

# **Development of a Dynamic Reservoir Flow Model: Sensitivity of Policy Impacts to Changing Hydrologic Conditions**

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# Motivation

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## POLICY FORUM

### CLIMATE CHANGE:

## Stationarity Is Dead: Whither Water Management?

P. C. D. Milly,<sup>1\*</sup> Julio Betancourt,<sup>2</sup> Malin Falkenmark,<sup>3</sup> Robert M. Hirsch,<sup>4</sup> Zbigniew W. Kundzewicz,<sup>5</sup> Dennis P. Lettenmaier,<sup>6</sup> Ronald J. Stouffer<sup>7</sup>

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.



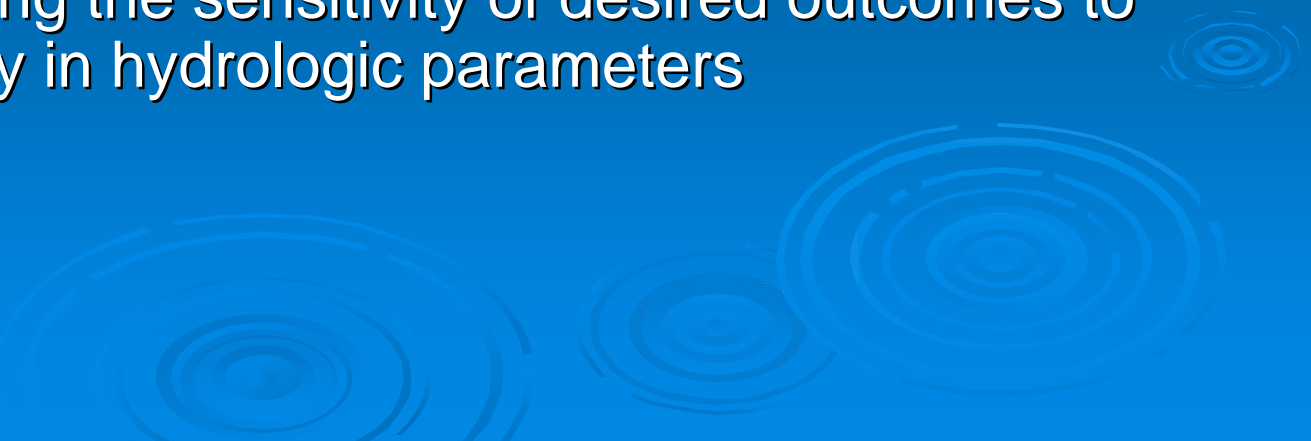
# What is stationarity?

“A stationary process has the property that the mean, variance and autocorrelation structure do not change over time.”

<http://www.itl.nist.gov/div898/handbook/pmc/section4/pmc442.htm>



# Project Rationale

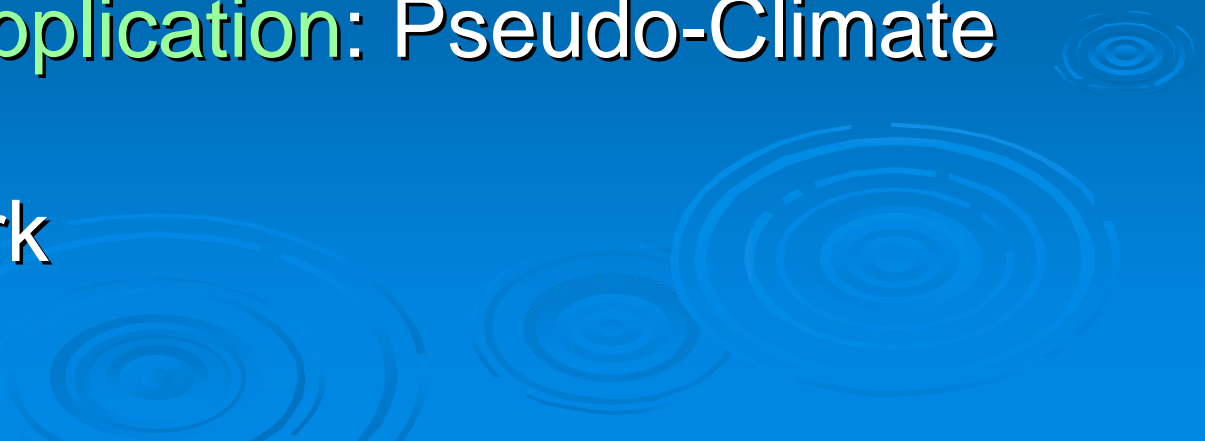
- Many water policy, management and infrastructure design decisions rest on the **stationarity assumption**
  - There is considerable **uncertainty** surrounding the effects of climate change on precipitation and streamflow in the northeast region
  - Preparation for and **adaptation to potential change** must include exploring the sensitivity of desired outcomes to non-stationarity in hydrologic parameters
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# Objective

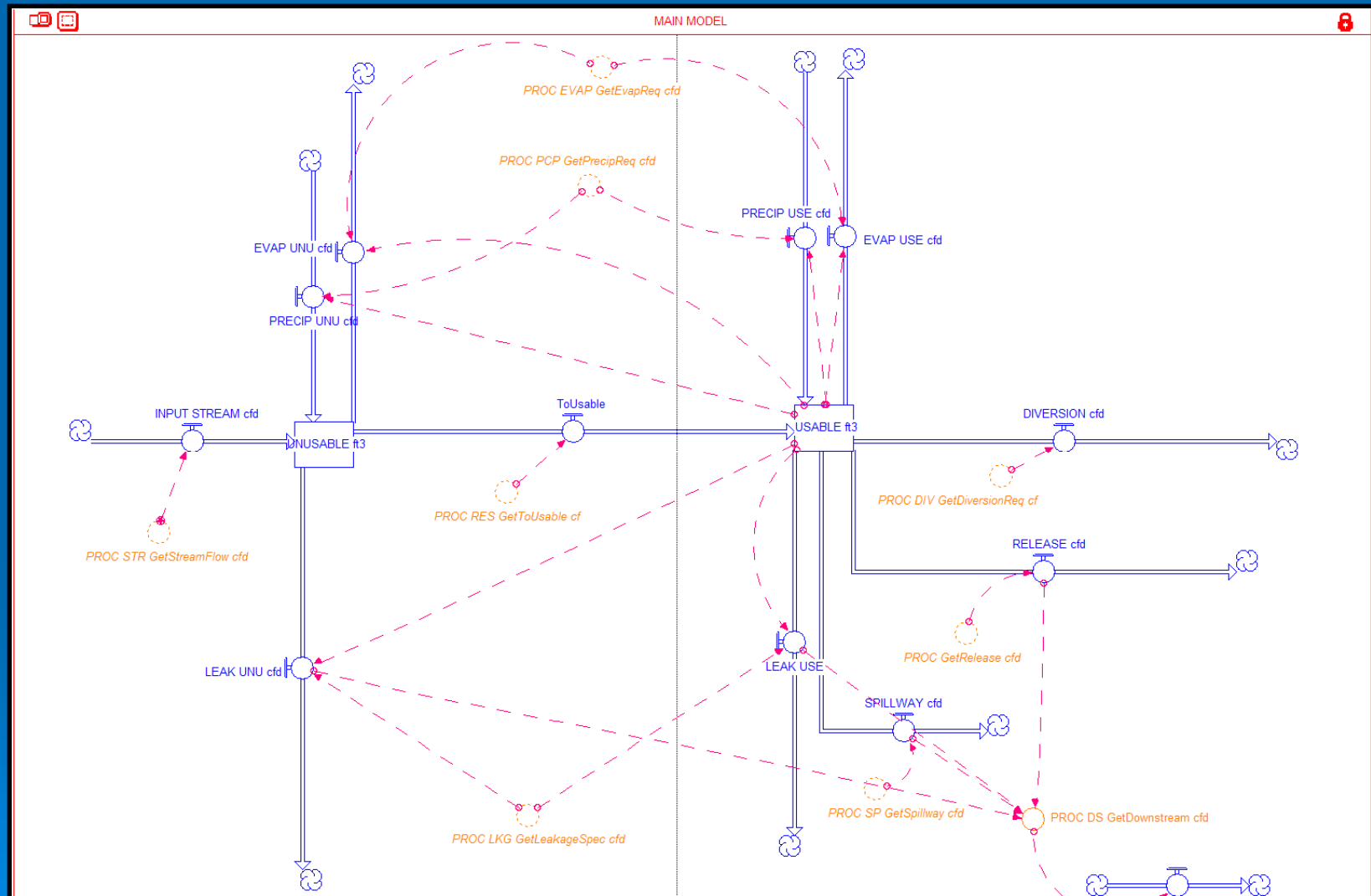
Design a modeling tool that will allow users to investigate how the outcomes of reservoir release policies may be affected by non-stationarity in input streamflow statistics



# Today's Talk

- I. Main components of the basic reservoir flow model
  - II. Design goals for hydrograph alteration component
  - III. Implementation
  - IV. Testing, refinement
  - V. Example application: Pseudo-Climate Change
  - VI. Future Work
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# I. The CTIWR Reservoir Model



# GUI: Basic Runtime Options

CTWR RESERVOIR MODEL: USER INTERFACE  
Version 8B. March 26, 2008

IMPORTANT!! Make sure the number of timesteps in the "Run Specs" matches the number in your dataset.

Step 1. Choose model RUNTIME OPTIONS

Step 3. OVERRIDE imported parameters if necessary

Step 4. Set SENSI SPECS if desired

Step 5. RESTORE Graphs & Tables

Step 6. RUN the model

Step 7. VIEW / EXPORT OUTPUT

MAIN MENU

SET MODEL RUNTIME OPTIONS

## PRECIPITATION

- Precip[NoPrecip]  
 Precip[UsePrecip]

"NoPrecip" sets Precipitation to zero for all timesteps  
"UsePrecip" Precipitation is set to the timeseries read in from the IMPORT file.

## RESERVOIR

- ReservoirType[Generic]  
 ReservoirType[Custom]  
 Leakage[NoLeakage]  
 Leakage[UseLeakage]

"Generic": Rating curves will be generated assuming a generic, conic shape. Parameters will be read from IMPORT FILE, may be overridden.  
"Custom" :: Rating Curves and MaxVolume will be read from the IMPORTED file.

"NoLeakage" Set leakage to zero for all timesteps.  
"UseLeakage" Leakage is set to the value read from the IMPORT file, which may be overden below.

## EVAPORATION

- EvapType[NoEvap]  
 EvapType[DPH]

"NoEvap" sets Evaporation to zero for all timesteps  
"DPH" Evaporation is an equation fitted to the seasonal evaporation rates listed in the DPH regulations for safe yield.

## DEMAND

- AveDailyDem[InputADD]  
 AveDailyDem[SensitivityADD]

"InputADD" :: ADD Parameter will be read from IMPORT file and may be overridden  
"SensitivityADD" :: REQUIRED when doing sensitivity run on "CONST DEM SensitivityADD cfd"

## RESERVOIR RELEASE RULES:

- ReleaseRule[NoReqRelease]  
 ReleaseRule[FracConstNoFloor]  
 ReleaseRule[FracConstFloor]  
 ReleaseRule[FixedConstAug]  
 ReleaseRule[FixedConstNonAug]  
 ReleaseRule[FixedMoNonAug]  
 ReleaseRule[FixedMoAug]  
 ReleaseRule[Adaptive]  
 ReleaseRule[RelTimeSeries]  
 ReleaseRule[FracMoFloor]

RULE NOTE: "FracMoFloor" Monthly fractions are currently all set to .75. These should be reconfigured before this rule is used.

# GUI: Input Parameters

MAIN MENU       **OVERRIDE IMPORTED PARAMETERS**       HELP

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**STREAM BASIN CONFIGURATION**

Override: Stream Basin Input Parameters ▼

<input type="checkbox"/> Stream[BasinArea]	equation on
<input type="checkbox"/> Stream[StartYear]	equation on
<input type="checkbox"/> Stream[StartMonth]	equation on
<input type="checkbox"/> Stream[StartDOM]	equation on
<input type="checkbox"/> Stream[NumTSDays]	equation on
<input type="checkbox"/> Stream[BasinScaleFactor]	equation on

**RESERVOIR CONFIGURATION**

Override Params: Both Reservoir Types ▼

<input type="checkbox"/> Reservoir[StartPercFull frac]	equation on
<input type="checkbox"/> Reservoir[MaxRelRate cfs]	equation on
<input type="checkbox"/> Reservoir[Leakage cfs]	equation on

Override Params: Generic Reservoir Only ▼

<input type="checkbox"/> Reservoir[CONStorageRatio frac]	equation on
<input type="checkbox"/> Reservoir[CONEM...AnnualInflow ft3]	equation on
<input type="checkbox"/> Reservoir[CONELateralSlope frac]	equation on
<input type="checkbox"/> Reservoir[CONeAxisSlope frac]	equation on
<input type="checkbox"/> Reservoir[CONEF...usableVol frac]	equation on

Override Params: Custom Reservoir Only ▼

<input type="checkbox"/> Reservoir[MaxUNUSABLEVol ft3]	equation on
<input type="checkbox"/> Reservoir[MaxTOTALVol ft3]	equation on

**DEMAND CONFIGURATION**

Override: Demand Input Parameters ▼

<input type="checkbox"/> Demand[ScaleFactor]	equation on
<input type="checkbox"/> Demand[TheInputADD MG]	equation on

**PREV RUN FILE VALUES**

LNK STR I...[BasinArea]	19.9
LNK STR I...[StartYear]	1,980
LNK STR I...StartMonth]	10
LNK STR I...[StartDOM]	1
LNK STR ...umTSDays]	14,610
LNK STR I...caleFactor]	1.000000
LNK RES I...cFull frac]	1.000000
LNK RES I...elRate cfs]	199.00
LNK RES I...akage cfs]	0.000000
Reservoir[... Ratio frac]	0.030000
LNK RES I...Slope frac]	0.004955
LNK RES I...Slope frac]	0.002478
LNK RES I...LEVol ft3]	0.000000
LNK RES I...TALVol ft3]	39,07...884000
LNK DEM I...aleFactor]	1.000000
LNK DEM ...utADD MG]	23,444.000000

## II. Design goals for hydrologic alteration component

*EX: “More total annual flow, higher winter flows, lower summer flows, more variability”*

- Must be able to change both the overall series statistics, individual monthly statistics, or both simultaneously
- Must be able to manipulate separate statistical parameters independently or simultaneously
- Must be able to apply constant changes, trends or both

### III. Implementation

#### Initial Signal Decomposition: Mean, Standard Deviation, Random Process

$$Q_t = \bar{Q} + q_t$$

$$Q_t = \bar{Q} + S X(t)$$

$$\frac{Q_t - \bar{Q}}{S} = X(t)$$

$$Q_t = \bar{Q}_{M_i} + S_{M_i} X_{M_i}(t)$$

$$Q_t = \alpha_{M_i} \bar{Q} + \beta_{M_i} S X_{M_i}(t)$$

$$Q_t = \alpha_{J_i} \bar{Q} + \beta_{J_i} S X_{J_i}(t)$$

# Alteration Method: Linear Scaling Functions

Four pre-calculated altered, statistical parameters:

- Monthly means
- Monthly standard deviation
- Series means
- Series standard deviations

$$\alpha'_{M_t}(t) = (a_0 + a_1 t) \alpha_{M_t}$$

$$\beta'_{M_t}(t) = (b_0 + b_1 t) \beta_{M_t}$$

$$\bar{Q}'(t) = (c_0 + c_1 t) \bar{Q}$$

$$S'(t) = (d_0 + d_1 t) S$$

# Internal Processing Steps

- **Step 1.** Extract the random process using the pre-calculated statistical parameters
- **Step 2.** Alter the statistical parameters
- **Step 3.** Reconstruct a hydrograph using ORIGINAL random process and ALTERED statistical parameters

# GUI: Hydrograph Alteration

## GENERATING ALTERED INPUT HYDROGRAPHS:

$$\text{ALTERED\_PARAM} = (\text{Intercept} + \text{FirstOrder} * t) * \text{ORIG\_PARAM}$$

StreamType[OrigStream]  
 StreamType[AlteredStream]

Click on "Altered" to use altered input stream

NOTE: To run the input stream "as is", without altering it, use "EQUATION ON" This will keep the intercepts at 1 and the first order terms at 0

### SERIES MEAN FUNCTION TERMS

SeriesMeanCoeff[Intercept]	1.05
SeriesMeanCoeff[FirstOrder]	equation on

### Previous Run Reference Series Mean:

TSS RefSeriesMean cfs 41.28

### SERIES STD D...FUNCTION TERMS

SeriesStdDevCoeff[Intercept]	1.2
SeriesStdDevCoeff[FirstOrder]	equation on

### Previous Run Reference Std Dev:

TSS RefS...sStdDev cfs 72.98

The monthly controls have 2 lists per parameter: Click on the triangle to see the other list.

### MONTHLY MEAN F...RMS: Intercepts

MonthlyMeanCoeff[1,Intercept]	1.1
MonthlyMeanCoeff[2,Intercept]	1.1
MonthlyMeanCoeff[3,Intercept]	1.1
MonthlyMeanCoeff[4,Intercept]	0.9
MonthlyMeanCoeff[5,Intercept]	0.9
MonthlyMeanCoeff[6,Intercept]	0.9
MonthlyMeanCoeff[7,Intercept]	0.9
MonthlyMeanCoeff[8,Intercept]	0.9
MonthlyMeanCoeff[9,Intercept]	0.9
MonthlyMeanCoeff[10,Intercept]	1.1
MonthlyMeanCoeff[11,Intercept]	1.1
MonthlyMeanCoeff[12,Intercept]	1.1

### Previous Run Reference Monthly Means:

TSS RefMoMean cfs[1]	42.24
TSS RefMoMean cfs[2]	43.31
TSS RefMoMean cfs[3]	82.53
TSS RefMoMean cfs[4]	94.95
TSS RefMoMean cfs[5]	50.54
TSS RefMoMean cfs[6]	29.88
TSS RefMoMean cfs[7]	13.72
TSS RefMoMean cfs[8]	11.32
TSS RefMoMean cfs[9]	13.87
TSS RefMo...an cfs[10]	25.18
TSS RefMo...an cfs[11]	42.72
TSS RefMo...an cfs[12]	45.98

### MONTHLY STDEV...RMS: Intercepts

MonthlyStdDevCoeff[1,Intercept]	equation on
MonthlyStdDevCoeff[2,Intercept]	equation on
MonthlyStdDevCoeff[3,Intercept]	equation on
MonthlyStdDevCoeff[4,Intercept]	equation on
MonthlyStdDevCoeff[5,Intercept]	equation on
MonthlyStdDevCoeff[6,Intercept]	equation on
MonthlyStdDevCoeff[7,Intercept]	equation on
MonthlyStdDevCoeff[8,Intercept]	equation on
MonthlyStdDevCoeff[9,Intercept]	equation on
MonthlyStdDevCoeff[10,Intercept]	equation on
MonthlyStdDevCoeff[11,Intercept]	equation on
MonthlyStdDevCoeff[12,Intercept]	equation on

### Previous Run Reference Monthly StdDev:

TSS RefM...Dev cfs[1]	65.05
TSS RefM...Dev cfs[2]	61.21
TSS RefM...Dev cfs[3]	106.63
TSS RefM...Dev cfs[4]	102.61
TSS RefM...Dev cfs[5]	69.59
TSS RefM...Dev cfs[6]	70.01
TSS RefM...Dev cfs[7]	38.26
TSS RefM...Dev cfs[8]	41.57
TSS RefM...Dev cfs[9]	49.57
TSS RefMo...ev cfs[10]	60.56
TSS RefMo...ev cfs[11]	55.07
TSS RefMo...ev cfs[12]	66.41

# IV. Testing the Alteration Process

## Test Questions

- Is the intended parameter scaled appropriately?
- Are there any significant, unintended side effects?
- Will this work on actual streamflow data?

# Alteration Test Scenarios

- Intercept terms only, not trend terms
- Data: Normal(1,1), Hubbard Brook 40 yr
- Scaled Series Mean
- Scaled Series Standard Deviation
- Scaled “March” Mean
- Scaled “September” Standard Deviation
- “Climate Change:”
  - Overall mean: 1.05
  - Monthly means: Oct-Mar, 1.1, Apr-Sep, 0.9
  - Overall standard deviation: 1.2

# Evaluation Metric: Altered/Orig

Means

SD

Means

SD

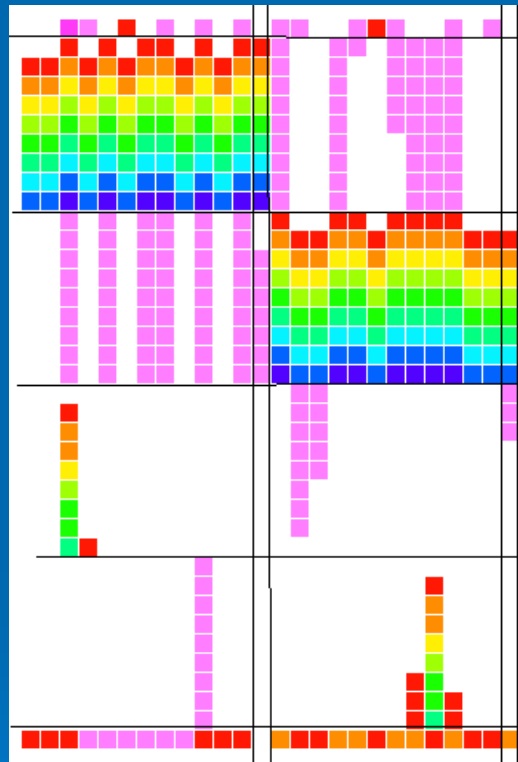
Series Mean: 1.1 – 1.9

Series SD: 1.1 – 1.9

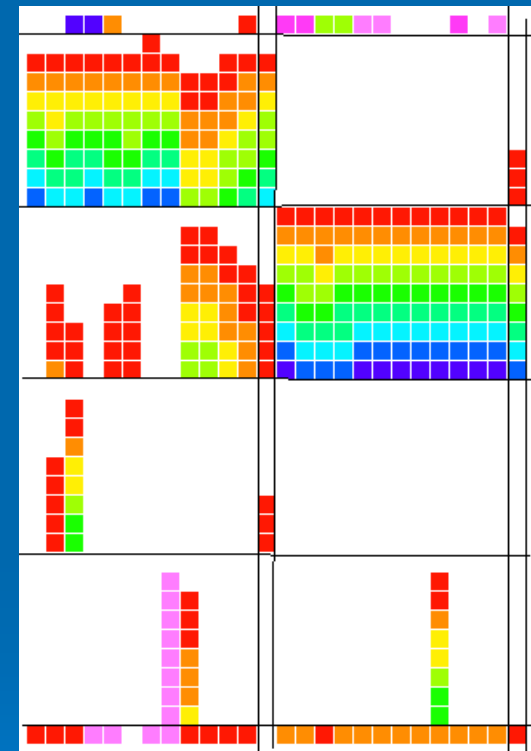
March Mean: 1.1 – 1.9

September SD: 1.1 – 1.9

“Climate Change”



Noise (1,1)



Hubbard Brook 40 yr

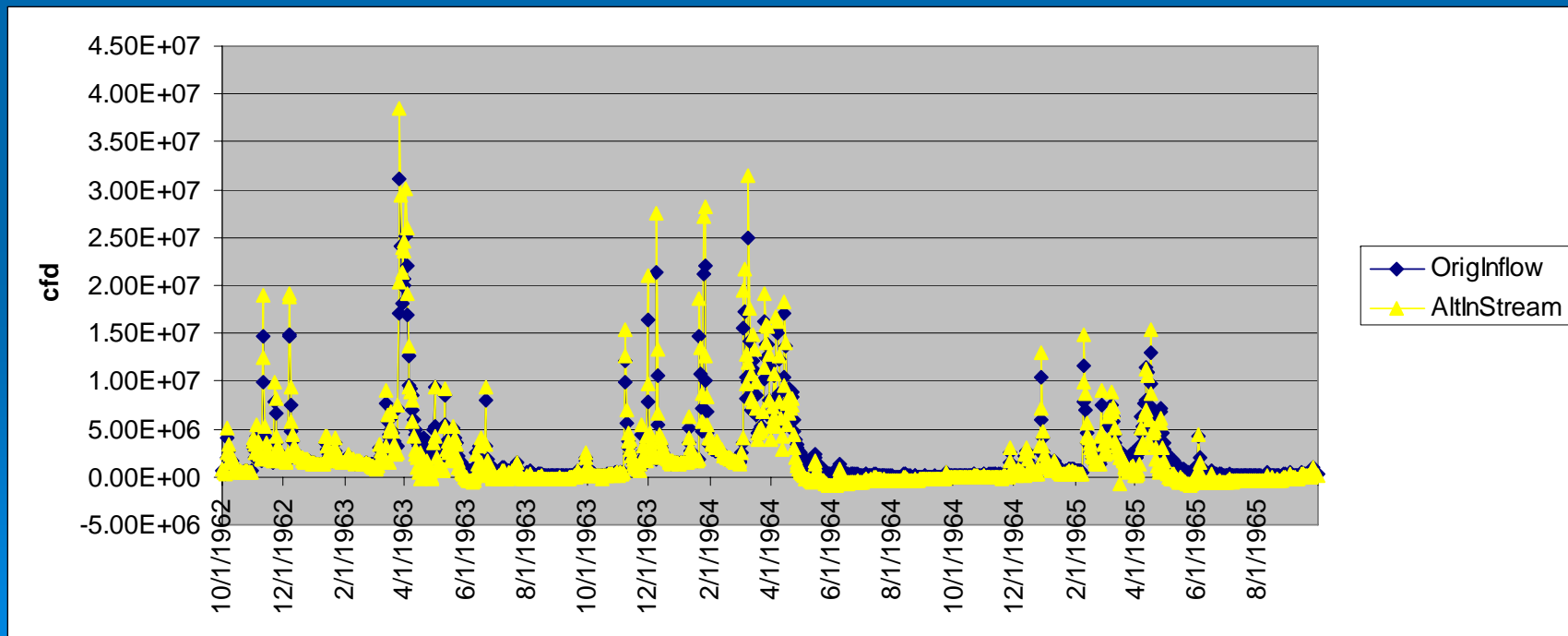
# V. Effects of Alteration on Flow: Pseudo-Climate-Change Scenario

HUBBARD BROOK: Release Rule: Fixed Constant Augmented, .2cfsm

ALTERATION: Series Mean: 1.05, Series SD: 1.3

“Wet” Mo Means: 1.1 “Dry” Mo Means: 0.8

NO CHANGE IN SAFE YIELD FOR STORAGE RATIO .6



# VII. Future work

- Current Approach: Mean, SD:
  - Finish testing, trend term
  - Decide how to handle negative flows (most likely by doing log transformation)
- Refined Approach: Stochastic parameterization (ie, autoregressive or similar)
- Evaluate robustness of release policies in the under different hydrologic alteration scenarios

# Acknowledgement

- Connecticut Department of Environmental Protection
- Colin Apse, Nature Conservancy