Study of Water Level and Release Issues at Smith Mountain and Leesville Lakes

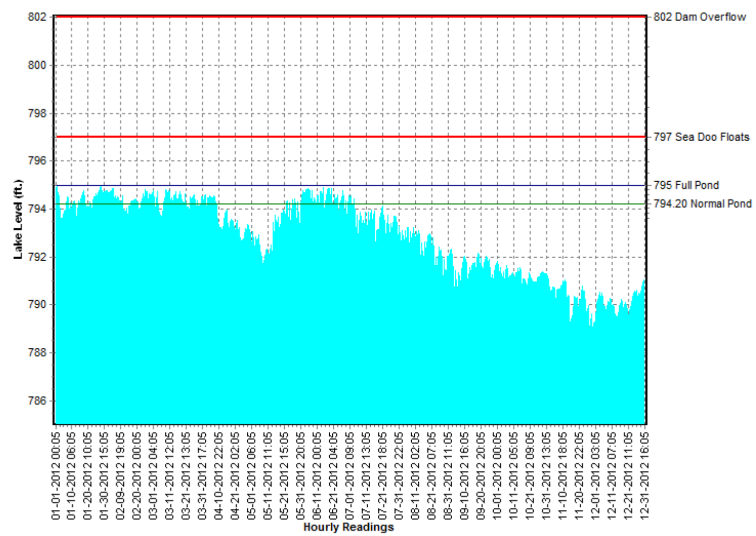
Smith Mountain Lake Association Board
Water Management Committee

February 15, 2015

The words for each slide are included in an accompanying pdf file

Background

- **Every 5 years, AEP will "…solicit comments on the performance of the project in maintaining lake levels and in providing flows necessary to protect instream beneficial uses."**
- **Release protocols have been adopted that meet the downstream biological needs**
- **Low lake levels can trigger lower releases from Leesville, reducing downstream flows**
- **Better predictions of low lake level events can avoid such events**
- **2012 was a low lake level year with no trigger points called until December**
    - ***Why did it happen?***
    - ***Will it happen again?***
    - ***Could it have been prevented?***



Four Major Topics are Addressed

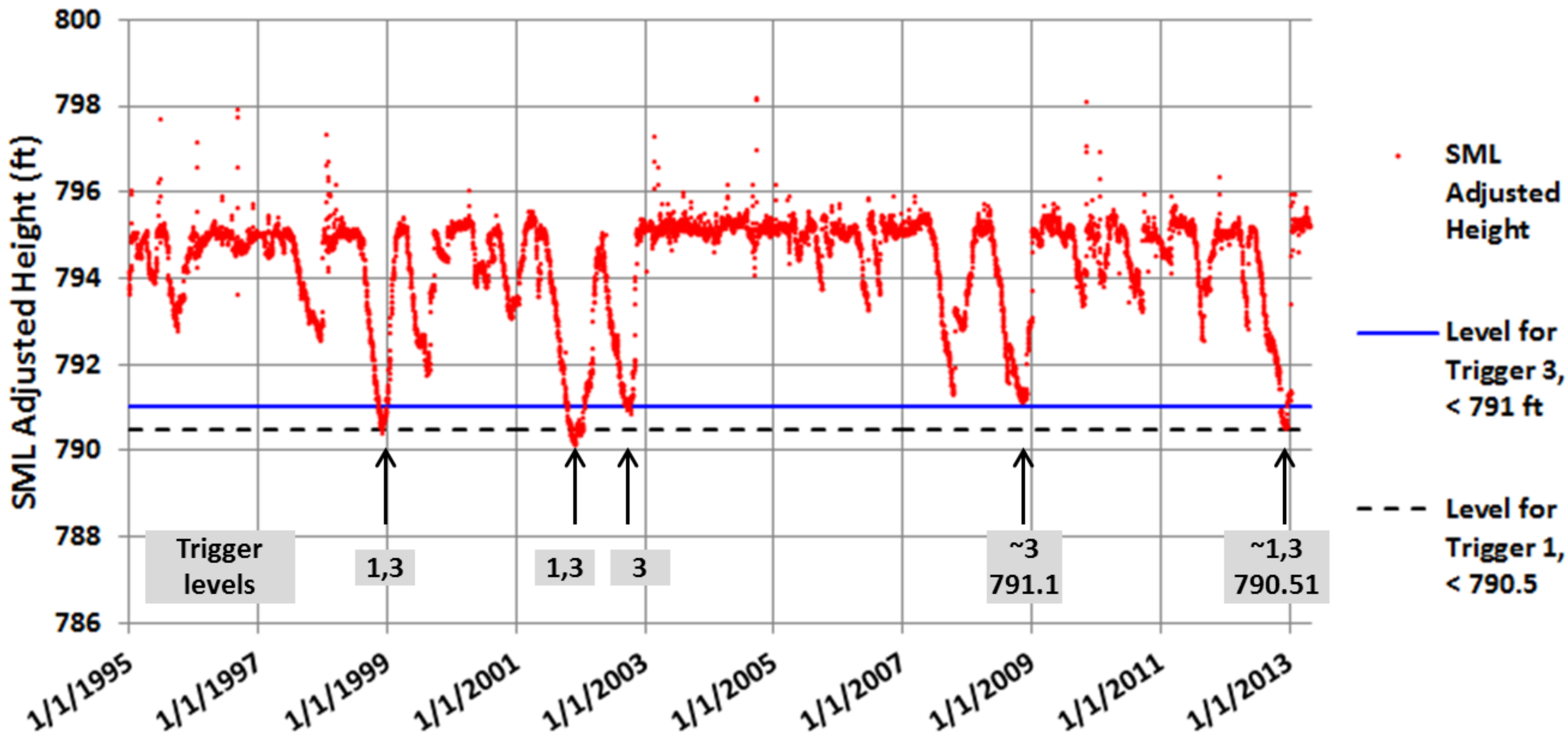
- How well can the current protocols be met?
- What are the major factors controlling lake level?
- Can the predictive model accuracy be improved?
- Analysis results and remaining issues and questions

Trigger Points for Reducing Leesville Discharges

Trigger	Conditions for Trigger Activation	Flow Reduction at Brookneal
Trigger 1	Forecasted lake level has a 20% chance of dropping below 790.5 feet adjusted in 16 weeks	**85%** of monthly Minimum Flow At Brookneal (Normal conditions - no trigger events in effect) **or "Floor"** Flow **whichever is larger**
Trigger 2	Forecasted lake level has a 2% chance of dropping below 790 feet adjusted in 10 weeks	**"Floor" Flow** at Brookneal"
Trigger 3	If Trigger 2 is in effect and adjusted elevation is less than 795 feet between December 1 and March 31 or anytime the adjusted elevation drops below 791.0 feet after September 30.	**70%** of monthly Minimum Flow At Brookneal (Normal conditions - no trigger events in effect)

- **The second trigger 3 condition does not have a specific probability specification**
- **Trigger 1 also implies the probability of dropping below 791 ft. in 16 weeks is at least 20%**
- **2012 did not have a trigger 1 or 2, only the second trigger 3 condition**
- **The new Bedford water withdrawal permit requires specific actions if a trigger 3 is declared**

Low Smith Mountain Lake Levels



- Assume lake stays high to end of 2014 (gives a 20 year history)
- Levels reflect actual Leesville discharges
    - Trigger 1 levels occur 2 times and almost a third time (≈ every 7 years)
    - Trigger 3 levels occur 4 times and almost a fifth time (≈ every 4 years)
    - Trigger 3 levels are approx. twice as frequent as trigger 1 levels
- AEP data through to 1-6-2008, DEQ data from 1-6-2008

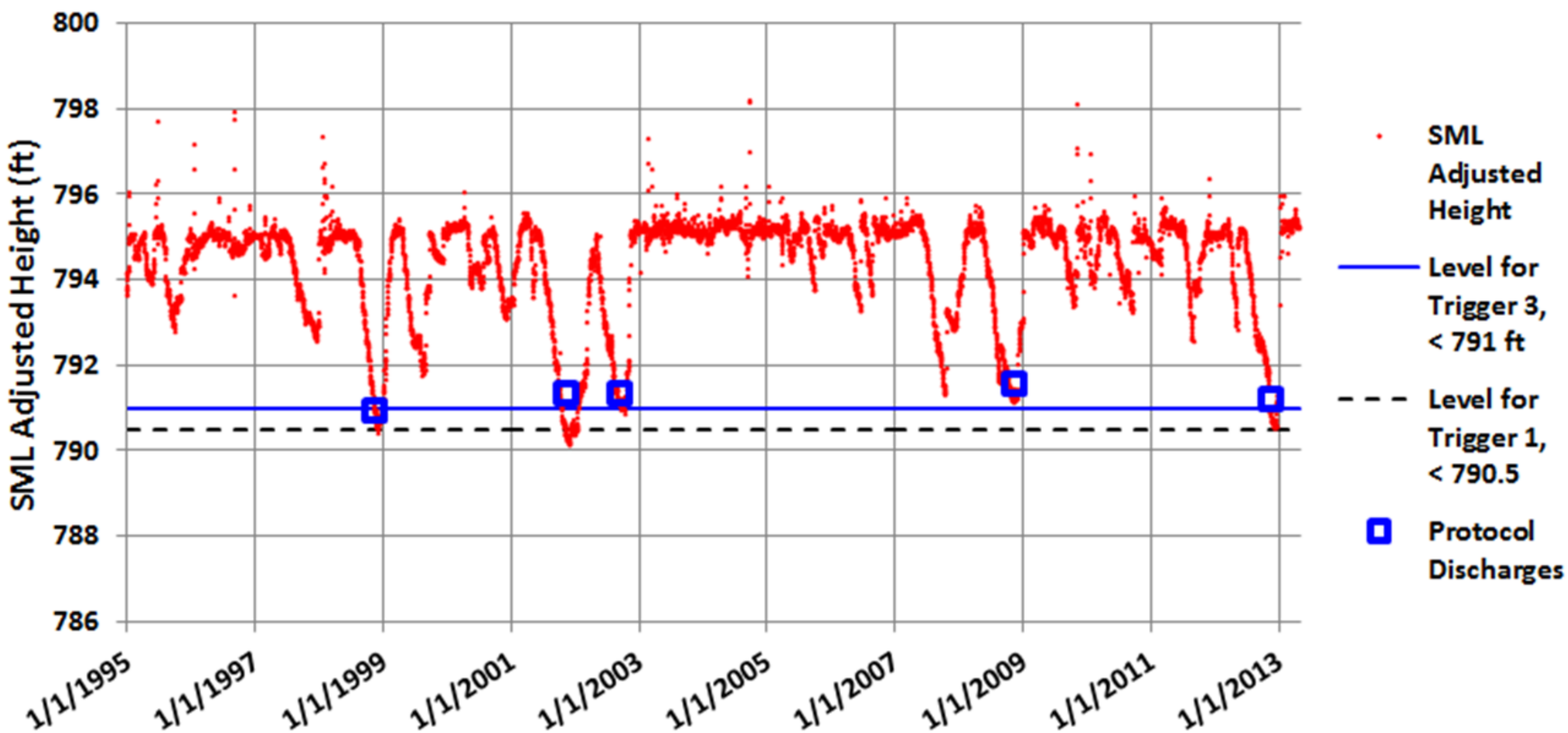
What Would a Perfect Predictive Model Do?

- **Simple water balance model**
  - ***Net inflow* – Leesville discharge = Change in lake level***
- **Lake levels and Leesville discharges are known exactly**
- **A perfect model would calculate *Net inflow** exactly**
  - ***Calculate net inflow for lake levels and discharge***
  - ***Calculate lake levels for protocol discharges***
  - ***Protocol discharges (cfs) for recreation flows:***

Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No trigger	650	650	650	409	400	375	375
Trigger 1	471	480	471	409	400	375	375
Trigger 2,3	418	422	418	406	400	375	375

**** Net inflow = streamflow + rainfall – evaporation – other losses***

Effect of Protocol Discharges



- No trigger in effect: Use greater of actual flow or ‘no trigger’ recreation flow
- 1998: Trigger 1 Aug 31, Trigger 2 Sep 28, Trigger 3 Dec 7
- 2001: Trigger 1 Jul 23, Trigger 2 Sep 24, Trigger 3 Dec 3 (lasts through 2002)
- 2008, 2012: Start “No trigger” flow levels in Oct (2008) and Oct (2012)

Minimum Lake Levels* vs Leesville Release

Year	Actual discharge	Discharge based on triggers	No Trigger Recreation Release
1998	790.66	790.91[1]	790.91
2001	790.24	791.31[1]	791
2002	791.12	791.28[1]	Lake stayed in trigger 3
2008	791.21[3]	791.52[2]	792.06
2012	790.66	791.16[2]	792.16

* Lake levels at end of month

1. Triggers taken from AEP Water Management Plan (June 2010)
2. Inferred triggers
3. Minimum level in 2008 was 791.15

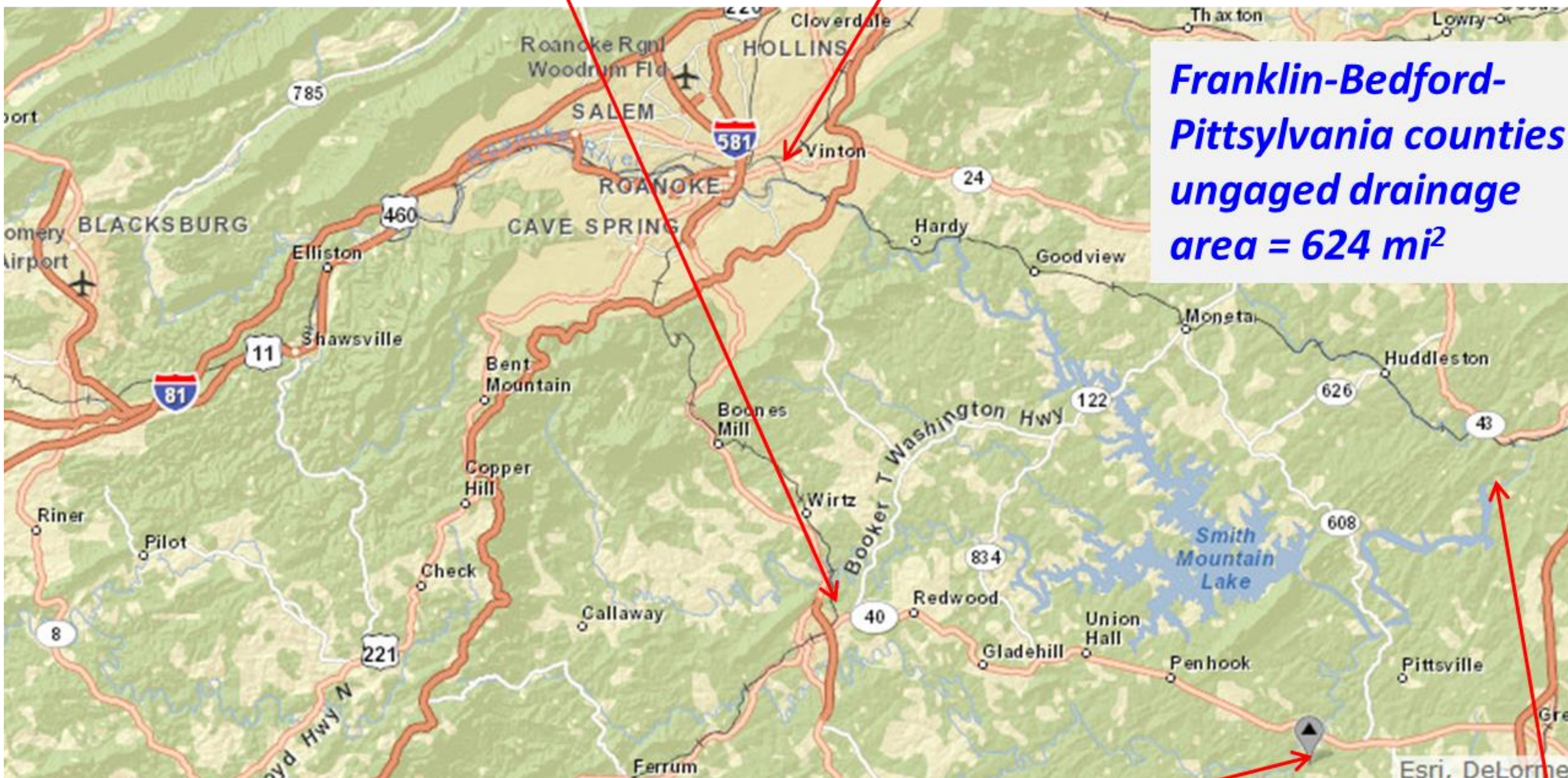
How Good are the Current Protocols?

- **The Recreation discharge protocols appear able to <u>generally</u> prevent the lake from falling below 791 ft and initiating a trigger 3 (second condition) <u>IF</u>:**
  - ***The probability of this trigger 3 event can be accurately predicted with sufficient advance notice, <u>AND</u>***
  - ***The recreation discharge protocols and minimum discharges are subsequently followed***
  - ***The "No trigger" recreation releases also generally keep the lake above 791 ft., but there are failures***
- **However, in severe droughts, the lake level may still fall below 791 ft.**

Major Factors Affecting Lake Levels: Ungaged Drainage Areas

Rocky Mount USGS gage 2056900- 115 mi²

Roanoke River USGS gage 2055000– 384 mi²

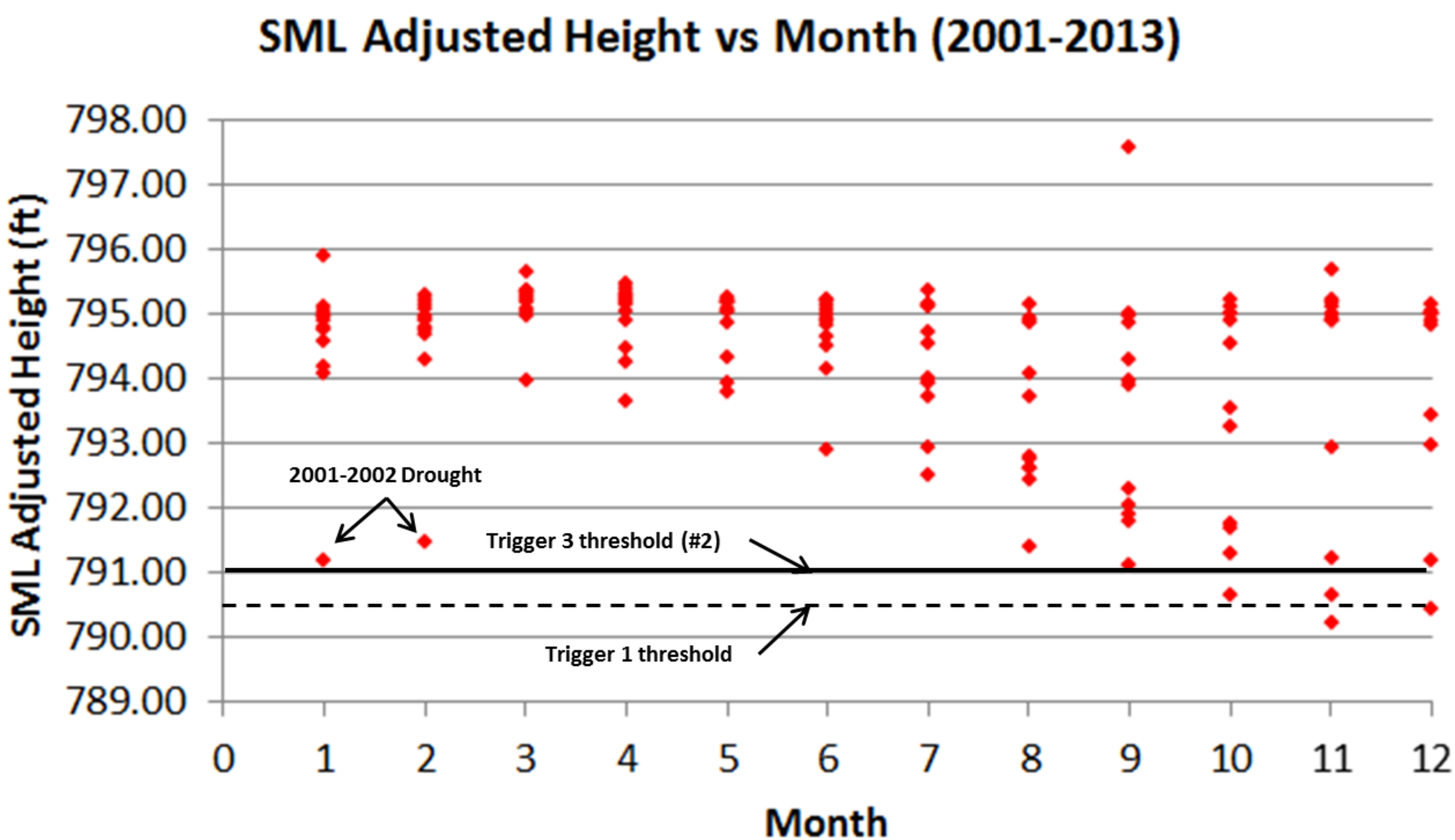


Franklin-Bedford-Pittsylvania counties ungaged drainage area = 624 mi²

Pigg River USGS gage 2058400 - 351 mi²

Leesville Dam- 1474 mi²

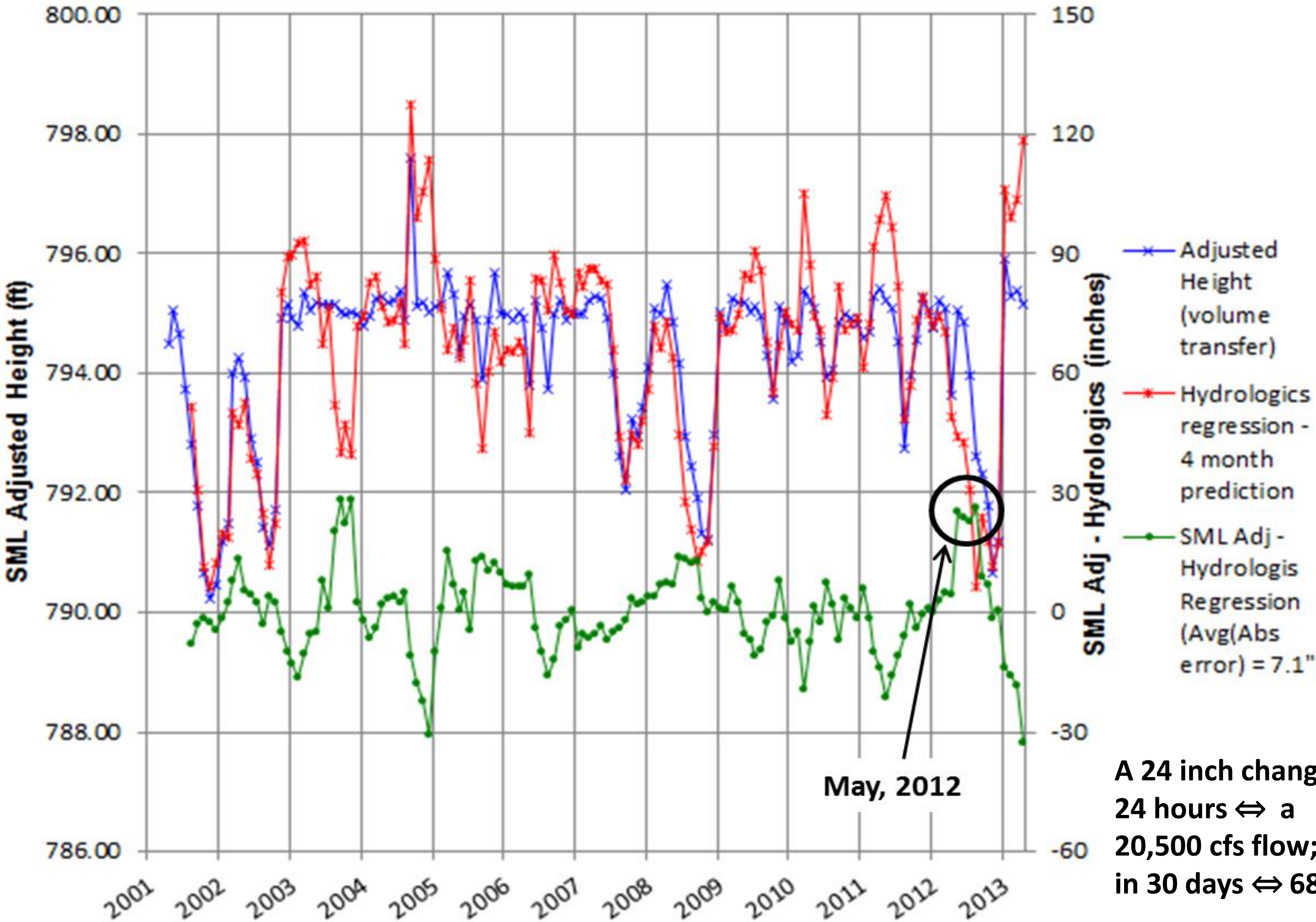
Low Lake Levels are a Summer/Fall Event



Key Terms in Water Balance Model

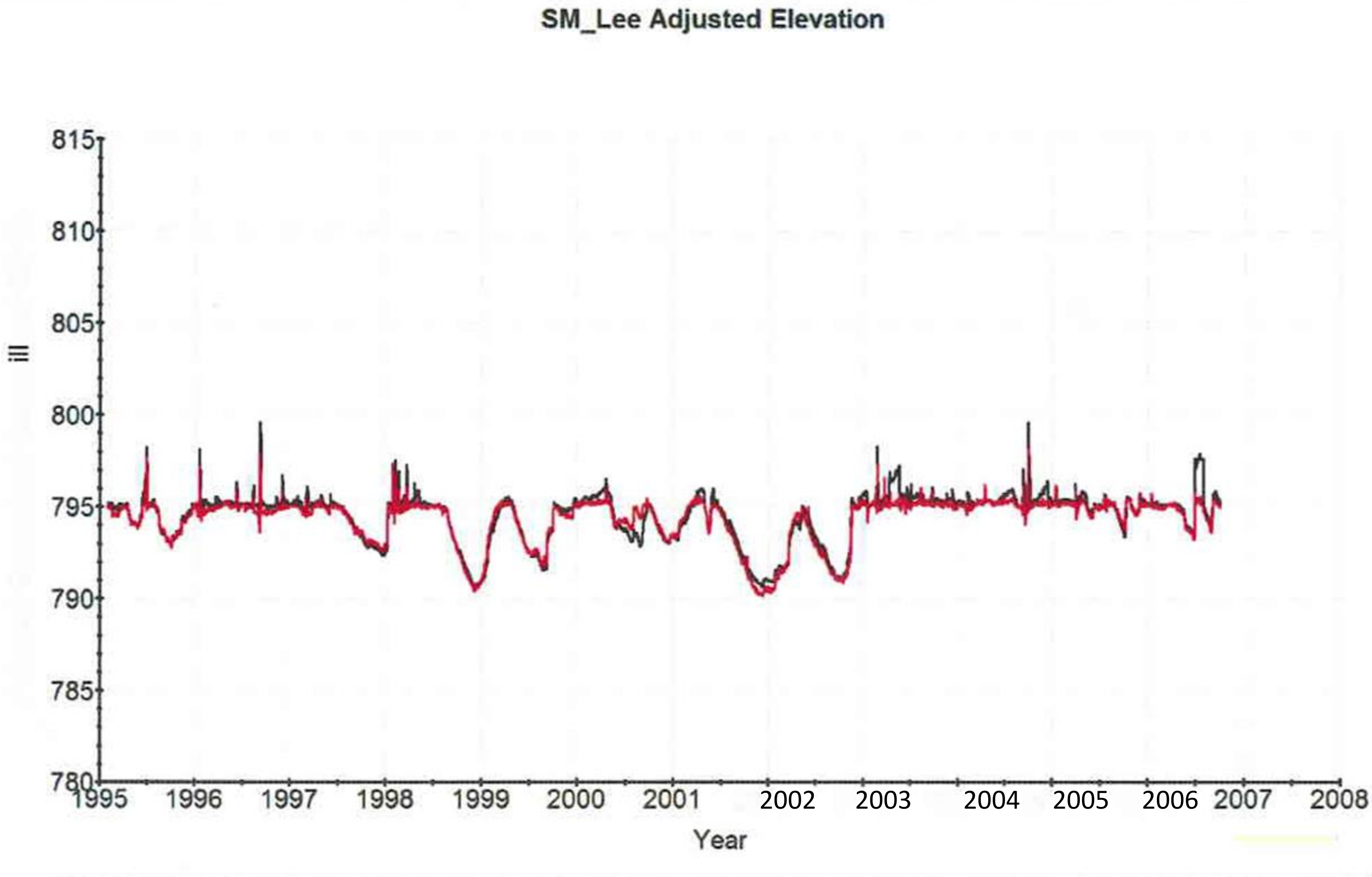
- **Inflow – Outflow = Change in lake height**
- **Hydrologics inflows to project**
  - ***Use Roanoke, Rocky Mount and Pigg USGS gages***
  - ***Correct Roanoke gage for Roanoke/Salem withdrawals***
  - ***Use linear scaling to estimate inflow from ungaged drainage areas***
  - ***Multiply by 1.18 to fit flows to pre-dam flow data***
  - ***Fit inflow to a cubic equation to minimize errors***
- **Discharge from Leesville dam**
- **Precipitation on lake surfaces**
- **Evaporation from lake surfaces**
- **Loss term: “Groundwater loss from lake beds”**

What Do Predictions 4 Months Ahead Look Like?



A 24 inch change in 24 hours ⇔ a 20,500 cfs flow; in 30 days ⇔ 683 cfs

Hydrologic Model Fits to Calibration Data



Red- historic, Black - computed

From "Flood and Drought Management Low Flow Operating Protocol Report", March 2008, Figure 3

Typical Model Values (cfs)

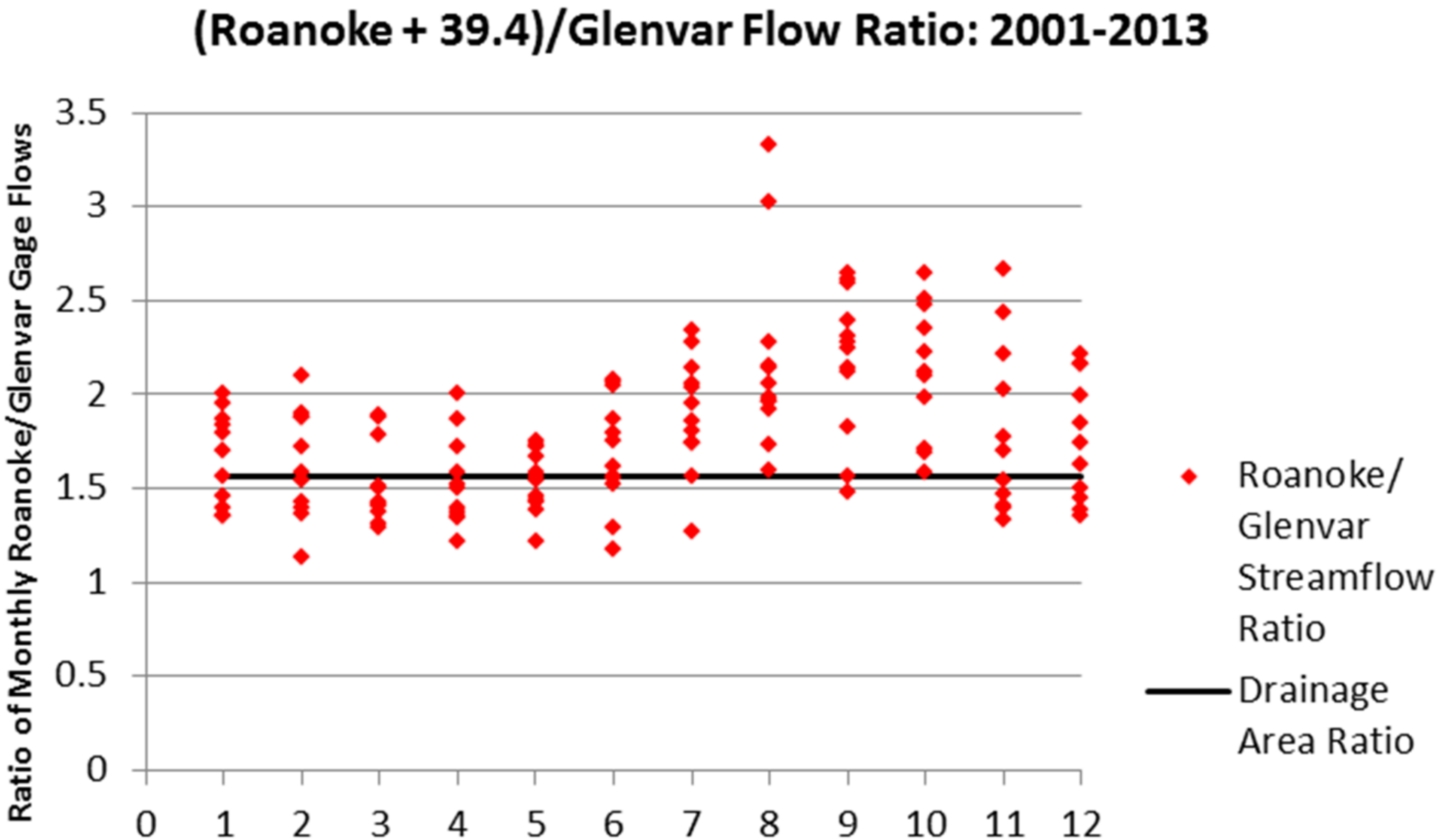
Parameter	Winter	Summer
Inflow	1000-3000	500-1000
Rain	90	120
Evaporation	20	120
Discharge	500-2500	500-1000
Groundwater*	140-300	140-300

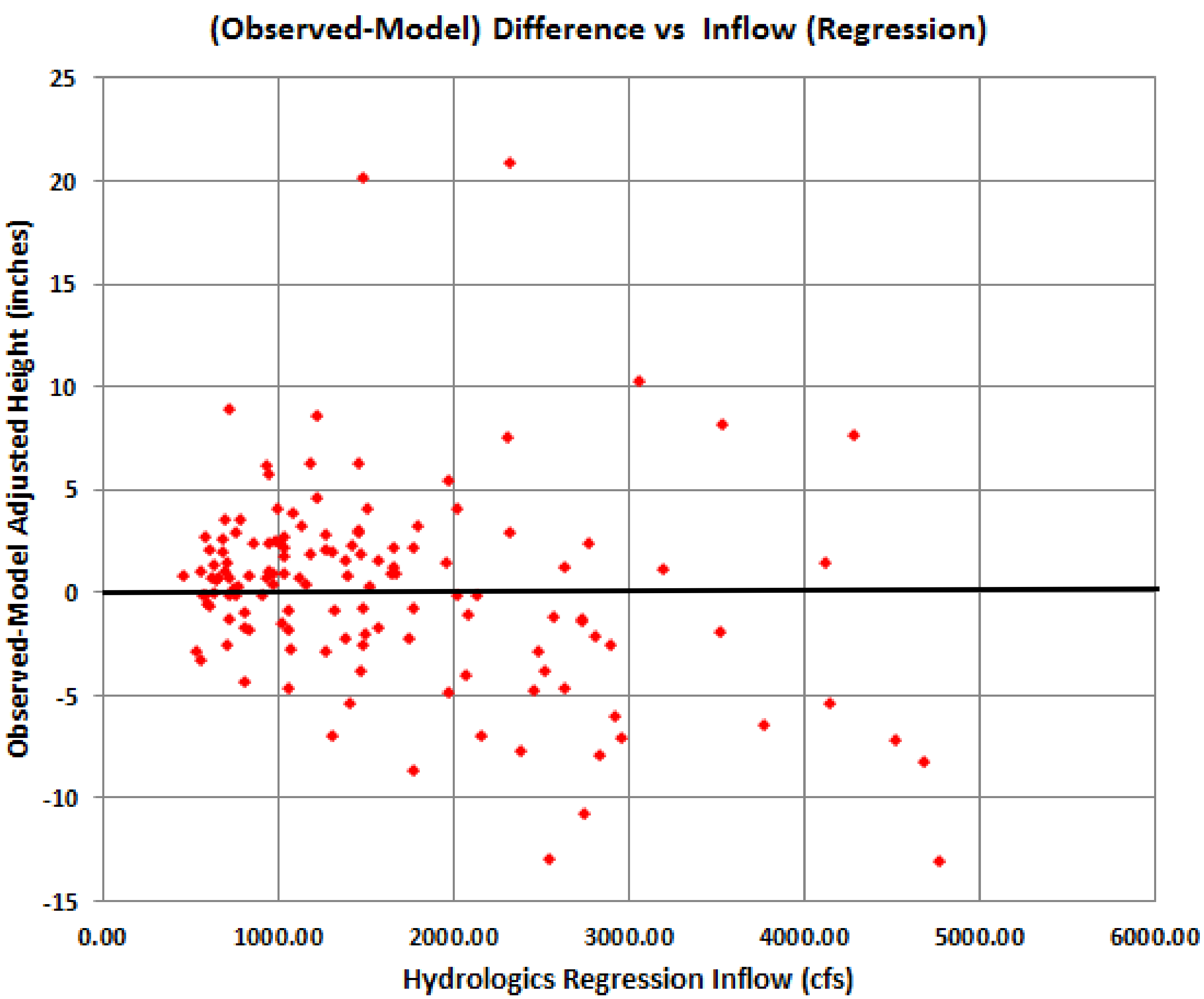
*** Groundwater loss is ≈ 300 cfs for the regression inflow equation; ≈ 140 cfs for the linear equation without the 1.18 adjustment**

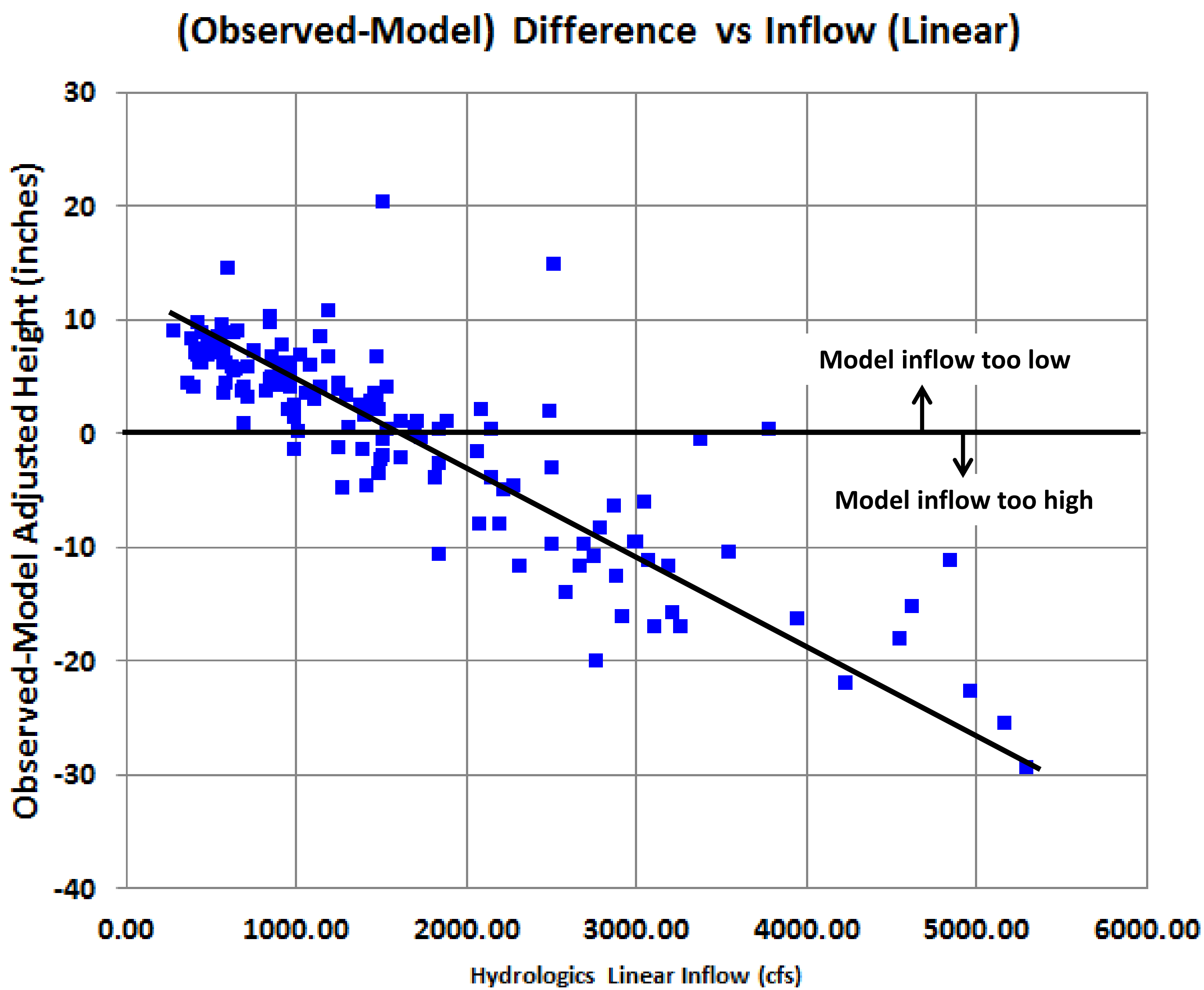
Factors that were Examined

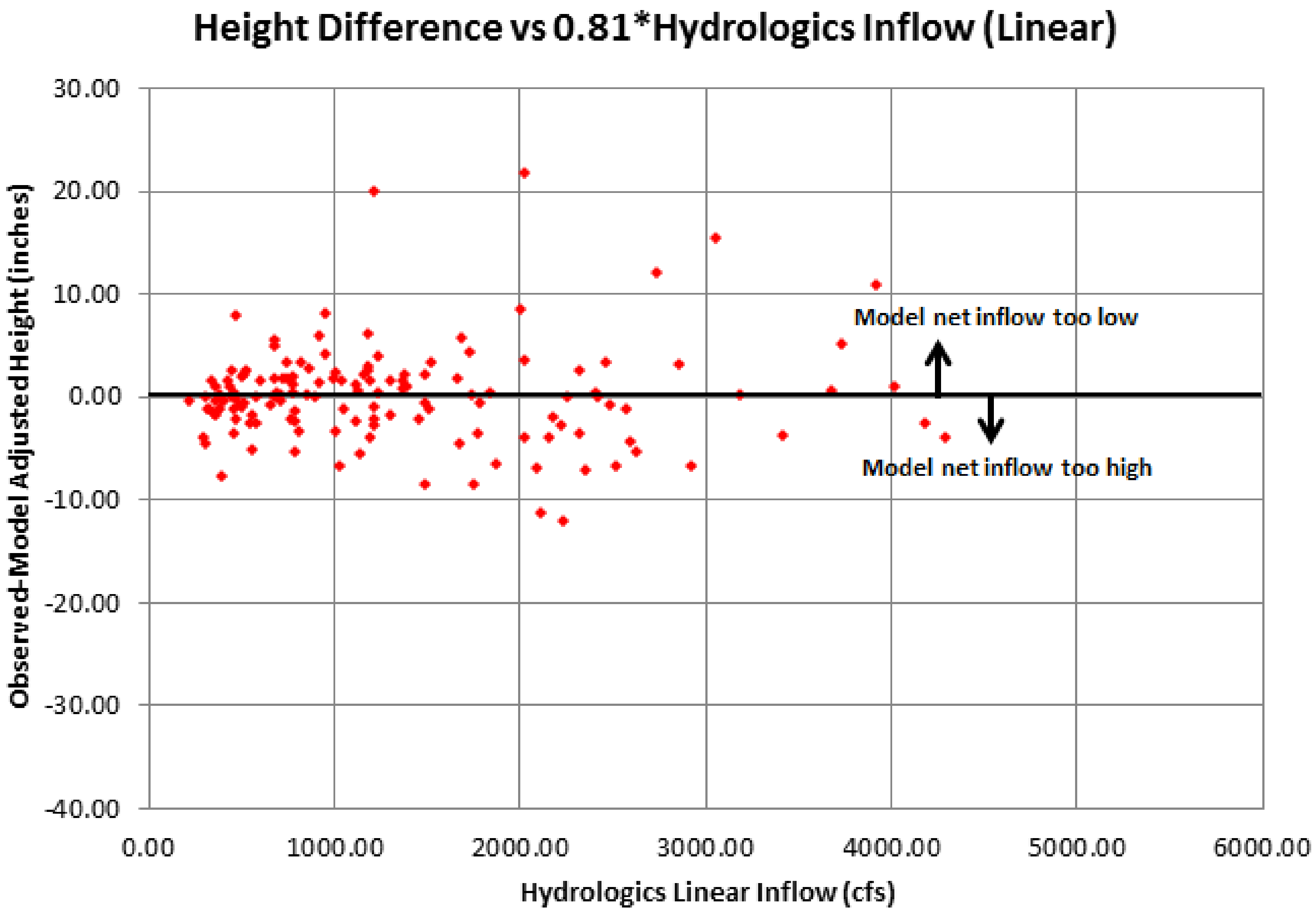
- **Errors in streamflow gages**
- **Errors in Leesville discharge**
- **Errors in Leesville overflow data**
- **Groundwater loss dependency on lake surface area**
- **Scaling for ungaged areas**
- **Wind surges (seiches)**
- **Bank effects**
- **Inflow equation**
  - ***Drainage area extrapolation***
  - ***Regression fit***
- **Localized rainfall**

Testing Drainage Area Scaling

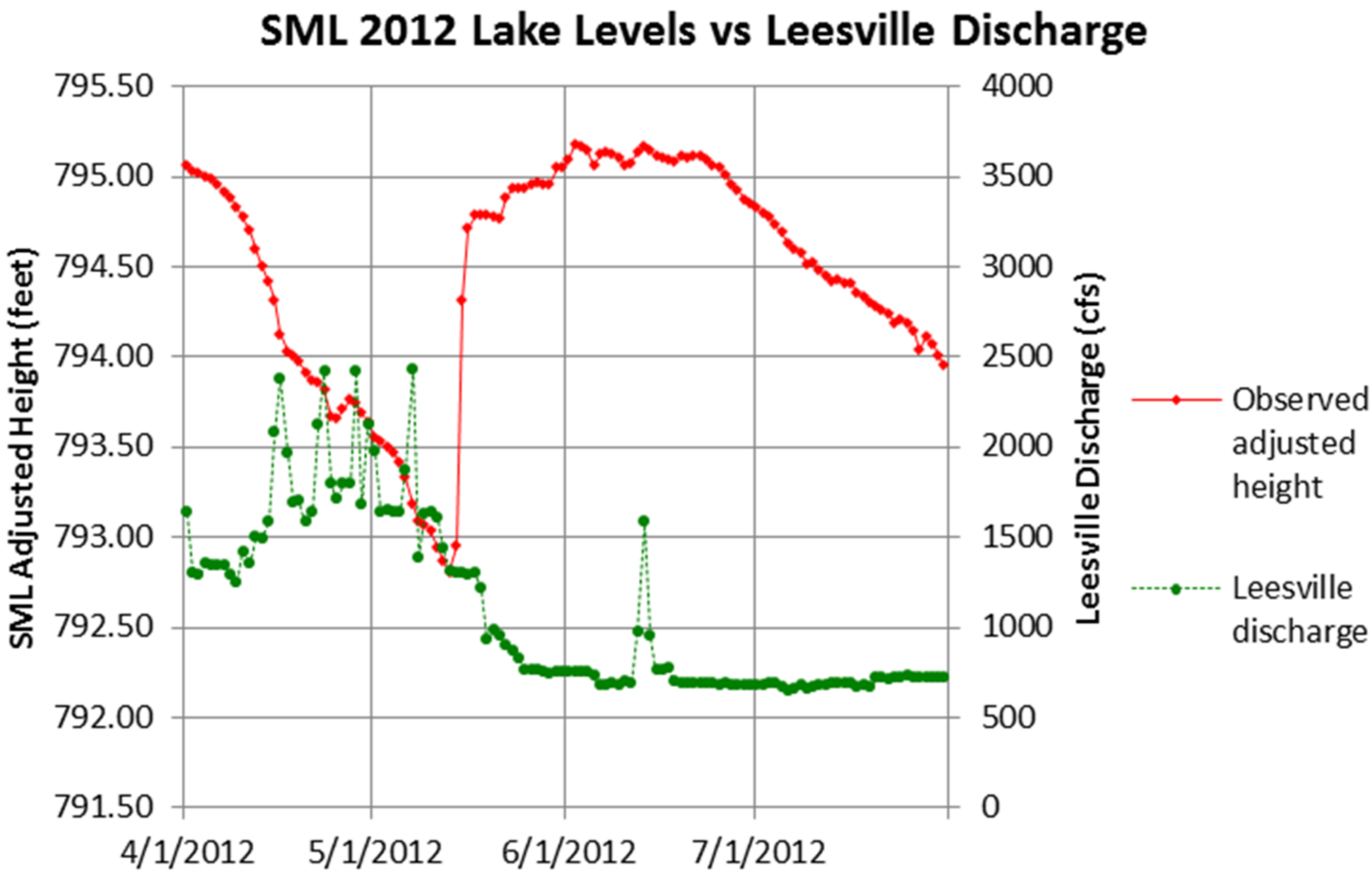



(Observed-Model) Difference vs Inflow (Regression)
25
20
15
10
5
0
-5
-10
-15
Observed-Model Adjusted Height (inches)
0.00
1000.00
2000.00
3000.00
4000.00
5000.00
6000.00
Hydrologics Regression Inflow (cfs)

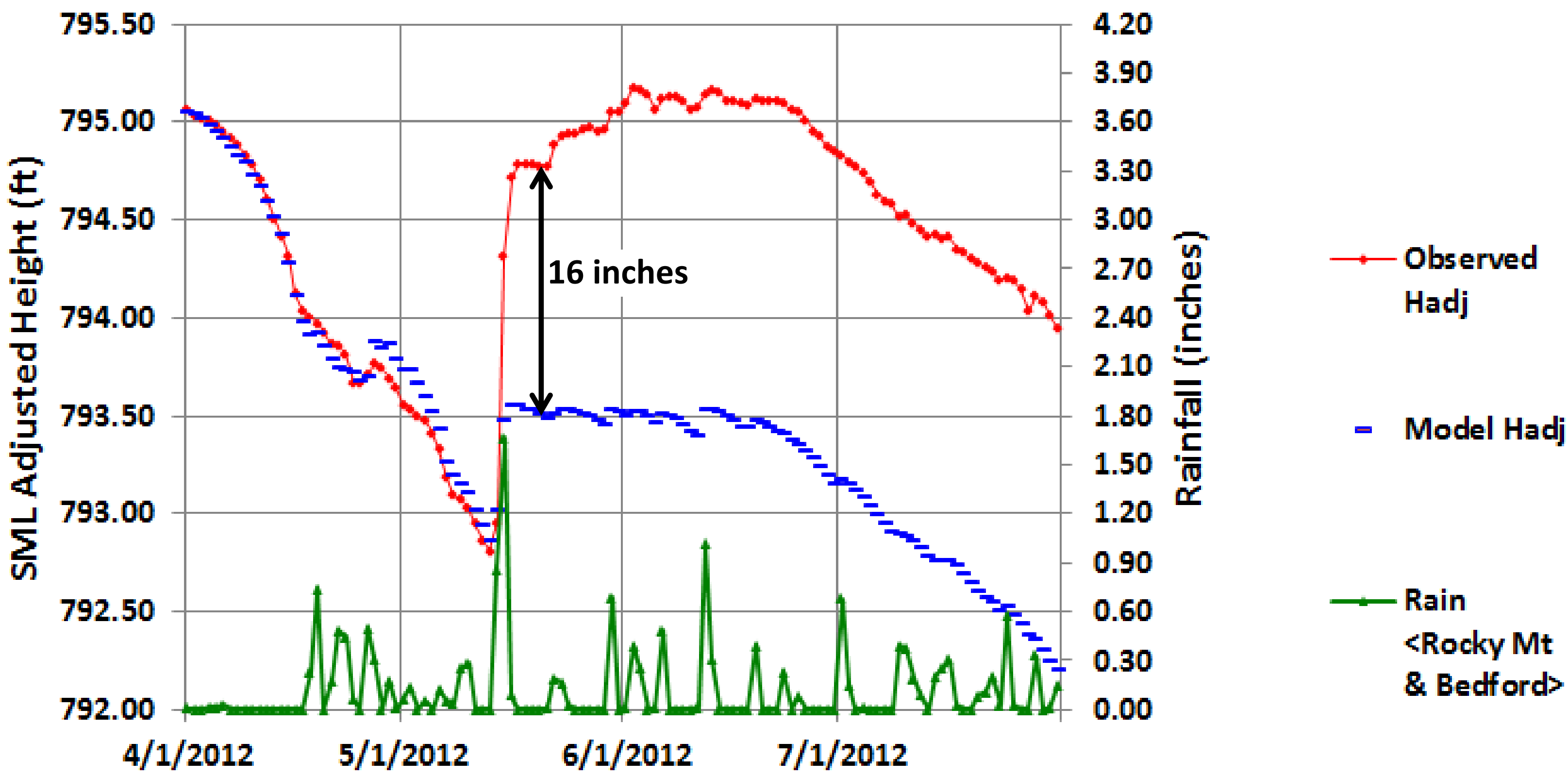

(Observed-Model) Difference vs Inflow (Linear)
Observed-Model Adjusted Height (inches)
30
20
10
0
-10
-20
-30
-40
0.00
1000.00
2000.00
3000.00
4000.00
5000.00
6000.00
Hydrologics Linear Inflow (cfs)
Model inflow too low
Model inflow too high



Height Difference vs 0.81*Hydrologics Inflow (Linear)
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
Observed-Model Adjusted Height (inches)
0.00
1000.00
2000.00
3000.00
4000.00
5000.00
6000.00
Hydrologics Linear Inflow (cfs)
Model net inflow too low
Model net inflow too high

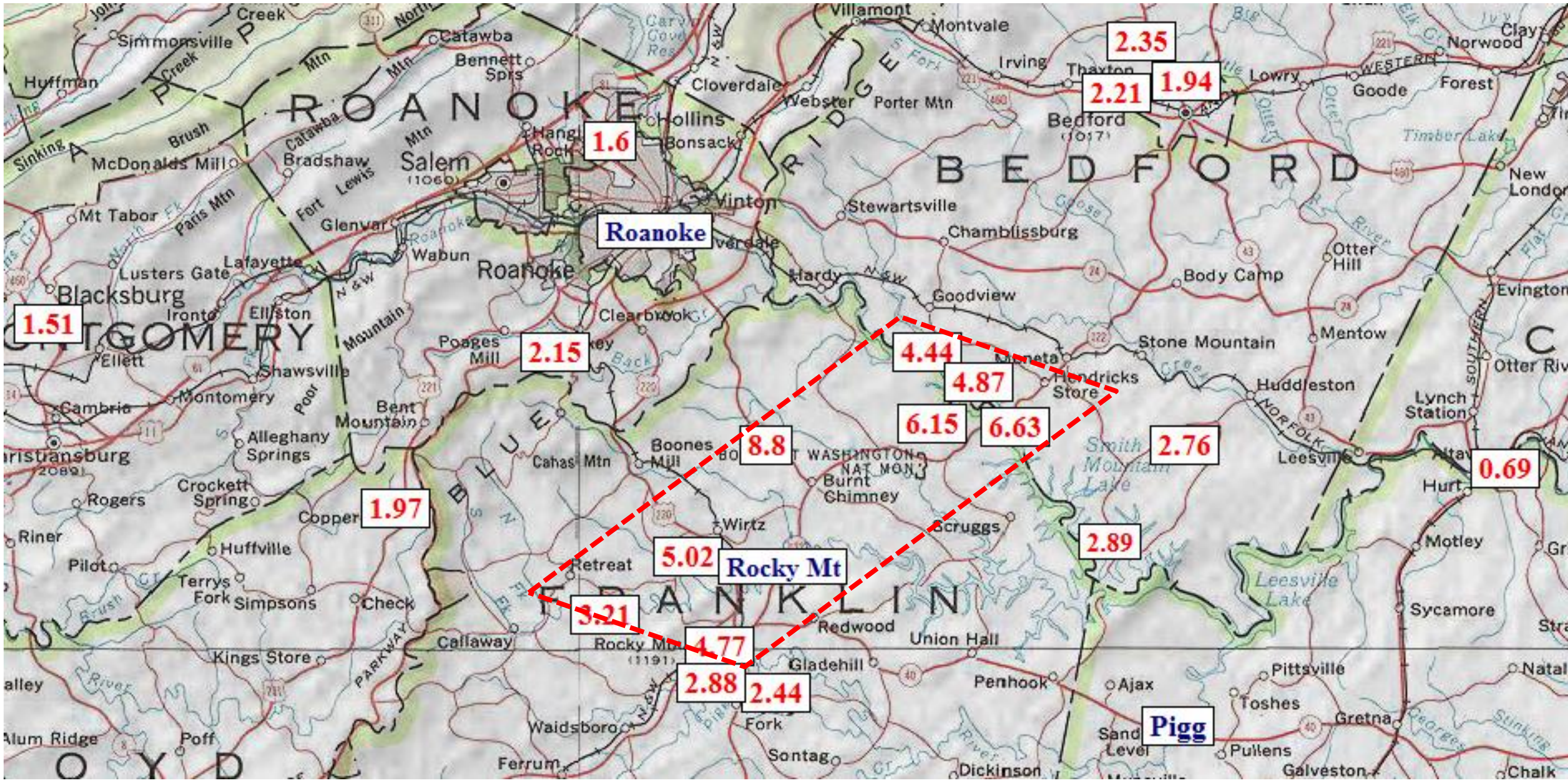

SML 2012 Lake Levels vs Leesville Discharge
795.50
795.00
794.50
794.00
793.50
793.00
792.50
792.00
791.50
SML Adjusted Height (feet)
4000
3500
3000
2500
2000
1500
1000
500
0
Leesville Discharge (cfs)
4/1/2012
5/1/2012
6/1/2012
7/1/2012
Observed adjusted height
Leesville discharge

Observed vs Linear Model Adjusted Height vs Rain



Linear Hydrologics model (1/1.18) run from 4-1 without updating

Inches of Rain on May 13-16, 2012



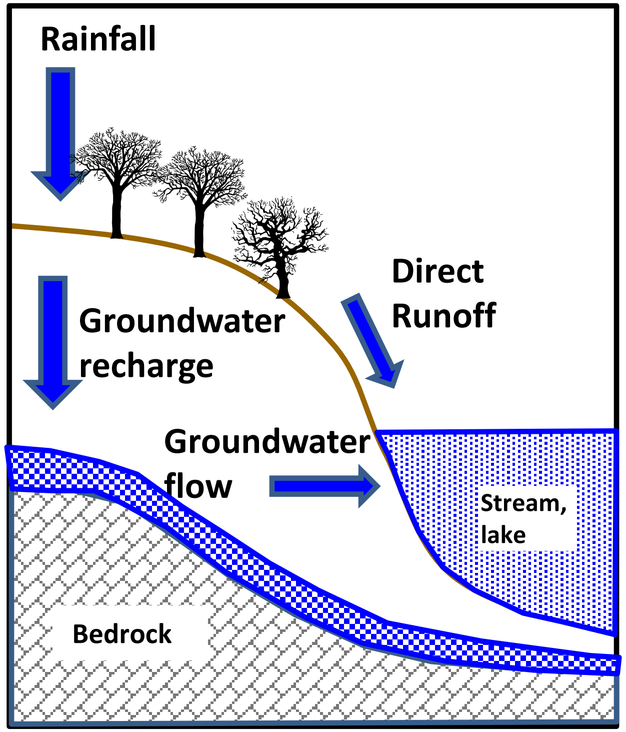
- Inches of rain shown in red
- Roanoke, Rocky Mount and Pigg USGS gage locations shown in blue

Major Factors Affecting Lake Level

- **Heavy rainfall appears to be the explanation for the major changes in lake level**
  - ***If the predictive model is re-initialized each time it is run, there is no effect on prediction accuracy***
  - ***Assuming heavy rain events are randomly distributed, there may not be a significant bias effect (60/40 for gaged/ungaged)***
- **Other factors that were examined did not explain these major lake level fluctuations**

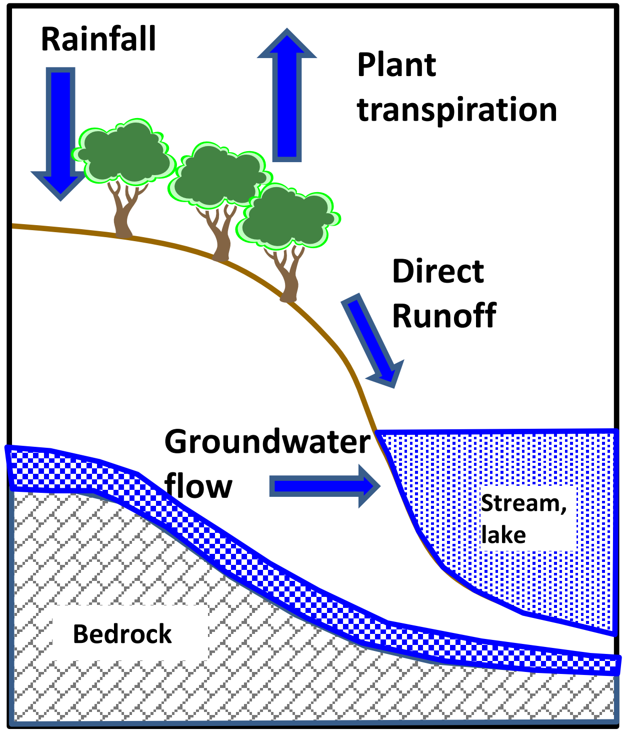
Can Predictive Accuracy be Improved? Groundwater Seasonal Cycle

Winter



Groundwater recharge period

Summer

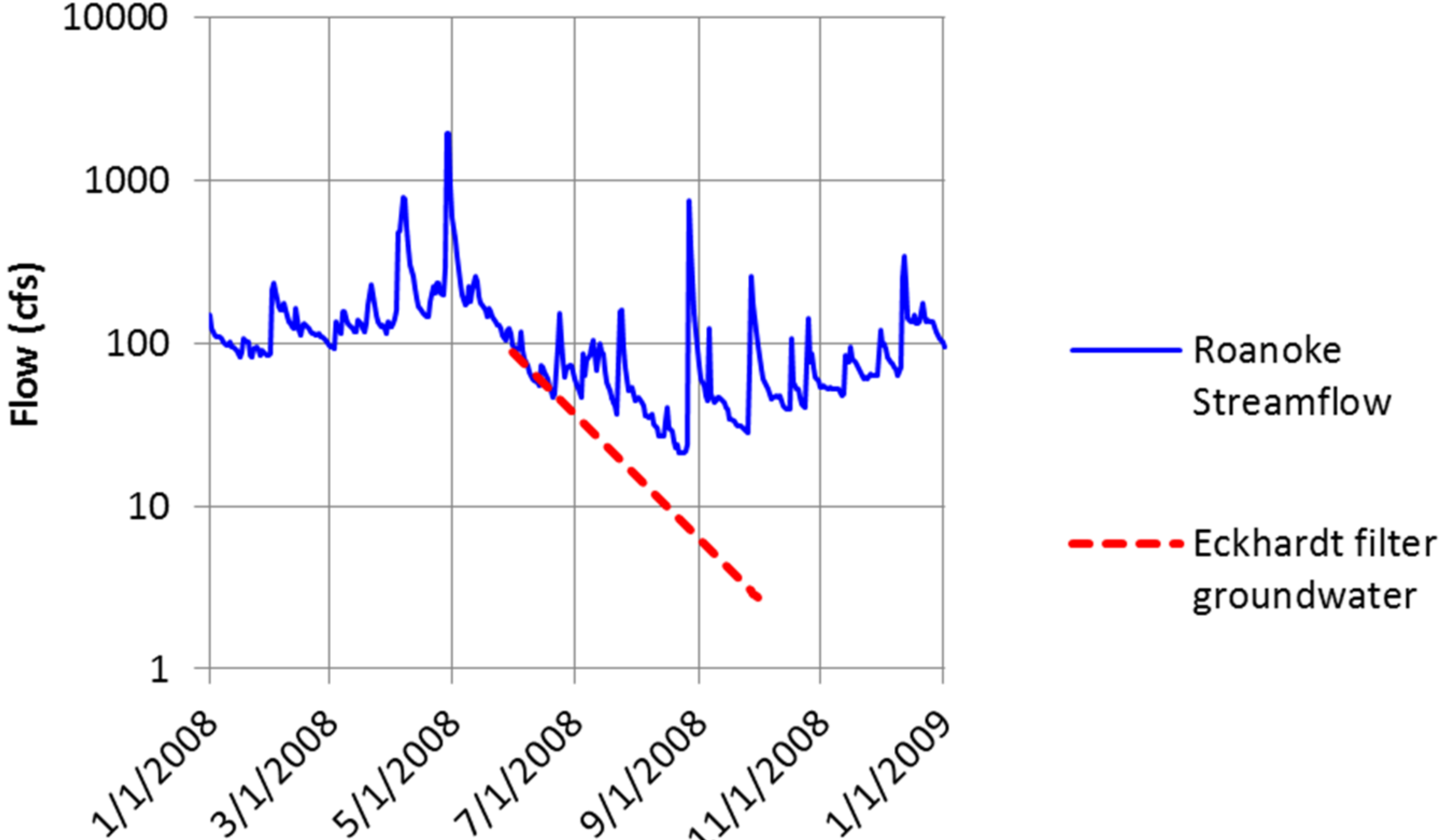


Groundwater flow can dominate the summer streamflow during low-rain summers

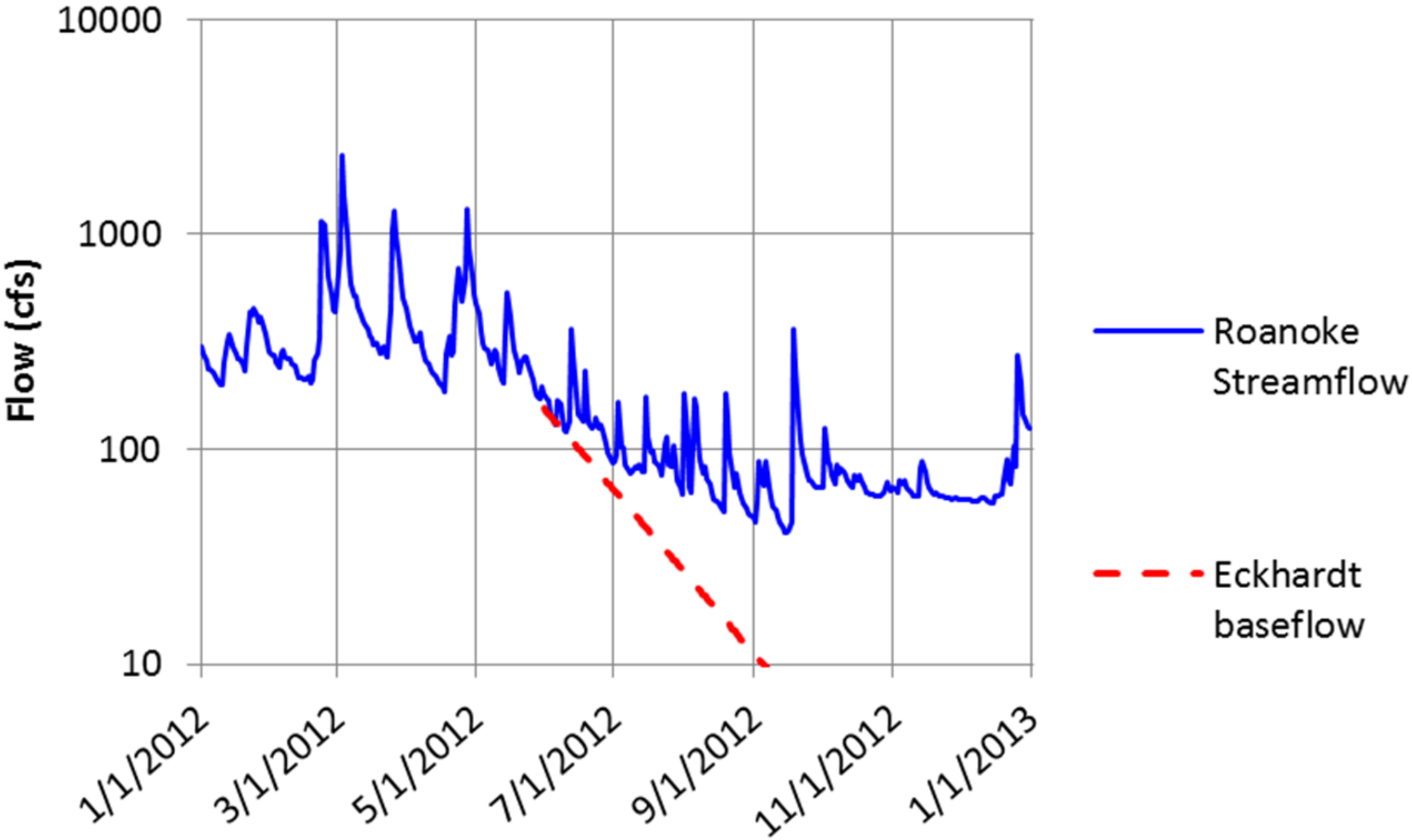
Where do we get Groundwater Flows?

- **Groundwater models of recharge and flow out**
  - ***Multiple groundwater models are available***
  - ***Vary from simple (and less accurate) to very labor- and data-intensive (and more accurate)***
- **Digital filters for baseflow (groundwater)**
  - ***Separate high-frequency rainfall events from low frequency groundwater flows***
  - ***Eckhardt filter has been used in a USGS on-line tool***

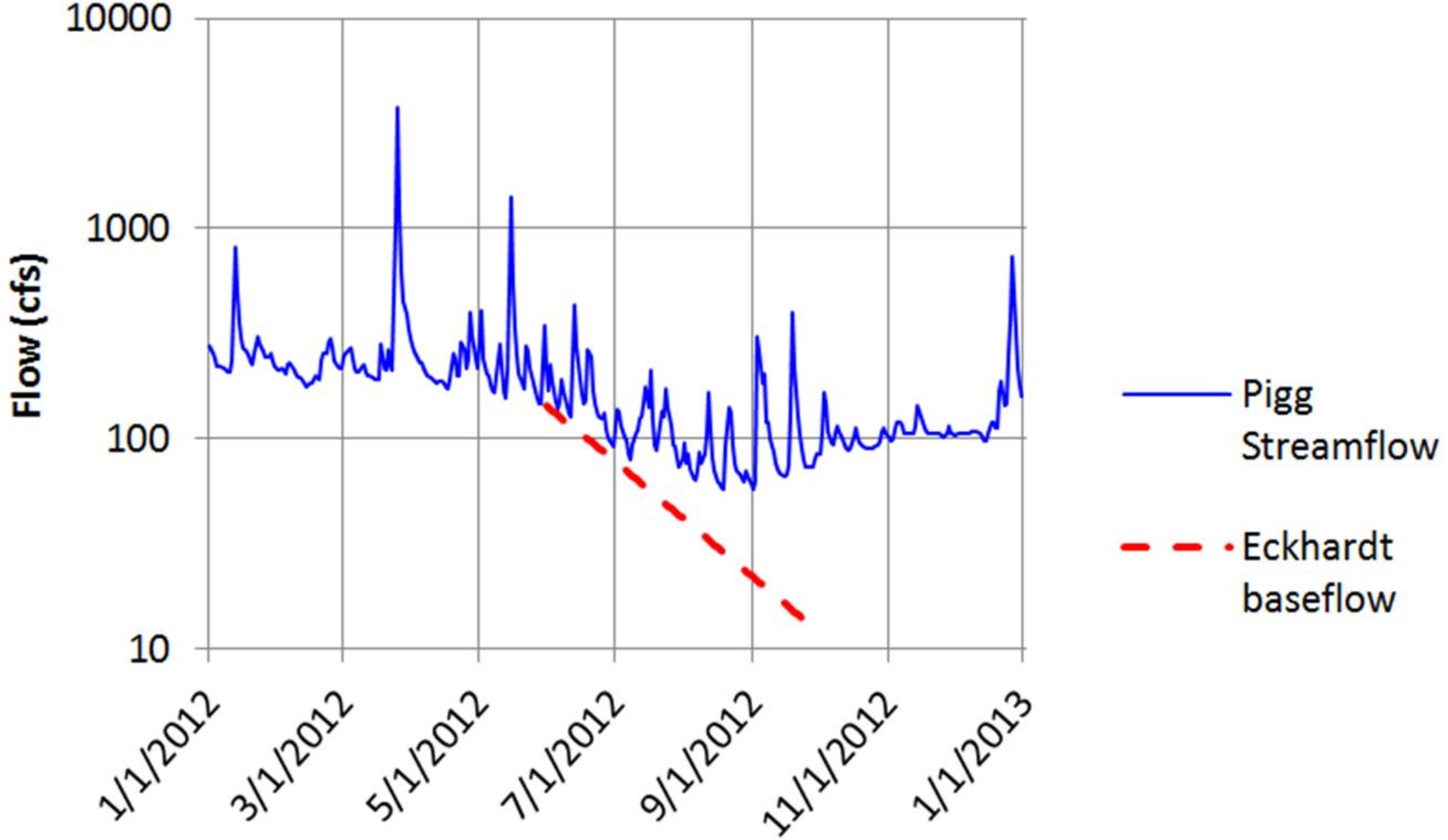
2008 Roanoke Summer Groundwater Flow



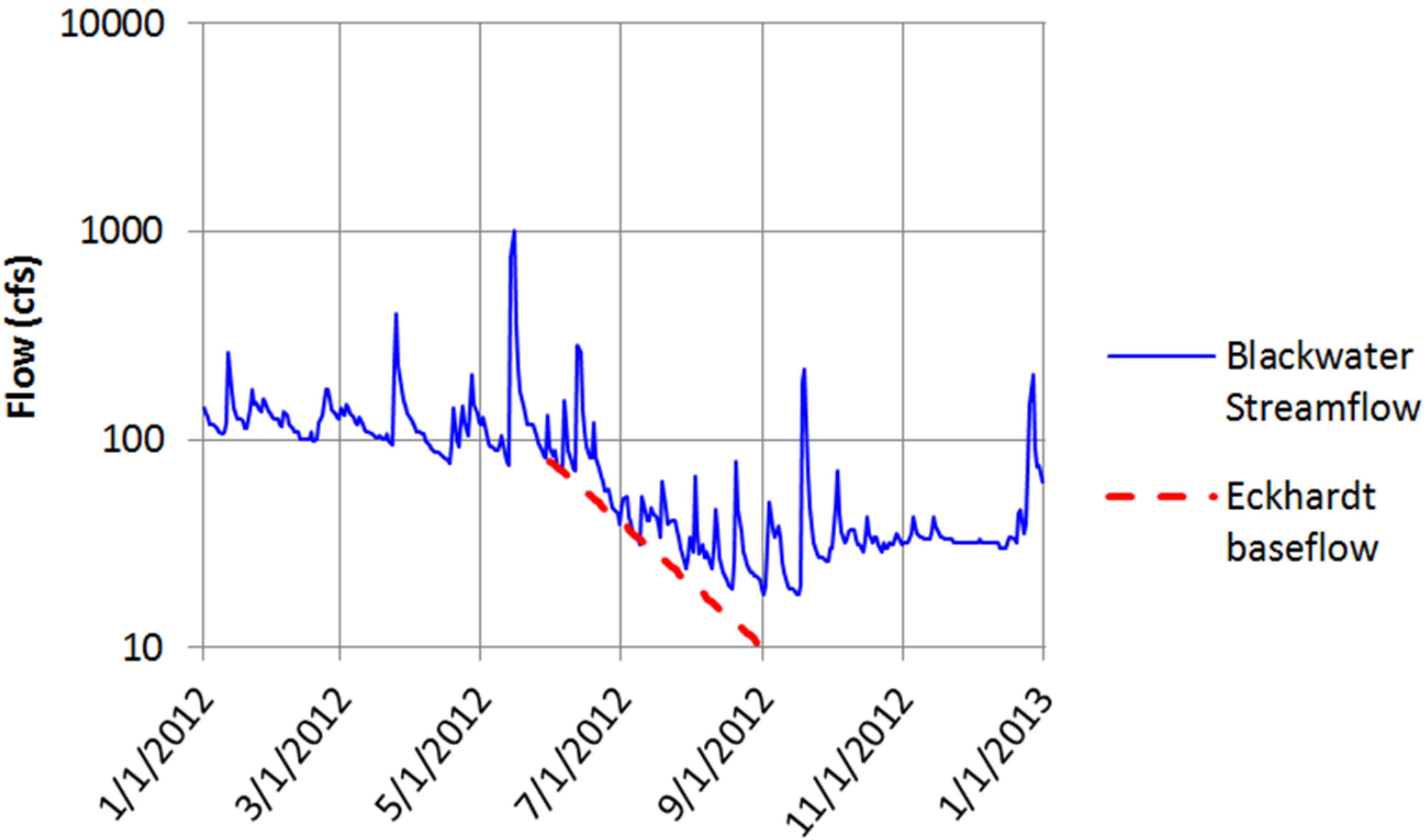
2012 Roanoke Summer Groundwater Flow



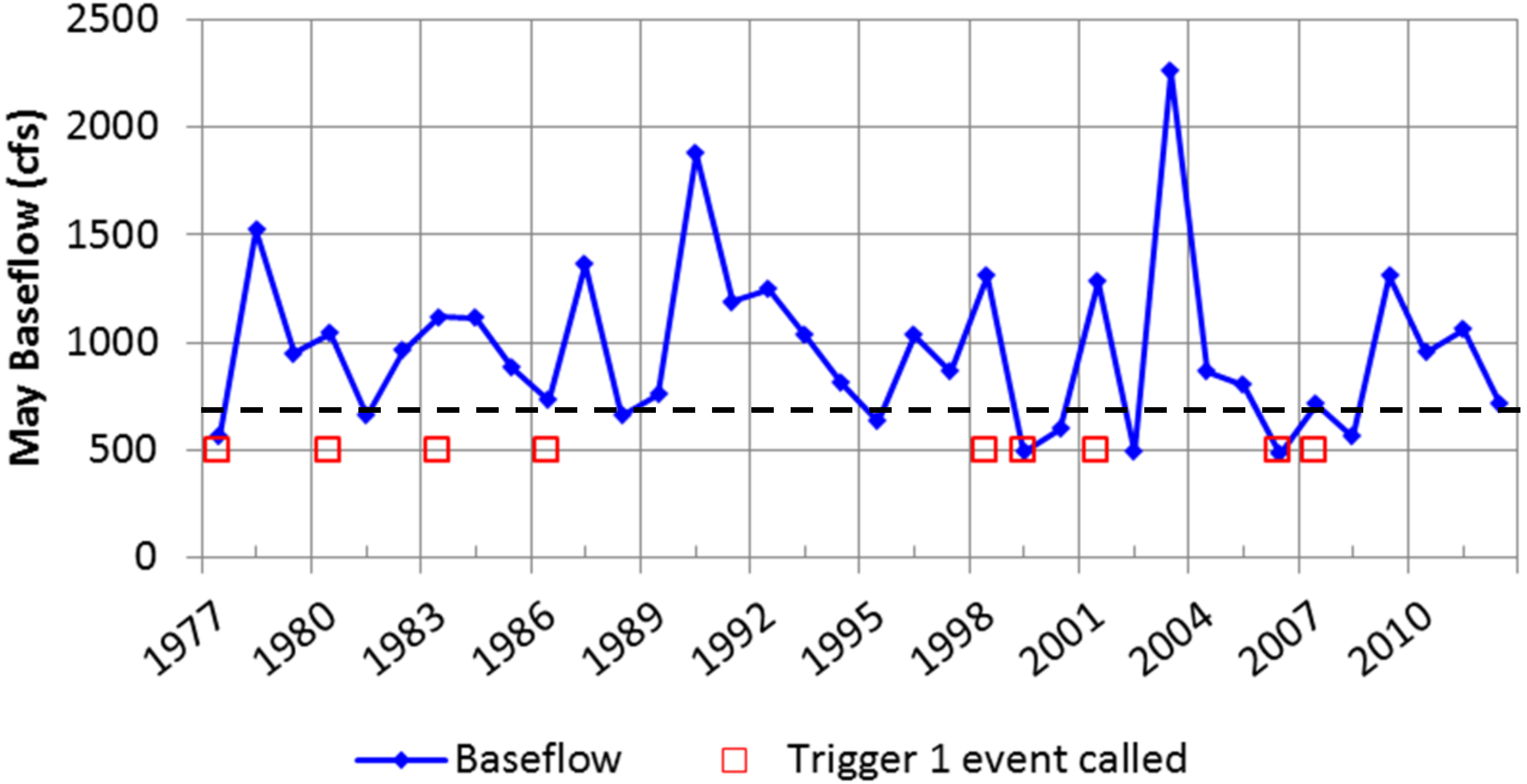
2012 Pigg Summer Groundwater Flow



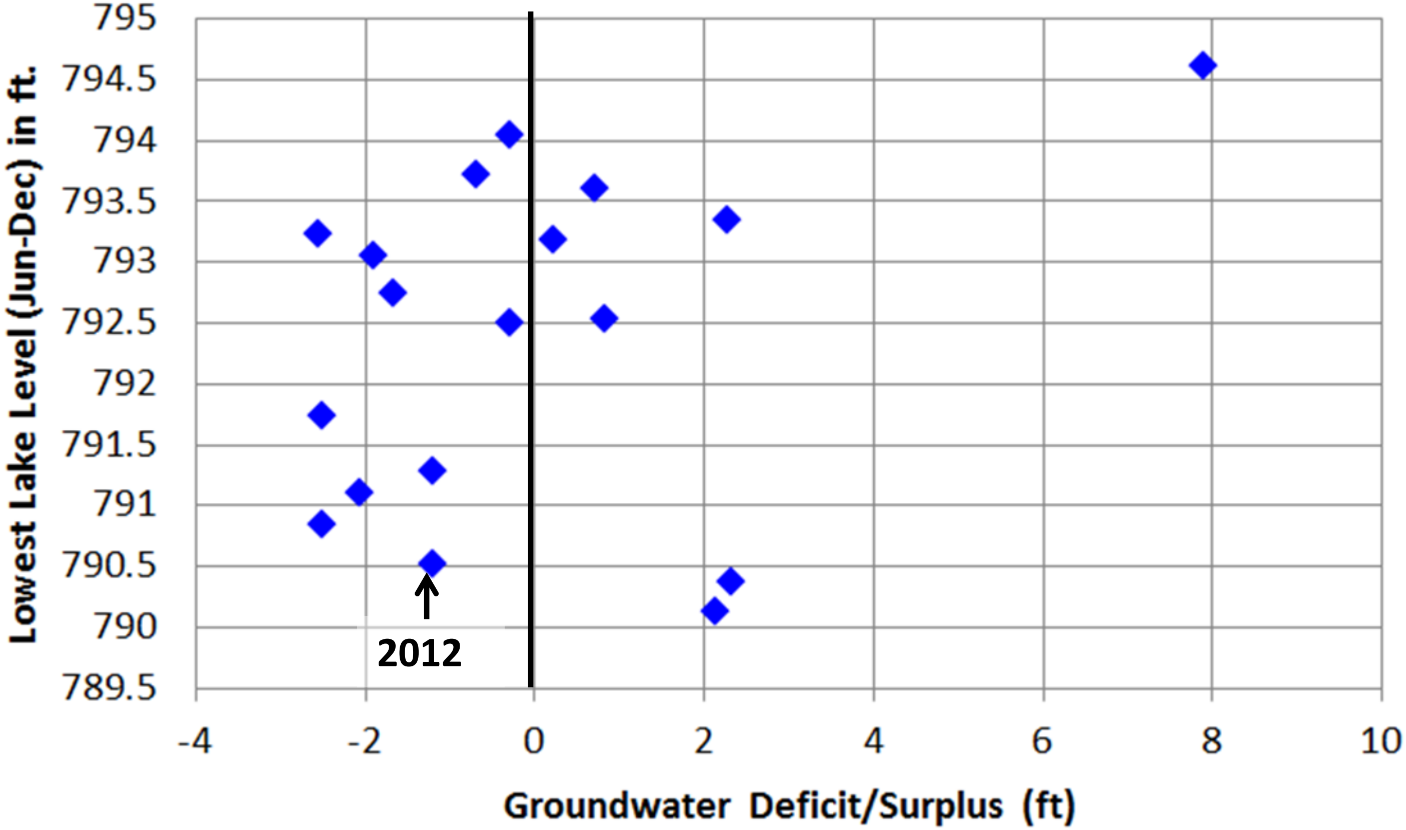
2012 Blackwater Summer Groundwater Flow



Linear Scaled May Baseflow

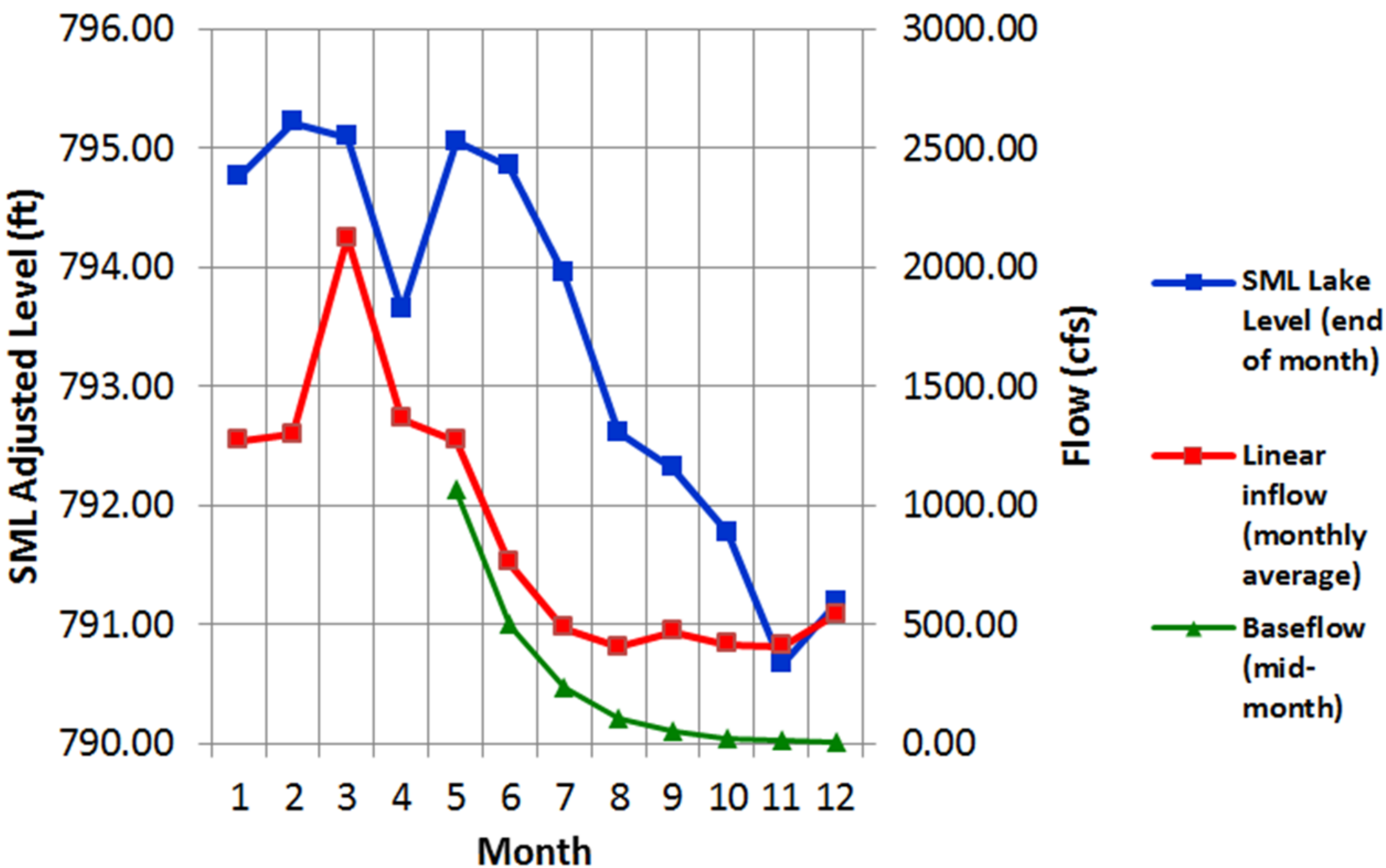


Low Lake Level vs. Ground Water Deficit/Surplus

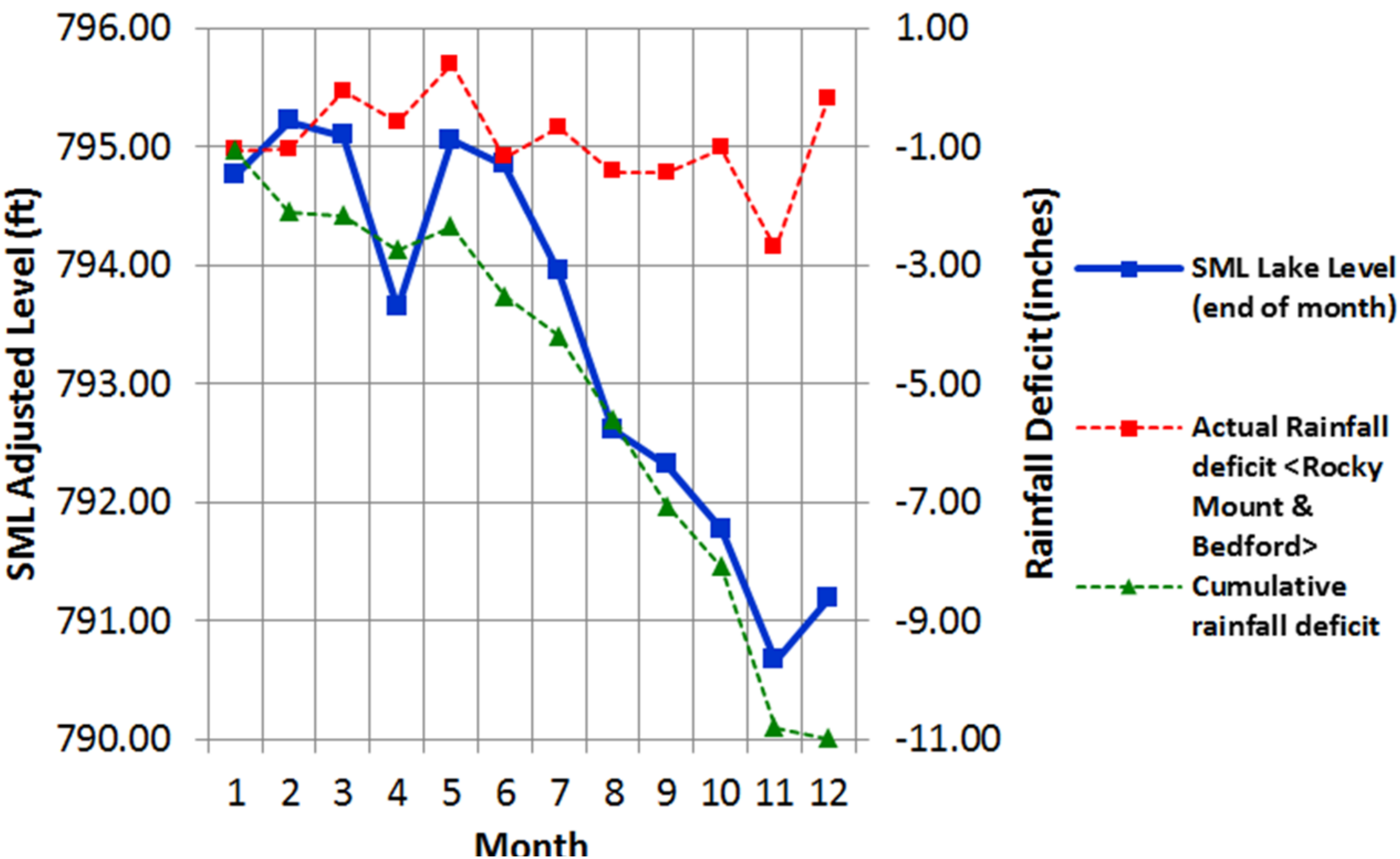


Note: Groundwater deficit/surplus calculated by integrating groundwater flow from mid-May and comparing to median groundwater flow (1977-2012) (see notes), then converting to feet of lake level

2012 Adjusted Lake Level vs Inflows



2012 Adjusted Lake Level vs Rainfall



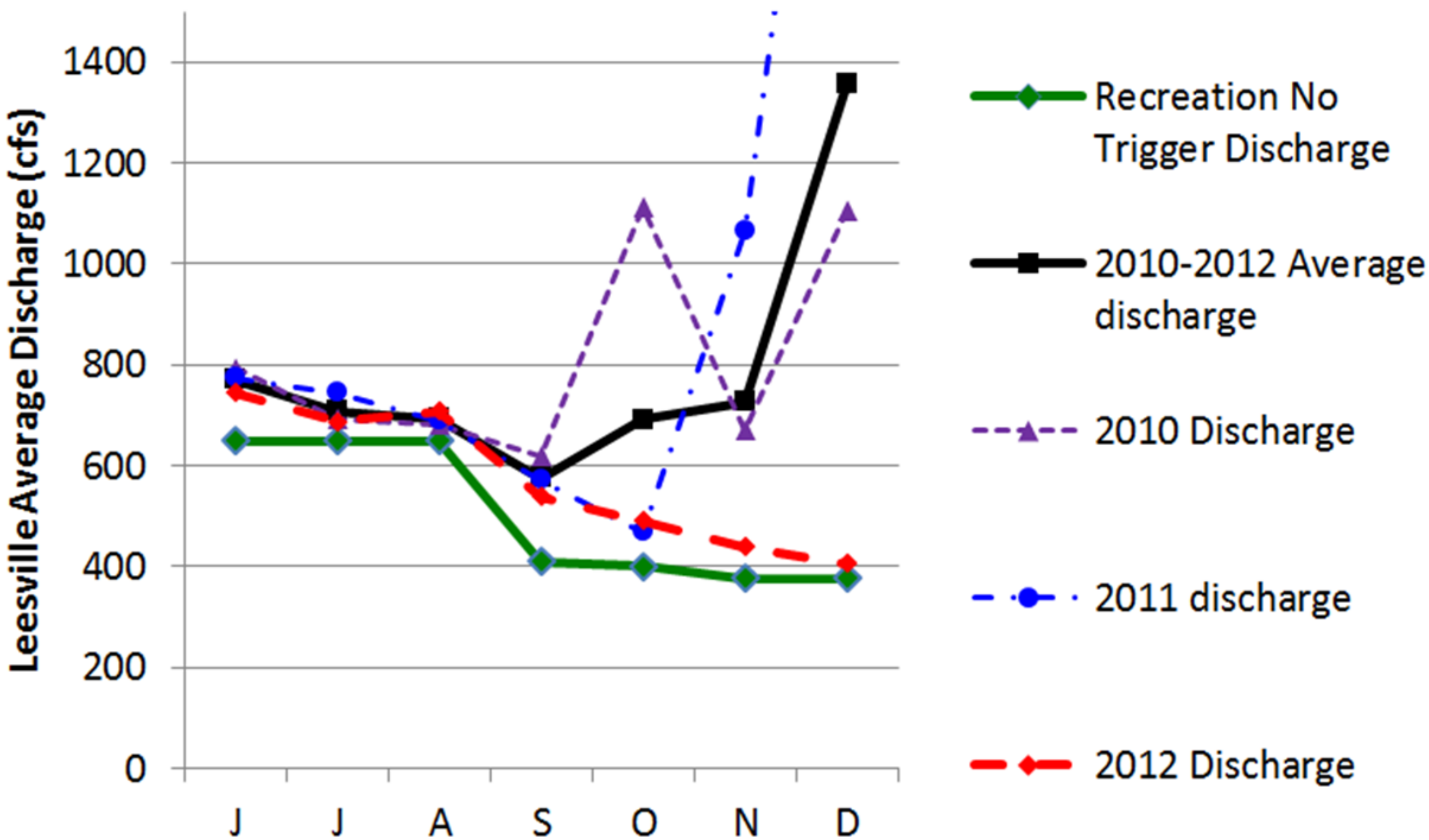
Two factors Caused 2012 Low Lake Levels

- **Low groundwater flows from winter recharge at the start of the summer**
  - ***Flows were in the bottom 1/3 range***
  - ***Exponential decay parallels the drop in inflow and lake levels in June-July***
  - ***Corresponds to the first 1 ft. drop in lake level***
- **Consistent rainfall deficit from June to December**
  - ***Cumulative 8 inch deficit over this period***
  - ***Loss of 10% runoff corresponds to a ~ 3 ft drop***
- **These two successive factors caused the 4 ft drop in 2012 lake levels and trigger 3**
- **Without the first 1 ft. drop from low groundwater, trigger 3 would not have occurred**

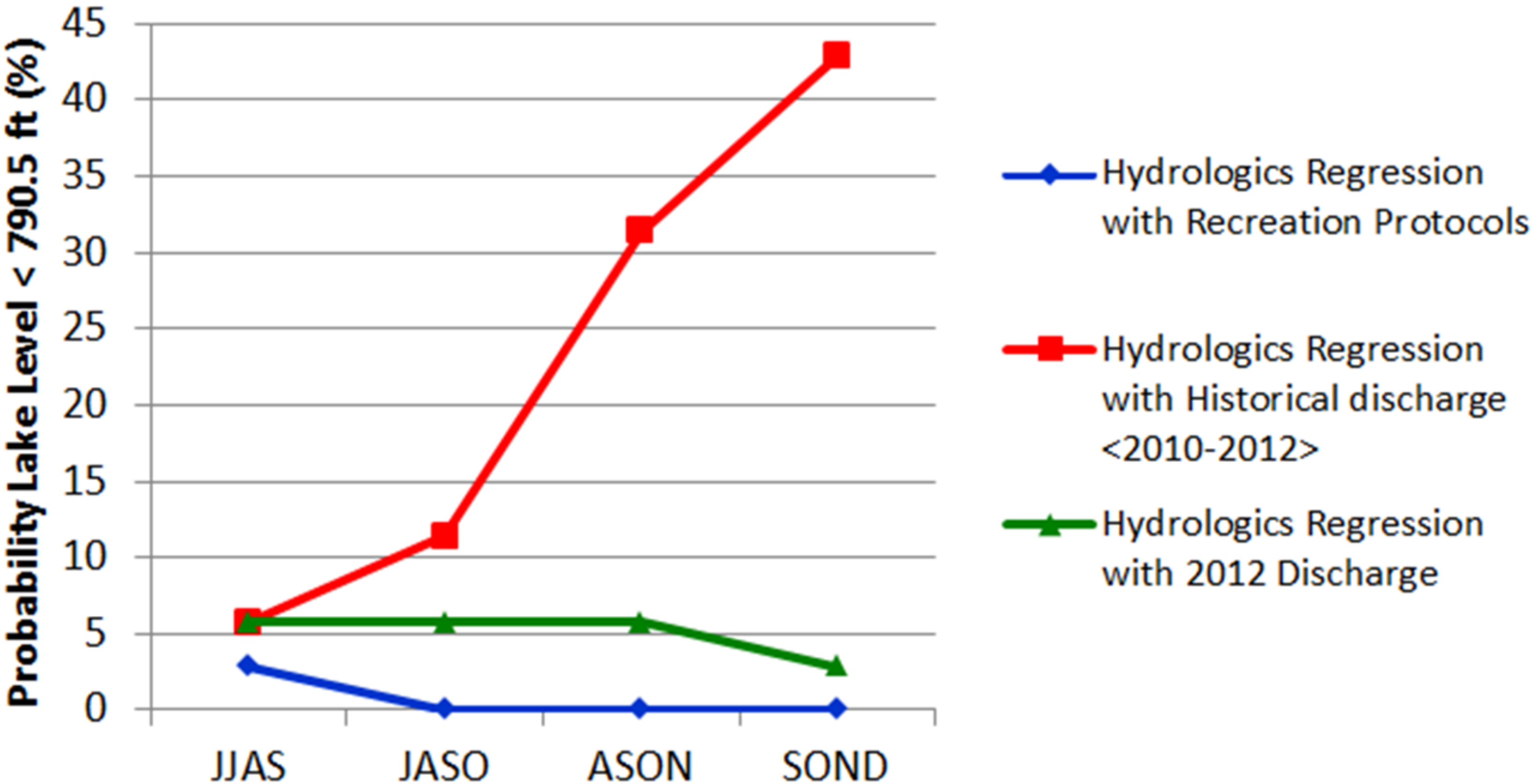
Can Predictive Accuracy be Improved?

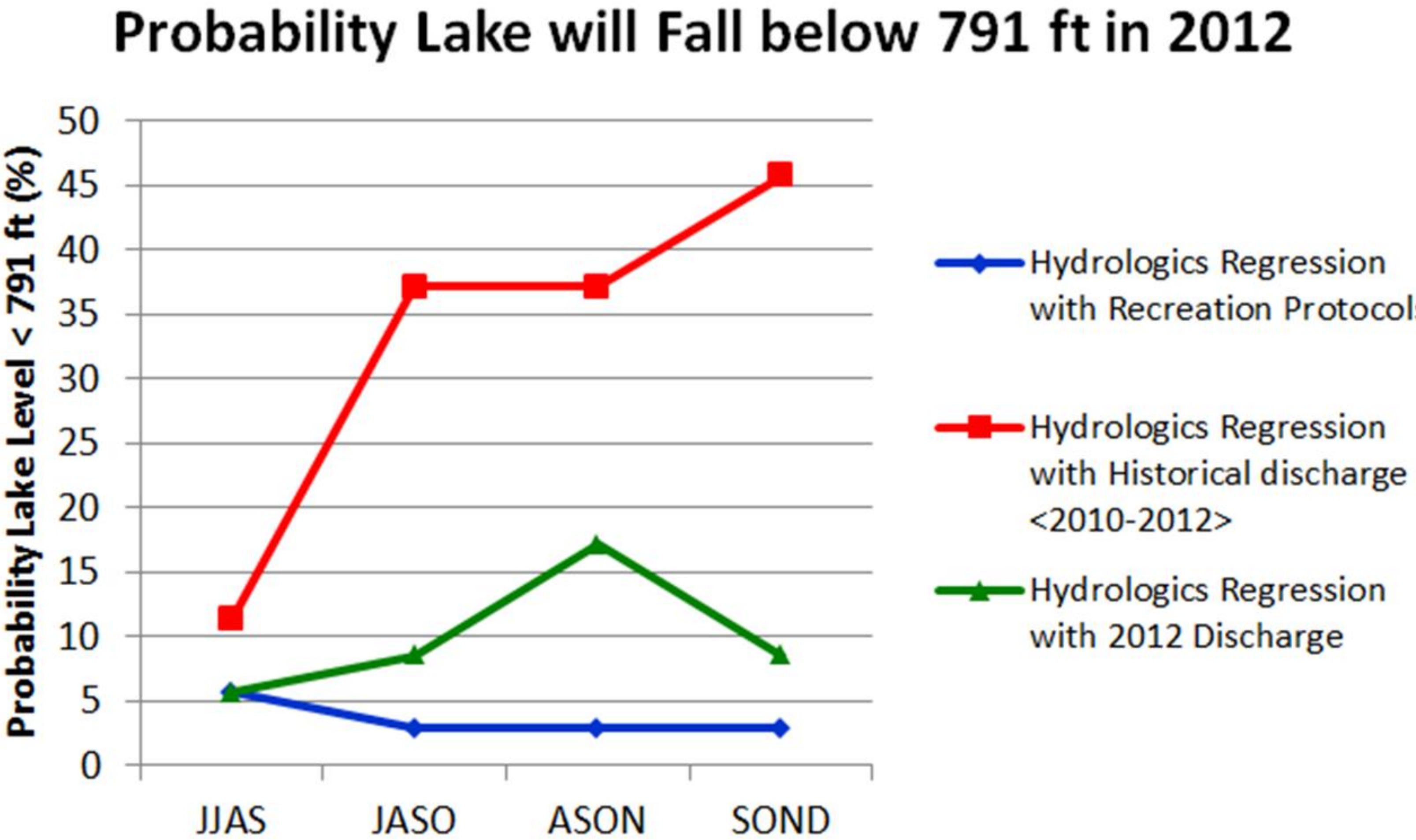
- **The emphasis to date has been on understanding and calibrating water balance models**
- **Prediction of future lake levels requires predicting both streamflows and Leesville discharges**
- **Hydrologics is using a synthetic streamflow model**
  - ***Autoregressive model using prior months streamflows to estimate future flows***
  - ***Potential month-to-month correlations in errors are handled by using same-year data to extrapolate***
- **Leesville discharges are based on meeting Brookneal flow targets using estimated inflows between Leesville and Brookneal**

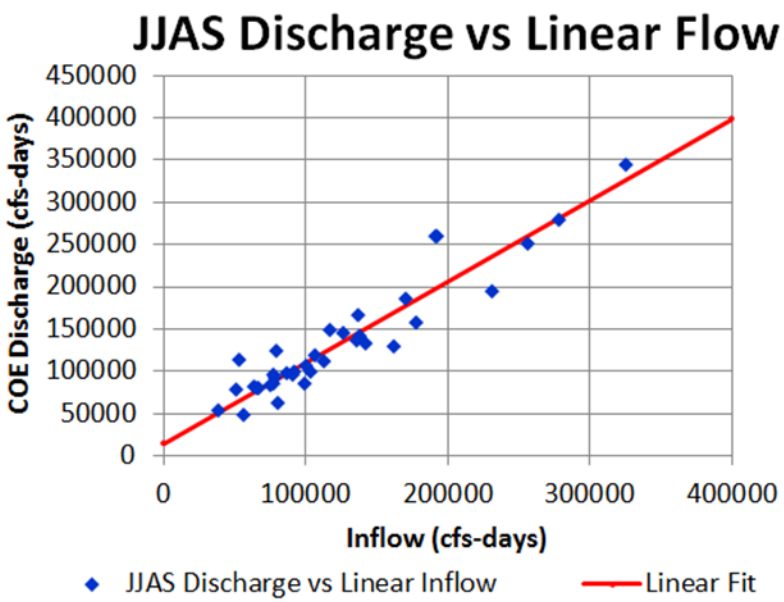
Leesville Monthly Average Releases

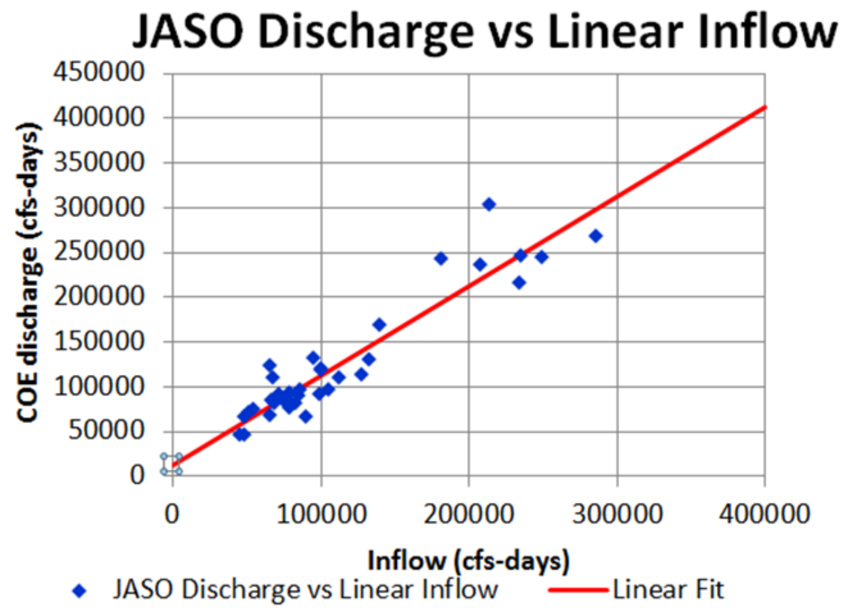


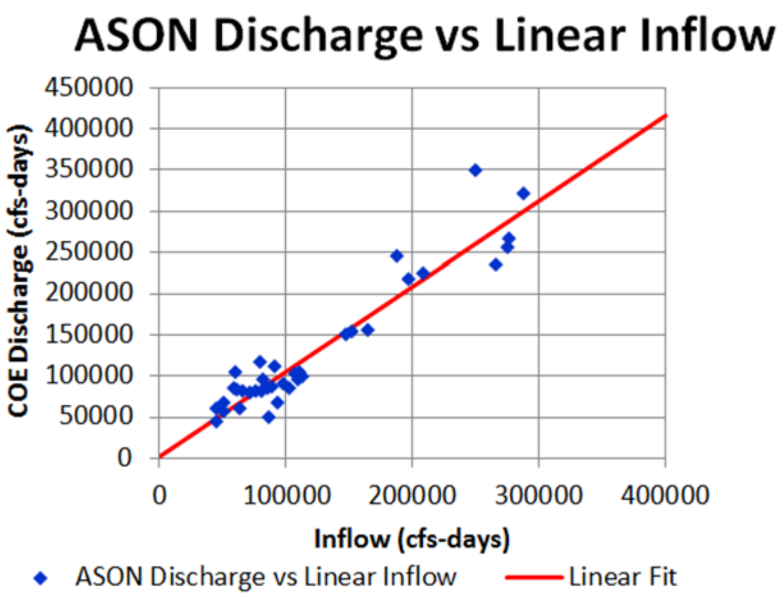
Probability a Trigger 1 will Occur in 2012

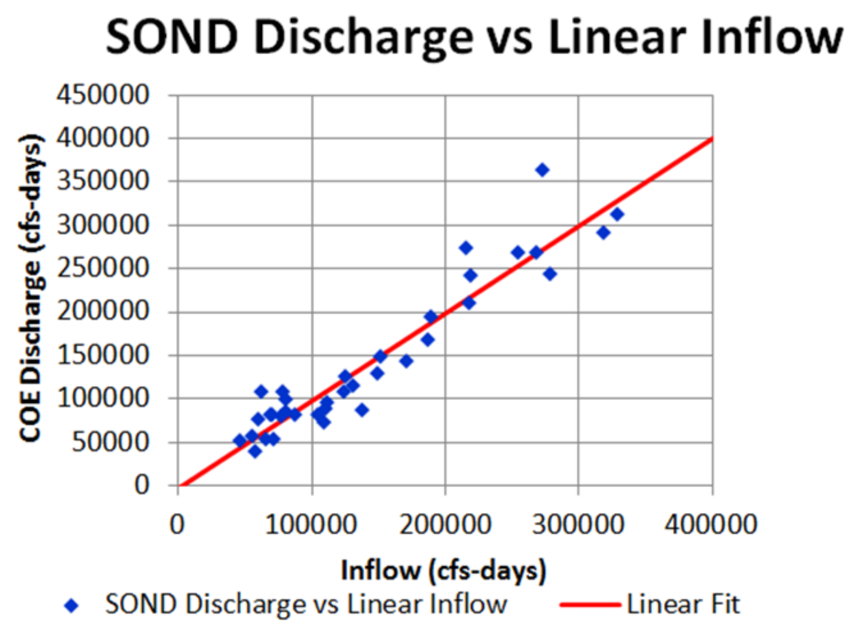



Probability Lake will Fall below 791 ft in 2012
Probability Lake Level < 791 ft (%)
50
45
40
35
30
25
20
15
10
5
0
JJAS
JASO
ASON
SOND
Hydrologics Regression with Recreation Protocols
Hydrologics Regression with Historical discharge <2010-2012>
Hydrologics Regression with 2012 Discharge

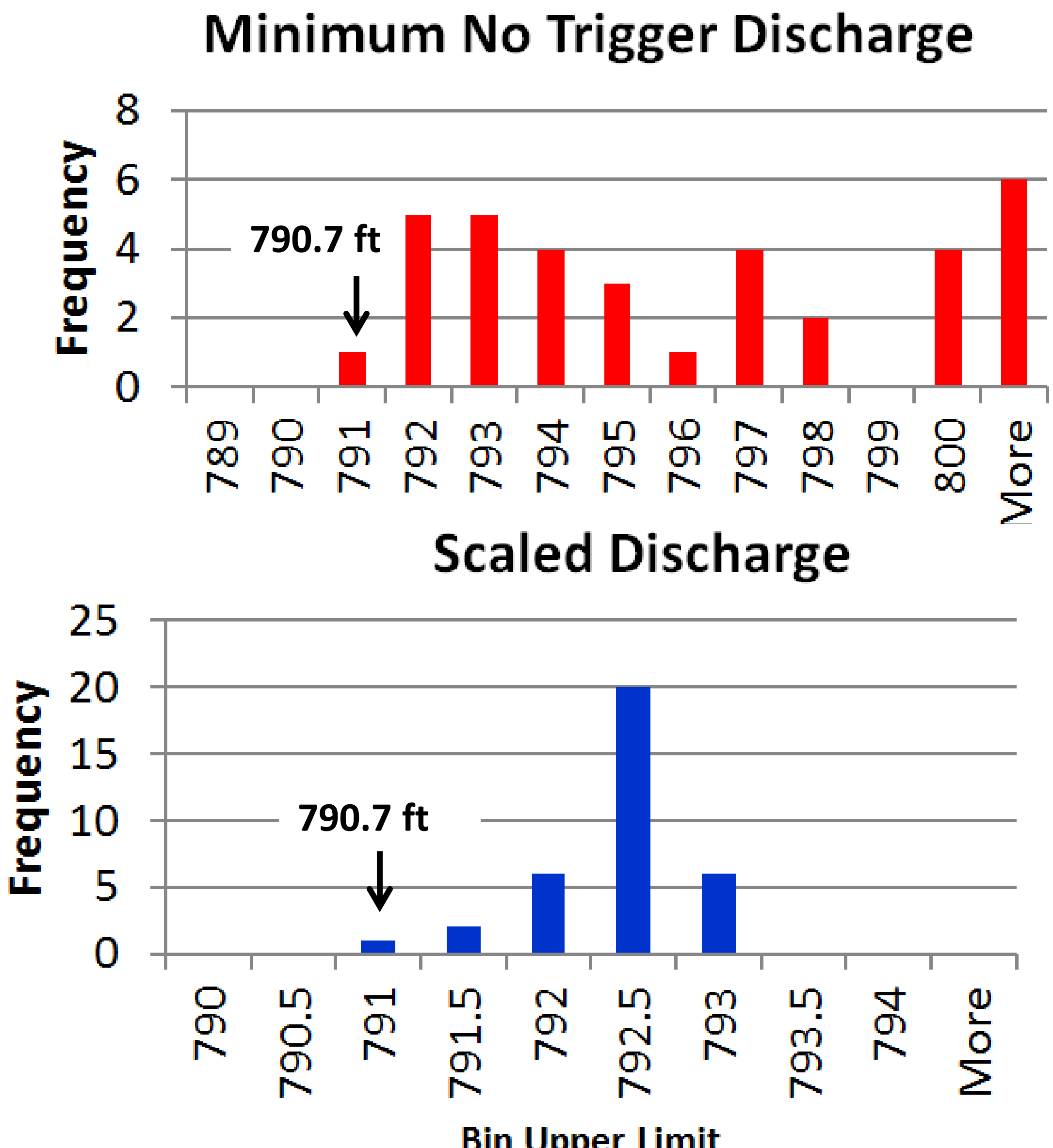

JJAS Discharge vs Linear Flow
COE Discharge (cfs-days)
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
0
100000
200000
300000
400000
Inflow (cfs-days)
JJAS Discharge vs Linear Inflow
Linear Fit


JASO Discharge vs Linear Inflow
COE discharge (cfs-days)
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
0
100000
200000
300000
400000
Inflow (cfs-days)
JASO Discharge vs Linear Inflow
Linear Fit

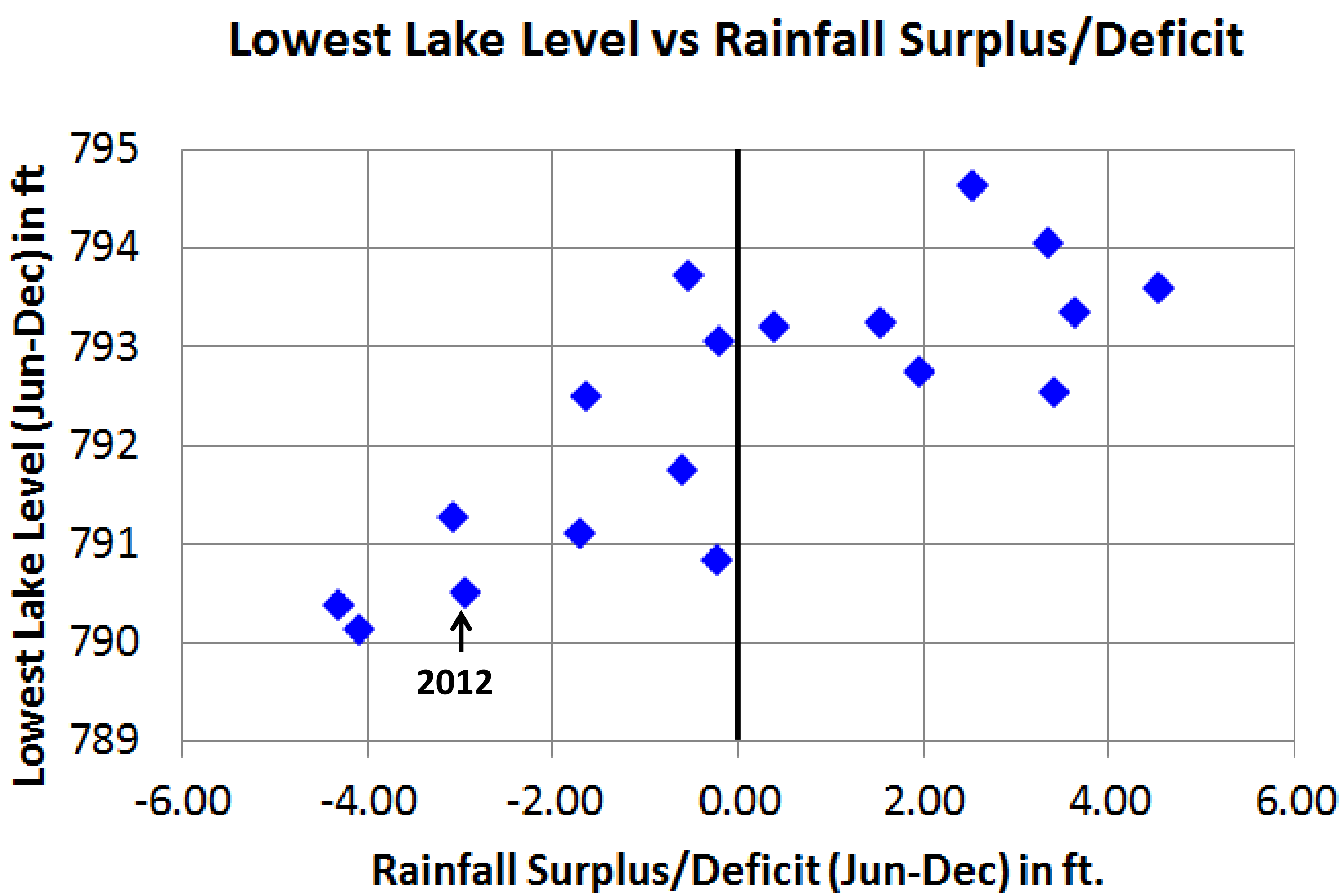

ASON Discharge vs Linear Inflow
COE Discharge (cfs-days)
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
0
100000
200000
300000
400000
Inflow (cfs-days)
ASON Discharge vs Linear Inflow
Linear Fit


SOND Discharge vs Linear Inflow
COE Discharge (cfs-day)
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
0
100000
200000
300000
400000
Inflow (cfs-days)
SOND Discharge vs Linear Inflow
Linear Fit

November 2012 Lake Level Predictions

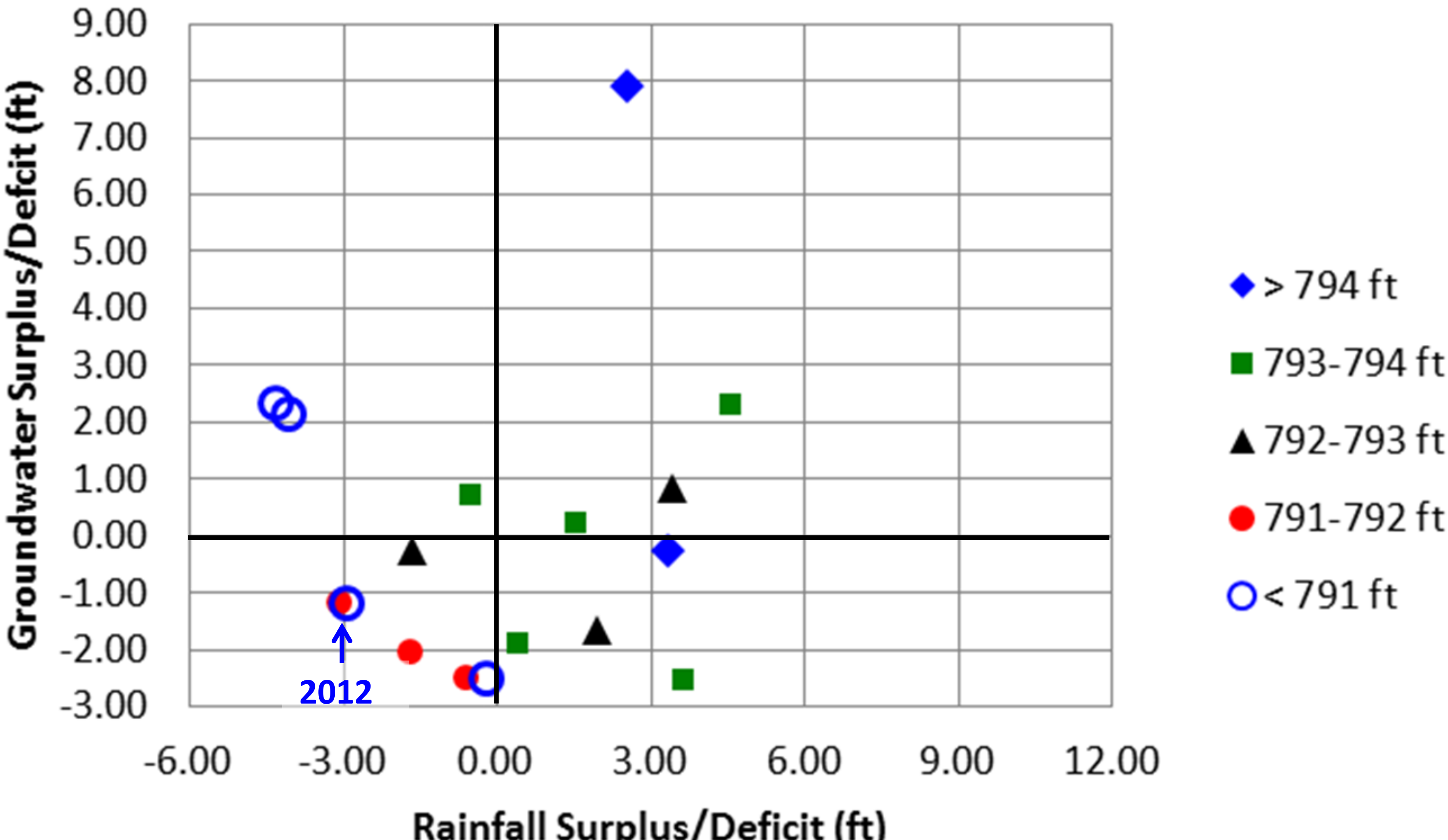


Actual minimum lake level at the end of November, 2012, was 790.7 ft.



Note: Surplus/deficits are converted to Feet of Lake Level

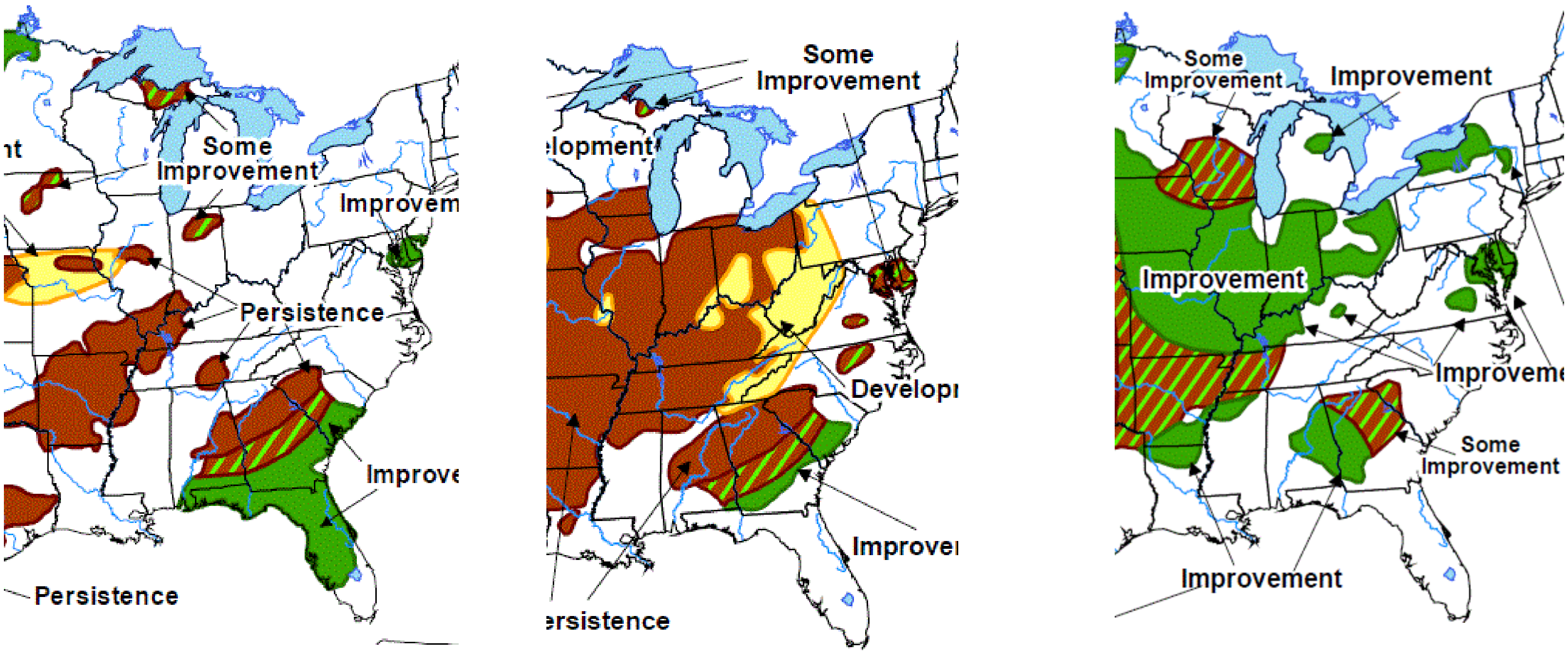
Lowest Lake Level vs Rainfall and Groundwater Surplus/Deficit



Note: Surplus/deficits are converted to Feet of Lake Level

U.S. Seasonal Drought Outlook
Drought Tendency During the Valid Period

June 7-Aug 31, 2012 | **Jul 5 - Sep 30, 2012** | **Sep 6- Nov 30, 2012**



KEY:

- Drought to persist or intensify
- Drought ongoing, some improvement
- Drought likely to improve, impacts ease
- Drought development likely

http://www.cpc.ncep.noaa.gov/products/expert_assessment/sdo_archive/2012/sdo_jja12-rev.gif

Recommendations

- **Use actual Leesville discharges since 2010 to improve predictive accuracy in the June-December timeframe (Hydrologics*)**
- **Maintain closer adherence to following the minimum Leesville discharges specified in the Water Management Plan (AEP*)**
- **Request adding a probability value for the lake falling below 791 ft. in the Trigger 3 definition (Bedford Regional Water Authority*)**
- **Request that DEQ renew the AEP permit for the next 5 years and review our recommendations and issues (DEQ*)**
- **Continue to assess predictive model performance and address issues during the next 5 years (SMLA*)**

*** Recommended responsibility**

Issues

- **Use NOAA CPC drought predictions to identify low rainfall years**
- **Examine more "realistic" groundwater models**
- **Examine interaction of rainfall and groundwater deficits**
    - ***Moderate rainfall and groundwater deficits are additive***
    - ***Large rainfall deficits dominate***
- **Examine effect of inflow/discharge correlations**
- **Consider alternate methods for generating synthetic streamflows**
- **Reevaluate the 40 cfs addition to the Roanoke gage**
- **Consider using the Niagara rather than the Roanoke gage**
- **Reconsider the "groundwater loss" term**
- **Examine evaporation loss variability**

Questions

- What are the coefficients used in the predictive model?
  - Synthetic model streamflow coefficients
  - Evaporation
  - Rainfall
  - Pre-1977 inflow calculations
- Does the trend between rainfall deficits and low lake levels also exist in the pre-1995 data

SMLA Says Thanks to:

- Hydrologics
- Appalachian Electric Power
- Dr. Eric Anderson
- The Water Management Committee
  - *Russ Johnson*
  - *Chuck Sinex*
  - *Bill Piatt*
  - *Jim Colby*
  - *Bill Brush*
  - *John Lindsey*
  - *Rob Whitener*