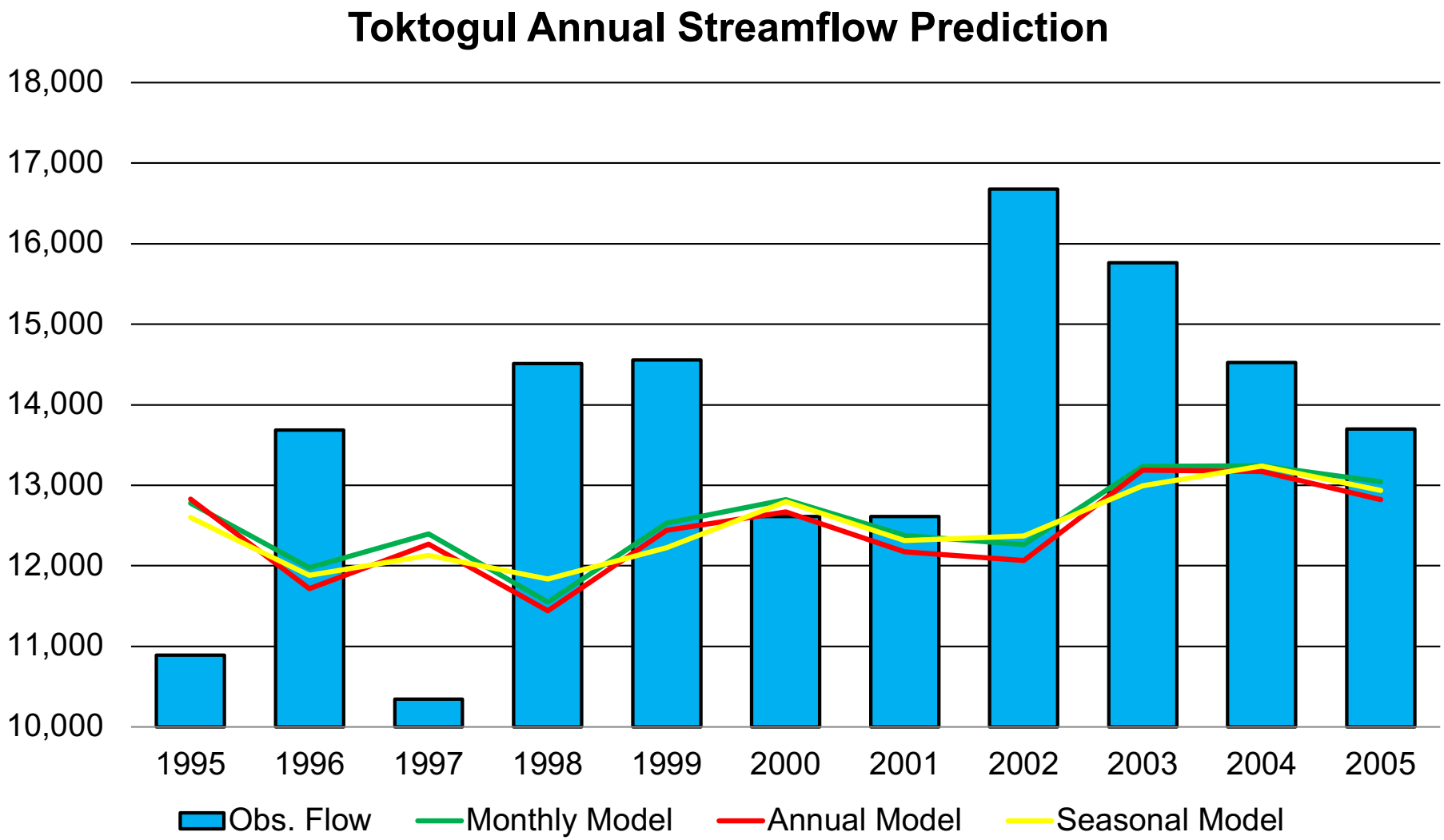






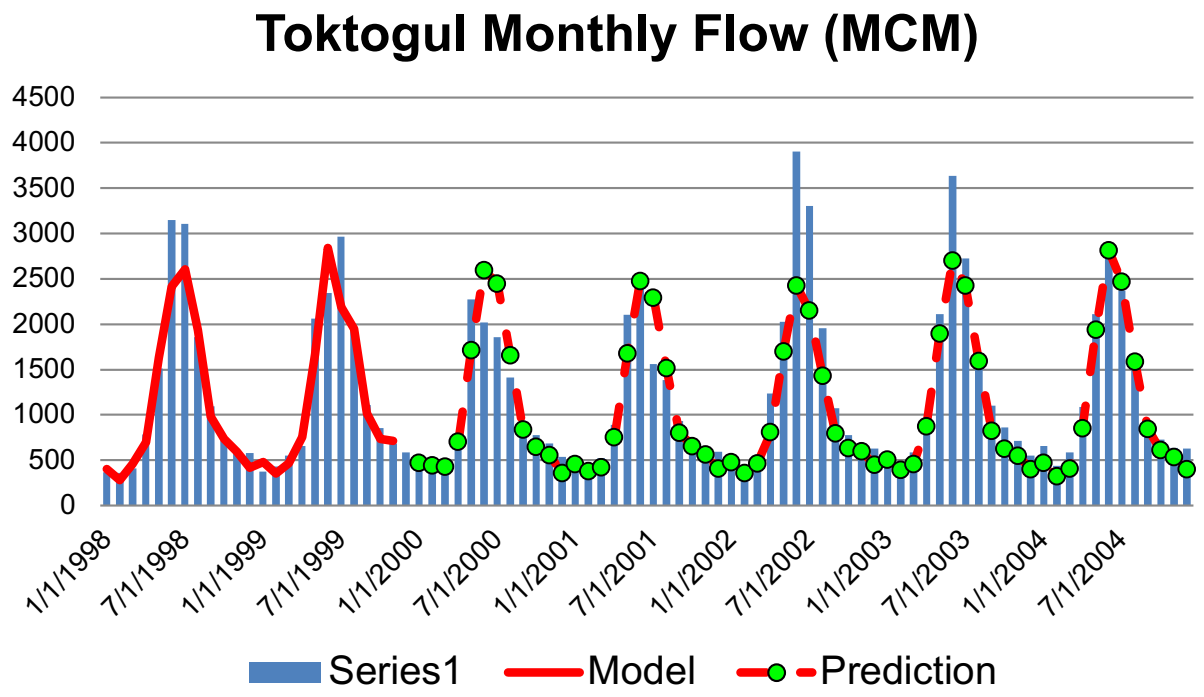


Model Comparison – One Year Prediction



Best Model for Predicting Annual Flow

Model	Coefficient of Determination	Predictive Variance
Monthly Model	0.079	1,597,370
Annual Model	0.063	5,471,120
Seasonal Model	**0.089**	**1,474,168**



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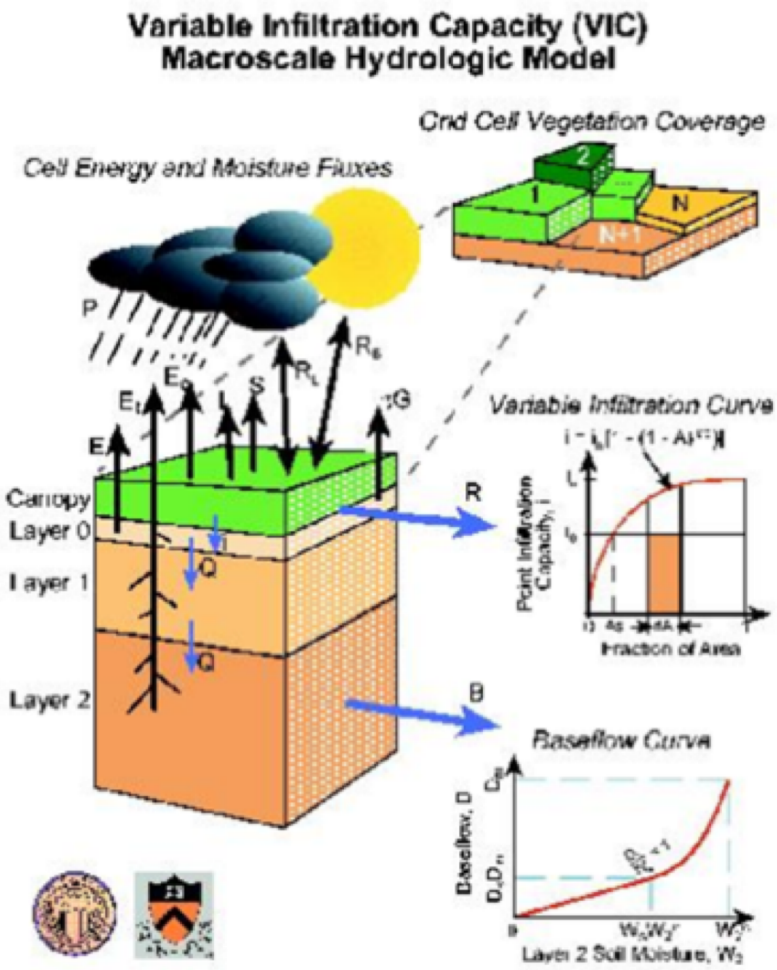
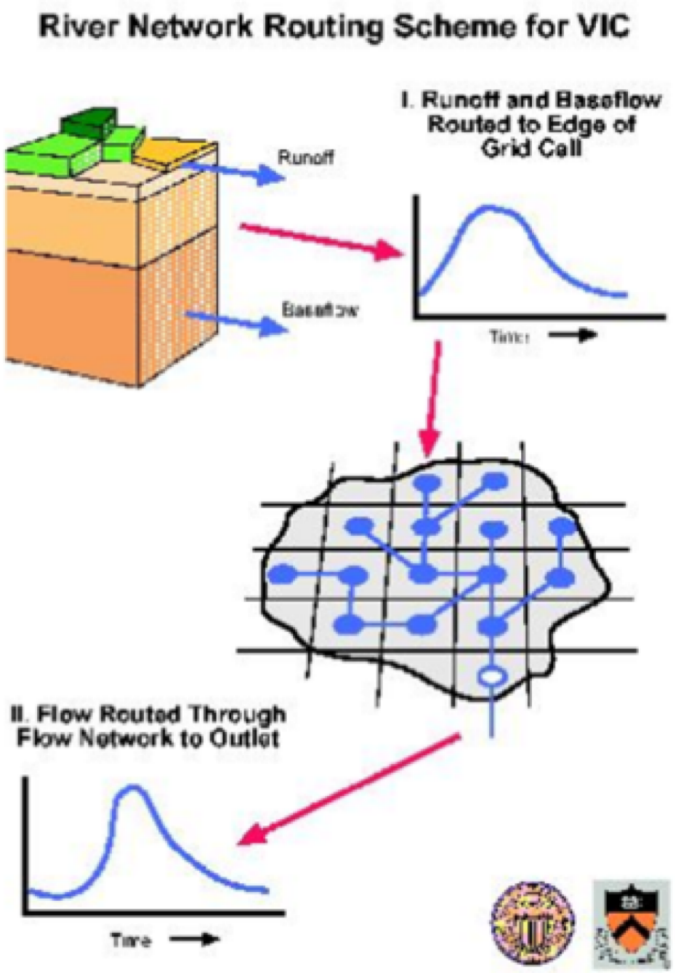
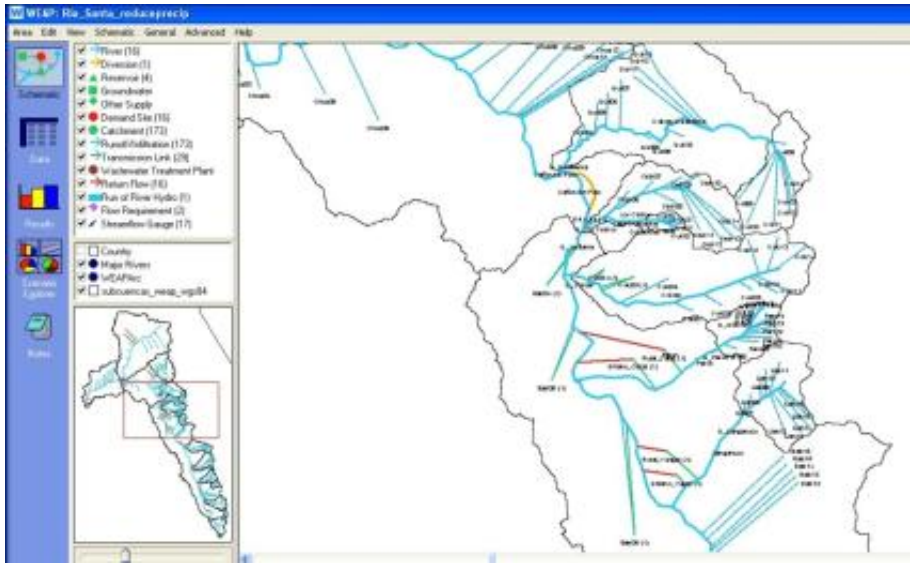
Hydrologic Models/Physical Models



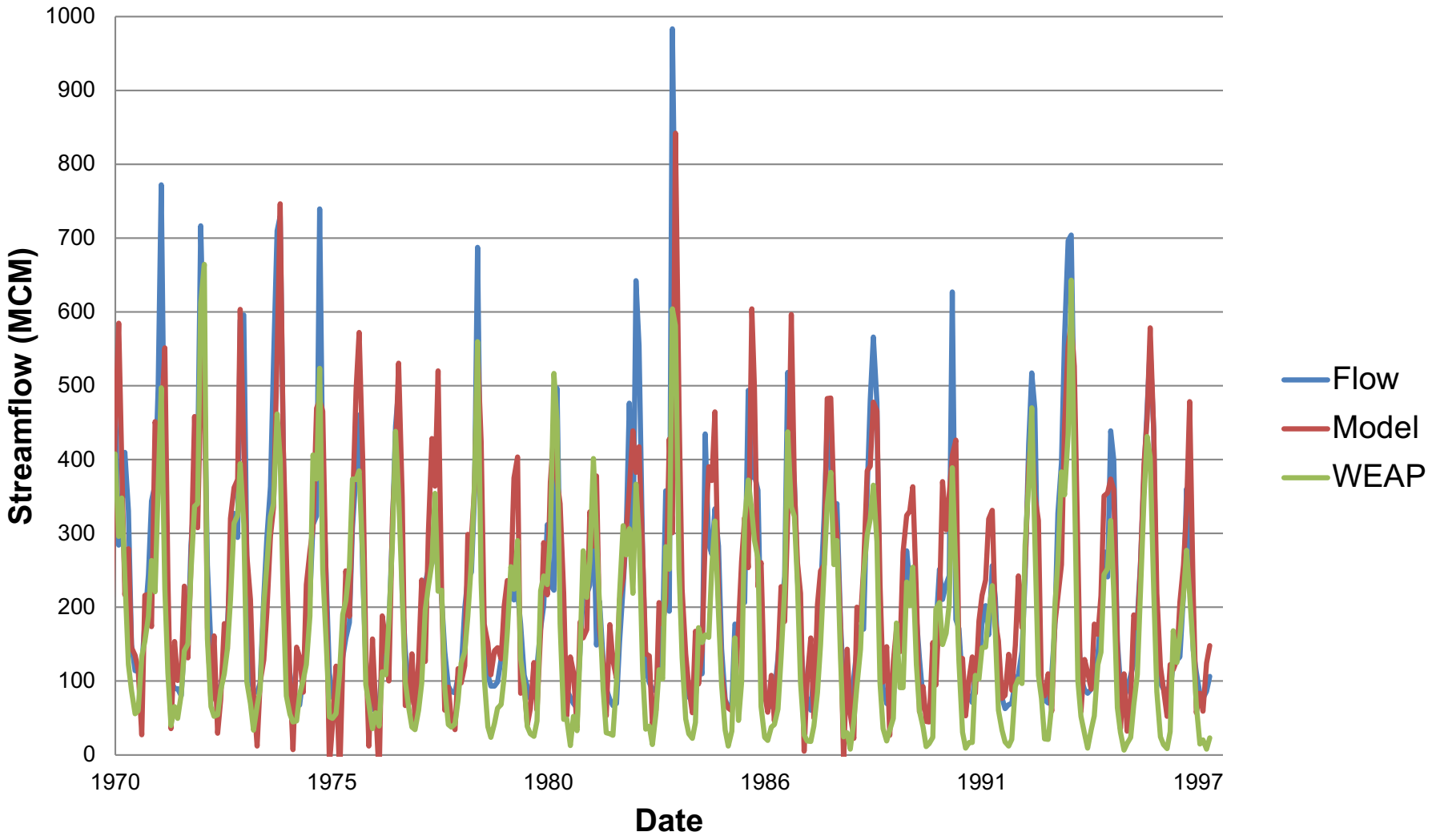


Water Evaluation and Planning (WEAP) Model

- Climate Inputs
  - Temperature, precipitation, humidity, wind speed
- Soil Moisture Model
- Glacier model
- Irrigation
- Scenario Exploration

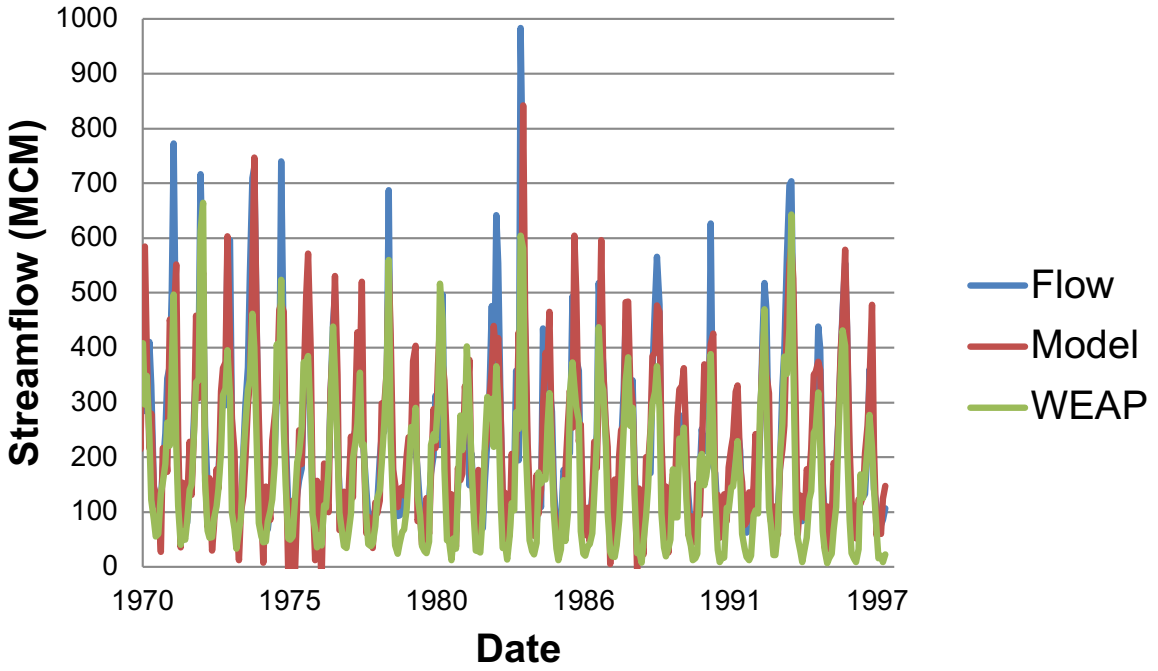


Canon del Pato Monthly Streamflow



Stochastic Models vs. Physical Models

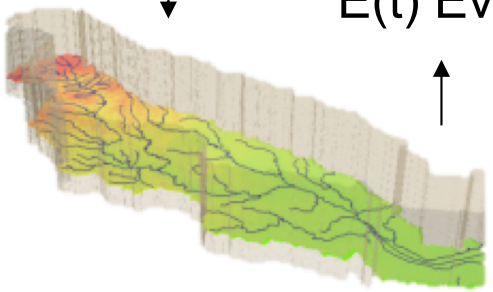
	Coefficient of Determination
Monthly ARMA Model	0.64
Monthly WEAP Model	**0.71**



Hydrologic Cycle

I(t) Precipitation

E(t) Evaporation



Q(t) Streamflow

$$Q(t) = I(t) - \boldsymbol{E(t)} - \Delta \boldsymbol{S(t)}$$

Questions?