Trends in Sediment Transport and Deposition in the lower Elk River 2001-2013

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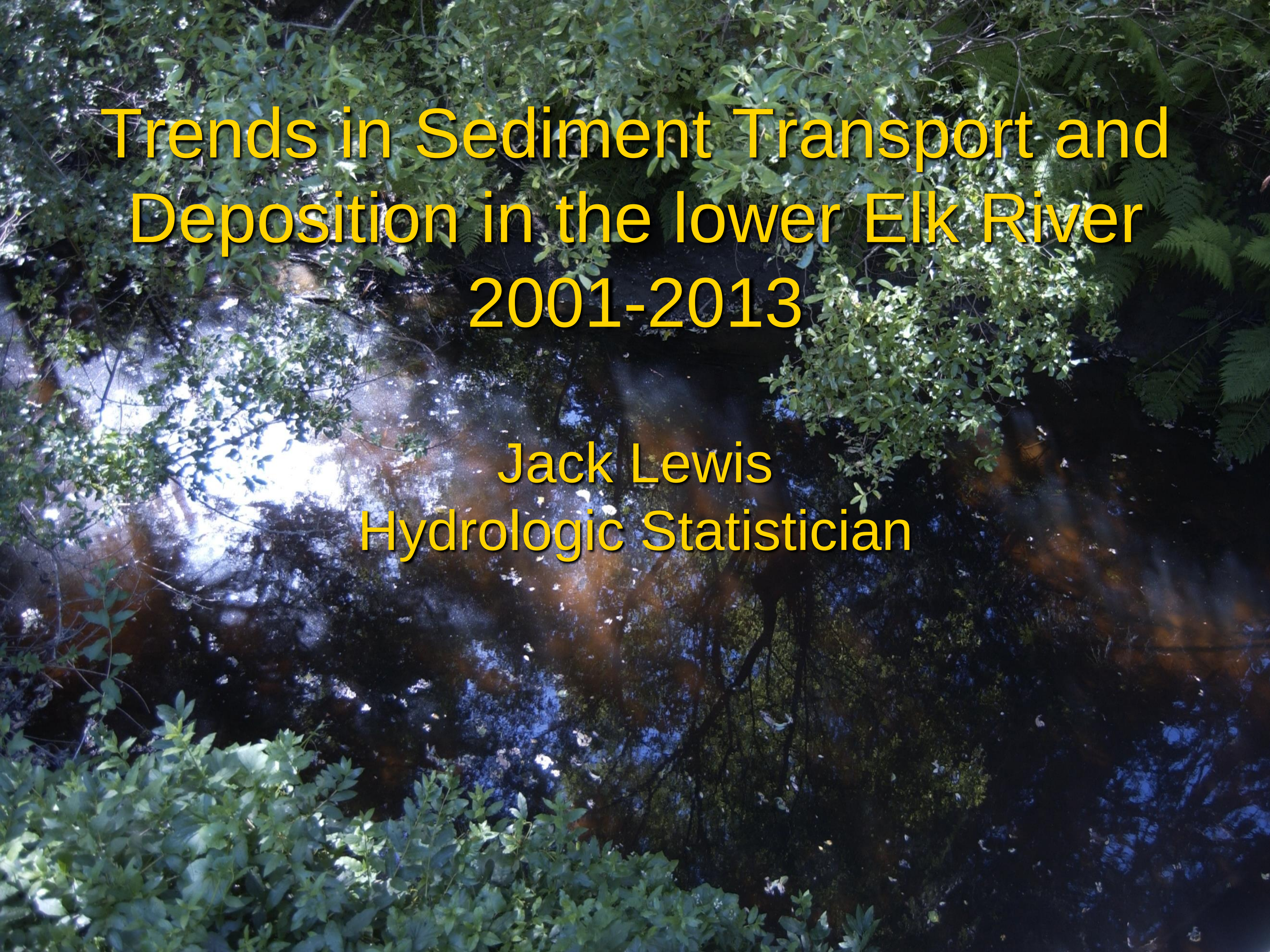
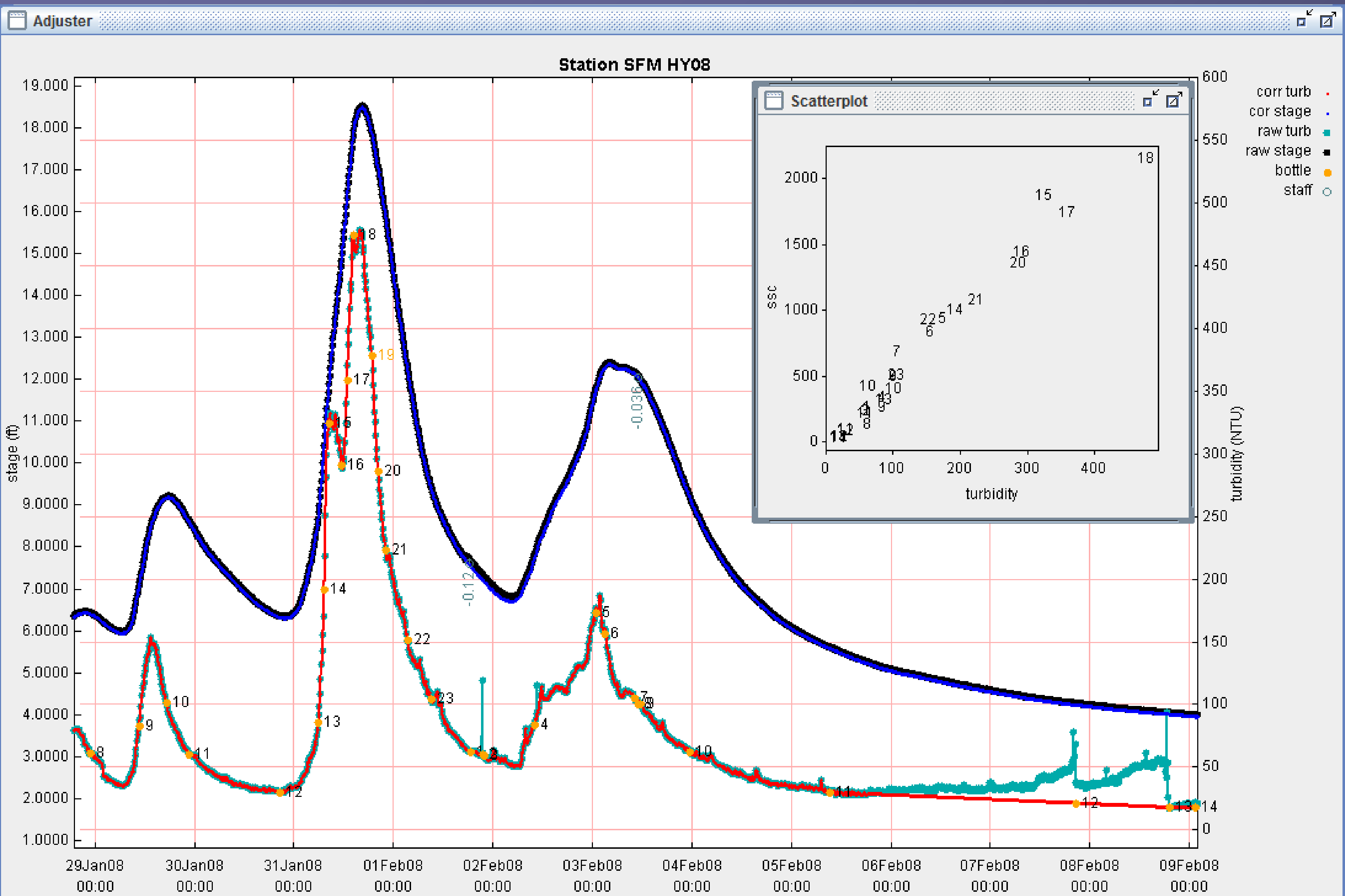
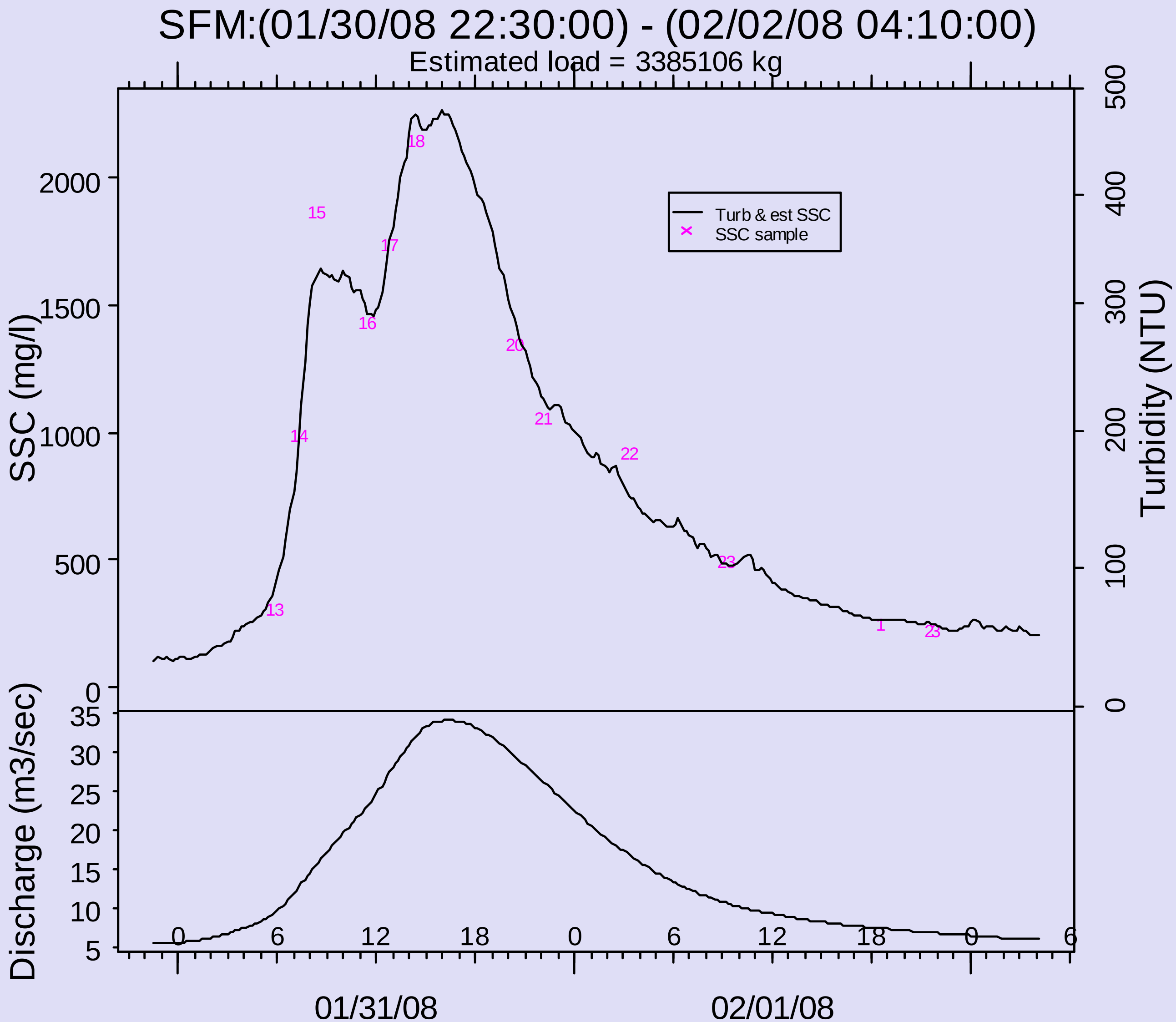


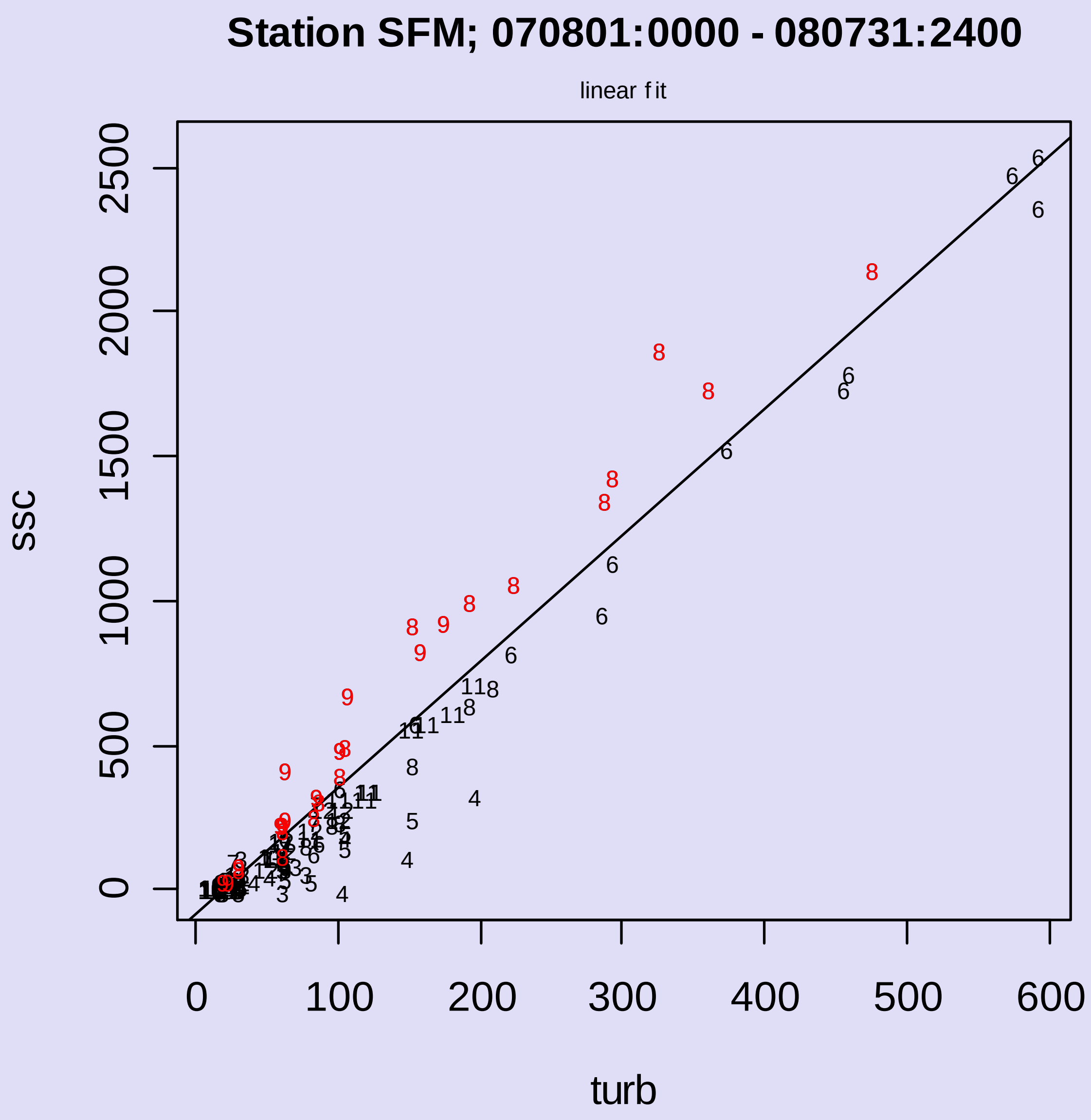
T-probe deployment at station SFM



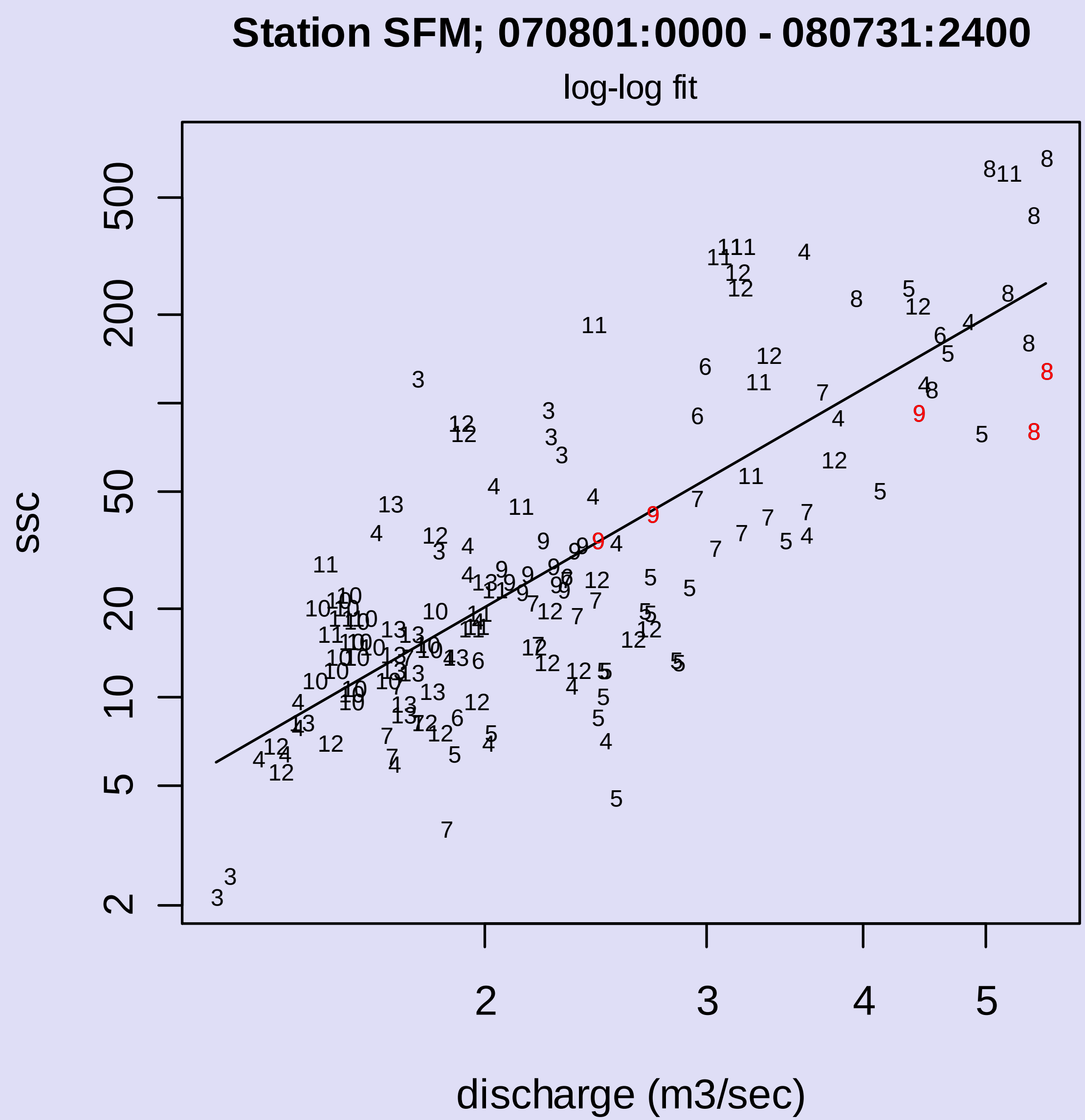
Typical record of a couple of storm events; some data cleanup was needed. Explain TTS.



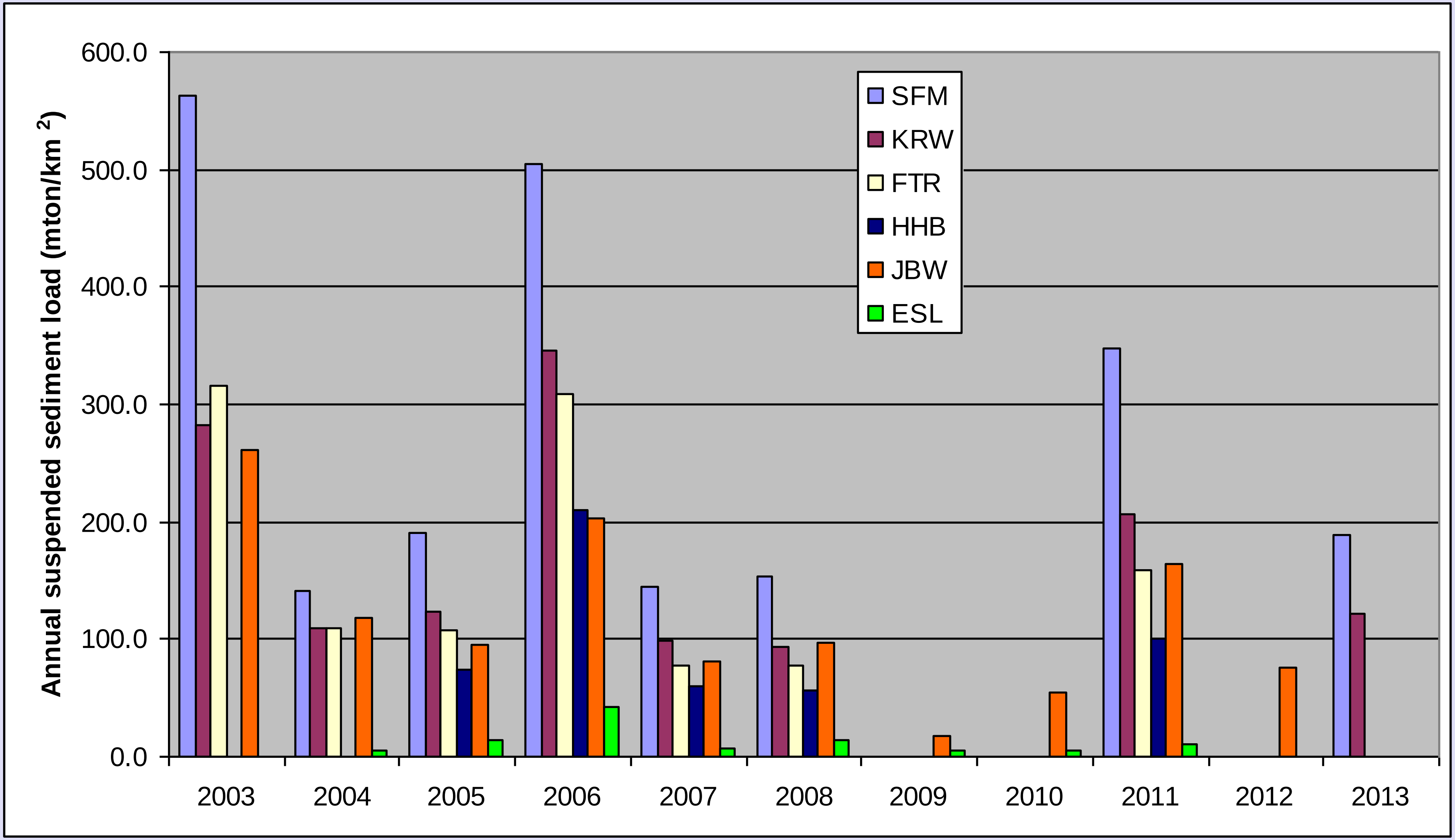
With the regression you can convert turbidity to SSC. Here they are represented with one curve and two scales. The load is the sum of products of discharge and SSC for each 10-min interval.



The annual load is estimated by adding the storm loads and the interstorm loads. The interstorm loads are estimated using an annual regression of SSC on turbidity



For interstorm periods when the turbidity is messed up and too difficult to reconstruct, we use a regression of SSC on discharge, ie. a standard sediment rating curve



Annual suspended sediment load (mton/km 2)
600.0
500.0
400.0
300.0
200.0
100.0
0.0
SFM
KRW
FTR
HHB
JBW
ESL
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

Trend Detection

- Multiple regression and scatterplots
  - Explain as much variation as possible, then evaluate trend
- Responses
  - Storm event peaks
  - Storm event loads
  - Storm event mean SSC = load / flow
  - Instantaneous SSC
- Predictors
  - Same response at another watershed (preferably unmanaged)
  - Another related response at same watershed
  - Rainfall totals and decaying indexes (API)
  - Time: use scatterplots to assess linearity

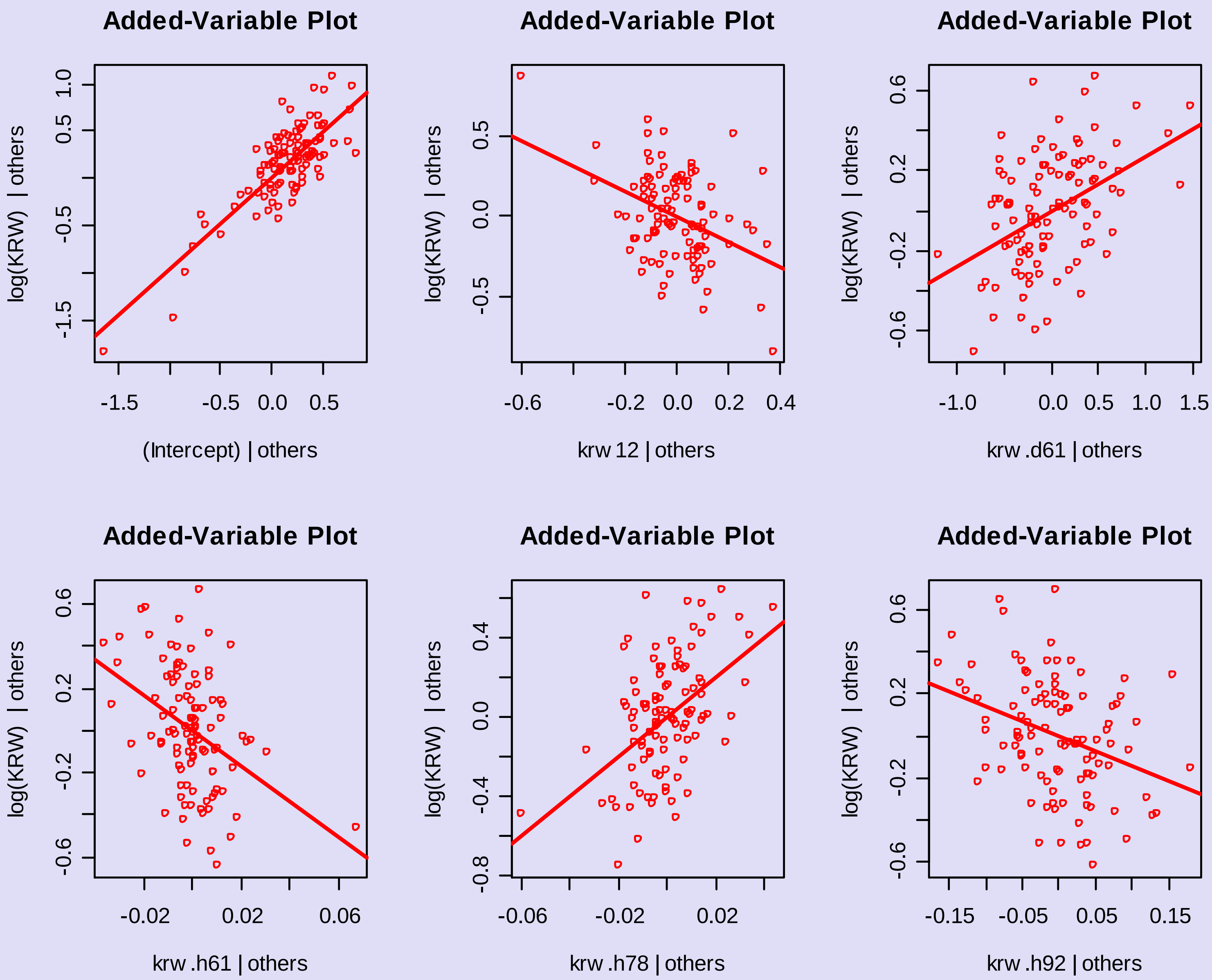
Models for Storm Peak Flow

- Response
  - Logarithm of 6-hr maximum flow
- Predictors
  - Rainfall in the 6, 12, 18, or 24 hrs before peak
  - $API_{k,i} = k\ API_{k,i-1} + P_i$: hourly, daily
    - Half-lives from 1.4 hours to 32 days
  - Up to 5 predictors from all possible subsets
- Variation explained: SFM 51%, KRW 49%

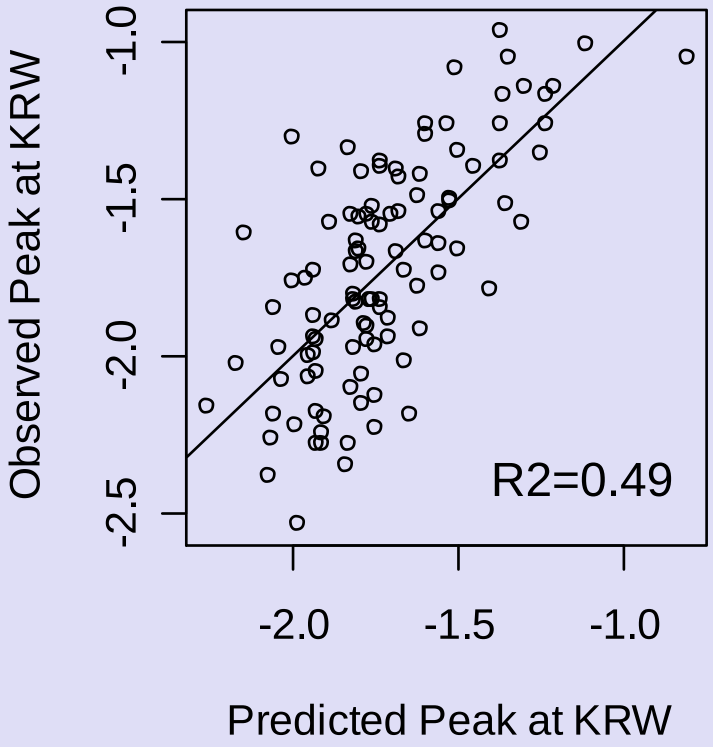
Daily API variables

Variable	Decay rate	Half-life (days)
D61	0.6125	1.41
D71	0.7071	2.00
D78	0.7827	2.83
D84	0.8409	4.00
D88	0.8847	5.66
D92	0.9170	8.00
D94	0.9406	11.3
D96	0.9576	16.0
D97	0.9698	22.6
D98	0.9786	32.0

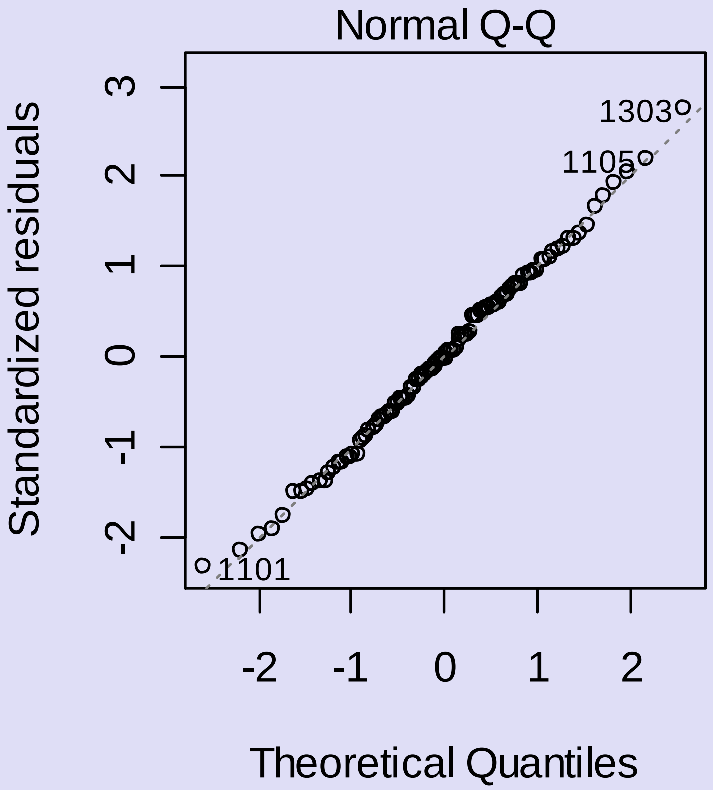
There is an analogous set of variables at an hourly time scale



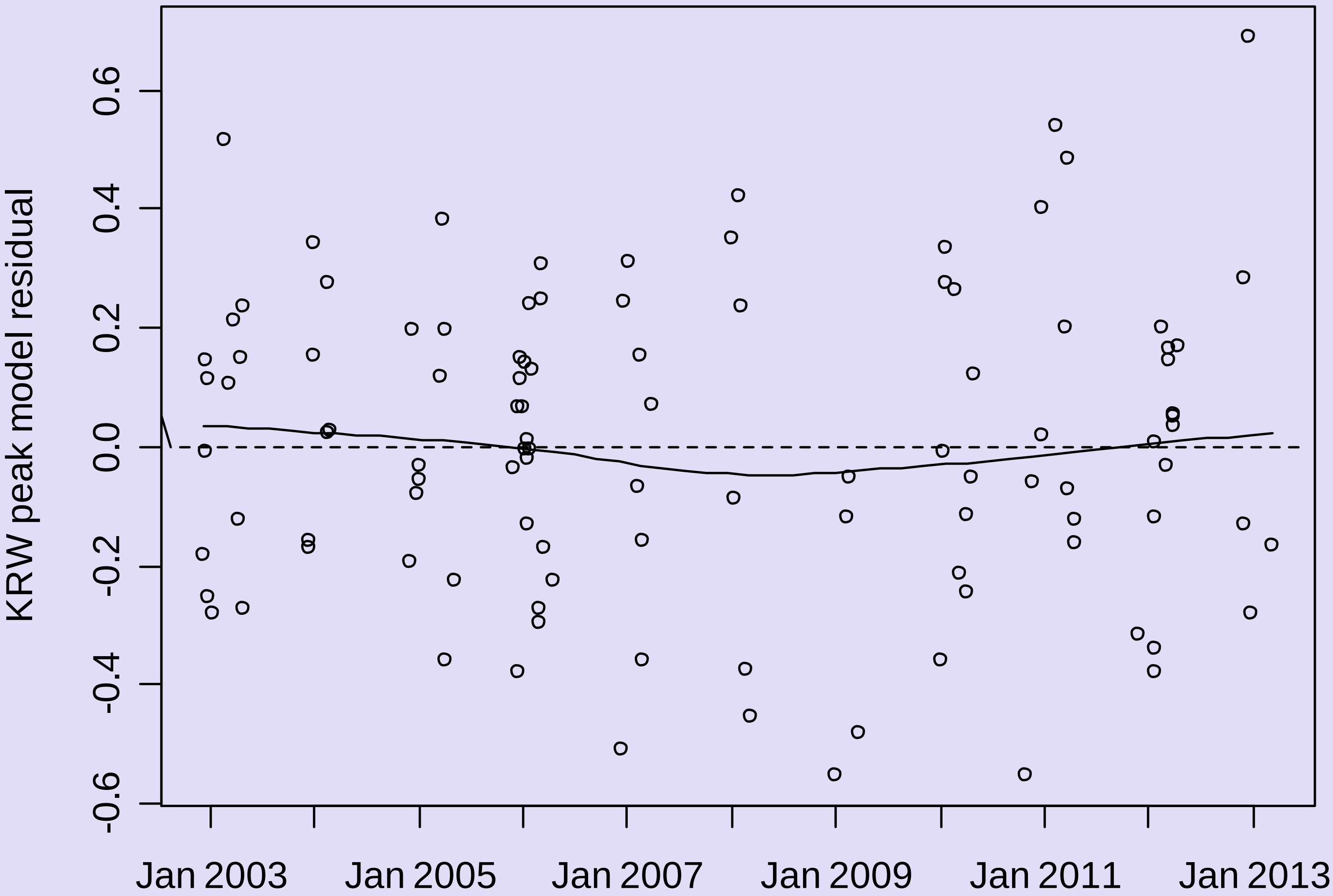
These show each individuals incremental contribution to a multivariate model after accounting for the influence of the other variables



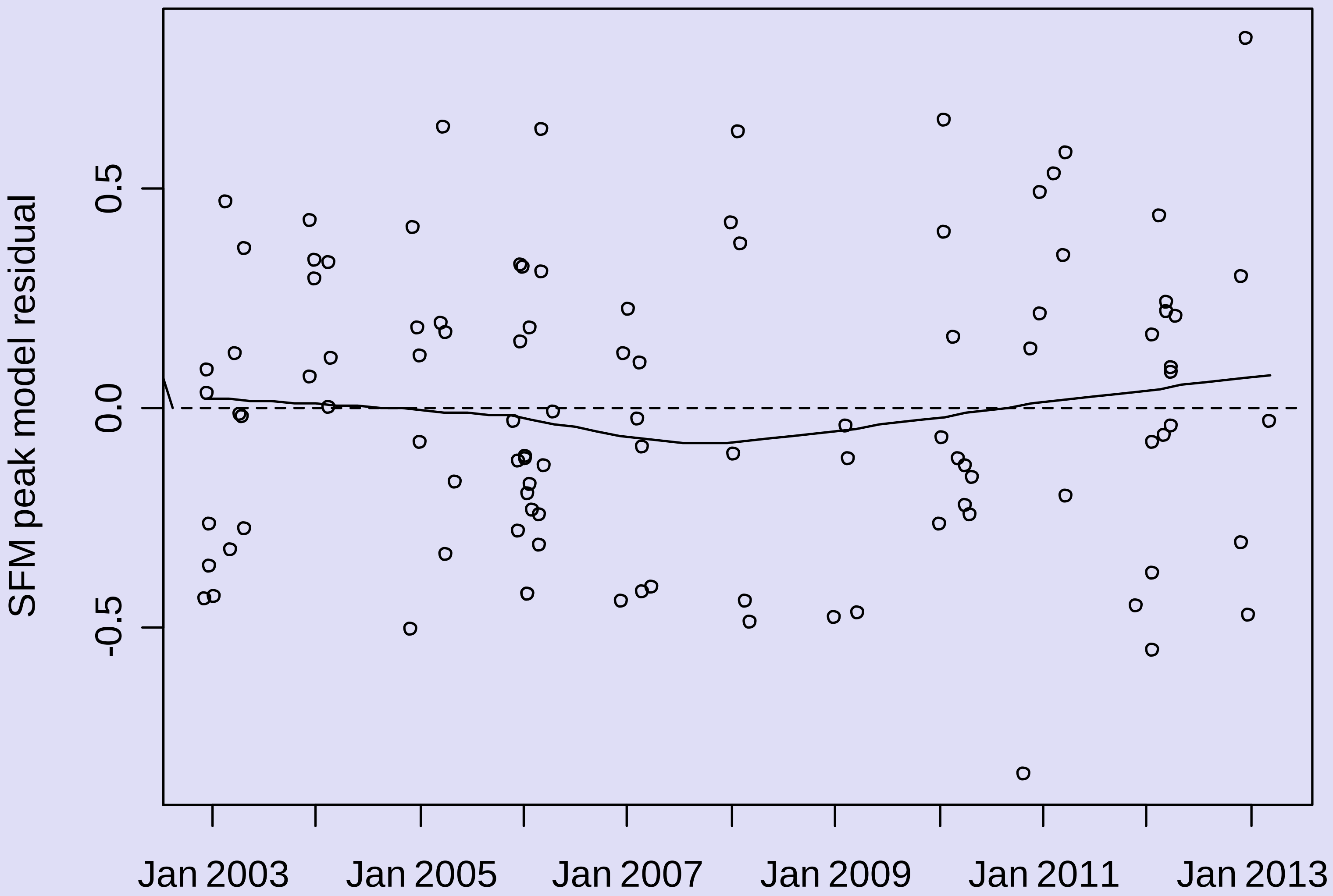
R2=0.49
Observed Peak at KRW
Predicted Peak at KRW
-1.0
-1.5
-2.0
-2.5
-2.0
-1.5
-1.0



Normal Q-Q
Standardized residuals
Theoretical Quantiles
1303
1105
1101
3
2
1
0
-1
-2
-2
-1
0
1
2



No trend. Good news or bad? Current management is not reducing peaks by growing more forest Nor is it increasing them.

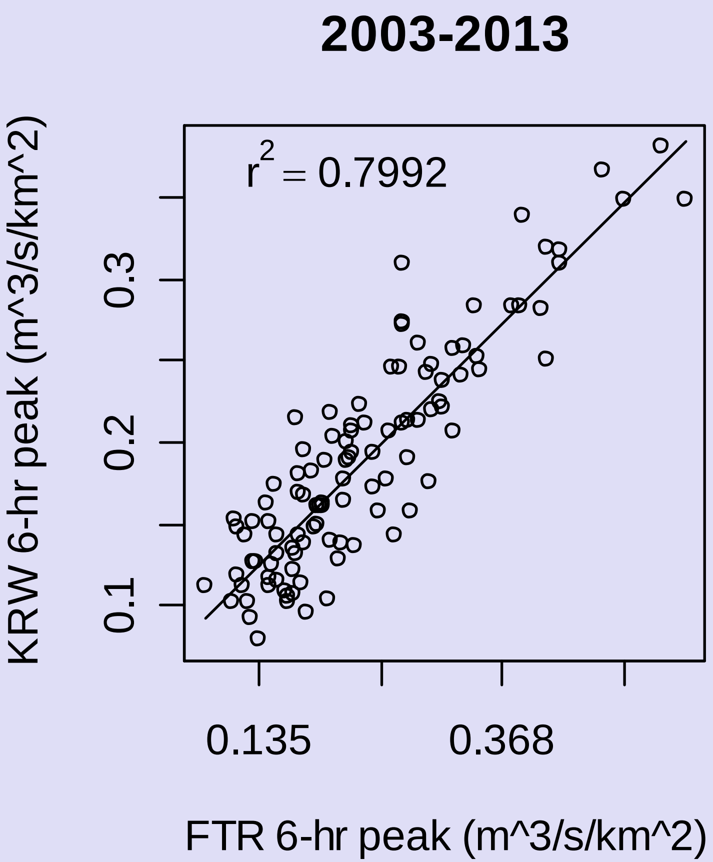


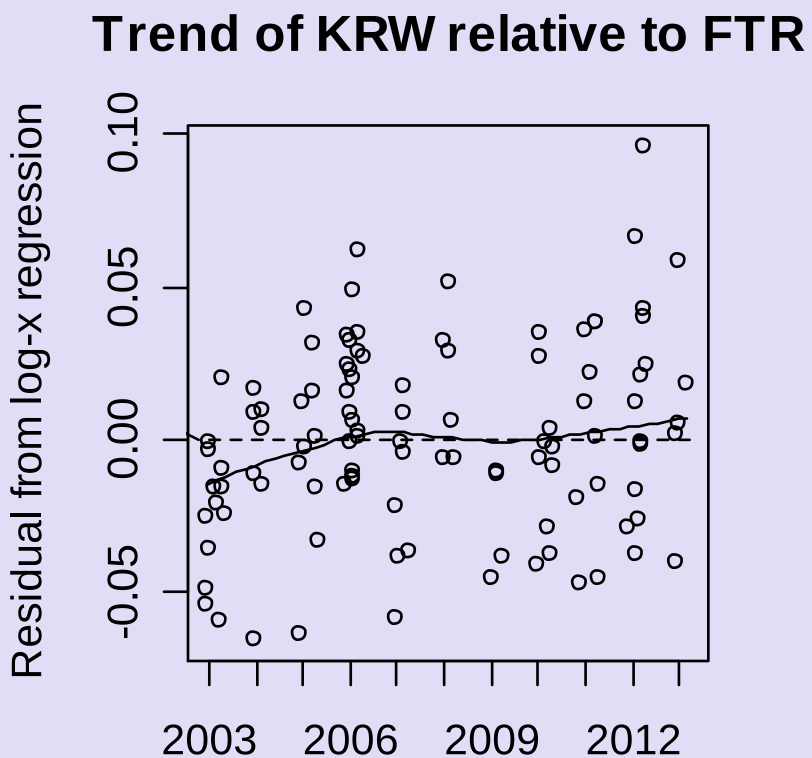
SFM peak model residual
0.5
0.0
-0.5
Jan 2003
Jan 2005
Jan 2007
Jan 2009
Jan 2011
Jan 2013

Paired watershed models for storm peaks

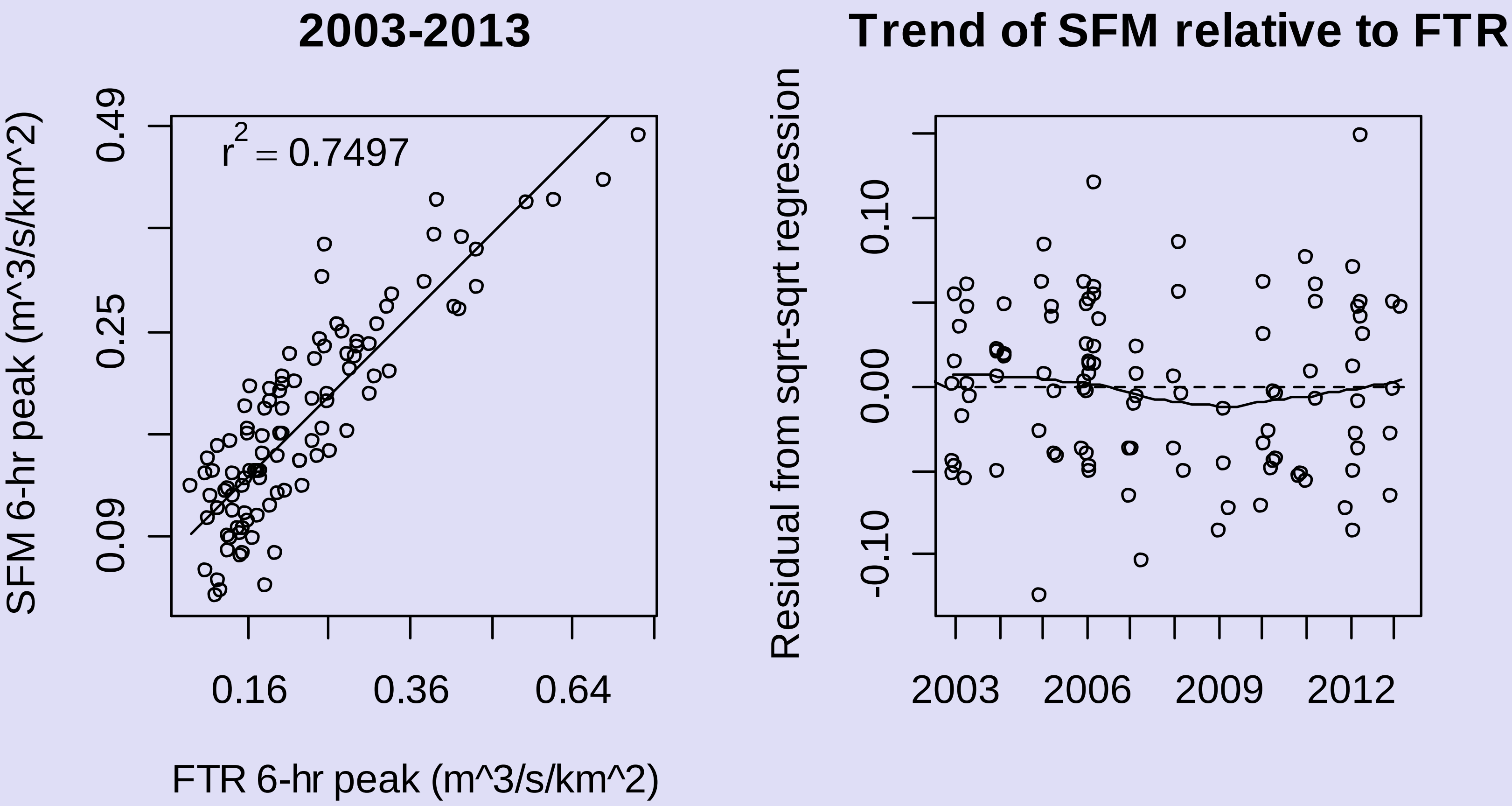
- Limited utility without a control watershed for the period of record
- Best pairings were KRW:SFM and FTR:HHB
- No significant trends identified

Paired watershed analysis: KRW vs FTR



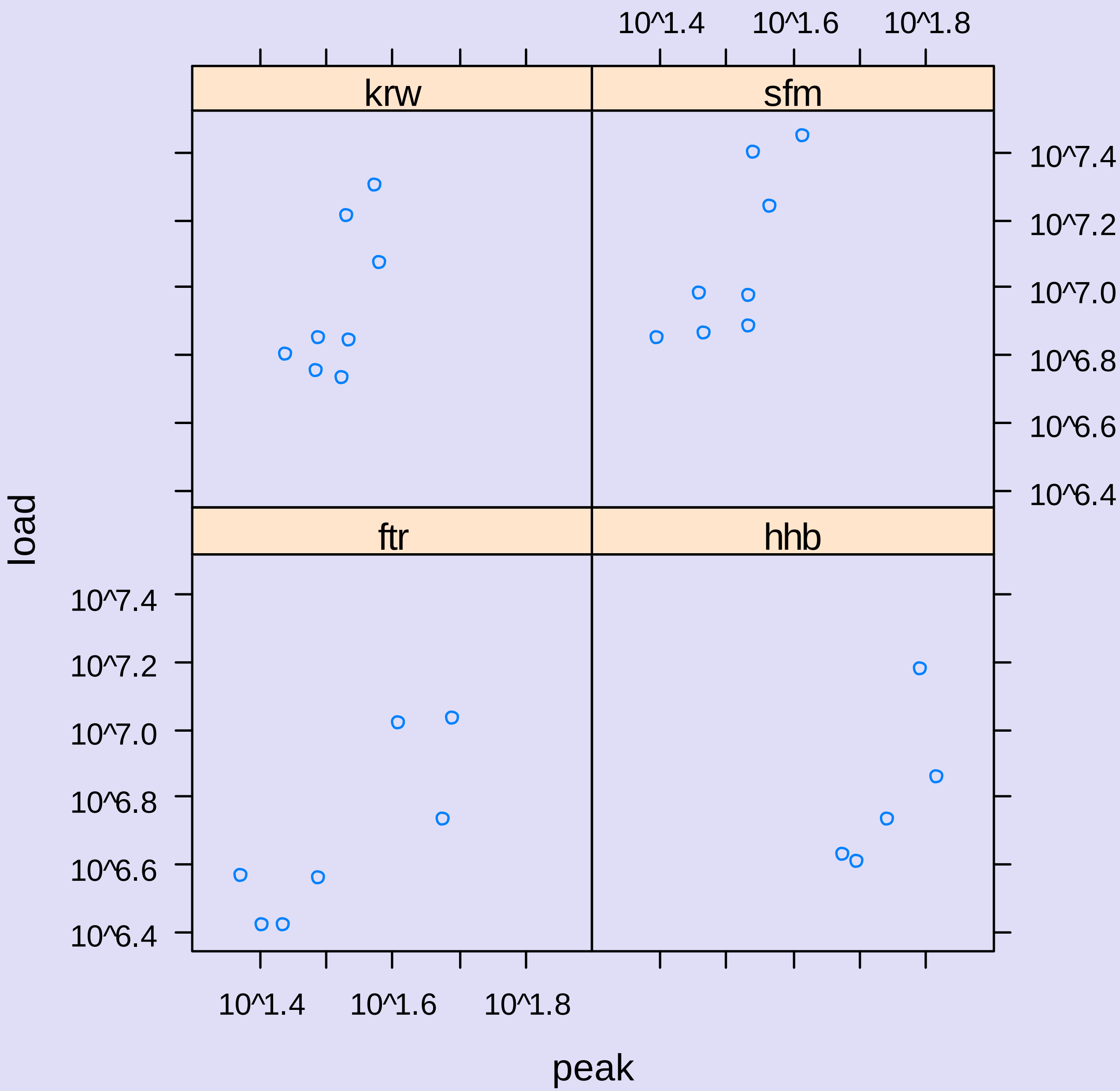


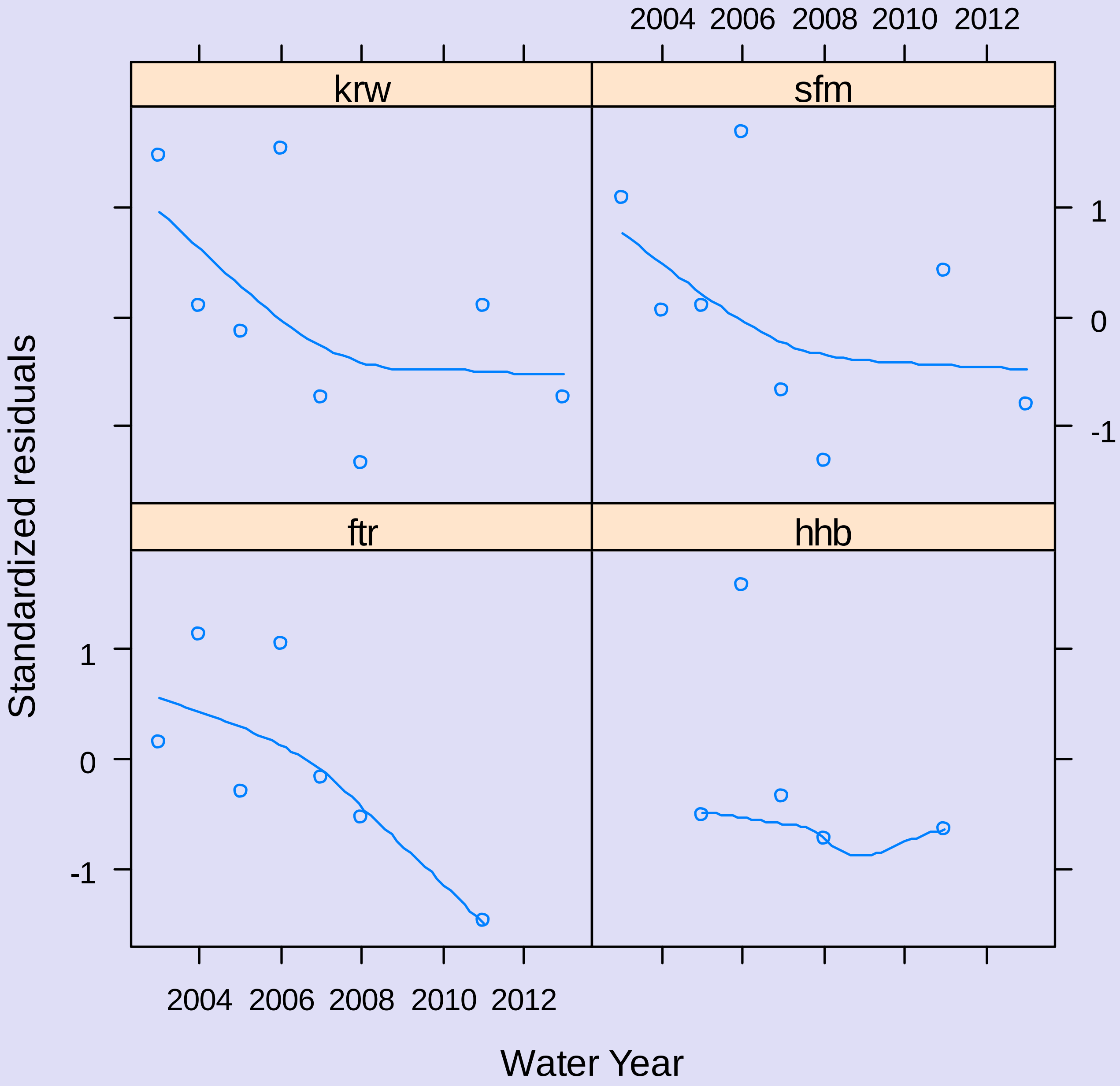
Paired watershed analysis: SFM vs FTR



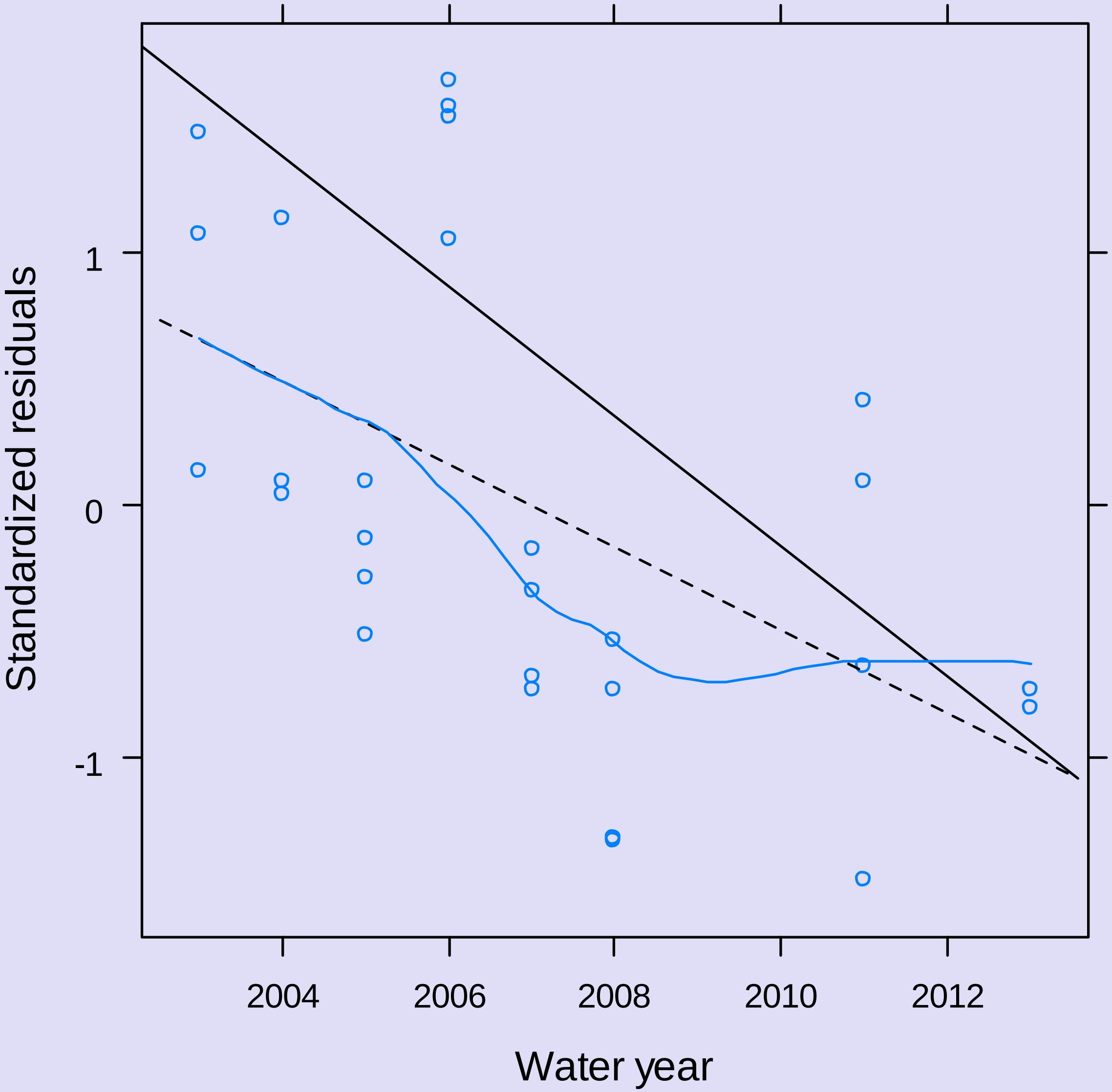
Exercise: Mixed-effects Model for Annual Event Load

- Like a regression model, but predictors are classified as fixed or random effects
  - No coefficients for random effects, only a variance
  - Appropriate for grouped data when you're not interested in the specific effects of each group
- Response
  - Logarithm of annual load
- Fixed effects
  - Logarithm of annual peak flow
  - Time
- Random effects
  - Watershed

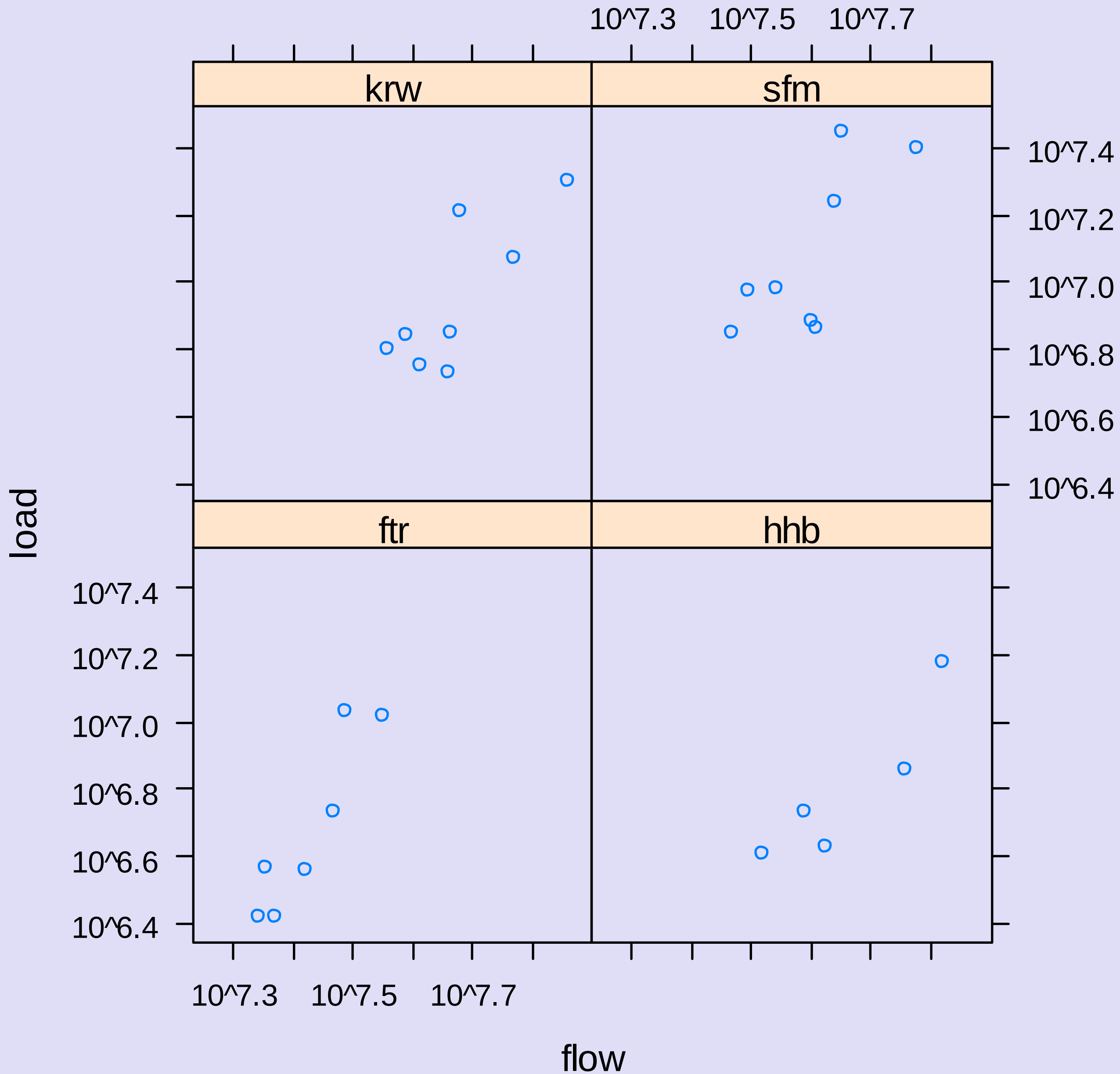

krw
sfm
ftr
hhb
load
peak
10^1.4
10^1.6
10^1.8
10^6.4
10^6.6
10^6.8
10^7.0
10^7.2
10^7.4

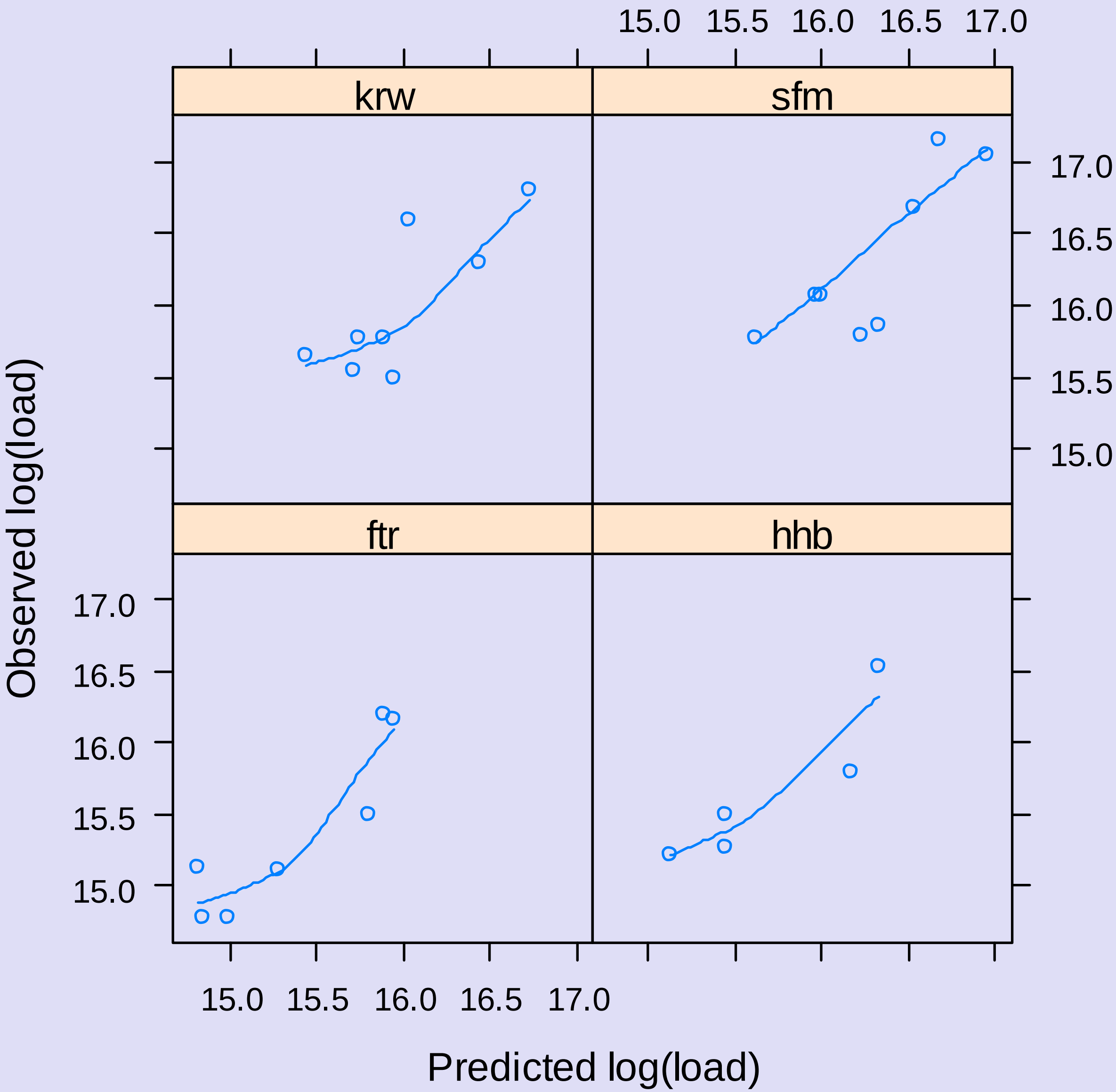


krw
sfm
ftr
hhb
2004
2006
2008
2010
2012
1
0
-1
Standardized residuals
Water Year

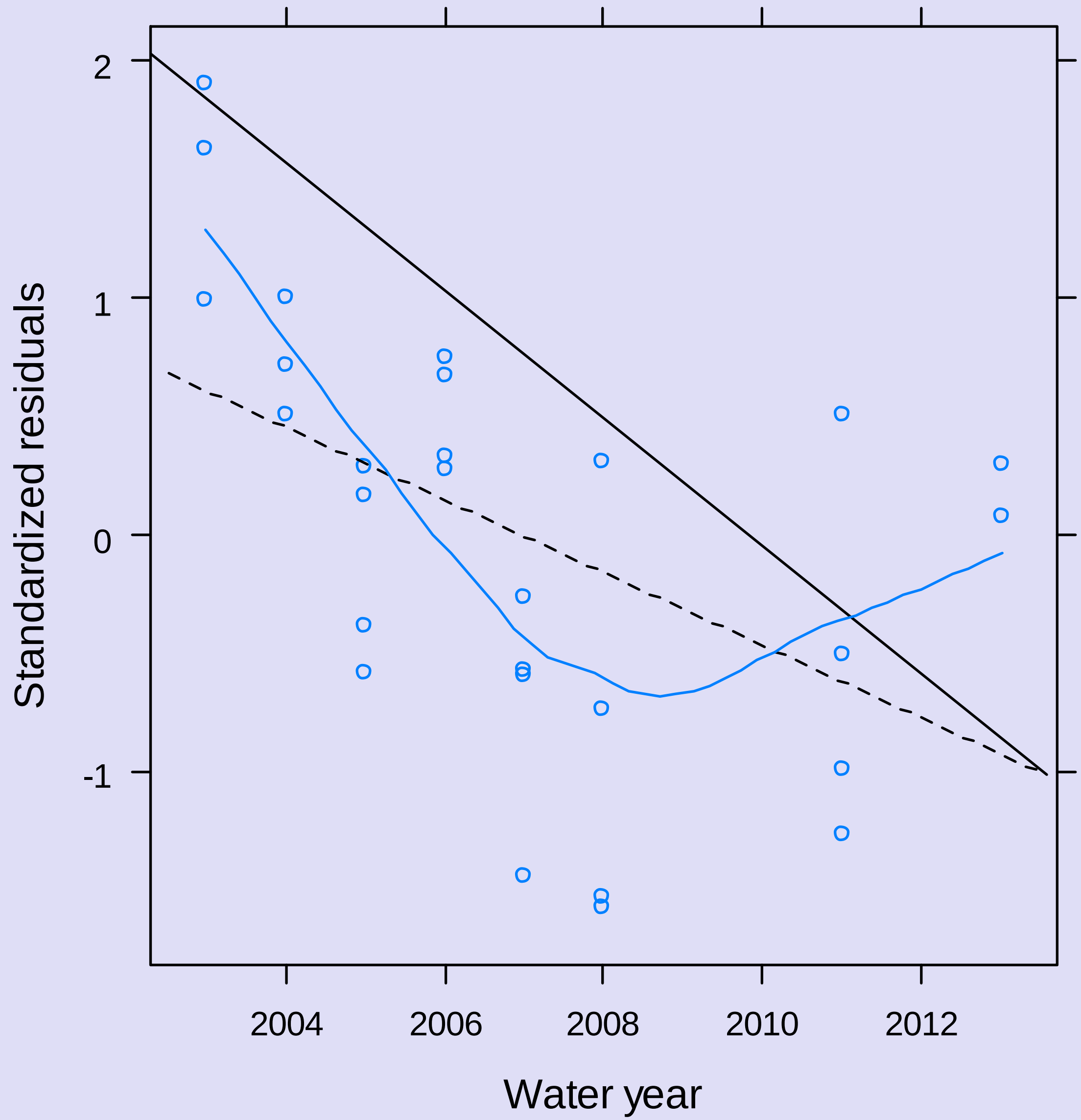


Model: log(load) ~ log(peak); but maybe this trend can be explained by another variable that is not management-related

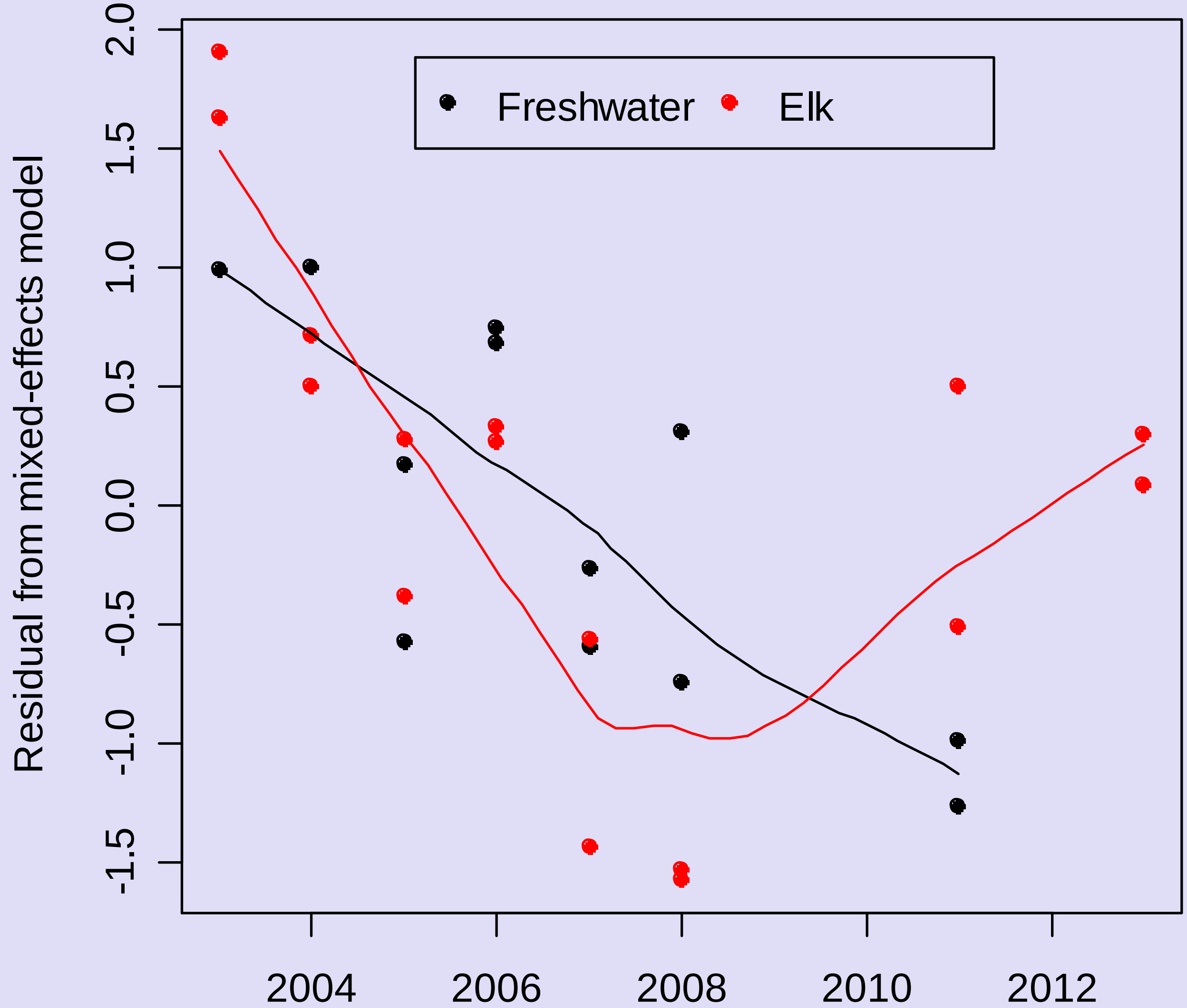

krw
sfm
ftr
hhb
10^7.3
10^7.5
10^7.7
10^6.4
10^6.6
10^6.8
10^7.0
10^7.2
10^7.4
load
flow



krw
sfm
ftr
hhb
15.0
15.5
16.0
16.5
17.0
Observed log(load)
Predicted log(load)

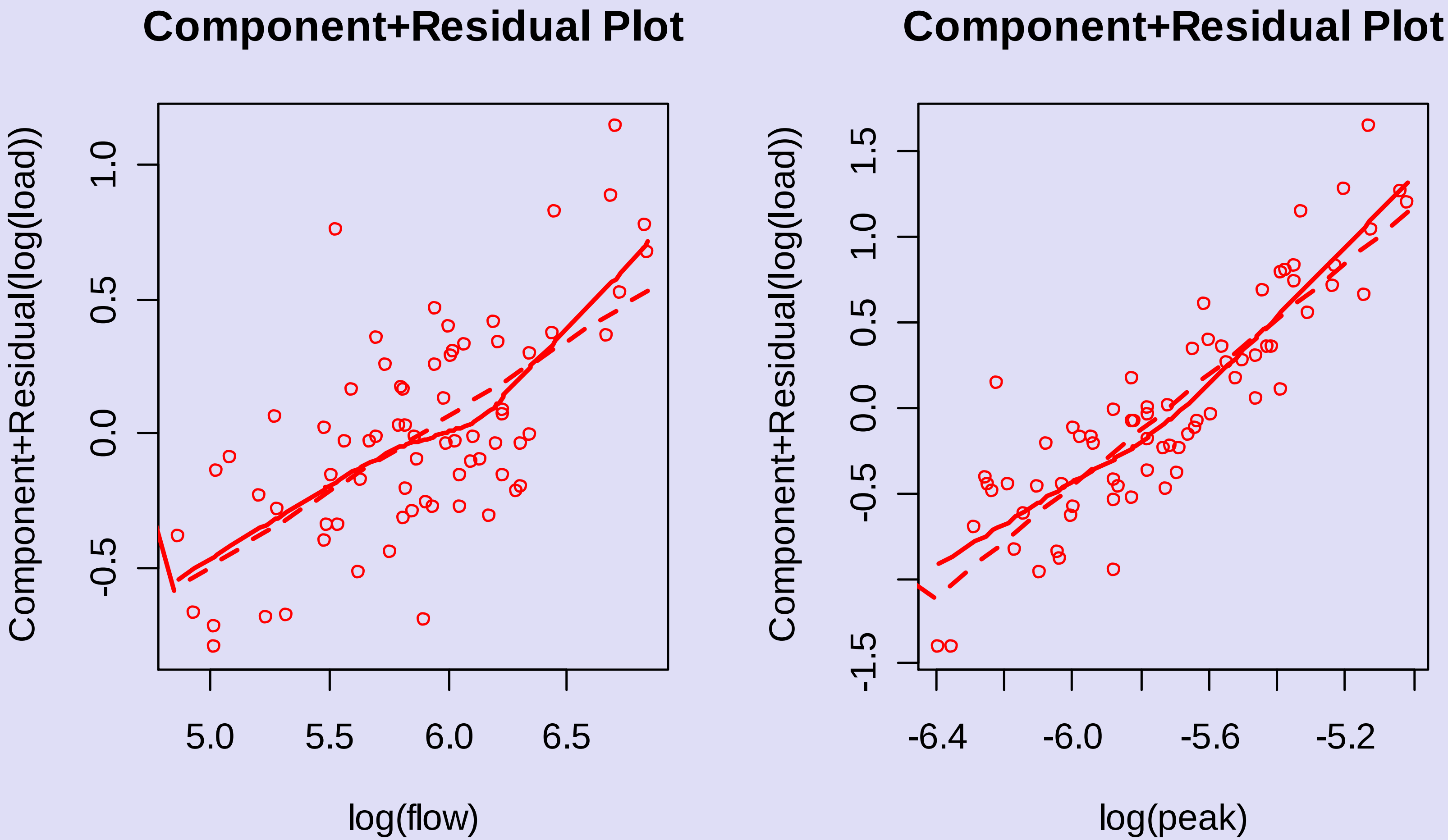


Model log(load) ~ log(peak) + log(flow)


Freshwater
Elk
Residual from mixed-effects model
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
2004
2006
2008
2010
2012

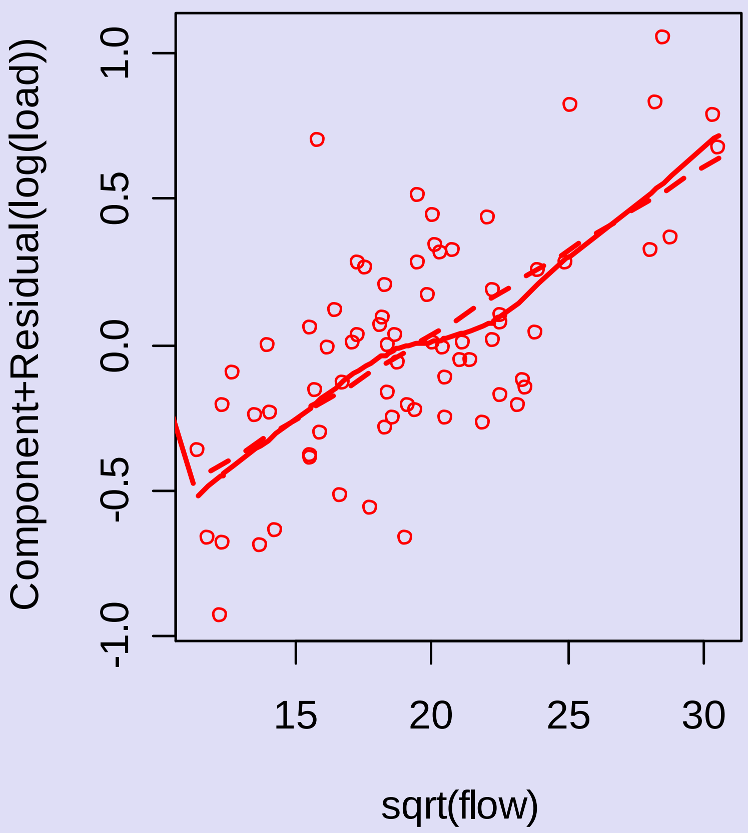
Regression Models for Storm Event Load

- Response
  - Logarithm of storm event load
- Predictors
  - Storm event flow volume (log or sqrt)
  - Storm event peak flow (log or sqrt)
- Residuals are not quite independent
  - Serial autocorrelation must be modeled

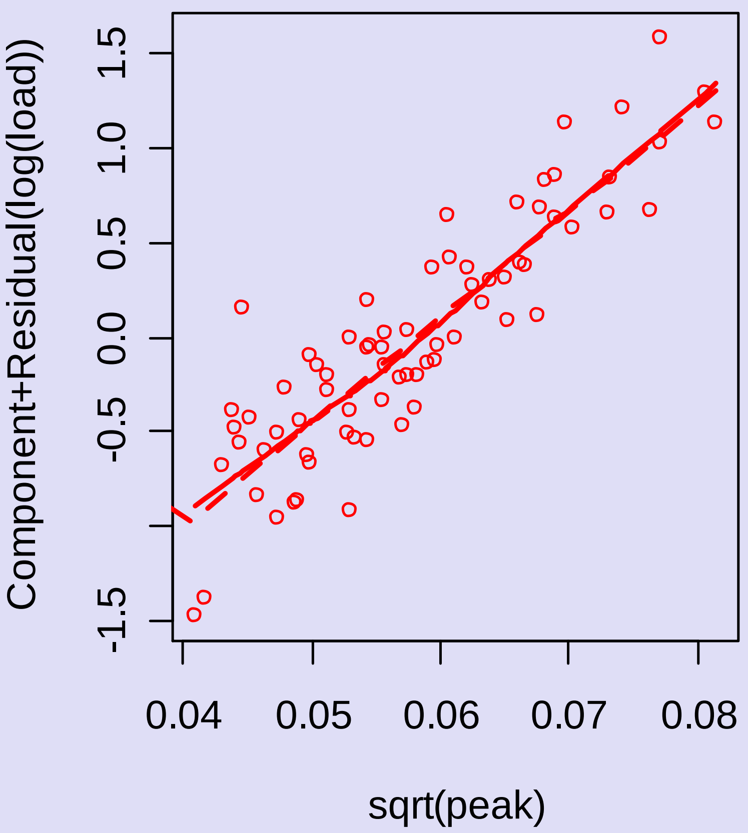


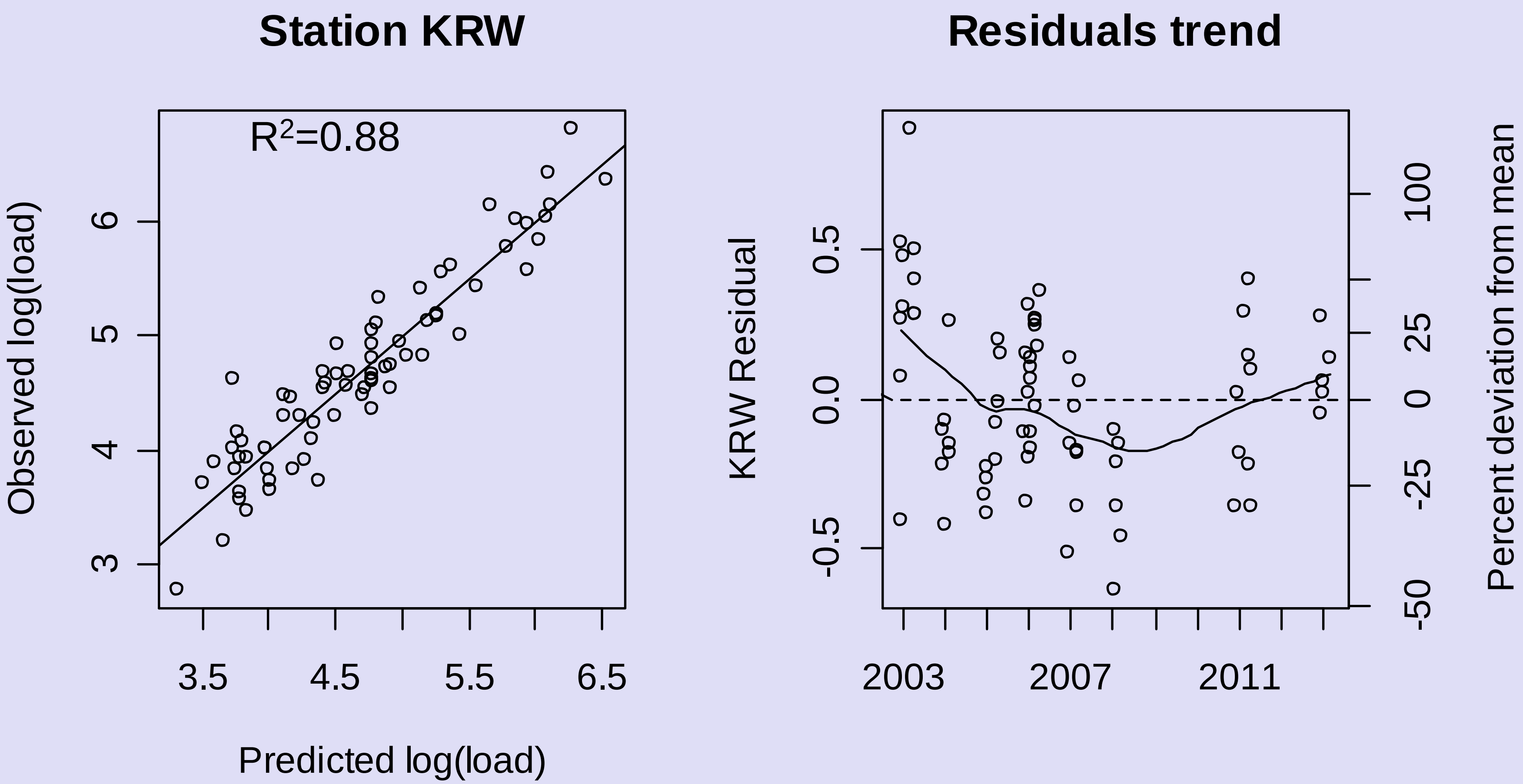
Shows that the influence of log(flow) and log(peak) are almost linear

Component+Residual Plot

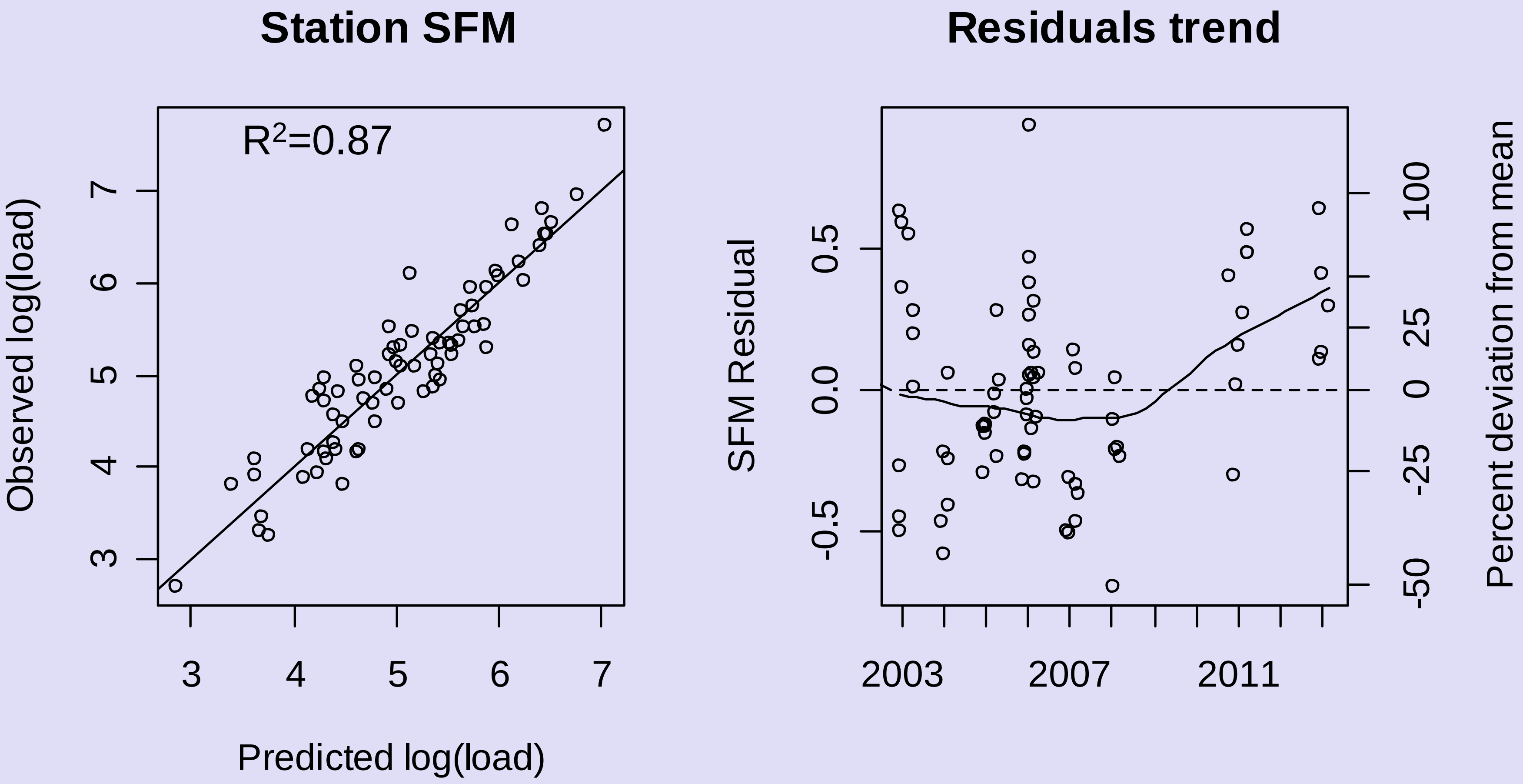


Component+Residual Plot





Station KRW
R²=0.88
Observed log(load)
Predicted log(load)
3.5
4.5
5.5
6.5
3
4
5
6
Residuals trend
KRW Residual
Percent deviation from mean
-0.5
0.0
0.5
-50
-25
0
25
100
2003
2007
2011

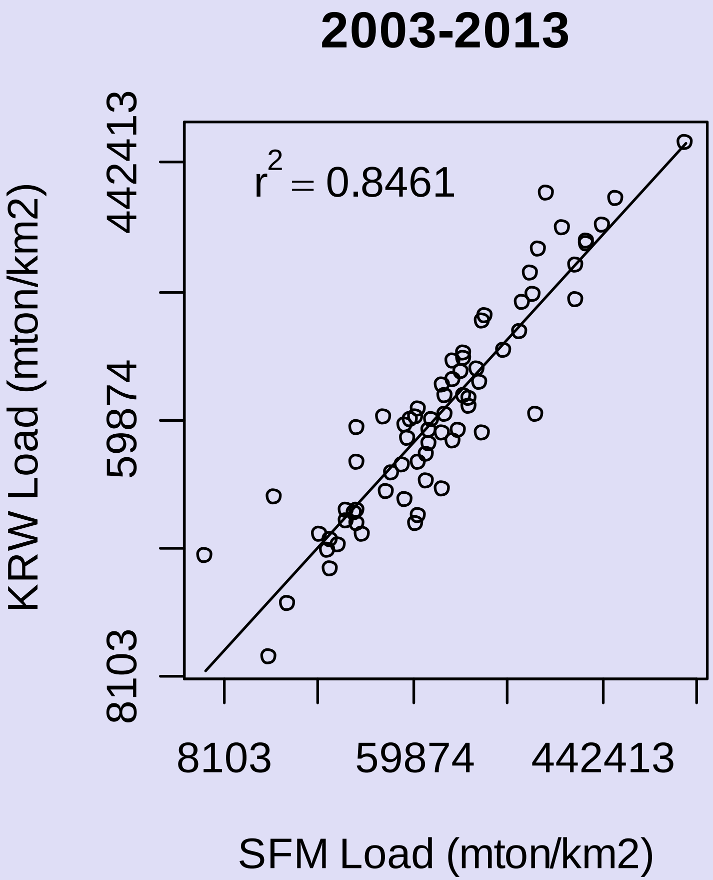

Station SFM
R²=0.87
Observed log(load)
Predicted log(load)
3
4
5
6
7
Residuals trend
SFM Residual
Percent deviation from mean
0.5
0.0
-0.5
100
25
0
-25
-50
2003
2007
2011

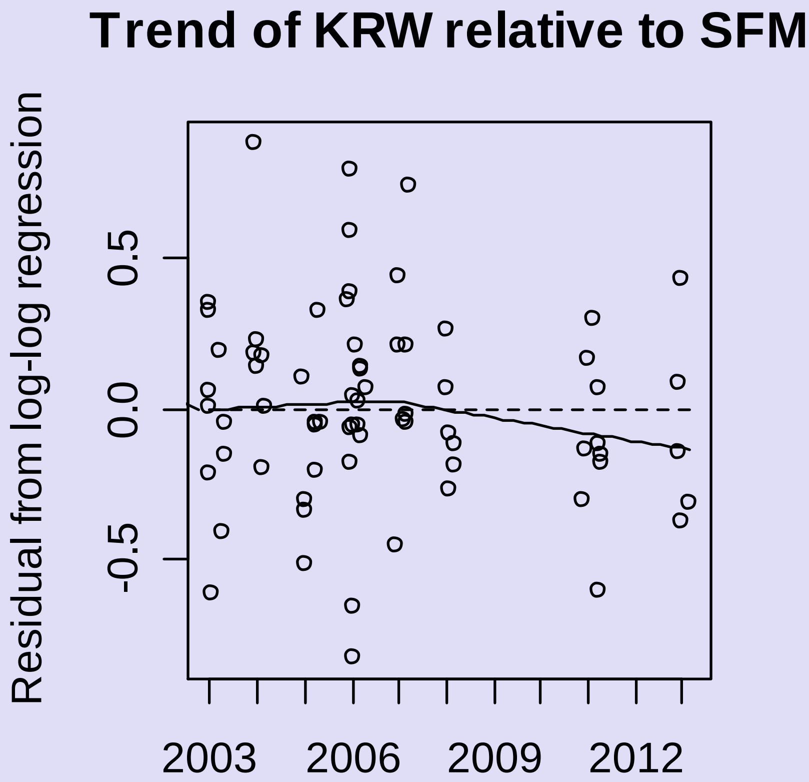
Significance tests for trend in storm event load

Station	Years	Flow variable	Peak variable	Adjusted R^2	Error model	Trend p-value
SFM	2003-2013	Log(flow)	Log(peak)	0.869	AR(2)	0.2045
	2006-2008	Log(flow)	Log(peak)	0.884	CAR(1)	0.3569
	2008-2013	Log(flow)	Log(peak)	0.881	IID	0.0027++
KRW	2003-2013	$flow^{0.5}$	$peak^{0.5}$	0.877	AR(3)	0.6798
	2006-2008	$flow^{0.5}$	$peak^{0.5}$	0.958	IID	0.0004--
	2008-2013	$flow^{0.5}$	$peak^{0.5}$	0.920	IID	0.0071+

These r^2 are before time was added to the models.

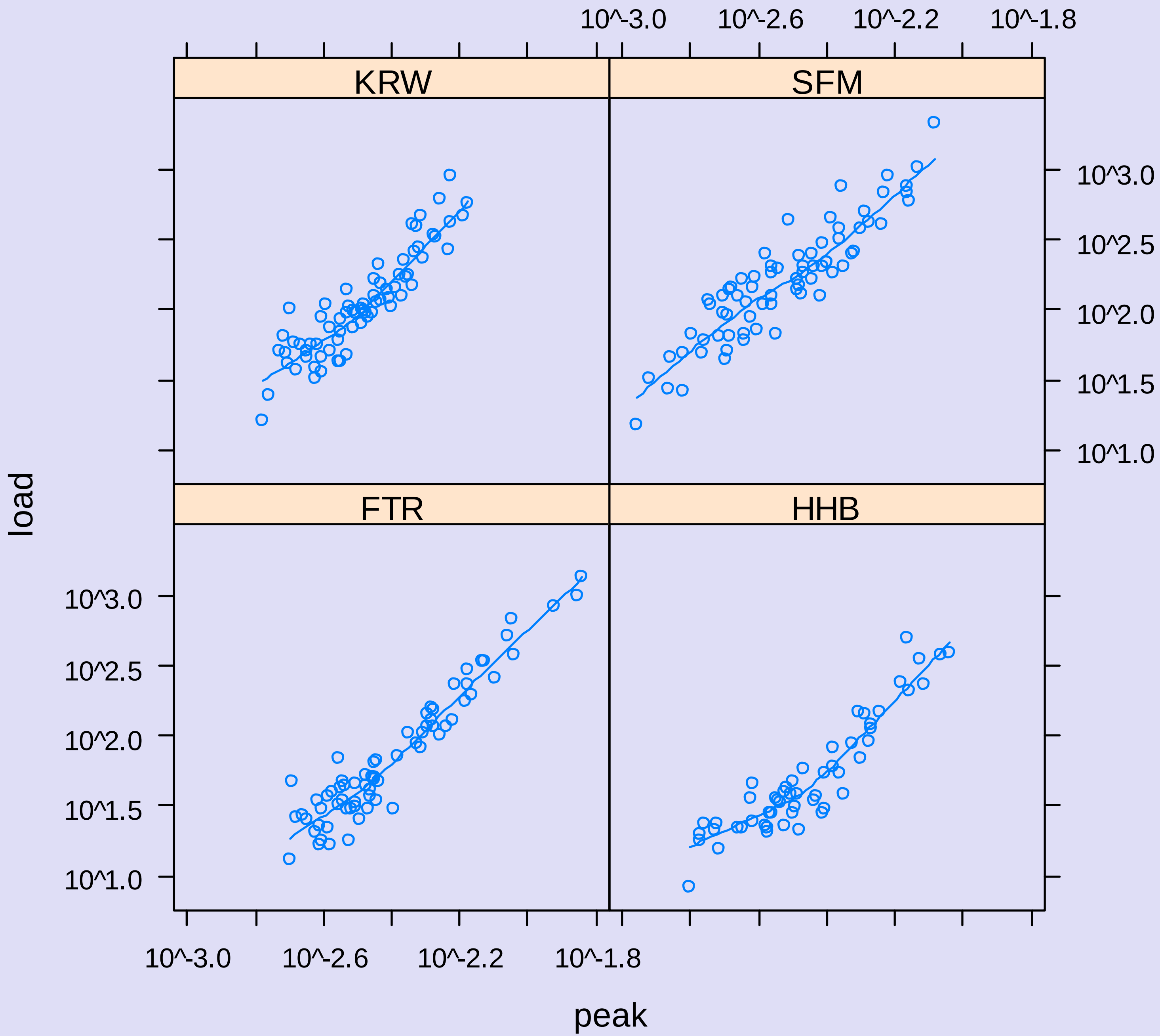
Simple paired watershed model



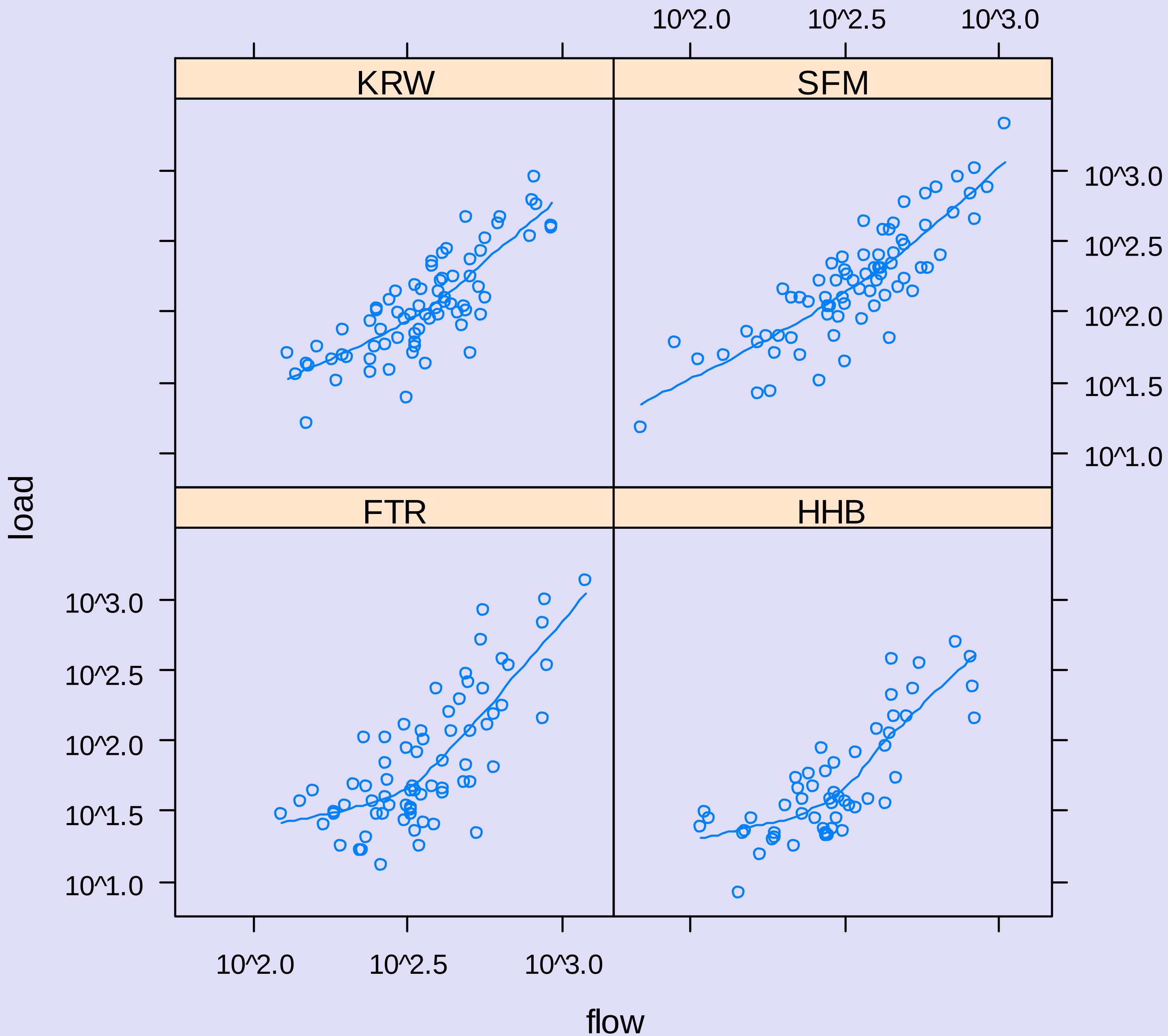


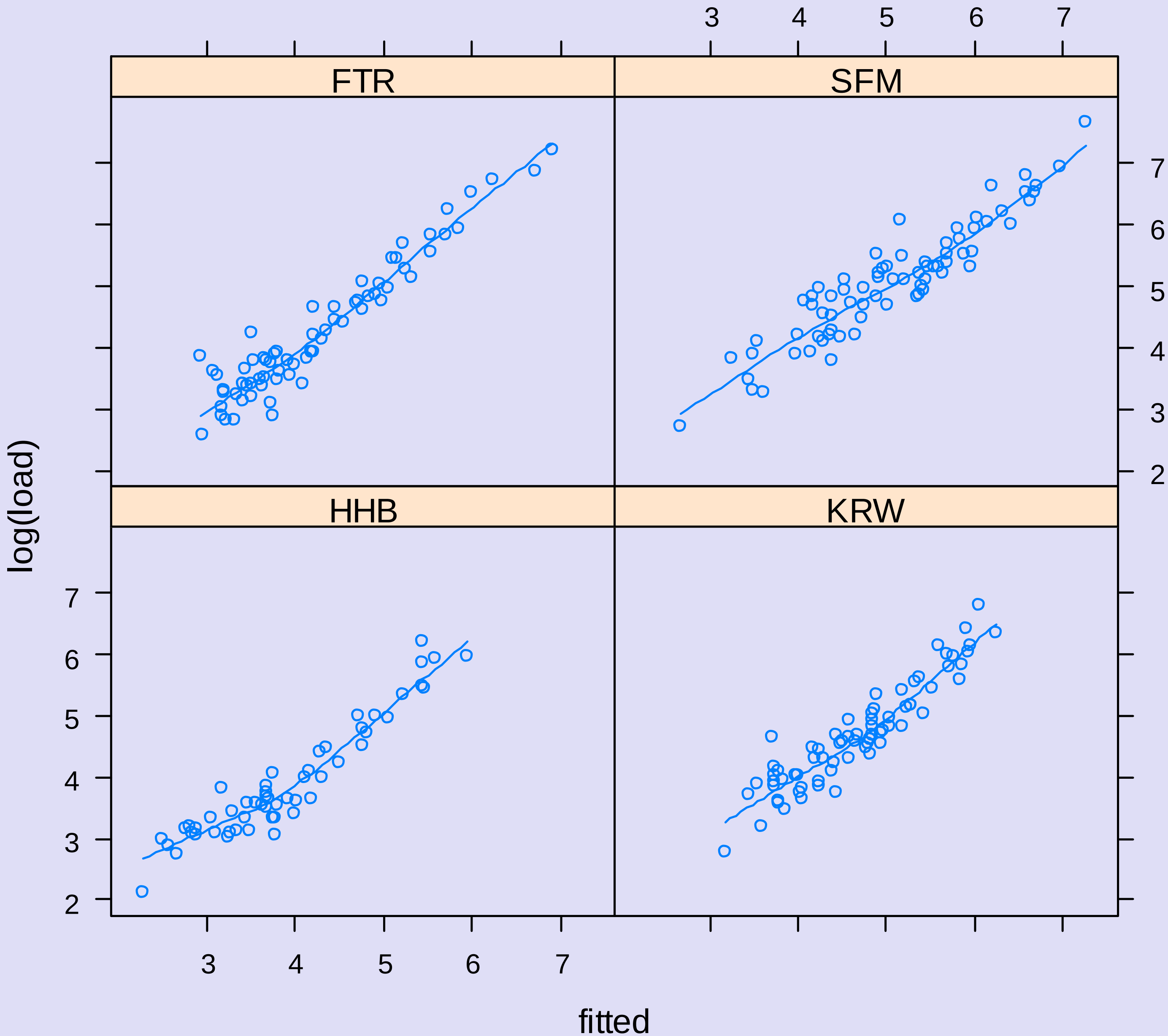
Mixed-effects Model for Storm Event Load

- Response
  - Logarithm of annual load
- Fixed effects
  - Logarithm of annual peak flow
  - Logarithm of annual flow volume
  - Time
- Random effects
  - Watershed

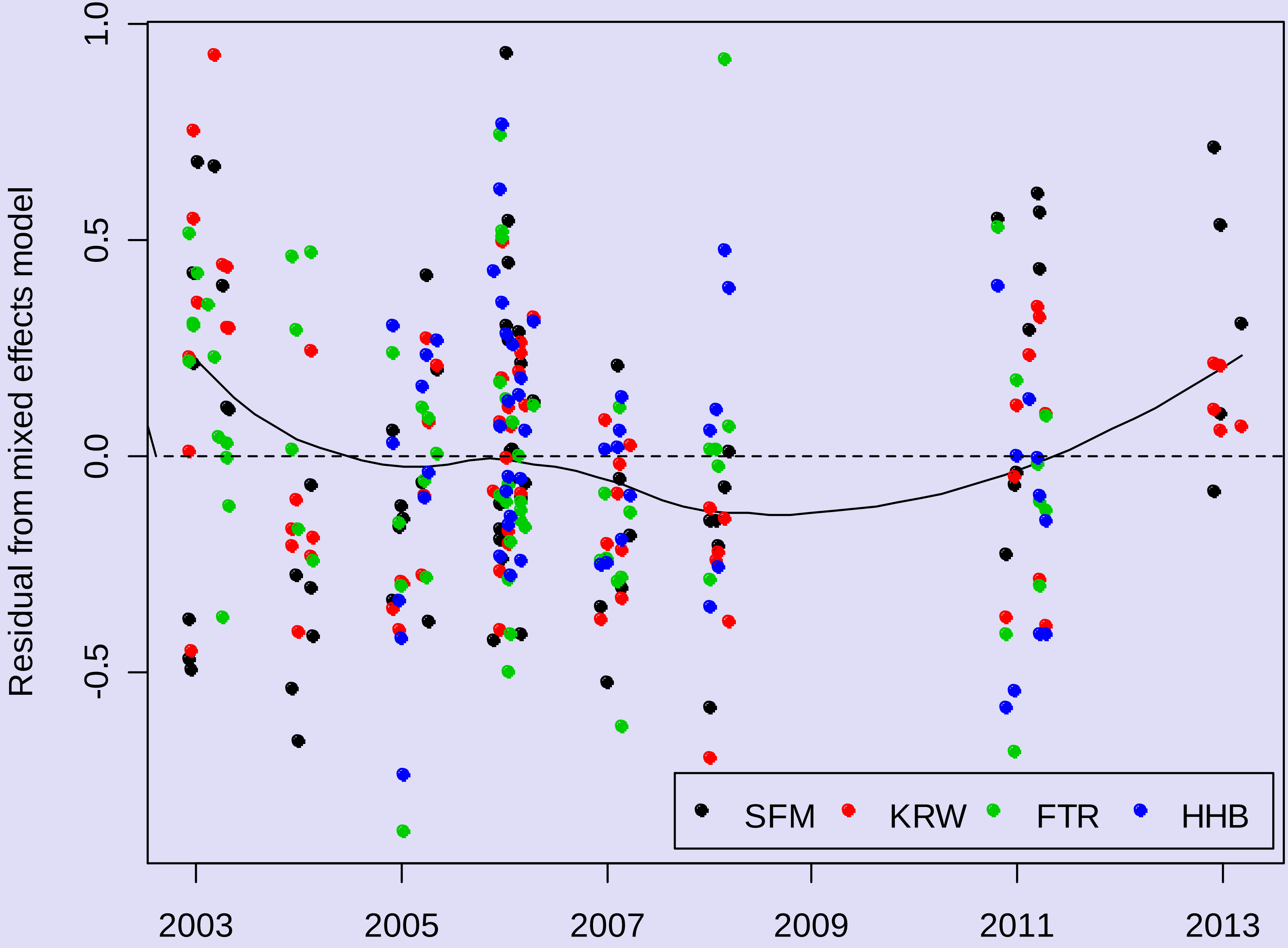


KRW
SFM
FTR
HHB
load
peak
10^-3.0
10^-2.6
10^-2.2
10^-1.8
10^1.0
10^1.5
10^2.0
10^2.5
10^3.0

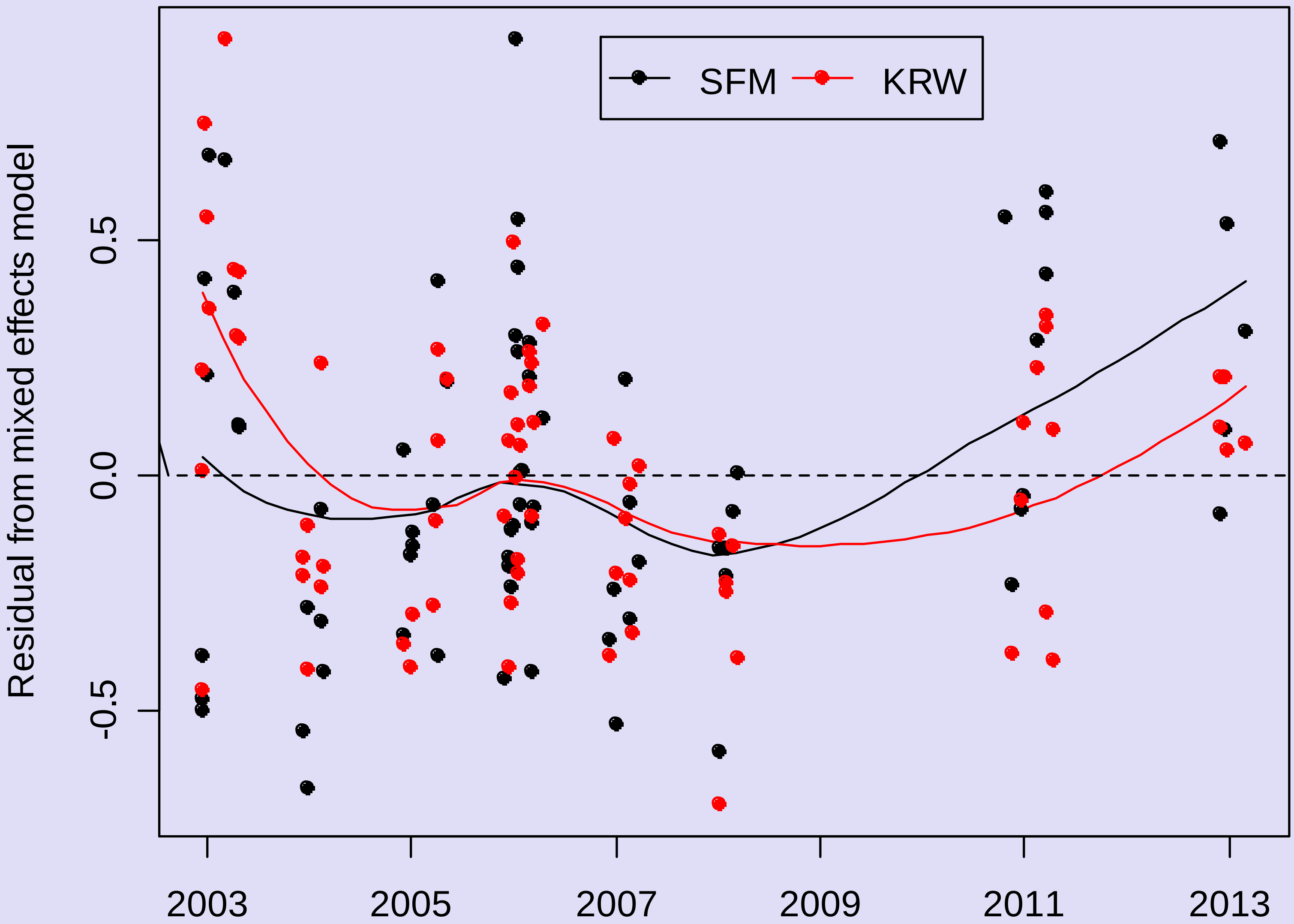

KRW
SFM
FTR
HHB
10^1.0
10^1.5
10^2.0
10^2.5
10^3.0
10^2.0
10^2.5
10^3.0
load
flow



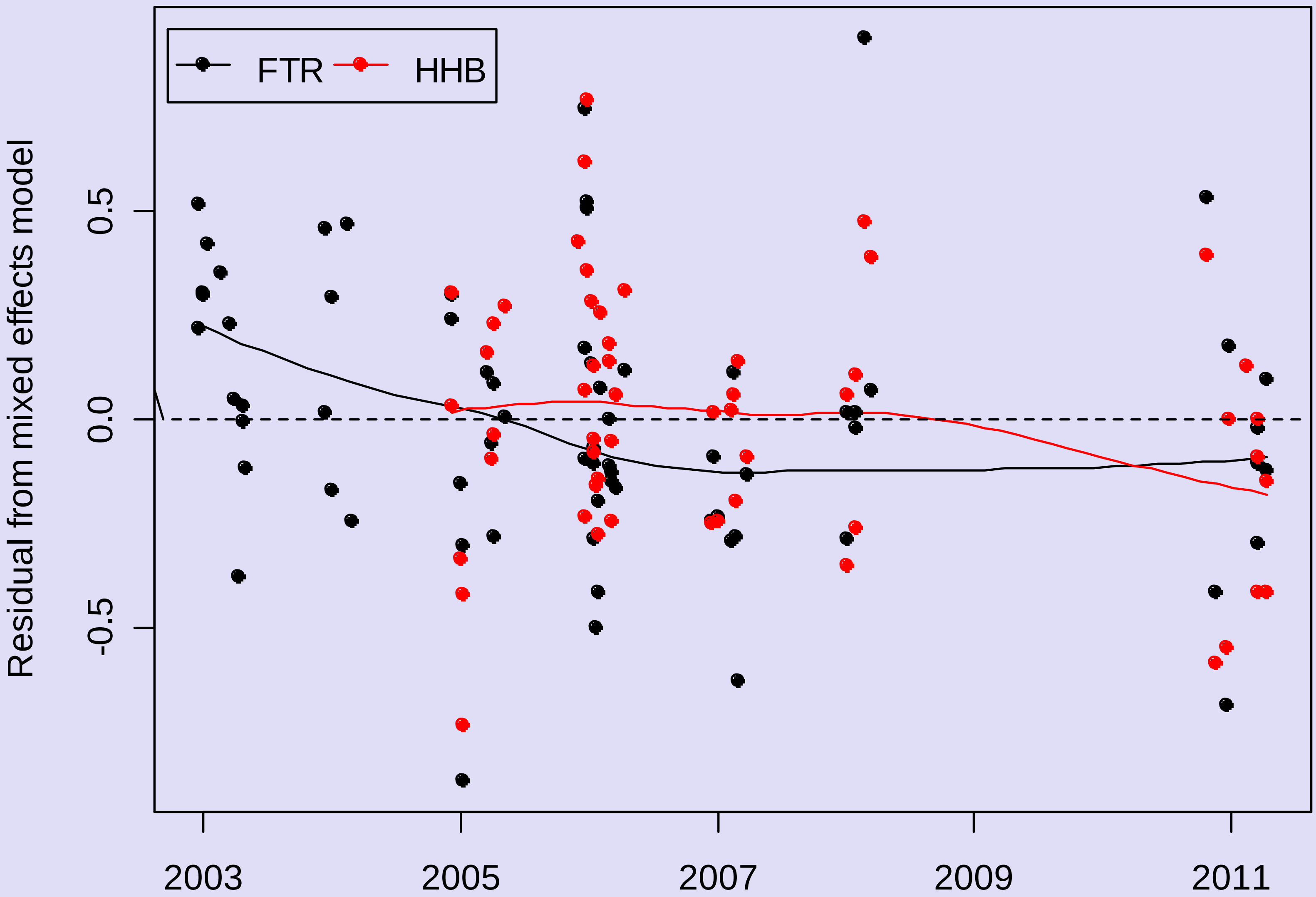
The model uses both sqrt(peak) and sqrt(flow) to predict log(load)



Residual from mixed effects model
1.0
0.5
0.0
-0.5
2003
2005
2007
2009
2011
2013
SFM
KRW
FTR
HHB



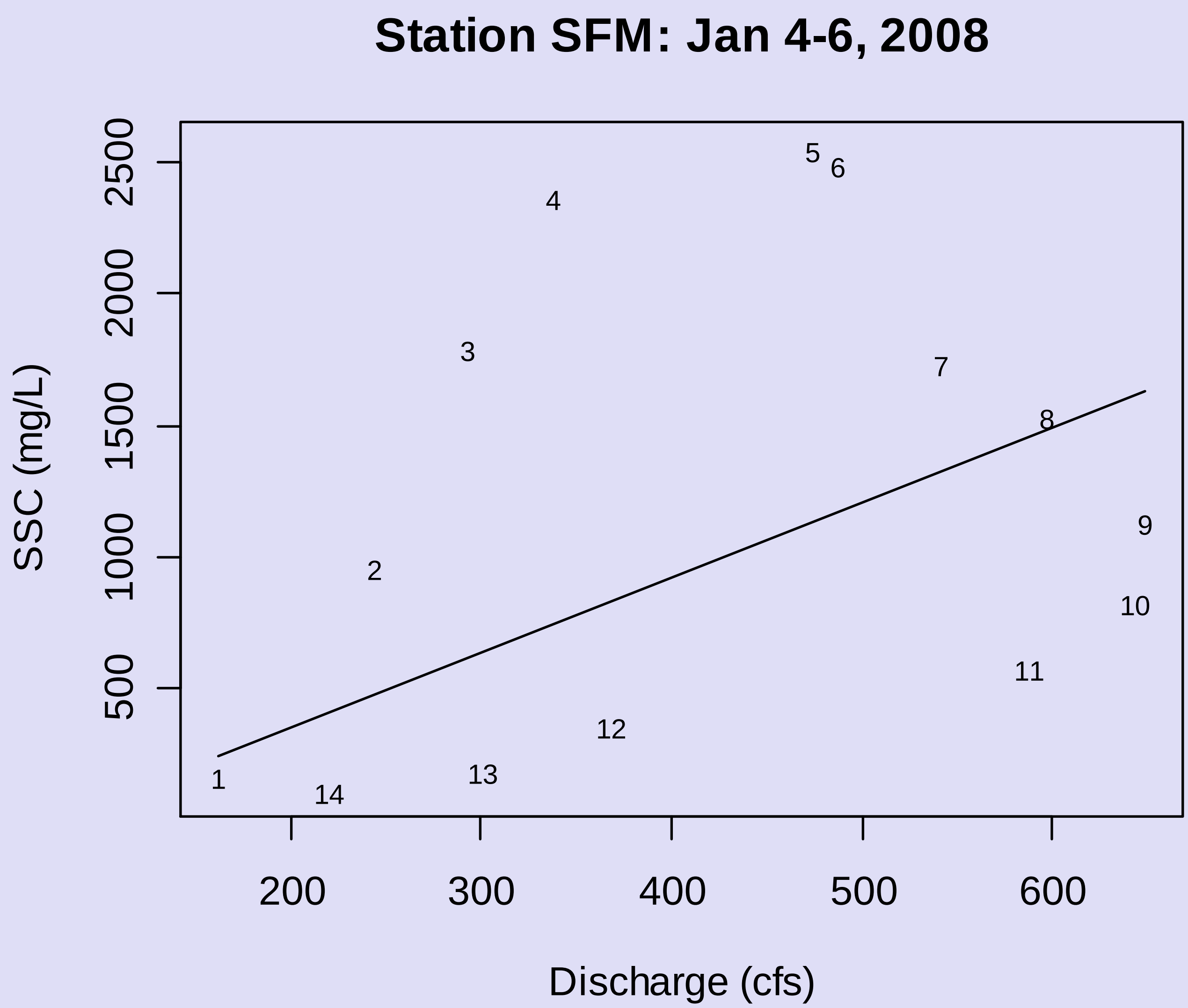
SFM
KRW
Residual from mixed effects model
-0.5
0.0
0.5
2003
2005
2007
2009
2011
2013



FTR
HHB
Residual from mixed effects model
0.5
0.0
-0.5
2003
2005
2007
2009
2011

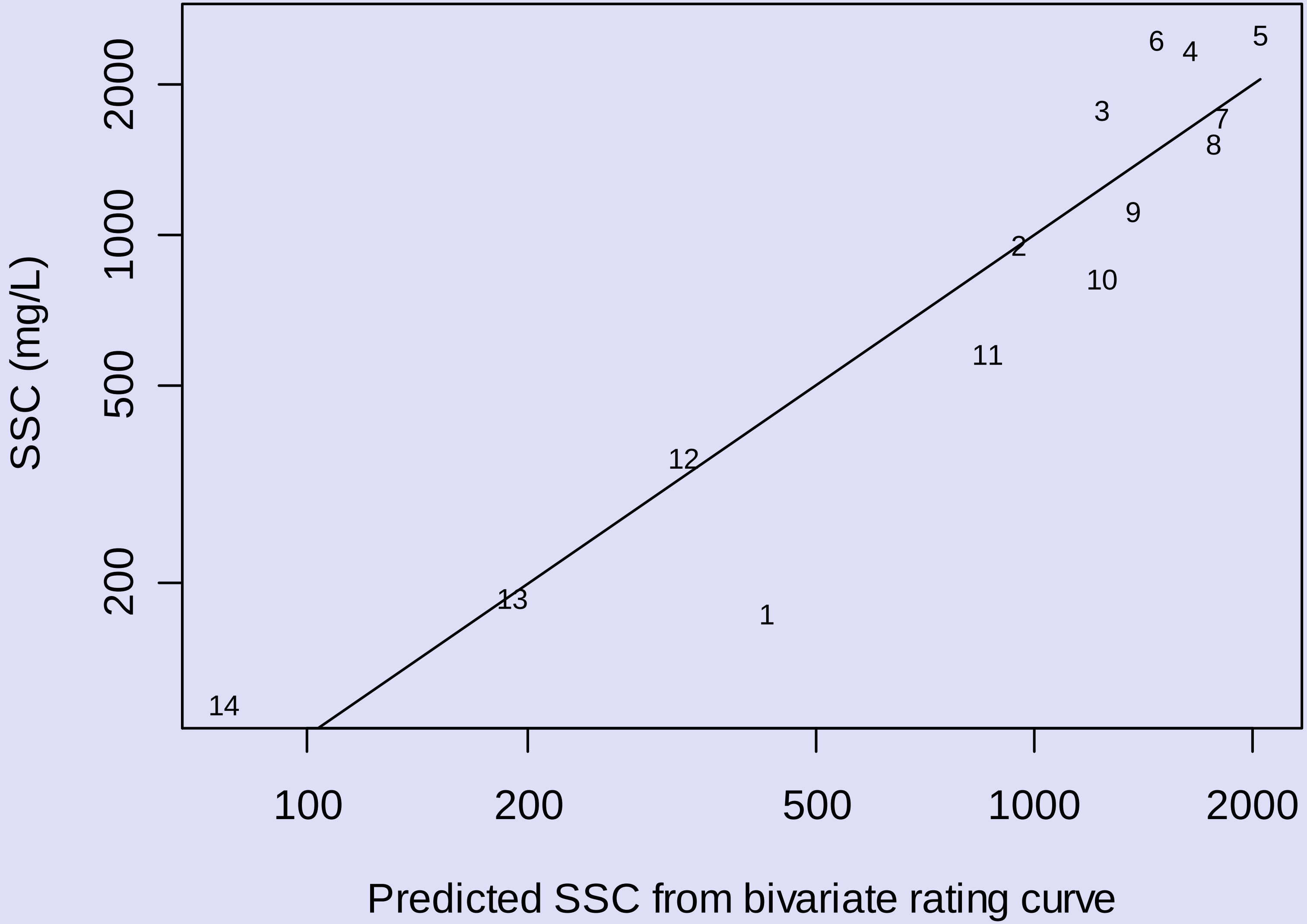
Models for Instantaneous SSC

- Response
  - Logarithm of SSC
- Predictors
  - Logarithm of simultaneous discharge
  - Hourly API, half-life 3-4 hrs
  - Two predictors only
- Serial autocorrelation important

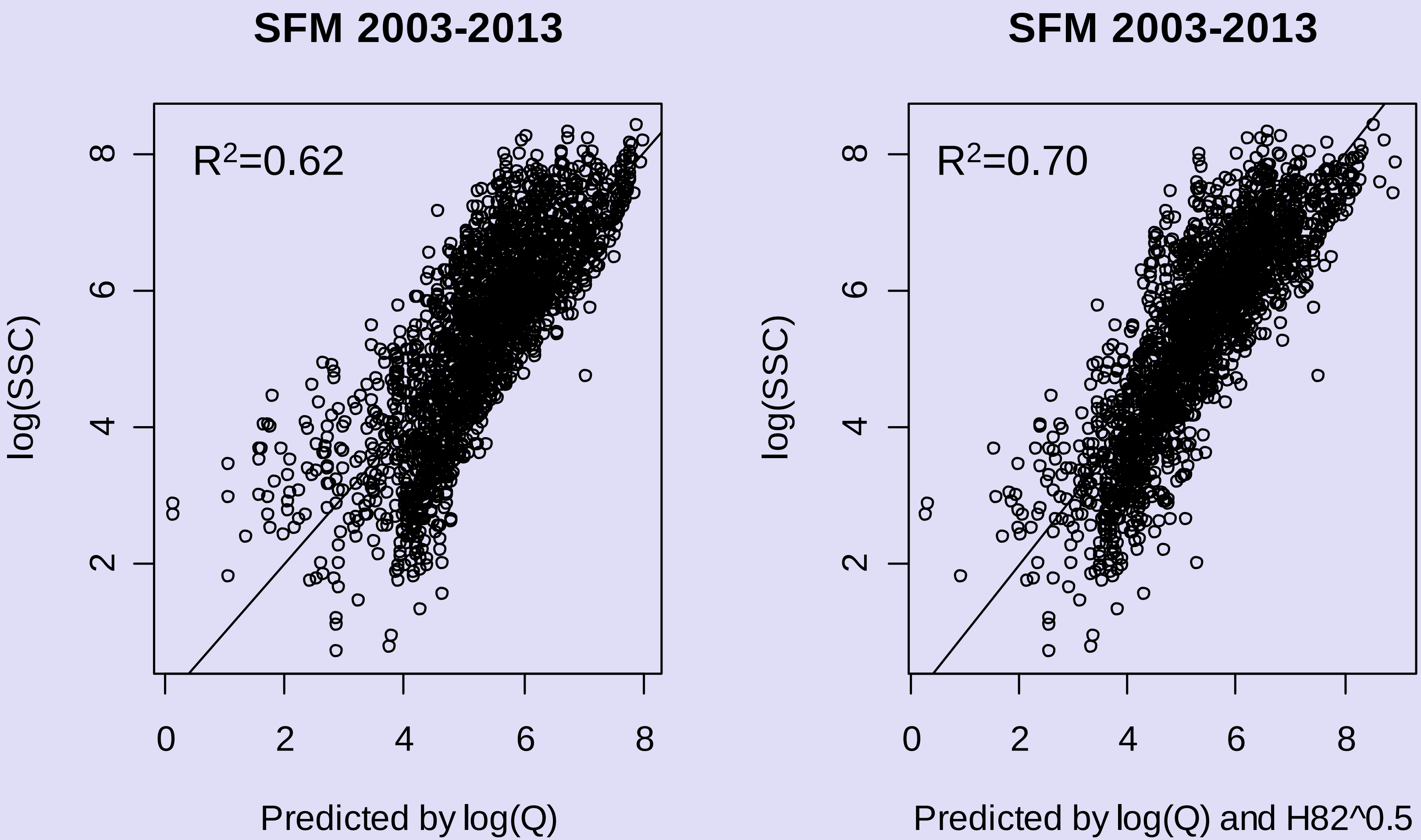


The hysteresis is caused by supply and depletion of transportable sediment during an event, and possibly by surface erosion caused by rainfall on bare soil. The key is to realize it's raining intensely during the rising limb and tapering or stopping during the falling limb.

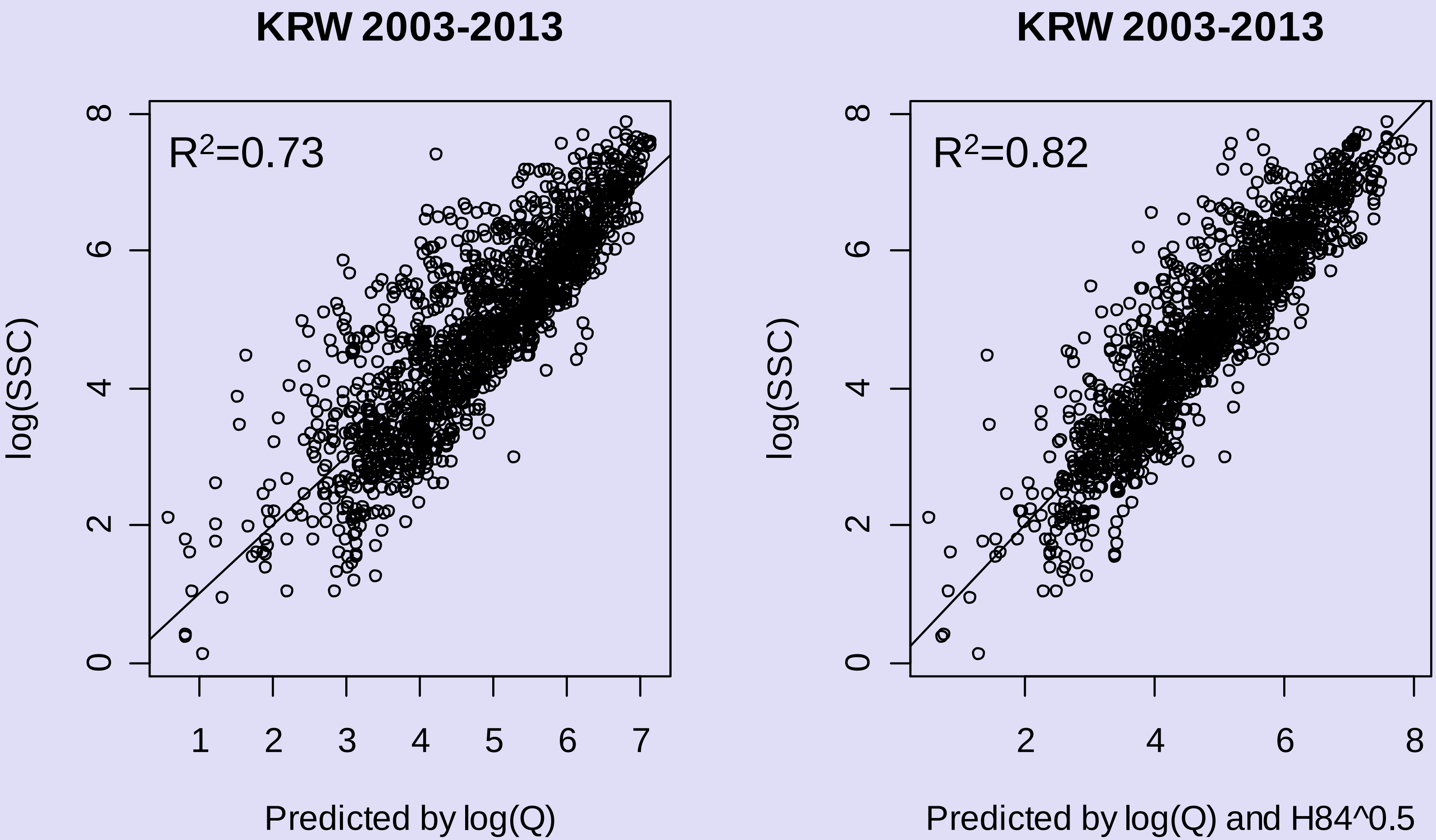
Station SFM: Jan 4-6, 2008



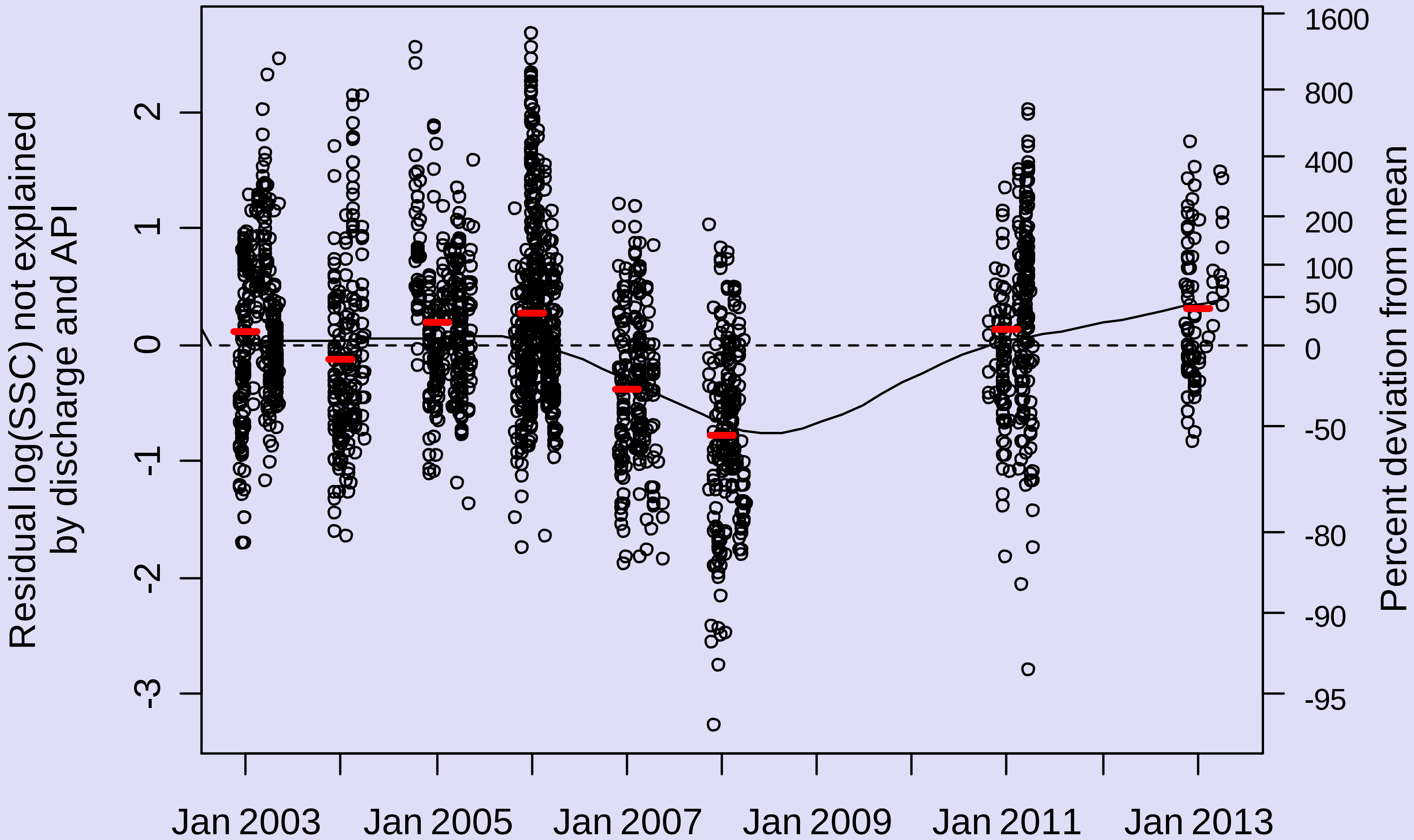
Half-life of the API is 3 hours

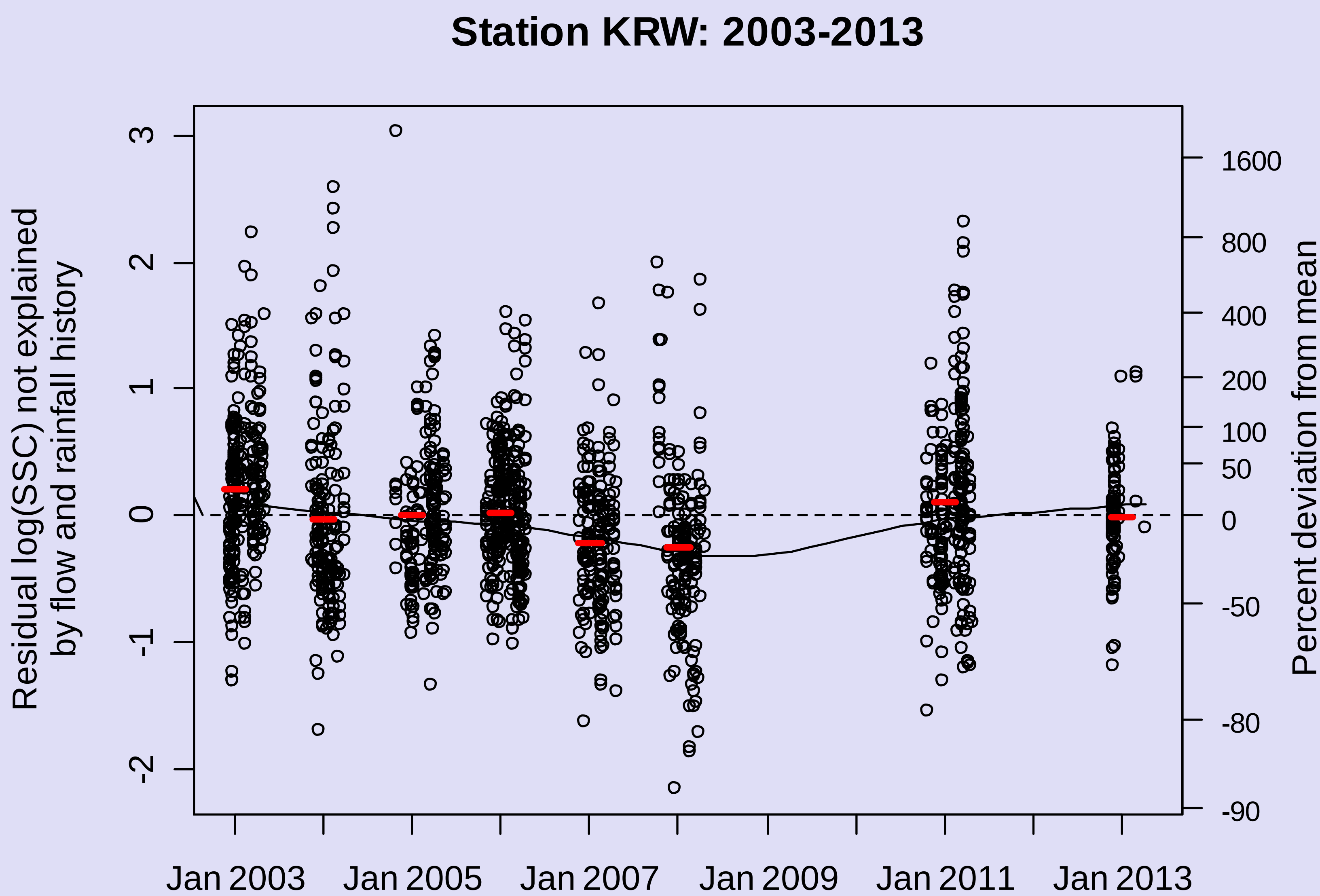


SFM 2003-2013
R^2=0.62
log(SSC)
8
6
4
2
0
2
4
6
8
Predicted by log(Q)
SFM 2003-2013
R^2=0.70
log(SSC)
8
6
4
2
0
2
4
6
8
Predicted by log(Q) and H82^0.5


KRW 2003-2013
R2=0.73
log(SSC)
Predicted by log(Q)
KRW 2003-2013
R2=0.82
log(SSC)
Predicted by log(Q) and H84^0.5

Station SFM: 2003-2013

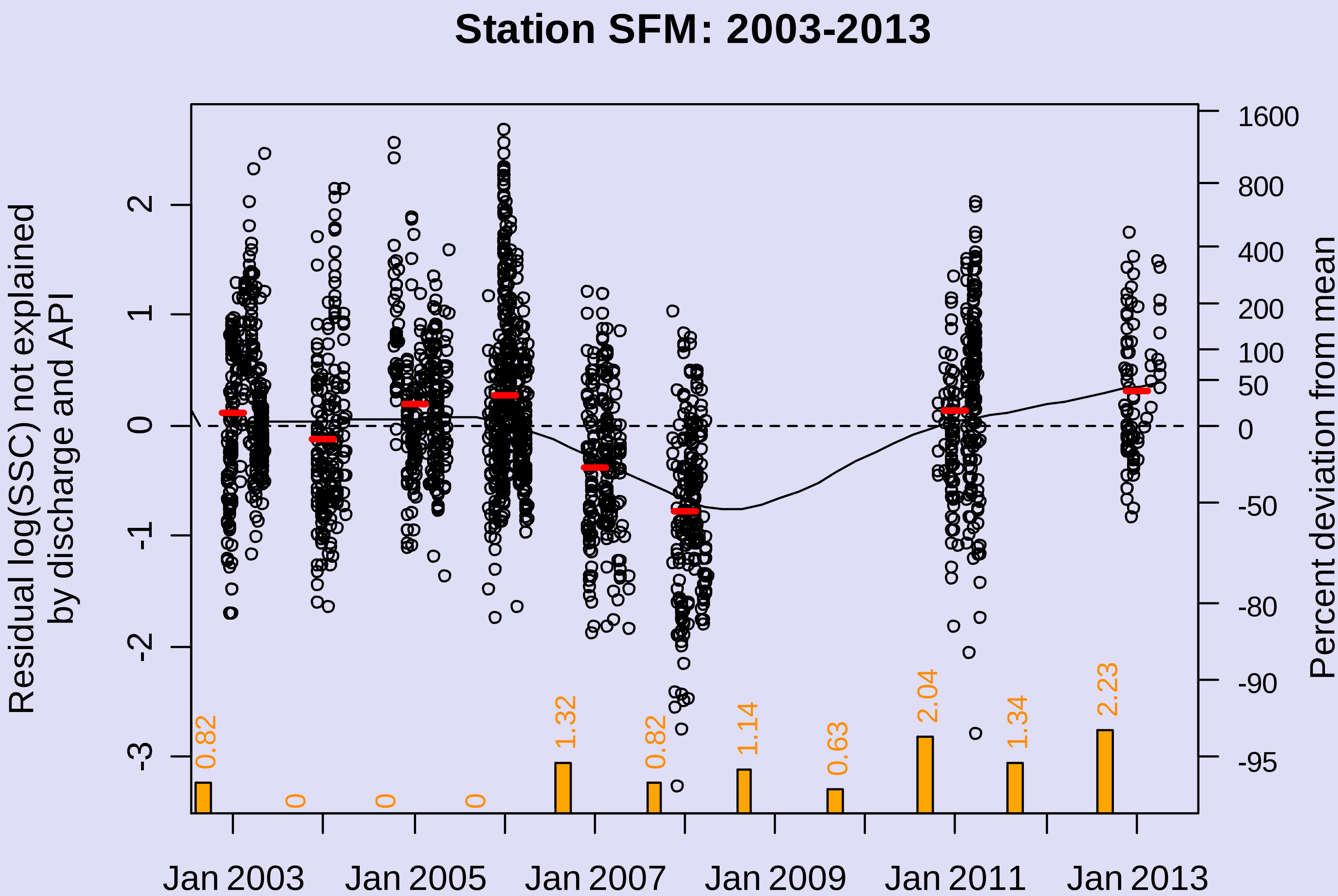




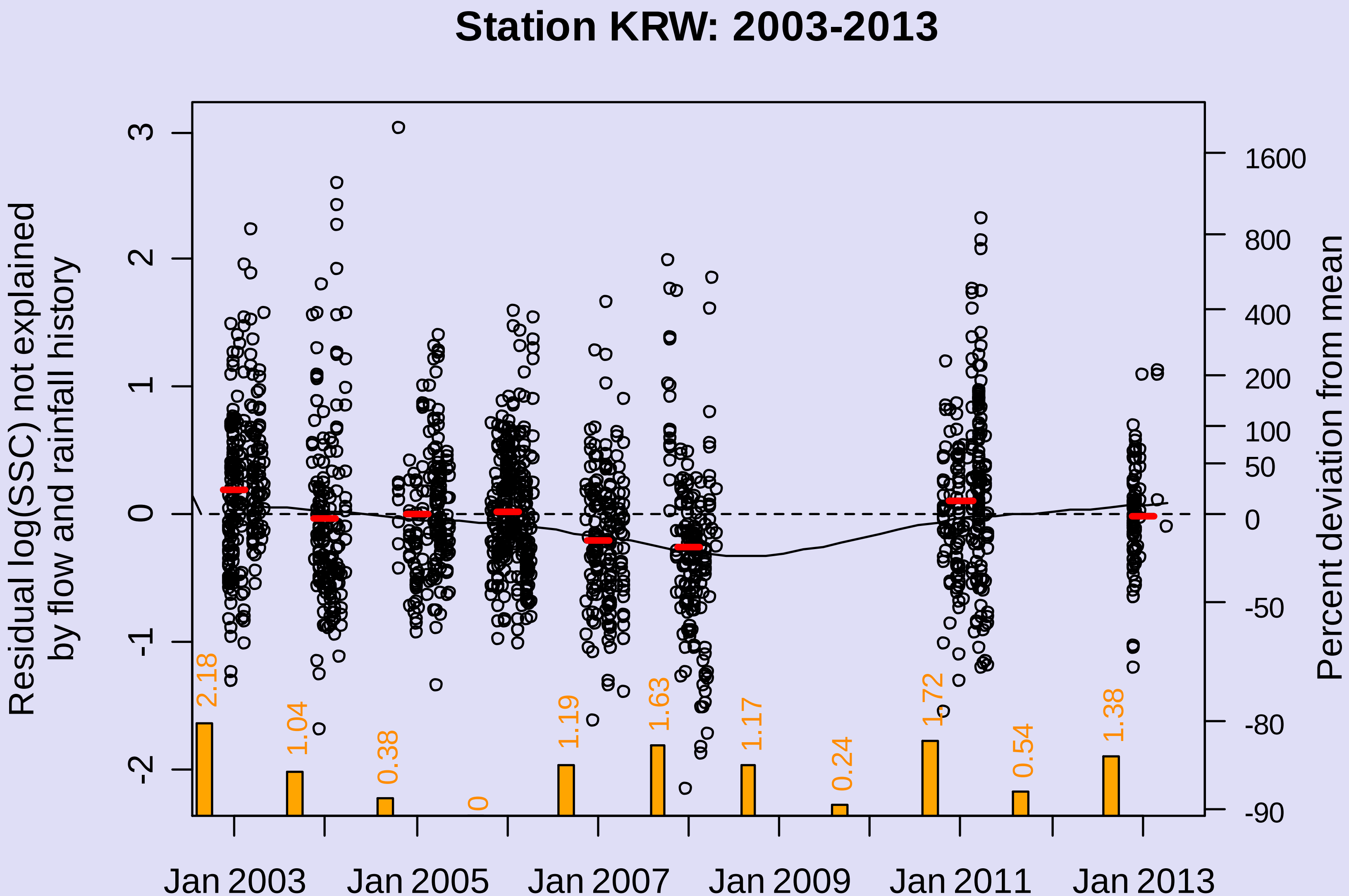
Station KRW: 2003-2013
Residual log(SSC) not explained
by flow and rainfall history
Percent deviation from mean
3
2
1
0
-1
-2
1600
800
400
200
100
50
0
-50
-80
-90
Jan 2003
Jan 2005
Jan 2007
Jan 2009
Jan 2011
Jan 2013

Significance tests for trend in instantaneous SSC

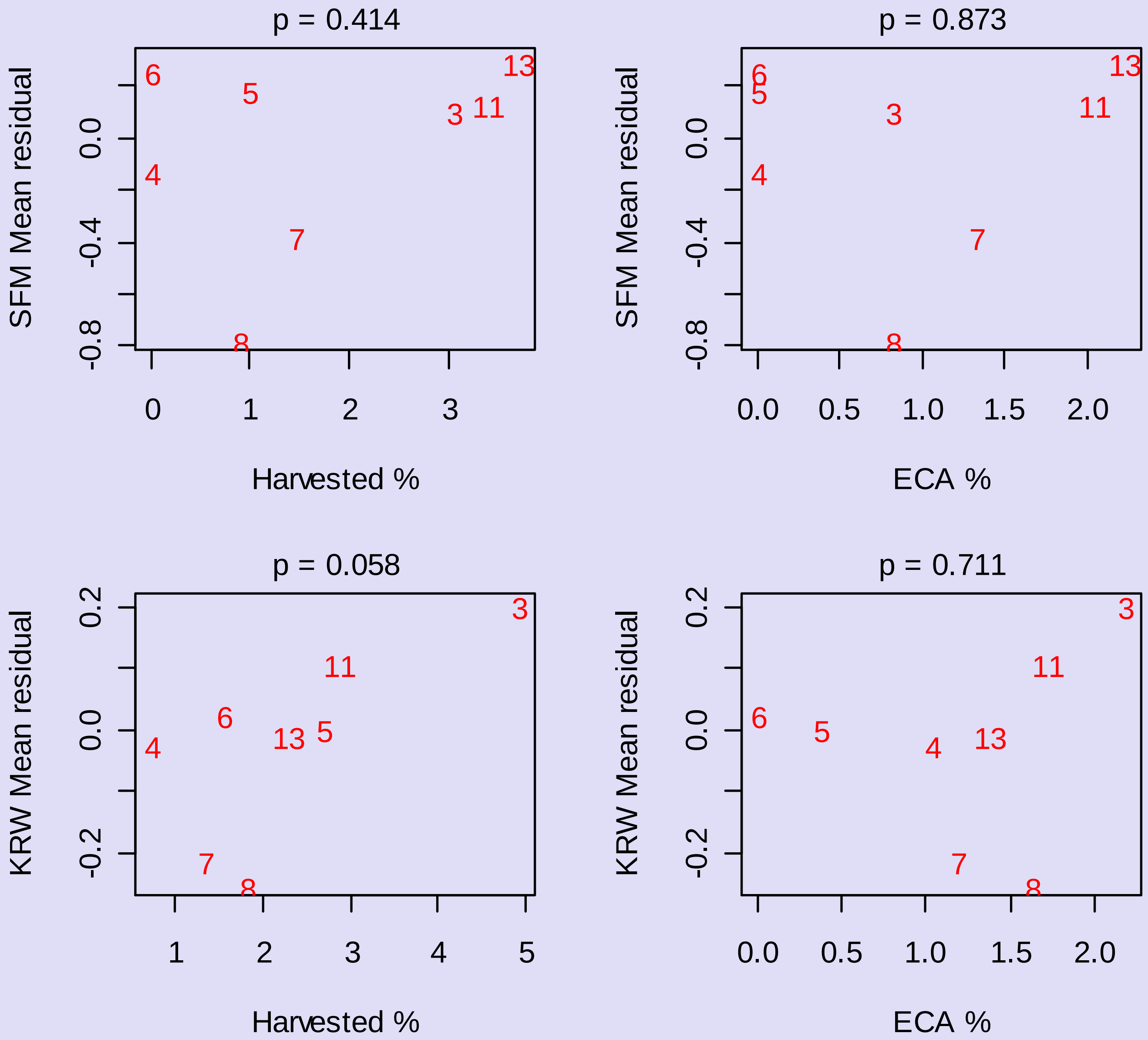
Station	Years	Flow variable	API variable	Adjusted R^2	Error model	Trend p-value
SFM	2003-2013	Log(Q)	$H82^{0.5}$	0.696	AR(4)	0.8960
	2006-2008	Log(Q)	$H84^{0.23}$	0.764	AR(2)	0.0003--
	2008-2013	Log(Q)	H80	0.834	AR(2)	0.0000
KRW	2003-2013	Log(Q)	$H84^{0.5}$	0.817	AR(2)	0.5703
	2006-2008	Log(Q)	$H90^{0.5}$	0.856	AR(2)	0.0050-
	2008-2013	Log(Q)	$H88^{0.66}$	0.781	AR(2)	0.2676



Yellow bars are equivalent clearcut acres (percent of watershed). 2011 was the biggest year for sediment removal (road rehab). Next biggest (2009) was only half as much. Unknown for 2013

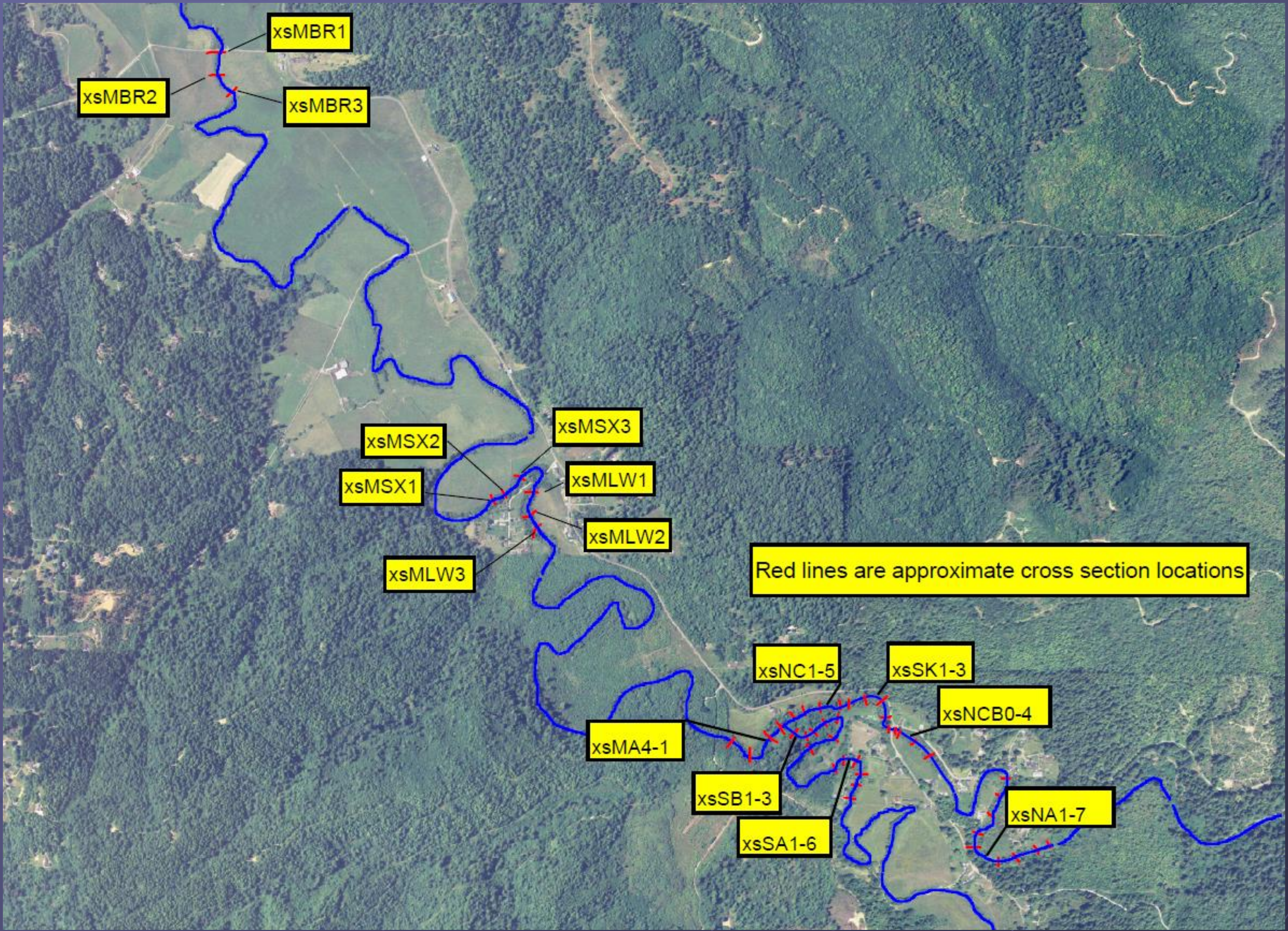


The yellow bars show individual calendar year harvest rate or ECA (%). Big years for sediment removal were, in order of magnitude: 2009, 2007, 2006, then 2011.

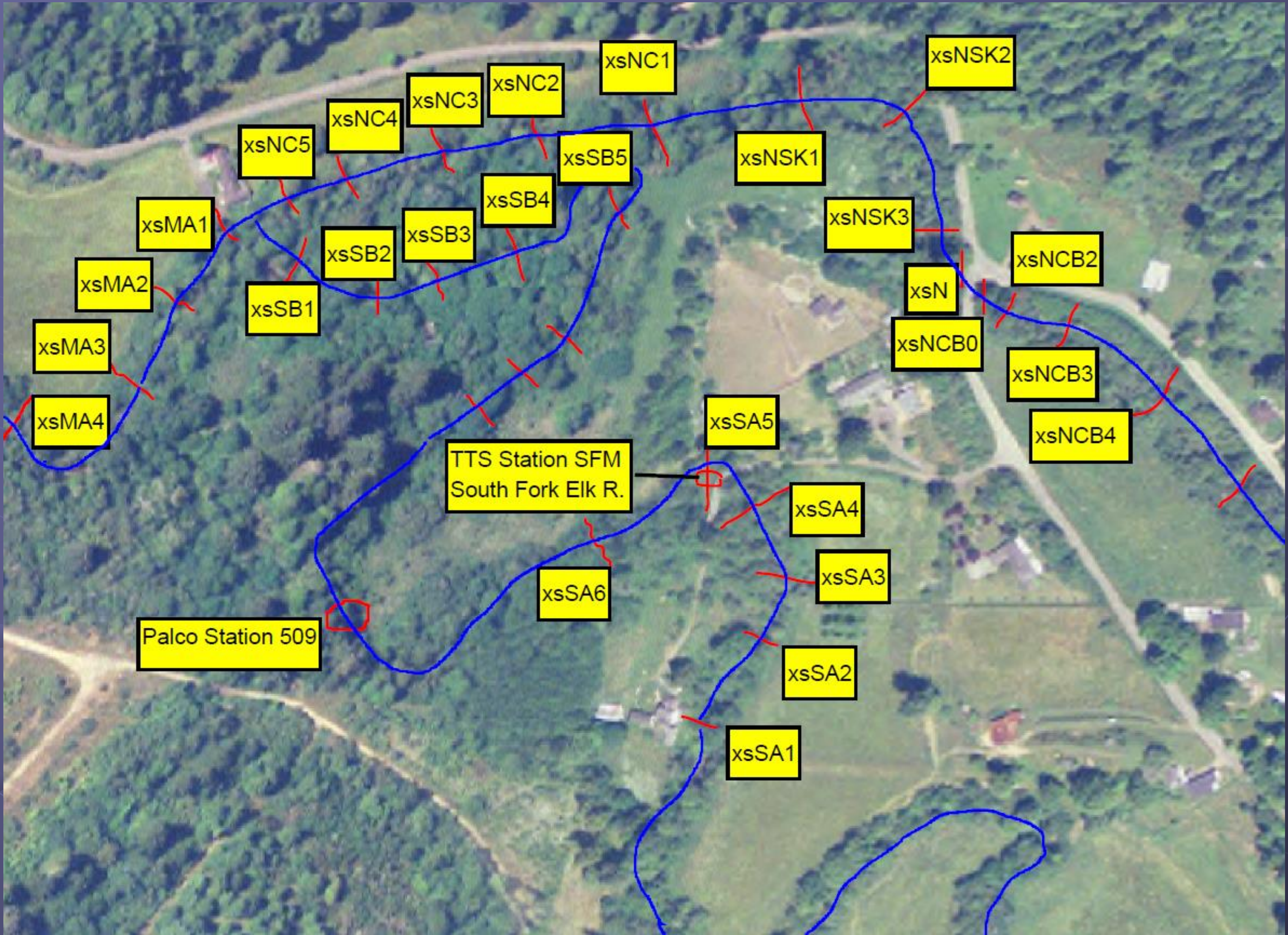


There is actually NOT good evidence here linking ECA with the trends in SSC

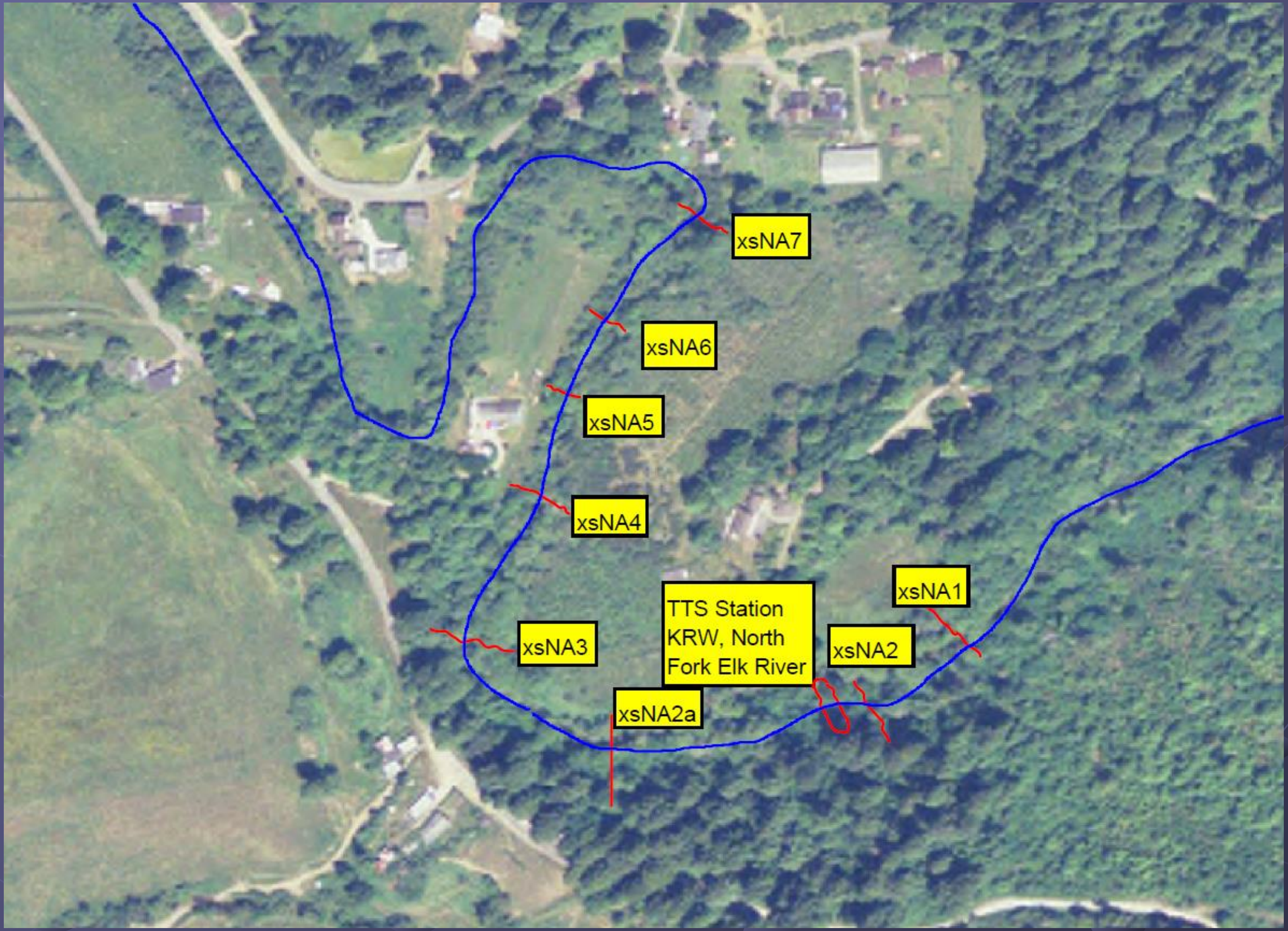
Elk River Cross-sections

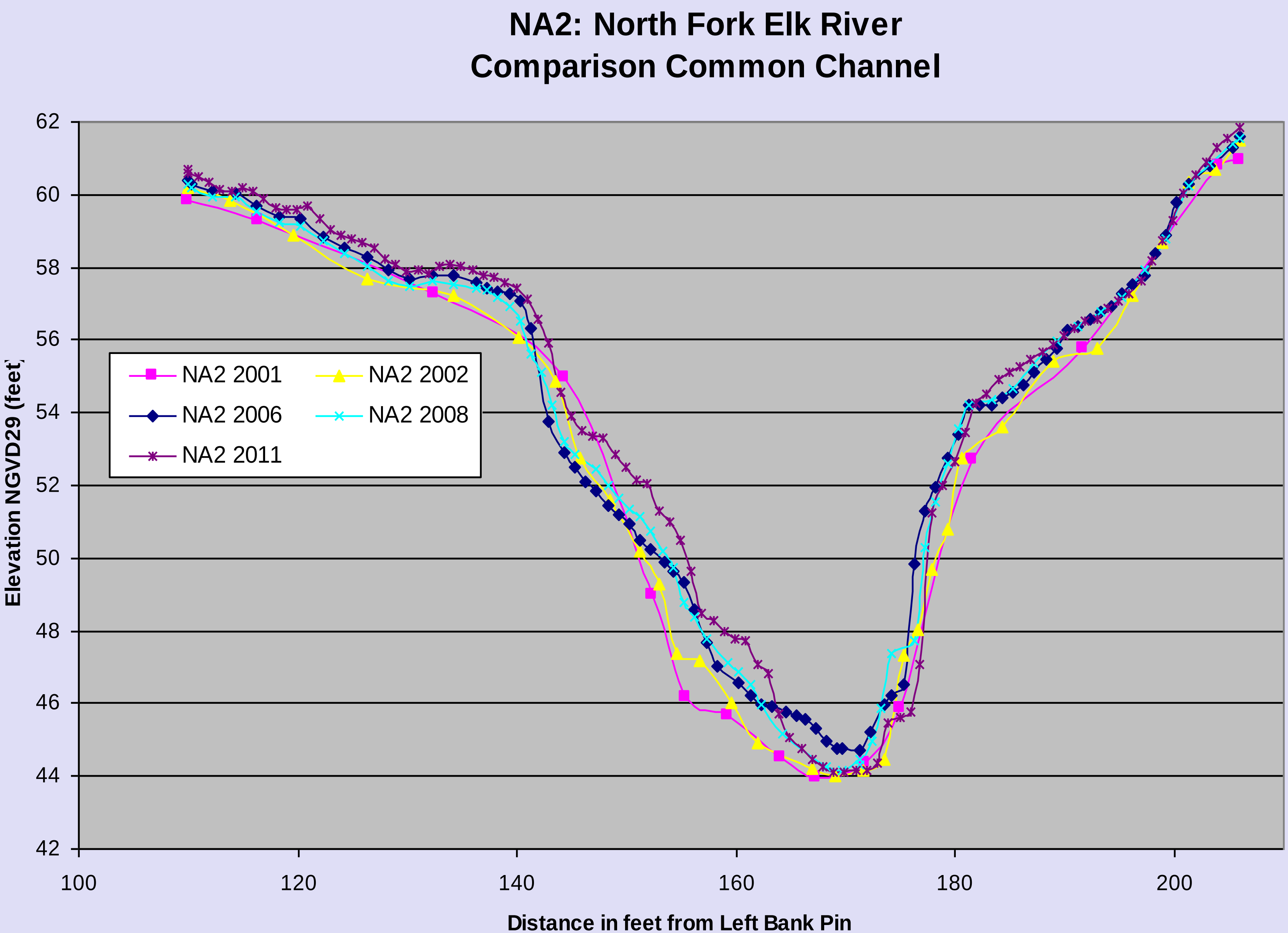


Cross-sections: Elk R. confluence

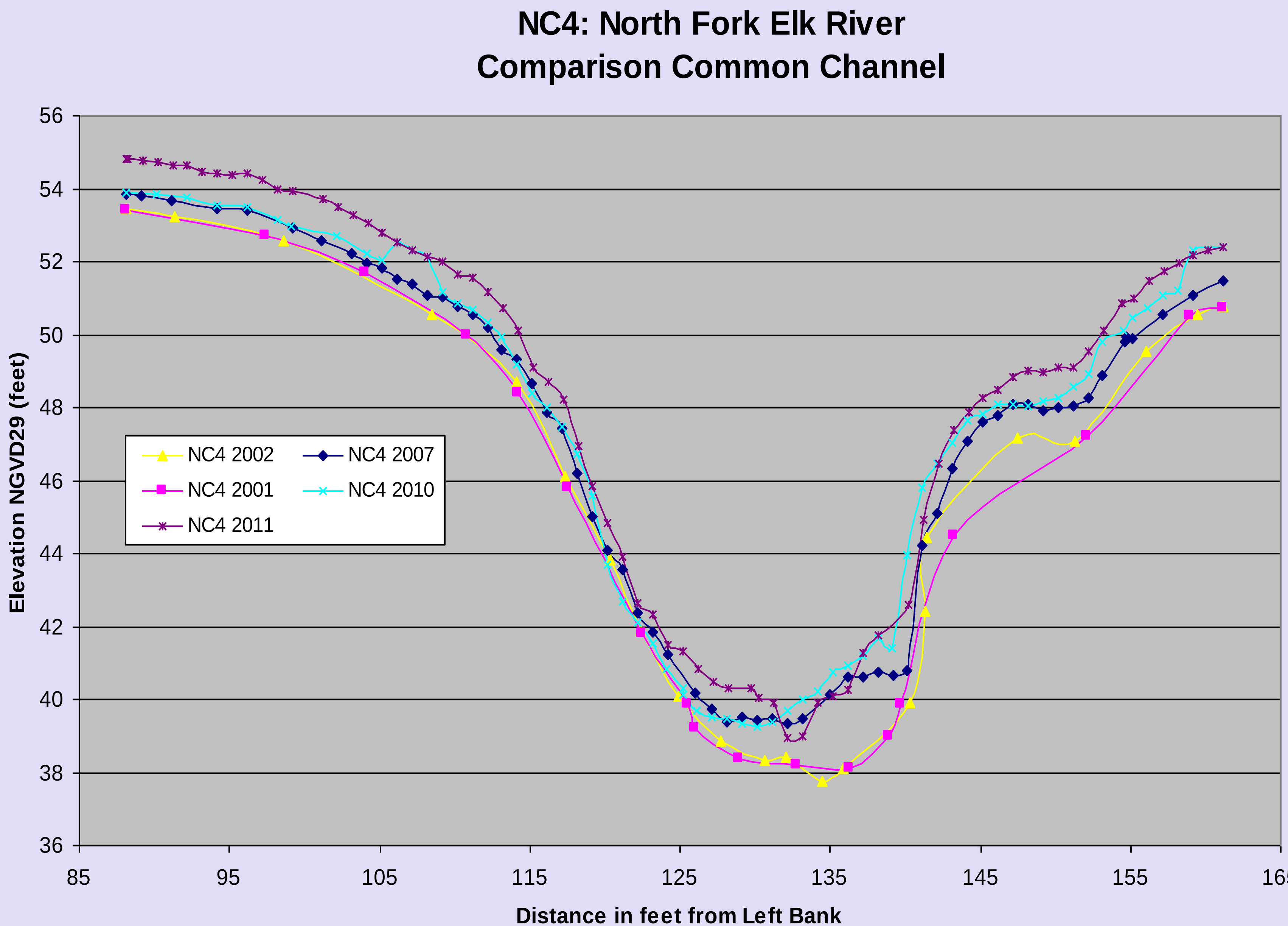


Cross-sections near KRW station



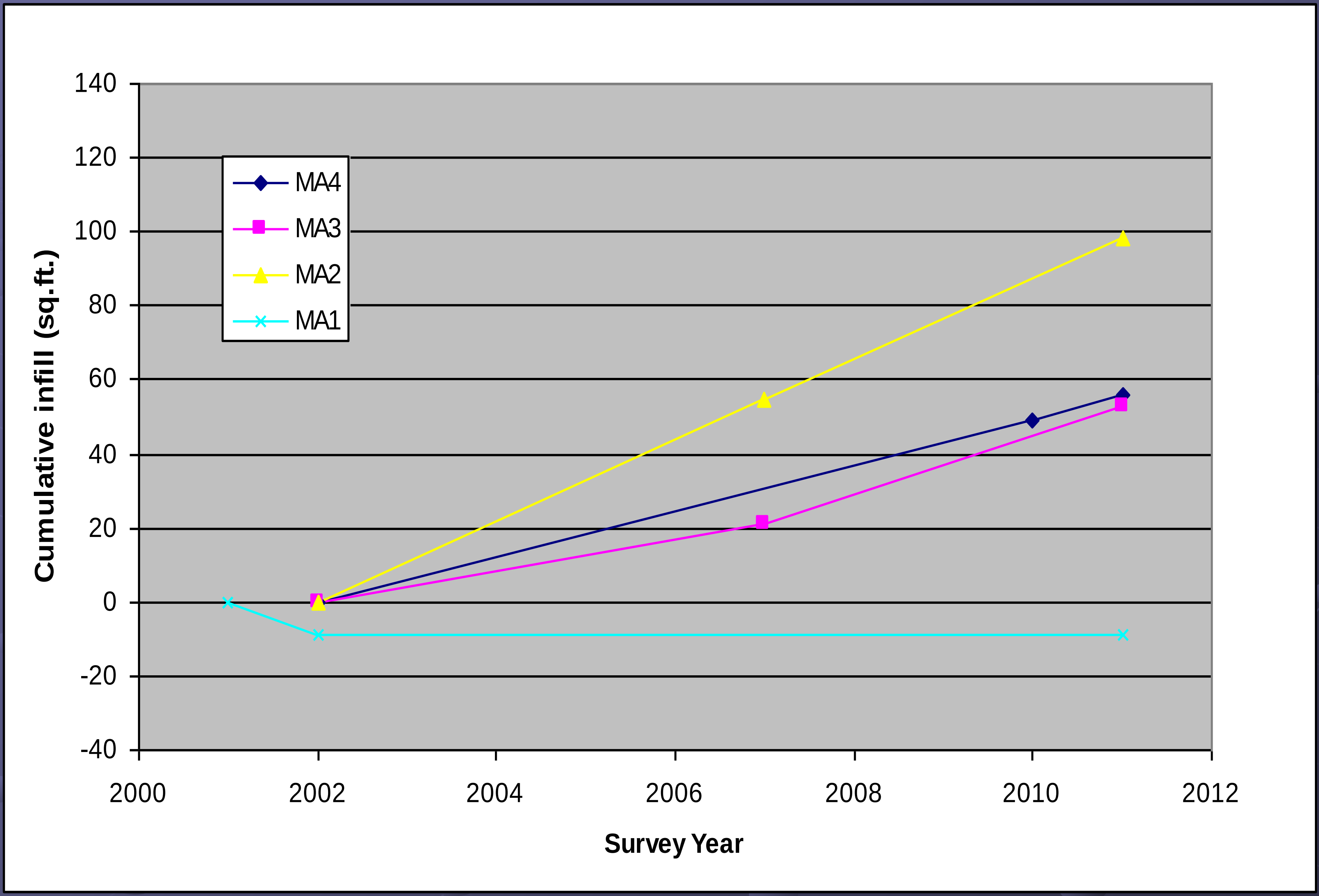


Vertical exaggeration is about 3.5 to 1

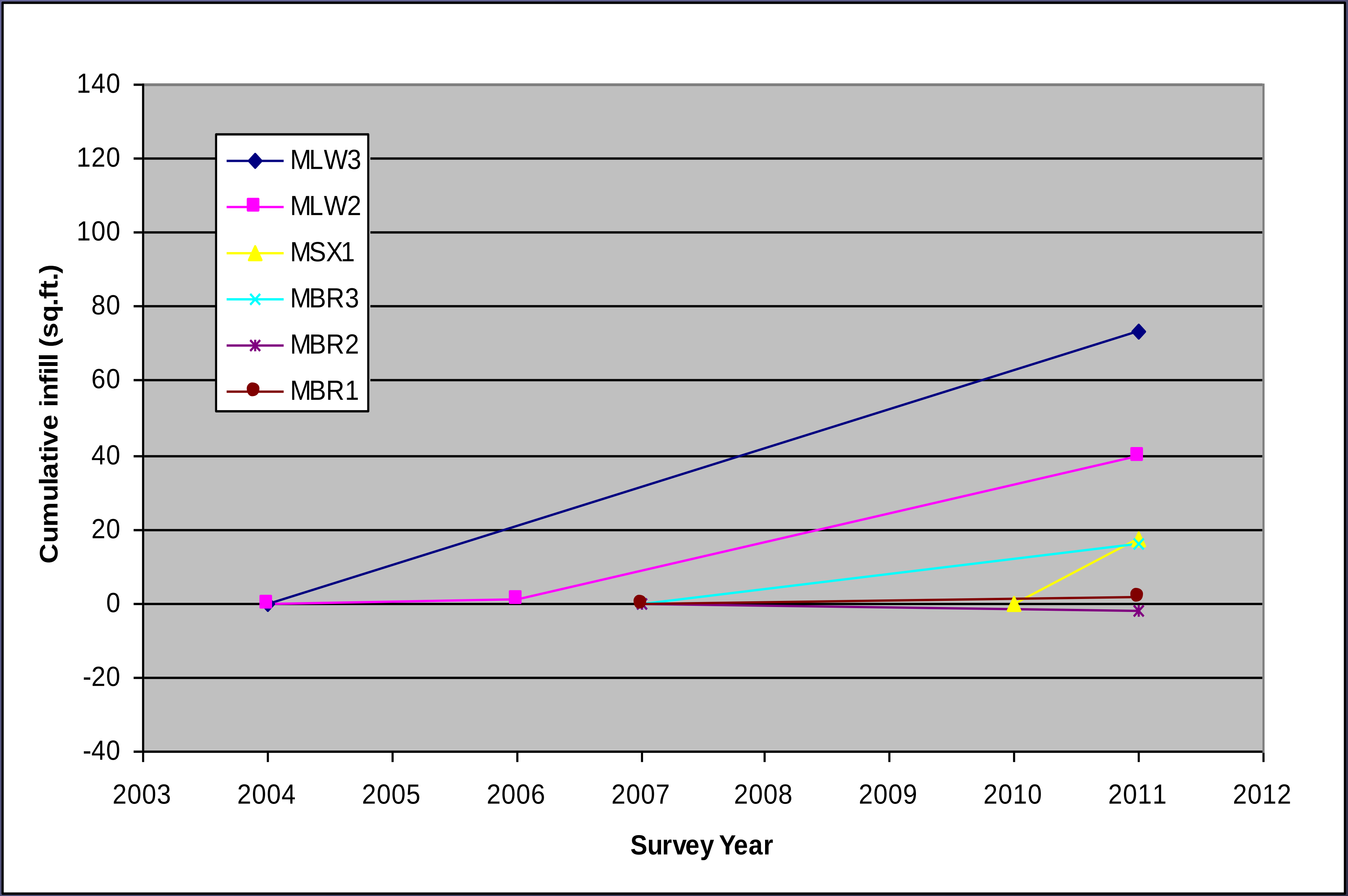


Vertical exaggeration is about 3:1

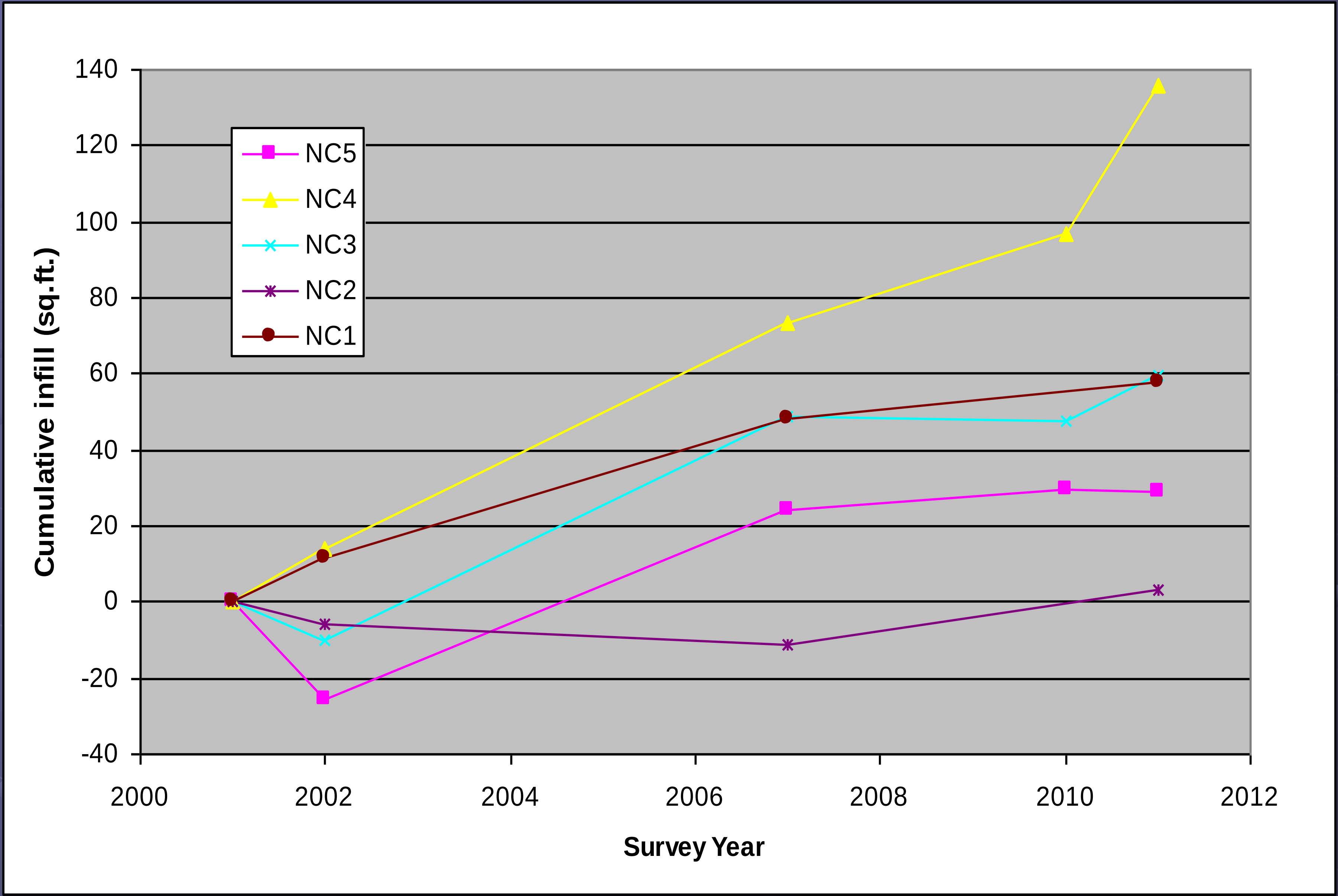
Mainstem below confluence



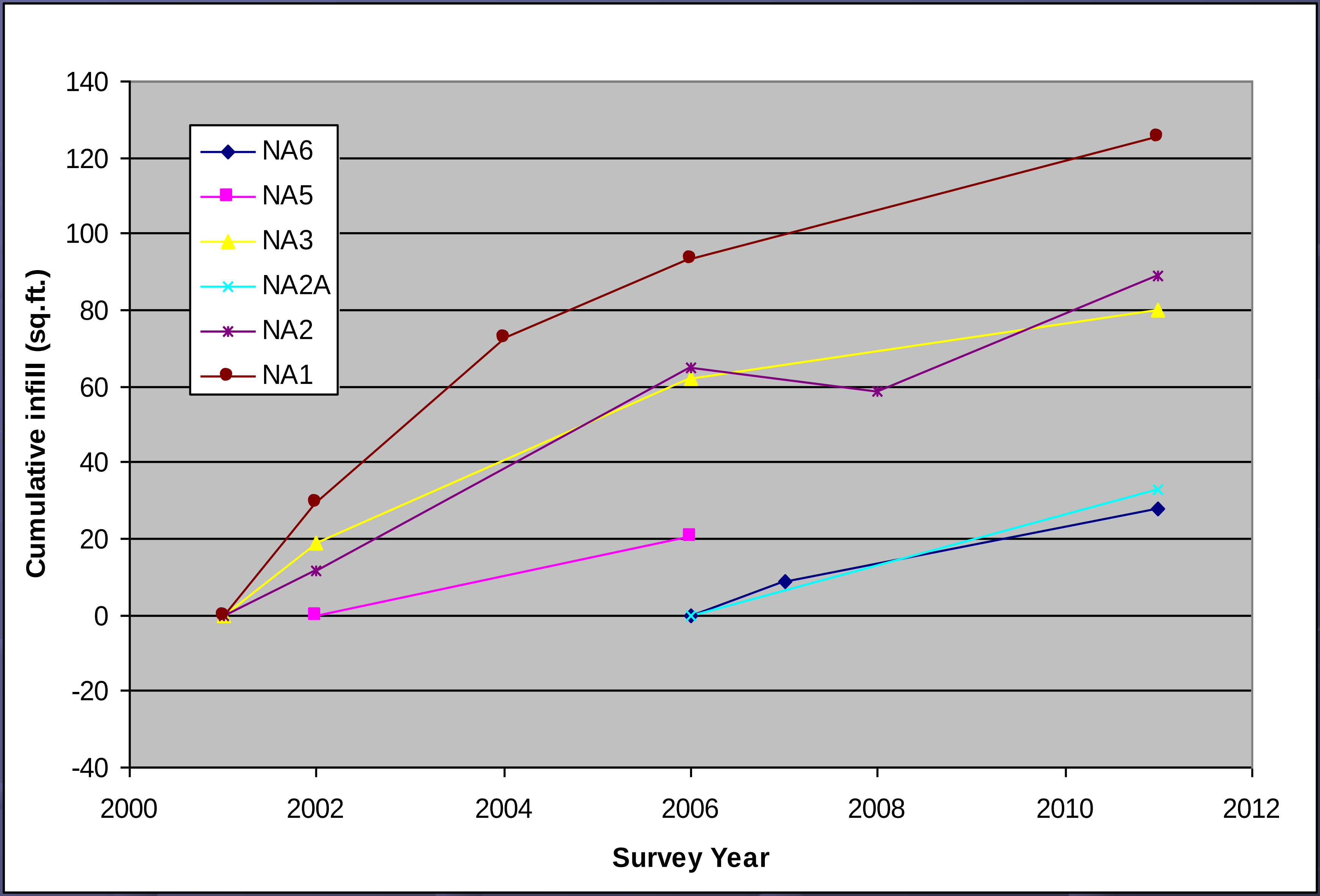
Larry Ward to Berta Road



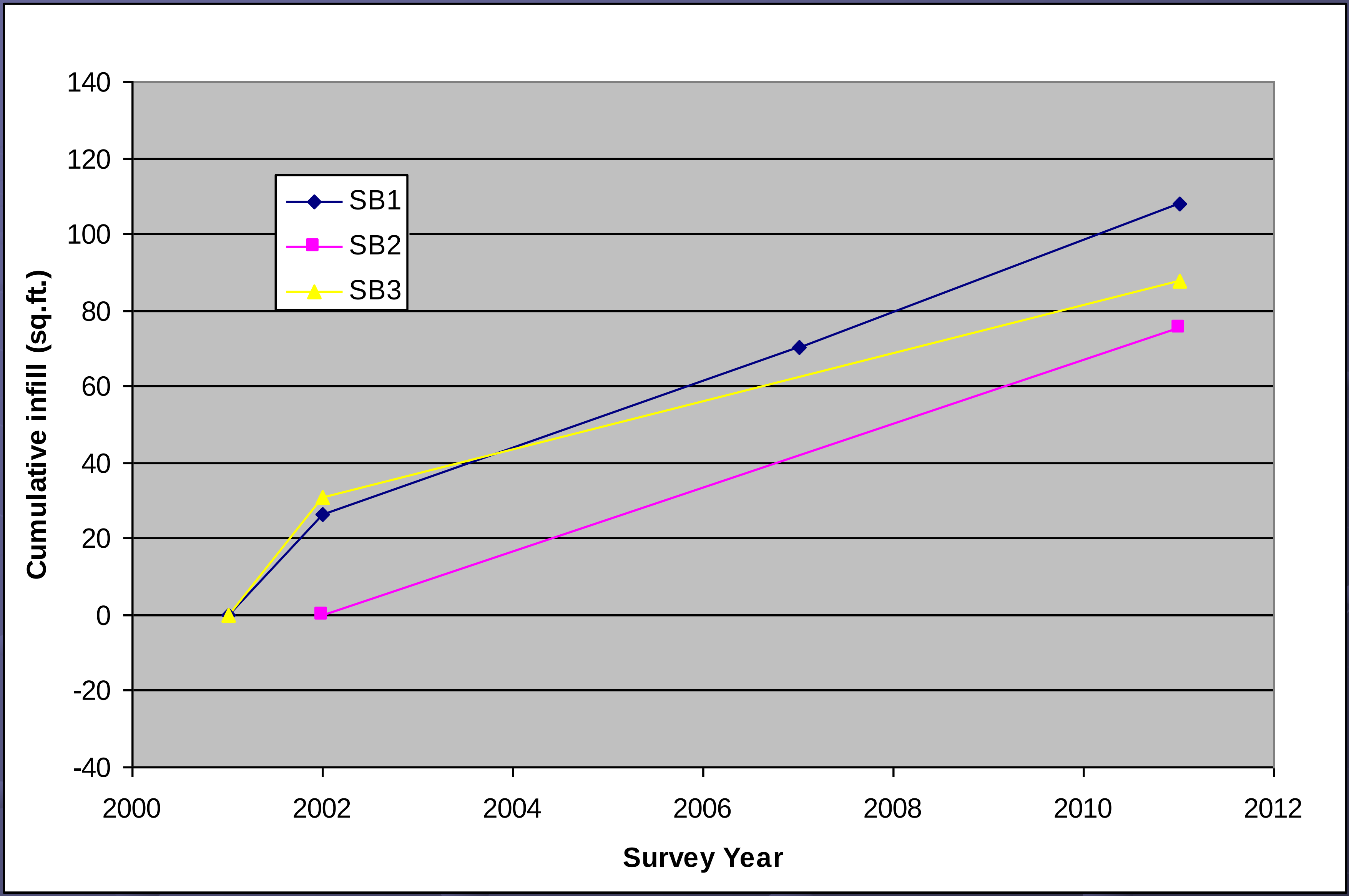
North Fork above confluence



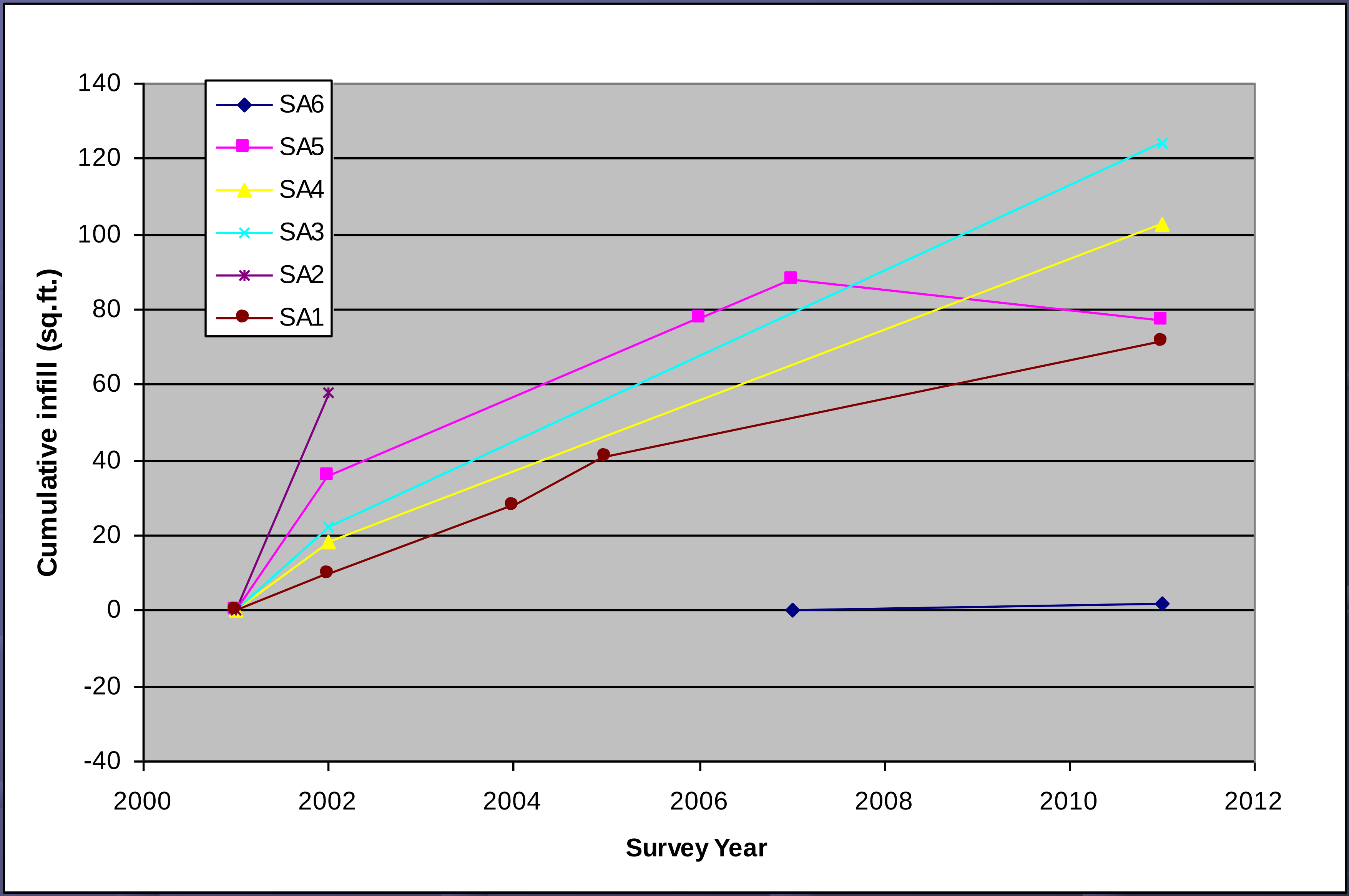
North Fork near KRW station

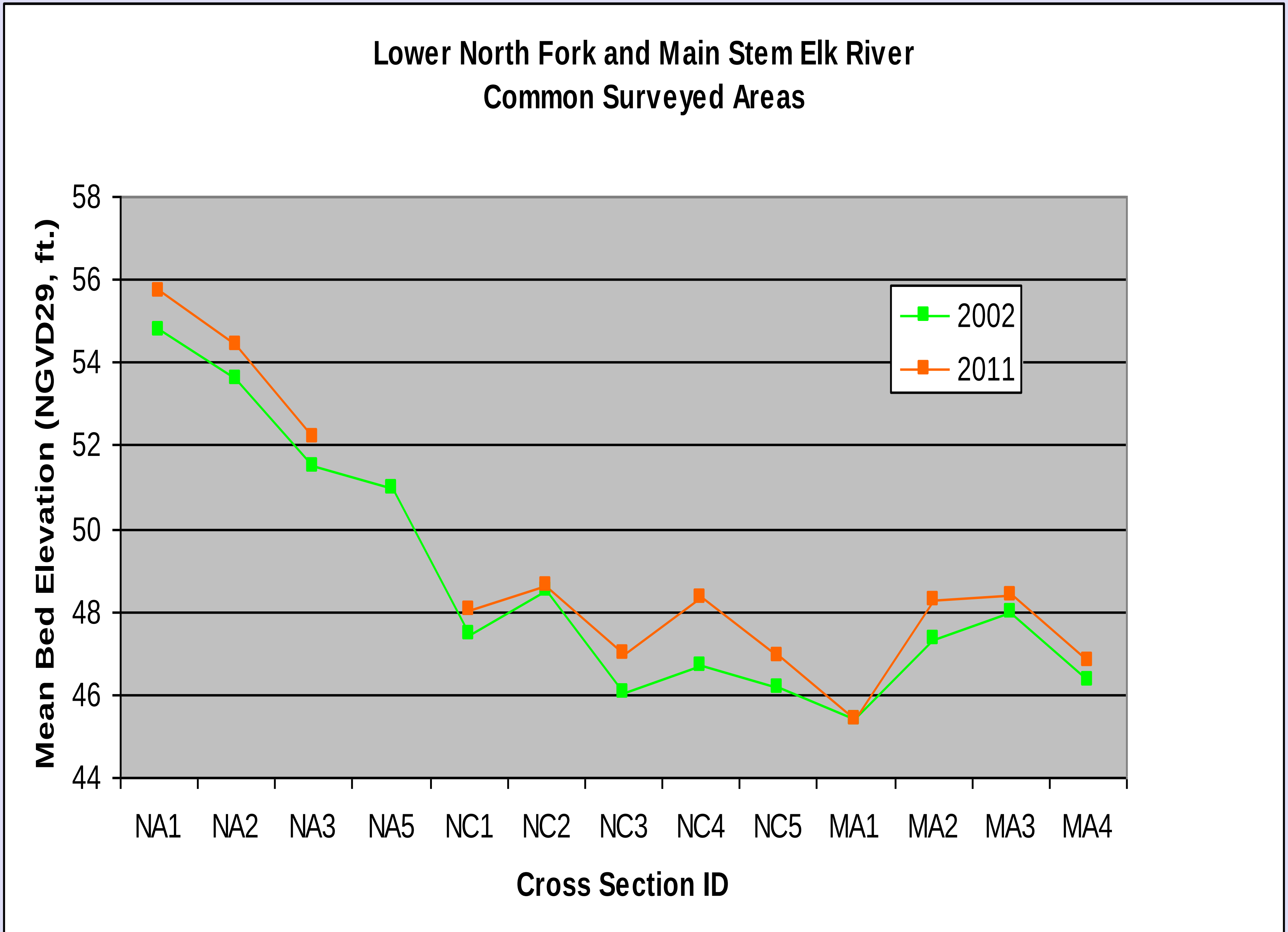


South Fork near confluence

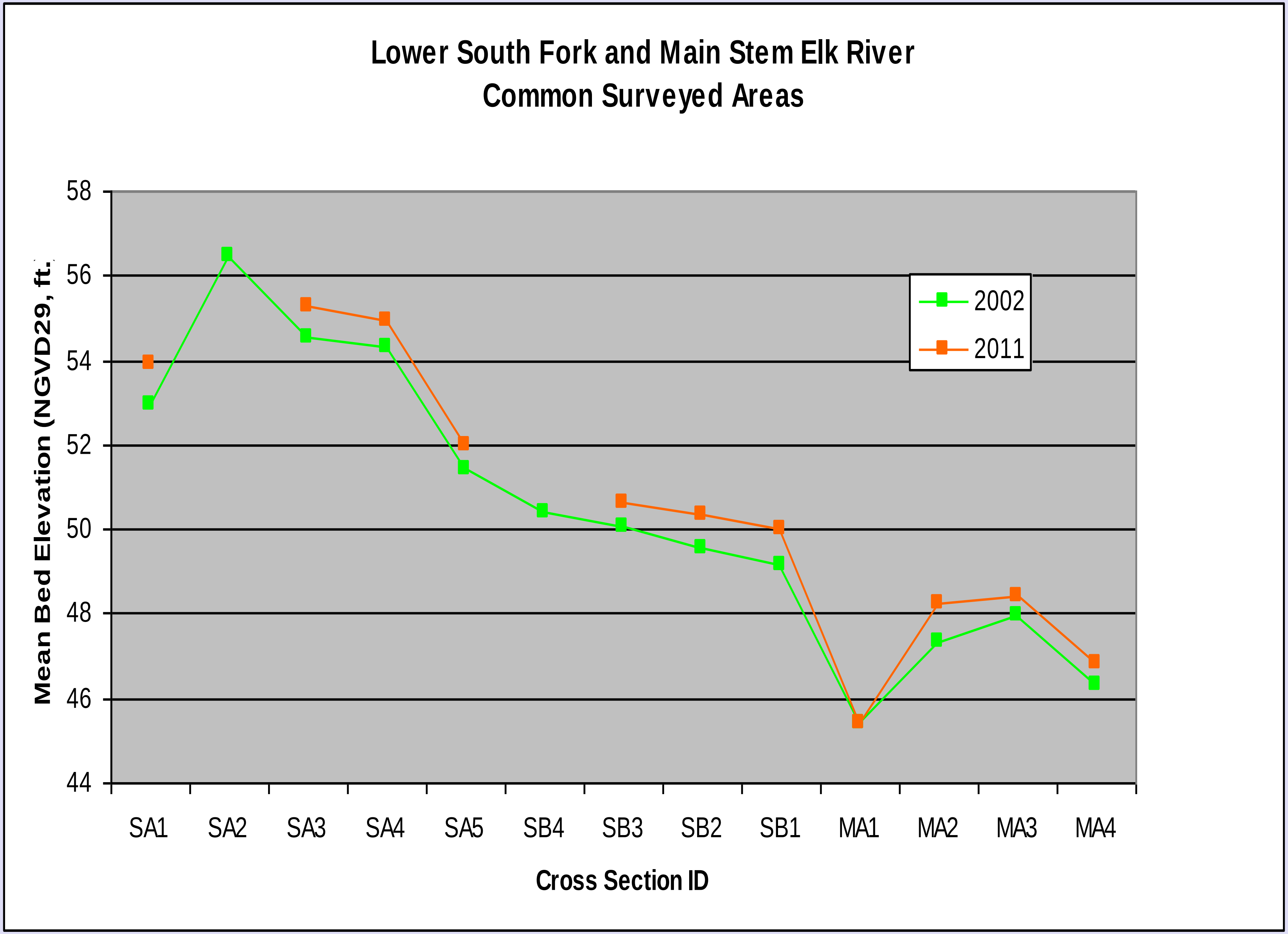


South Fork above SFM station





x axis is not to scale and distance between x-sections actually varies


Lower South Fork and Main Stem Elk River
Common Surveyed Areas
Mean Bed Elevation (NGVD29, ft.)
58
56
54
52
50
48
46
44
2002
2011
SA1
SA2
SA3
SA4
SA5
SB4
SB3
SB2
SB1
MA1
MA2
MA3
MA4
Cross Section ID

Elk River Findings

- SFM has consistently the highest loads of streams monitored in the Humboldt Bay region. In most years, KRW is a distant second.
- Aggradation continues at most cross-sections in lower Elk River, often exceeding 1 ft or 100 ft^2 for the decade: SF > NF > main
- No trends in peak flows detected in Elk R
- Both Elk stations saw a decline in storm event loads and SSC prior to 2008, followed by a bounce in 2011. In 2013 SFM increased to 35-37% above the mean.
  - Due to road rehab or harvesting or legacy impacts?
  - Need to try and link these results with source inventories

92 ft2 SF - 65 ft2 NF - 54 ft2 MS

Broad Interpretations (Elk R only)

1. Management is now benign and the monitoring reflects it – unsupported
2. Management is now benign but it will take more time for the monitoring to reflect it – plausible
3. Management has not improved enough and that's why we don't see improvements downstream – maybe

Monitoring Recommendations

- We have a long enough record to begin to identify trends in watershed responses but it will take longer before trends may be attributed to recent mgmt changes
- Fund Salmon-Forever to bring their analyses up-to-date; continue x-sections and stream gaging
- Share and pool data with HRC and GDRC
- Improve access and continue monitoring Little South Fork Elk (Headwaters), or
- Establish a more accessible control watershed where logging will not occur. It need not be pristine or large, as long as its responses are well-correlated with other watersheds in the basin.

Management Recommendations

- Be cautious until improvements are measurable. We know how to limit erosion:
  - Don't use the roads when they are wet
  - Keep canopy openings small (<0.25 acre?)
  - Avoid the most unstable areas
  - Minimize ground disturbance, esp near stream channels, and maintain soil cover
  - Reduce the frequency of reentry
  - Be selective/smart when fixing legacy issues

We know that removing too much canopy has erosional consequences, but we need a better understanding of the relationship between canopy opening size and hillslope hydrology.