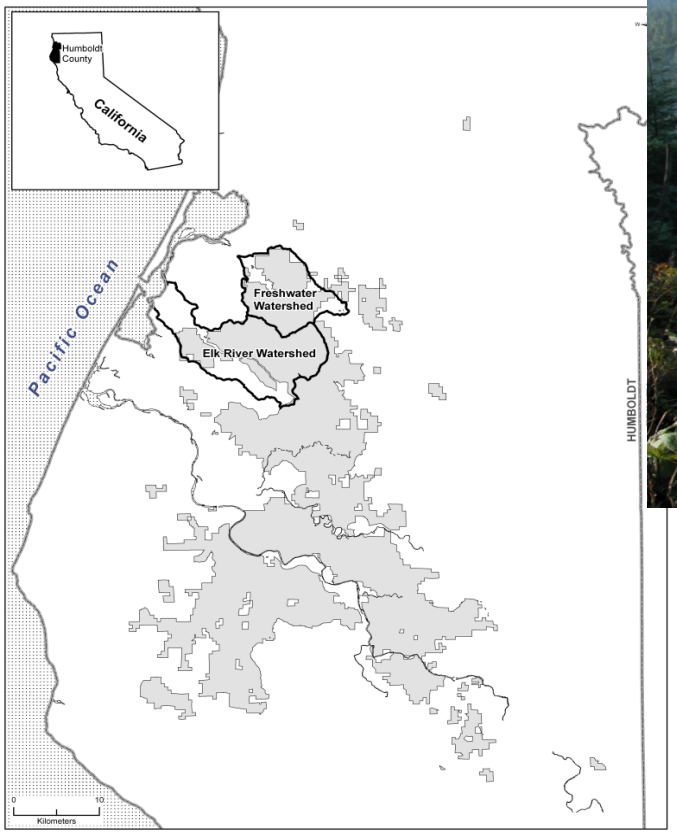
Trends in Sediment-Related Water Quality After a Decade of Forest Management Under the Habitat Conservation Plan

Elk River and Freshwater Creek

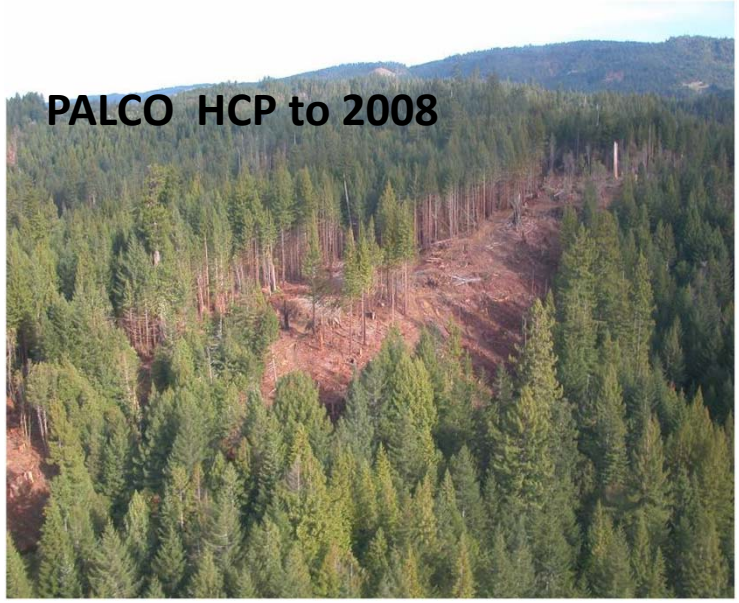
Kate Sullivan,Ph.D., David Manthorne, Rich Rossen, Aaron Griffith, Tommy Bohrmann Ph.D.

Humboldt County



- 2nd and 3rd generation redwood/Douglas-fir
- In continuous forest management since 1860's

Historical Evolution of Forest Practices



Aquatic Habitat Conservation Plan 1999

- **50-Year agreement designed to protect and restore habitat for endangered aquatic species--SALMON**
- **Changed all aspects of forest management on property**
  - Riparian leave areas expanded
  - High hazard area avoidance, geologic investigation
  - Road improvements
    - Road improvement program to be completed in 20 years
    - Upgrade roads to stormproofed standard
    - Remove roads
  - Road use restrictions
    - Wet weather
    - Seasonal
  - Terrestrial wildlife protection

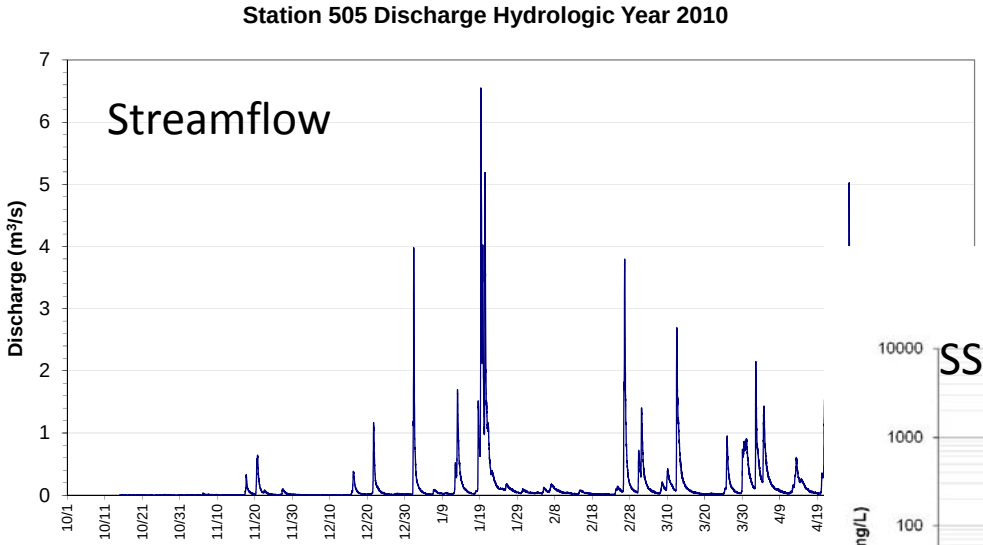
Scientific Investigation

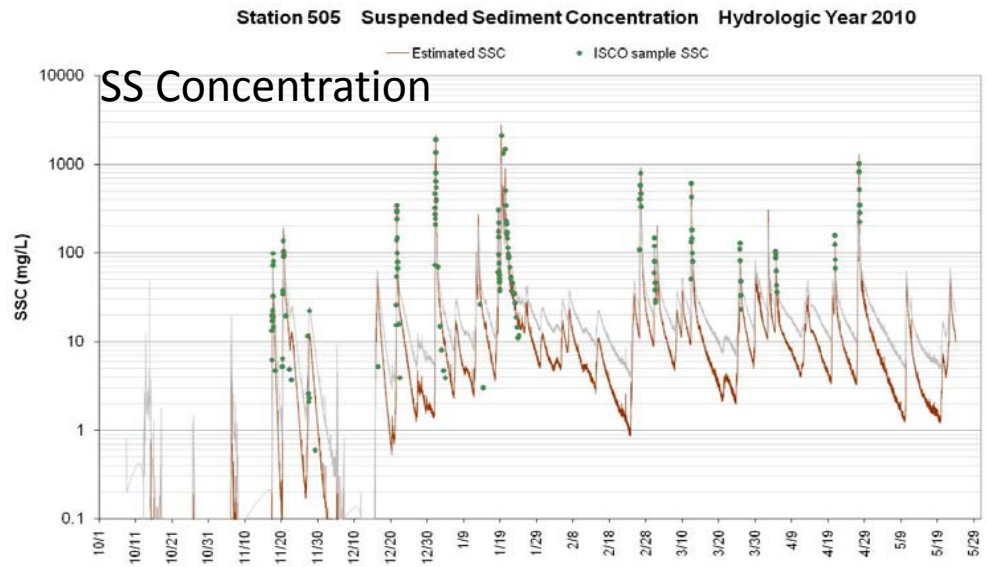
- **Sediment source assessments**
  - Road crossings
  - Skid trail crossings
  - Stream channel bank erosion and streamside landslides
  - Landslides
- **Watershed Analysis (sediment budgets)**
- **Monitoring Projects**
  - Long-term trends
    - **Water quality and Sediment Yields**
    - Fish habitat characteristics
  - Effectiveness monitoring—THPS, roads

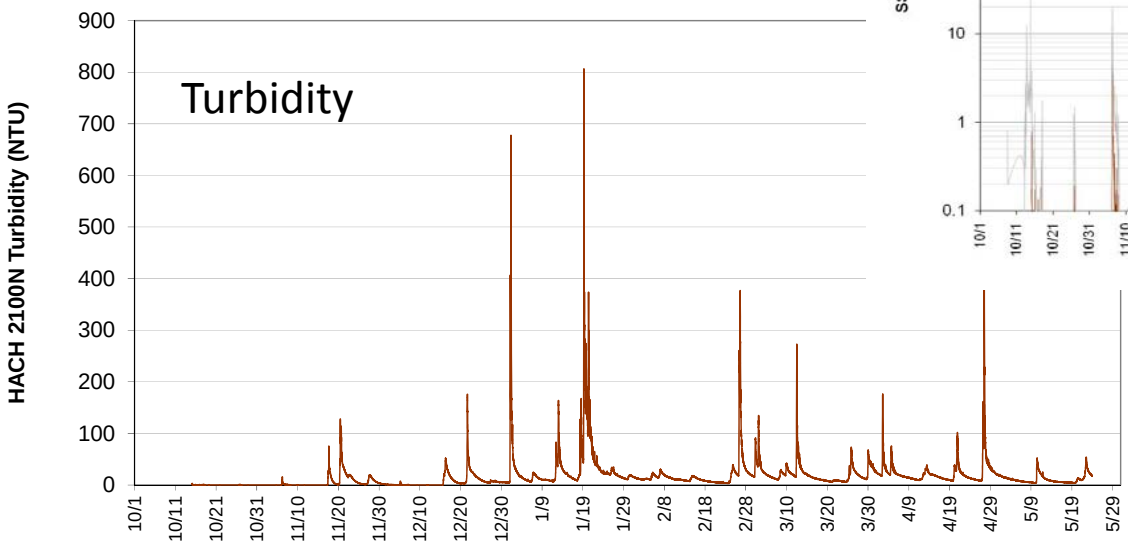
Water Quality Trend Monitoring

- Run-of-the-River
- TTS (but not exactly)

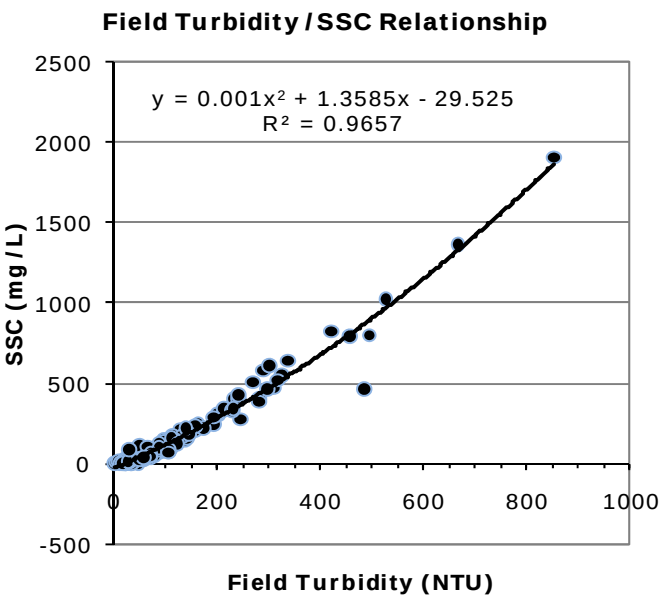
Water Quality Data

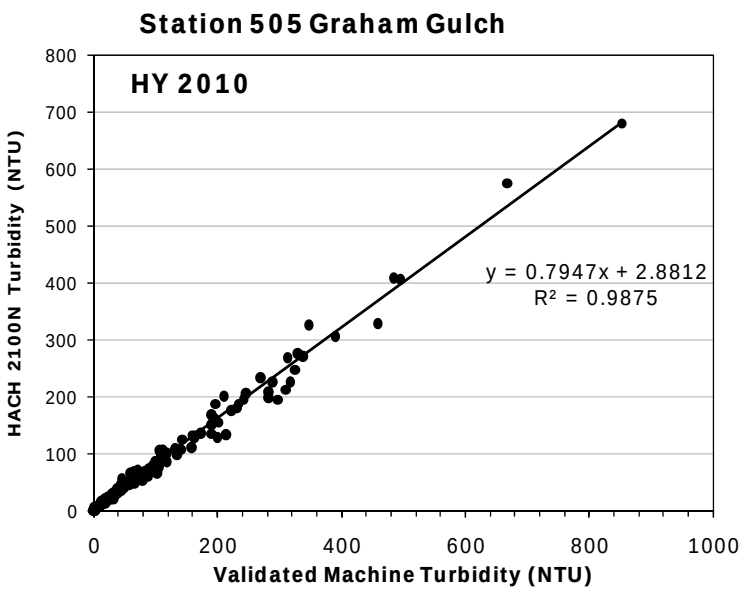


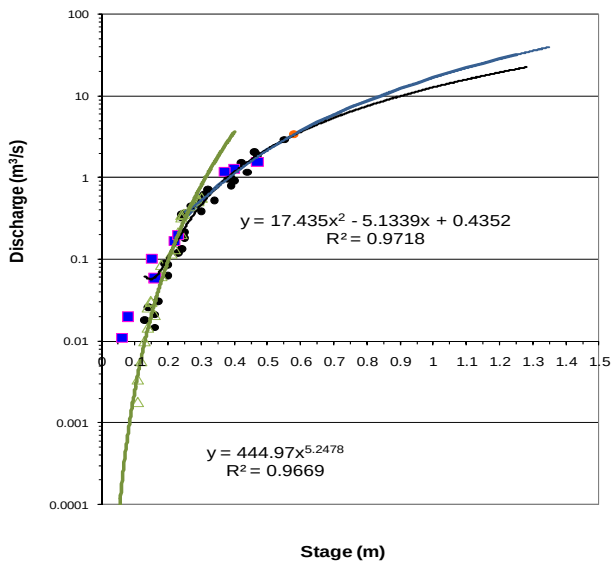


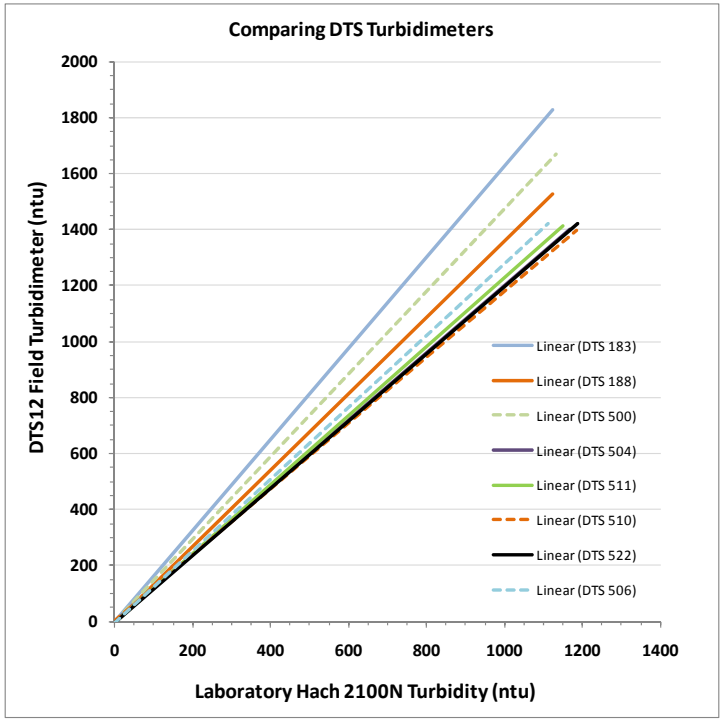


WQ Relationships





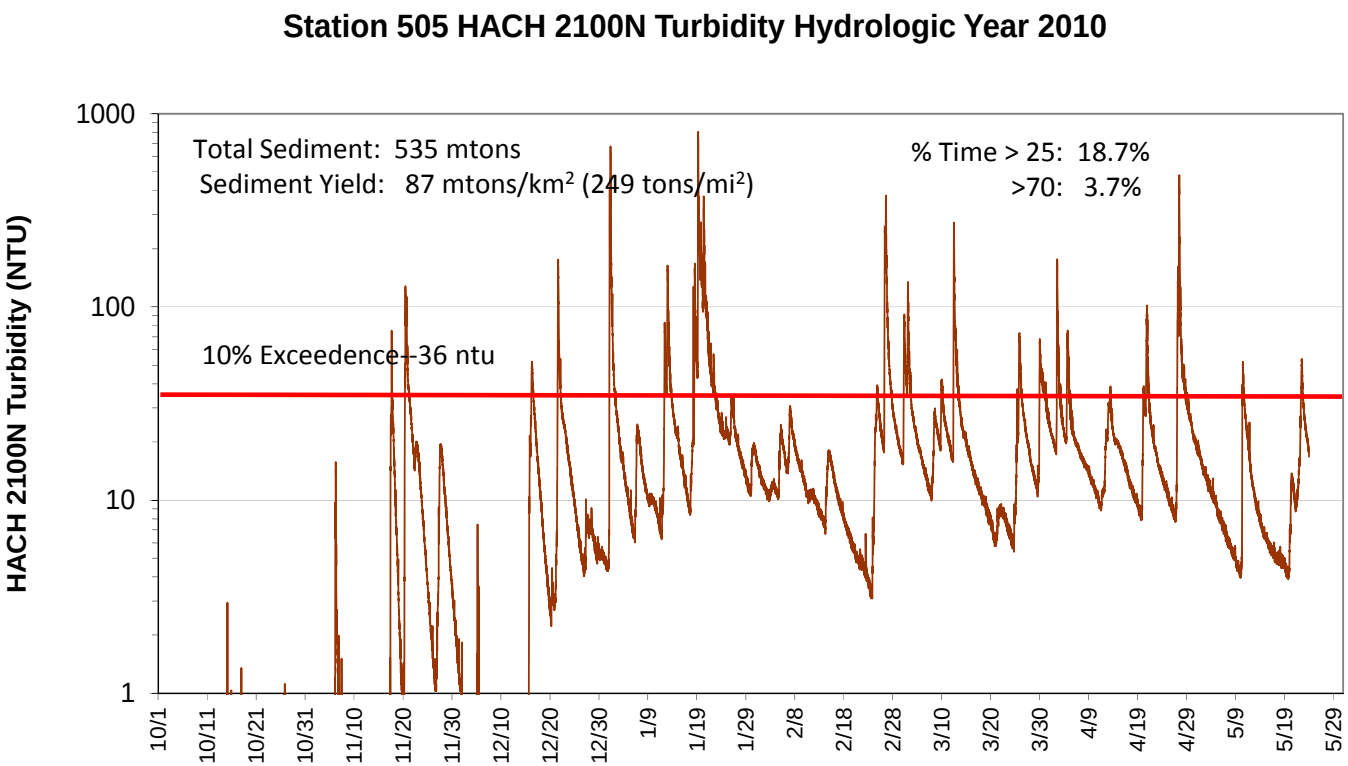




HRC Standard Data Set

Station 505 2010		Measured Data							Q Calculations					Sediment Calculations			Total Q (m^3)	Total Sediment (metric tons)
Site	Date:time	Temp (^0C)	Depth (m)	Turb NTU	**Validated Turbidity (NTU)**	Turb Validation Code	**Validated Depth (m)**	Depth Validation Code	Stage (m)	Q (cms)	Unit Area Q ($m^3/s/km^2$)	Time Interval (min)	**Q per Interval (m^3)**	HACH 2100N Turbidity (NTU)	SSC (mg/L) (g/m^3)	**Sediment (kg)**	**2,777,900**	**535.8**
HRC505	1/19/10 2:00	9.6	0.212	57.8	57.8	111	0.212	111	0.33	0.663	0.108	15	596.5	45.9	42.78	25.5	87 mtons/km^2	
HRC505	1/19/10 2:15	9.6	0.21	57.3	57.3	111	0.21	111	0.33	0.626	0.102	15	563.2	45.5	42.24	23.8		
HRC505	1/19/10 2:30	9.6	0.21	54.1	54.1	111	0.21	111	0.33	0.626	0.102	15	563.2	42.9	38.85	21.9		
HRC505	1/19/10 2:45	9.6	0.211	59.6	59.6	111	0.211	111	0.33	0.644	0.105	15	579.7	47.3	44.73	25.9		
HRC505	1/19/10 3:00	9.6	0.212	54.4	54.4	111	0.212	111	0.33	0.663	0.108	15	596.5	43.2	39.16	23.4		
HRC505	1/19/10 3:15	9.6	0.213	65.0	65	111	0.213	111	0.34	0.682	0.111	15	613.5	51.6	50.76	31.1		
HRC505	1/19/10 3:30	9.6	0.213	62.3	62.3	111	0.213	111	0.34	0.682	0.111	15	613.5	49.4	47.71	29.3		
HRC505	1/19/10 3:45	9.6	0.216	61.2	61.2	111	0.216	111	0.34	0.740	0.120	15	666.0	48.6	46.49	31.0		
HRC505	1/19/10 4:00	9.5	0.218	64.8	64.8	111	0.218	111	0.35	0.780	0.127	15	702.3	51.4	50.53	35.5		
HRC505	1/19/10 4:15	9.5	0.222	72.1	72.1	111	0.222	111	0.36	0.864	0.140	15	777.8	57.2	59.03	45.9		
HRC505	1/19/10 4:30	9.5	0.23	97.4	97.4	111	0.23	111	0.38	1.046	0.170	15	941.0	77.4	91.59	86.2		
HRC505	1/19/10 4:45	9.5	0.236	117.7	117.7	111	0.236	111	0.40	1.193	0.194	15	1073.8	93.0	119.58	128.4		
HRC505	1/19/10 5:00	9.5	0.248	175.9	175.9	111	0.248	111	0.44	1.518	0.247	15	1366.6	139.1	214.73	293.5		
HRC505	1/19/10 5:15	9.5	0.259	300.3	300.3	111	0.259	111	0.47	1.852	0.301	15	1666.8	238.4	470.20	783.7		
HRC505	1/19/10 5:30	9.6	0.283	446.0	446	111	0.283	111	0.54	2.697	0.438	15	2426.9	354.4	836.95	2031.2		
HRC505	1/19/10 5:45	9.6	0.299	613.3	613.3	111	0.299	111	0.58	3.349	0.544	15	3013.8	487.2	1329.07	4005.6		
HRC505	1/19/10 6:00	9.6	0.327	805.7	805.7	111	0.327	111	0.66	4.662	0.757	15	4195.4	639.7	1975.23	8286.9		
HRC505	1/19/10 6:15	9.6	0.345	977.0	977	111	0.345	111	0.72	5.621	0.912	15	5058.8	776.4	2617.61	13242.0		
HRC505	1/19/10 6:30	9.6	0.351	1015.1	1015.1	111	0.351	111	0.73	5.961	0.968	15	5364.7	806.6	2766.96	14843.8		
HRC505	1/19/10 6:45	9.6	0.361	978.1	978.1	111	0.361	111	0.76	6.549	1.063	15	5894.5	777.2	2621.51	15452.4		
HRC505	1/19/10 7:00	9.6	0.361	908.6	908.6	111	0.361	111	0.76	6.549	1.063	15	5894.5	721.6	2353.17	13870.6		
HRC505	1/19/10 7:15	9.6	0.358	906.5	906.5	111	0.358	111	0.75	6.370	1.034	15	5732.9	720.0	2345.63	13447.3		
HRC505	1/19/10 7:30	9.6	0.355	744.0	744	111	0.355	111	0.74	6.193	1.005	15	5573.6	591.3	1761.38	9817.2		
HRC505	1/19/10 7:45	9.6	0.35	619.2	619.2	111	0.35	111	0.73	5.903	0.958	15	5313.1	491.9	1348.02	7162.1		
HRC505	1/19/10 8:00	9.6	0.346	543.1	543.1	111	0.346	111	0.72	5.677	0.922	15	5109.2	431.5	1114.22	5692.8		
HRC505	1/19/10 8:15	9.6	0.342	516.4	516.4	111	0.342	111	0.71	5.455	0.886	15	4909.3	410.1	1034.58	5079.0		
HRC505	1/19/10 8:30	9.6	0.34	466.4	466.4	111	0.34	111	0.70	5.345	0.868	15	4810.8	370.3	892.07	4291.6		
HRC505	1/19/10 8:45	9.6	0.339	421.7	421.7	111	0.339	111	0.70	5.291	0.859	15	4762.0	334.6	769.61	3664.9		

Water Quality Measures



Annual Values

Sediment Yield

(use turbidimeter)

Turbidity

--10% Exceedence

--% of time greater than

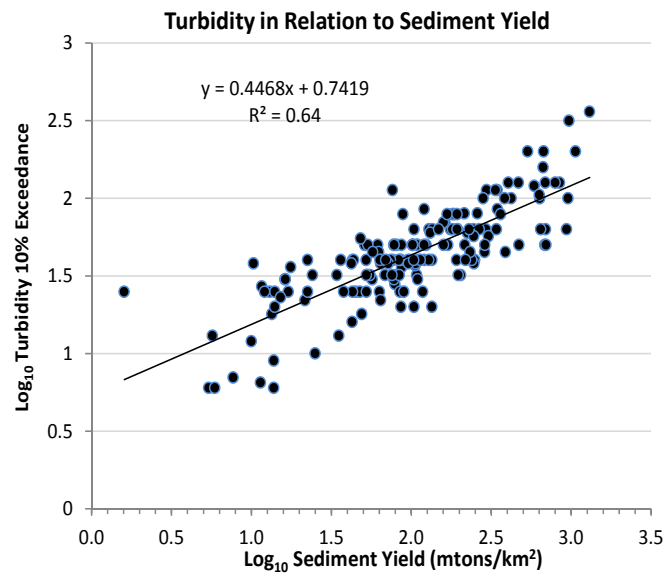
--25 ntu

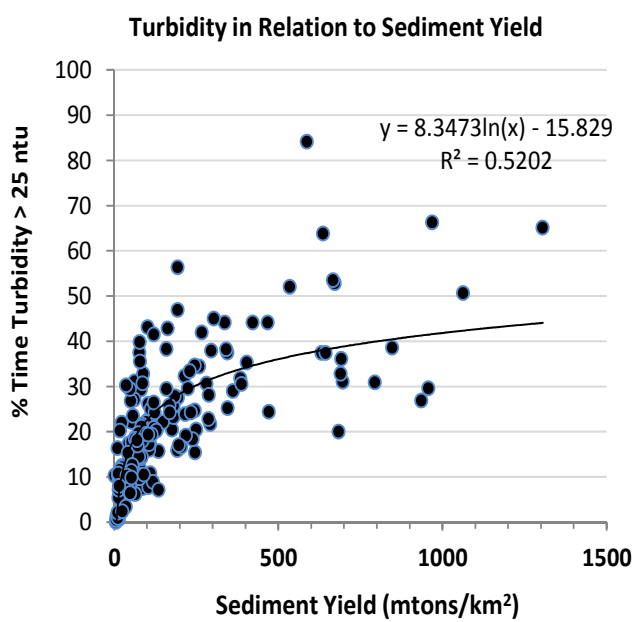
--70 ntu

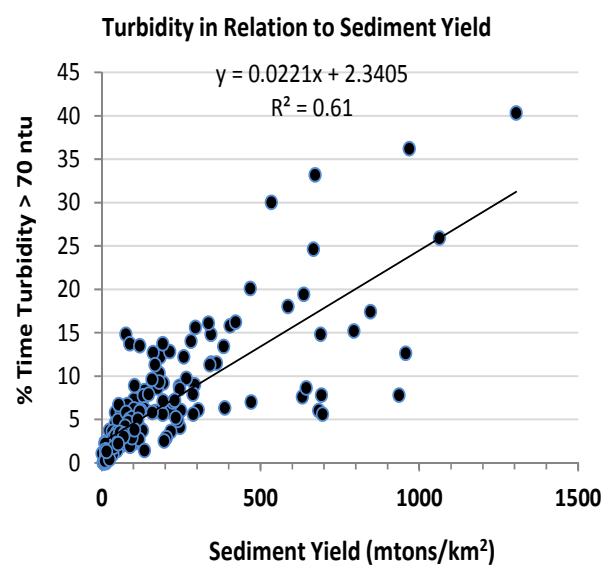
(use lab standardized)

Water Quality Parameters—Relationship to each other

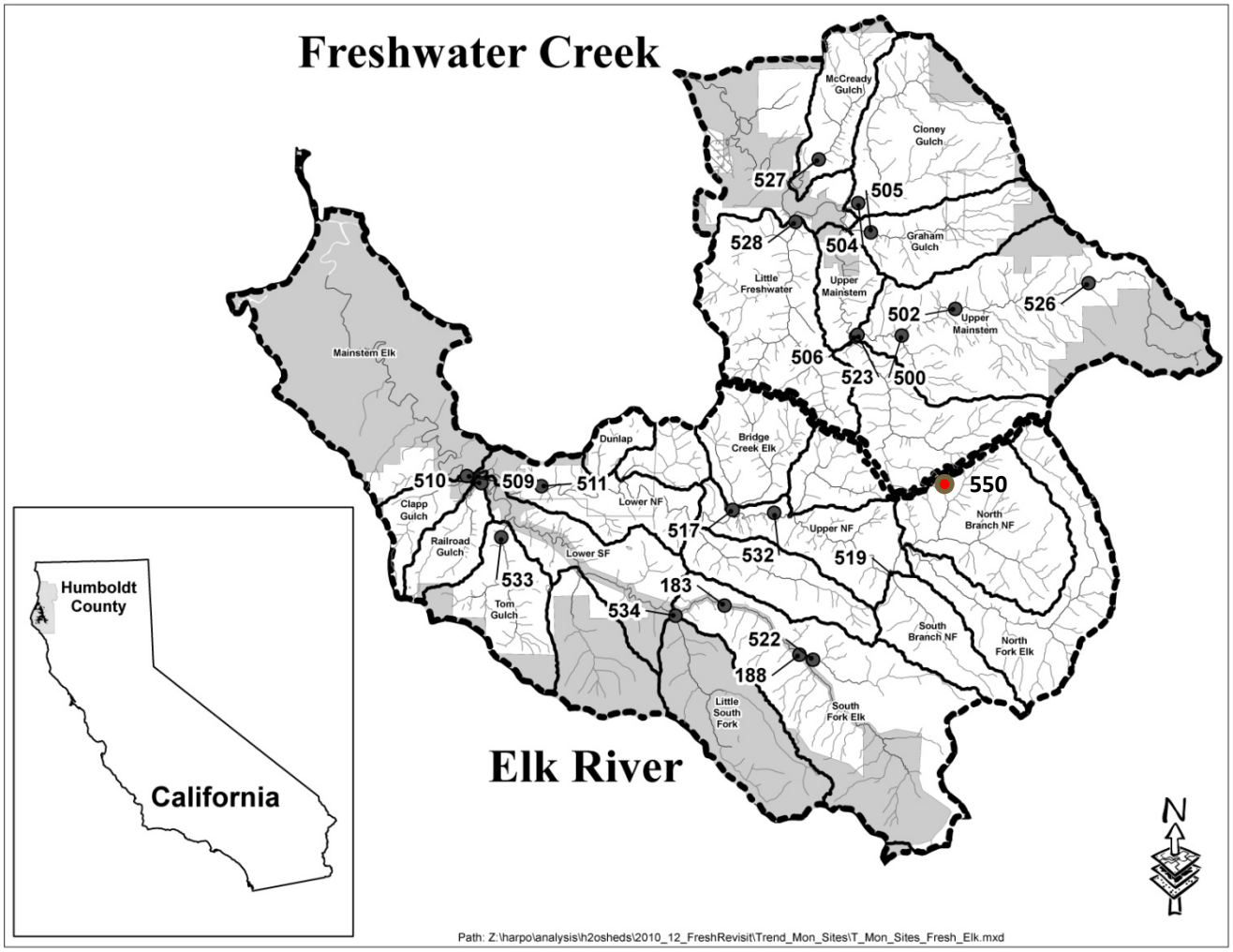
- **Sediment Yield**
- **Turbidity**
  - 10% Exceedence
  - % of Time > 25 ntu
  - % of Timbe> 70 ntu







WQ Monitoring Sites

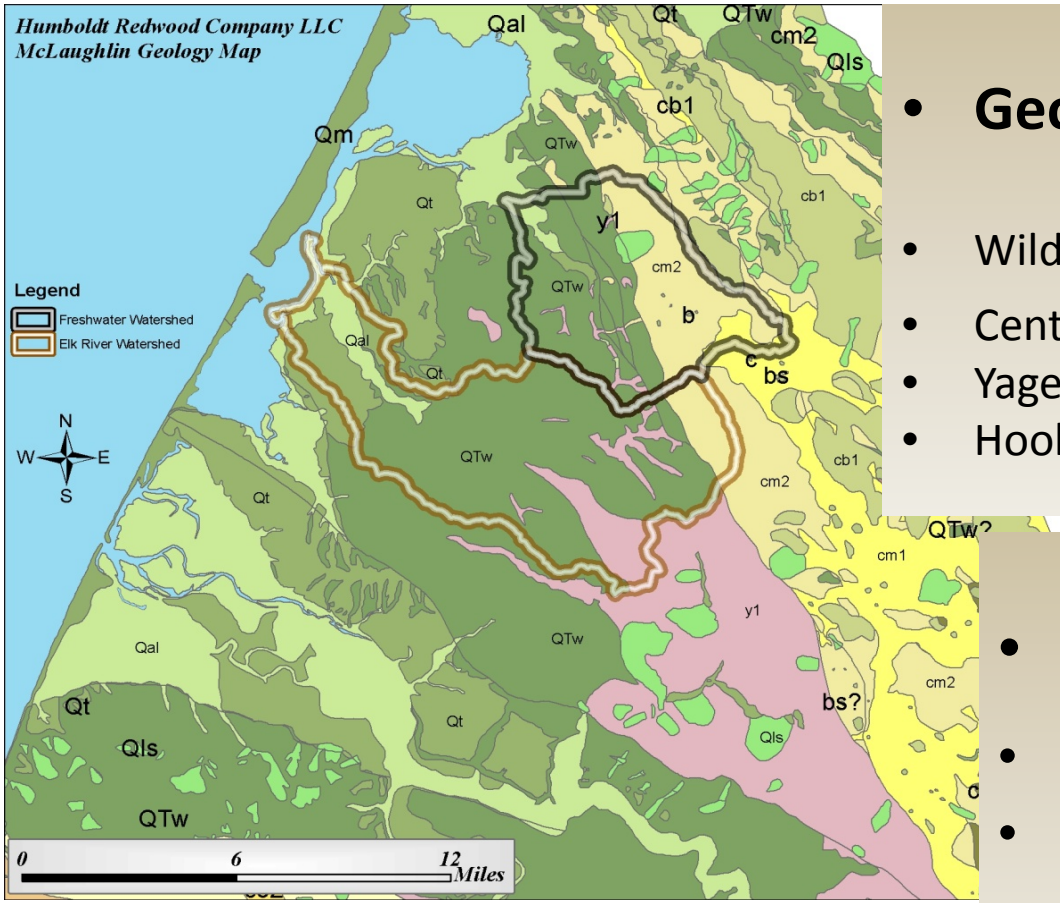


- 21 Sites
  - Brought online 2003-2006
- Basin Area

0.13 -111.0 km^2

- Management
  - 2 subbasins with no management
    - Old Growth 534
    - 60 yr SG 550
  - All others with harvest, road construction/ deconstructon

Sedimentary Geology



- **Geologic Formations**
- Wildcat
- Central Belt Franciscan
- Yager
- Hookton

- **Sedimentary Rocks**
- Poorly consolidated
- Fine-grained: clays, silts, sands to the west
- Coarse inclusions

South Fork Elk River Sites

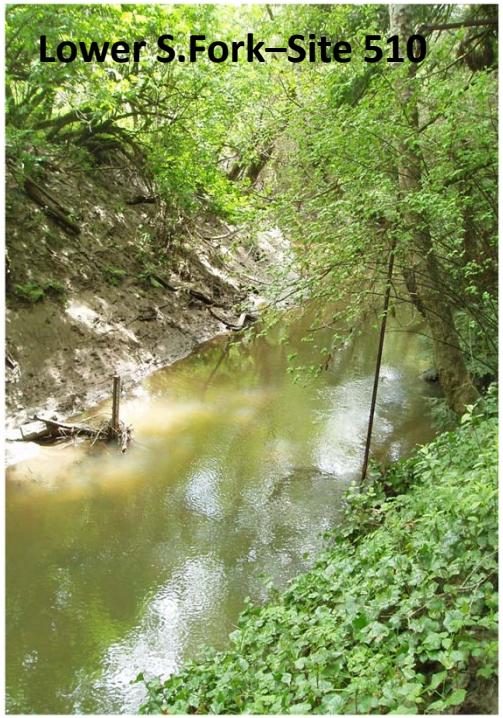
Corrigan Creek –Site 522

Tom Gulch –Site 533

Old Growth –Site 534

Upper S. Fork–Site 188

Lower S.Fork–Site 510



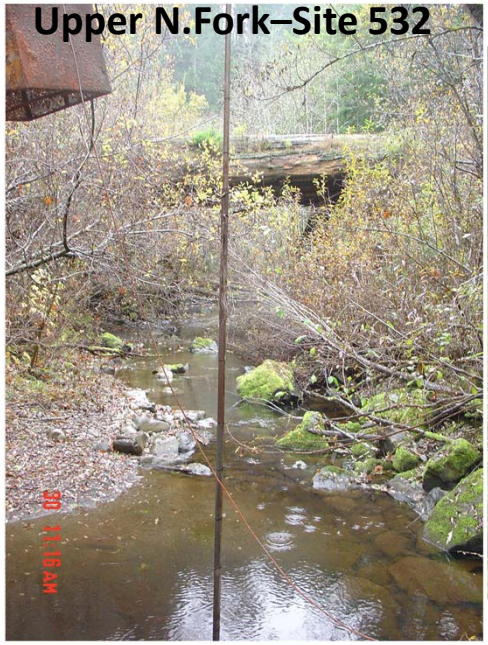
North Fork Elk River Sites

S. Branch N.Fork–Site 519

Tiny Trib–Site 550

Bridge Cr–Site 517

Upper N.Fork–Site 532



Lower N.Fork–Site 511

Mainstem Elk–Site 509

Freshwater Creek

S.Fork Freshwater–Site 506

Trib to Mainstem (Becks)–Site 500

Graham Gulch–Site 504

McCready Gulch–Site 505

Mainstem Freshwater–Site 502

Little Freshwater–Site 508

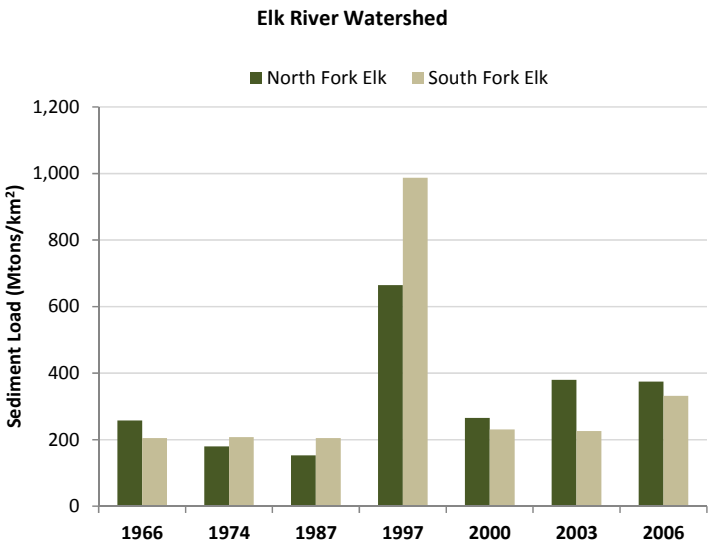
Formulating Hypotheses

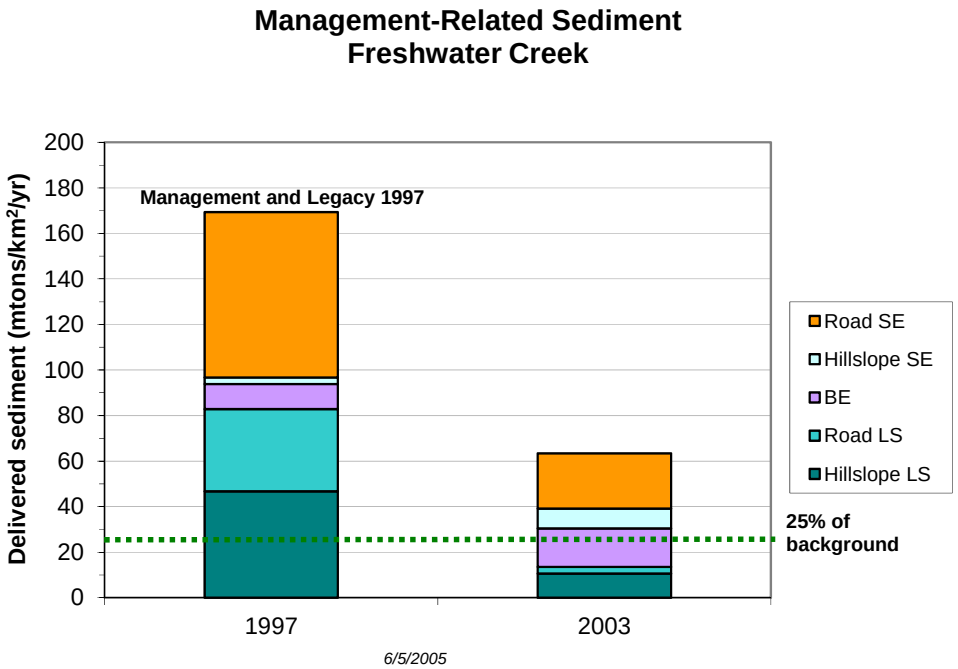
- **No excellent "unmanaged" controls**
  - Old growth and Legacy logging sites very helpful
  - Did not cover the entire span of the record
  - Uncertainties in data from the hard-to-access OG site
- **Management is on-going virtually everywhere**
  - "Preventive" measures probably eliminate sediment
  - On-going forest management activities probably produce sediment but at much lower rate than the past
  - Legacy sediment sources probably continue to produce sediment
  - "Restoration" activities probably produce and reduce sediment
- **No water quality data between 1997 and 2003**
  - Dec 1996 storm put huge volumes of sediment into the streams
  - How much of this material may still be in the streams?
- **Weather is important in determining annual yield**
  - Short water quality record
  - Must be addressed with absence of controls

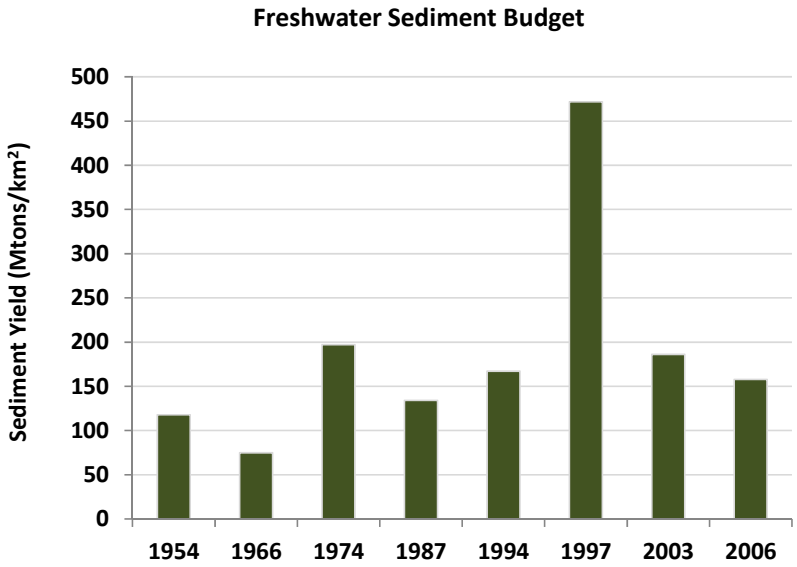
Formulating Hypotheses

Sediment Budgets used to develop hypotheses for sediment trends

- Many key sources readily observable
- Allowed assessment back to 1996





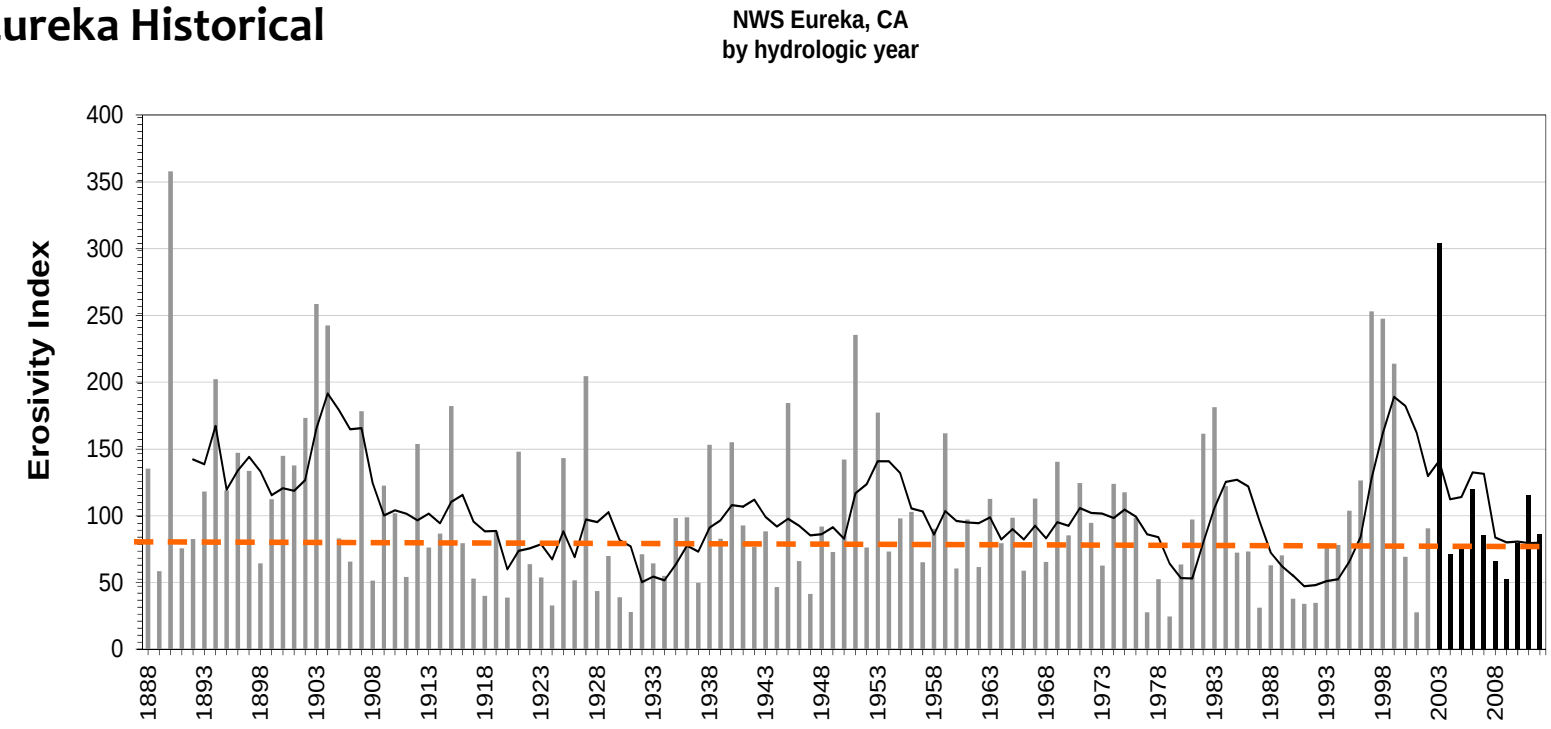


Formulating Hypothesis

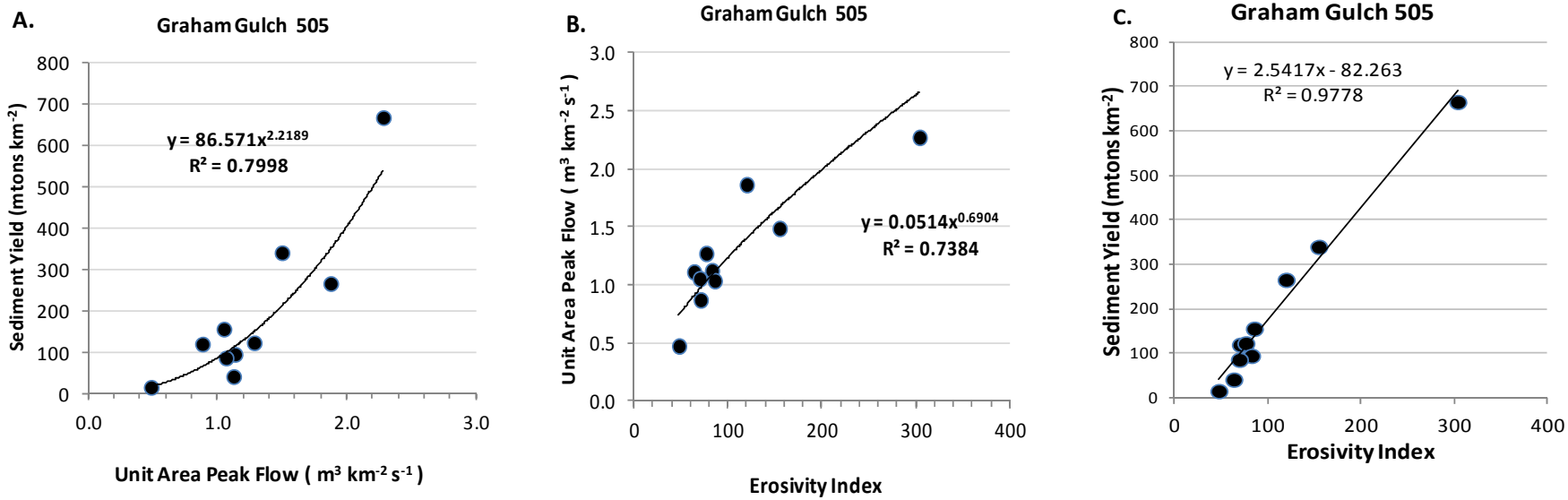
Weather Accounted for by the "Erosivity Index"

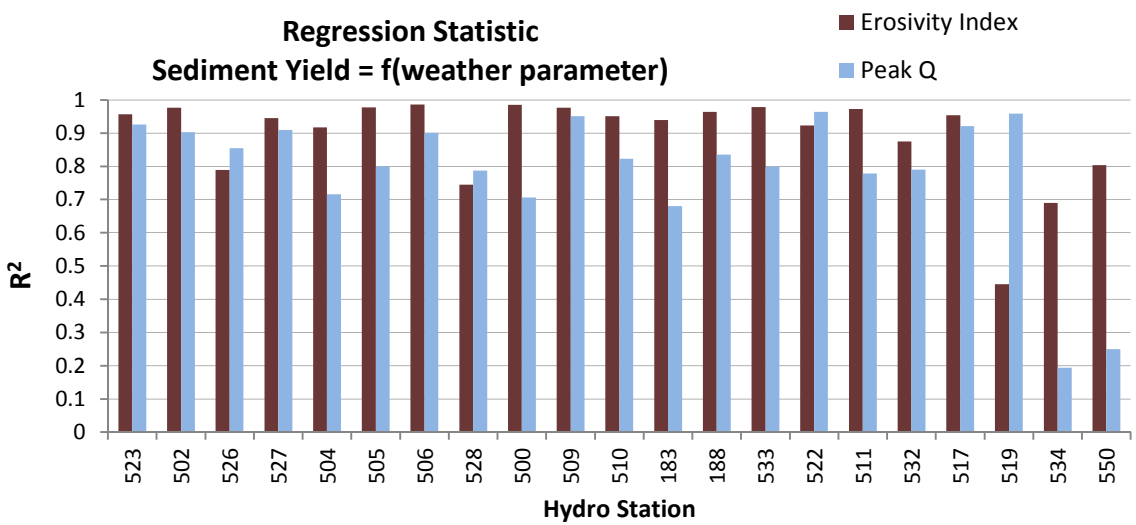
= Annual Rainfall (in.) x Maximum Daily Rainfall (in.)

Eureka Historical

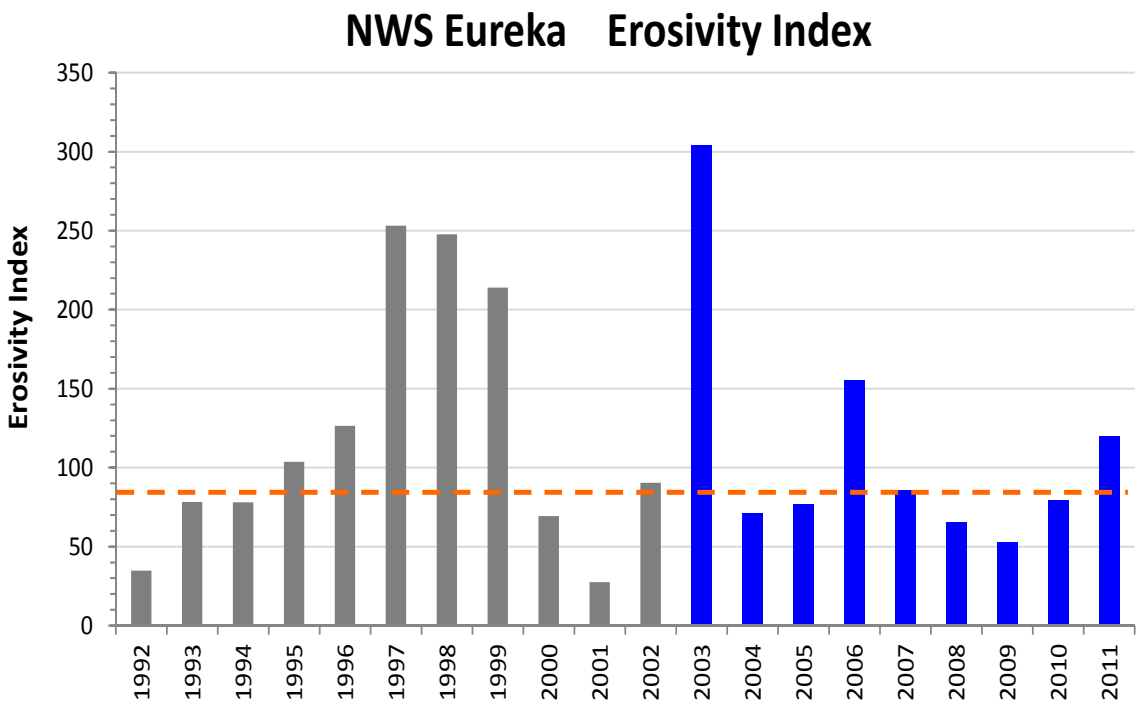


Erosivity Index and Annual Unit Area Peak Q effective in explaining sediment yield in this dataset



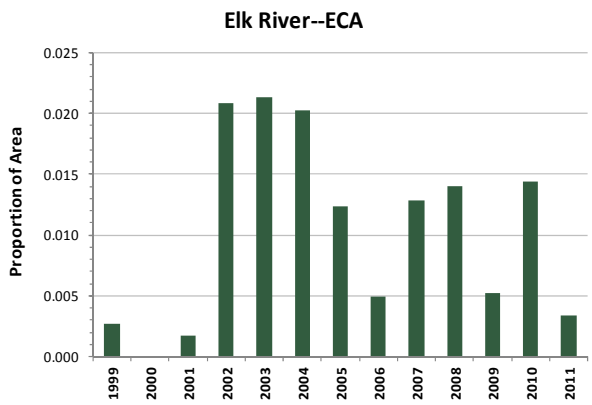


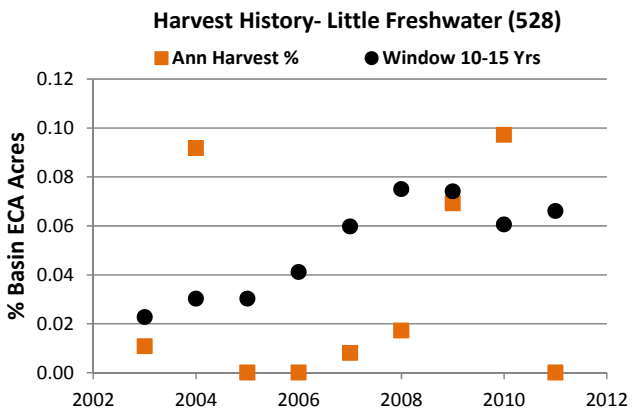
Weather during the study period



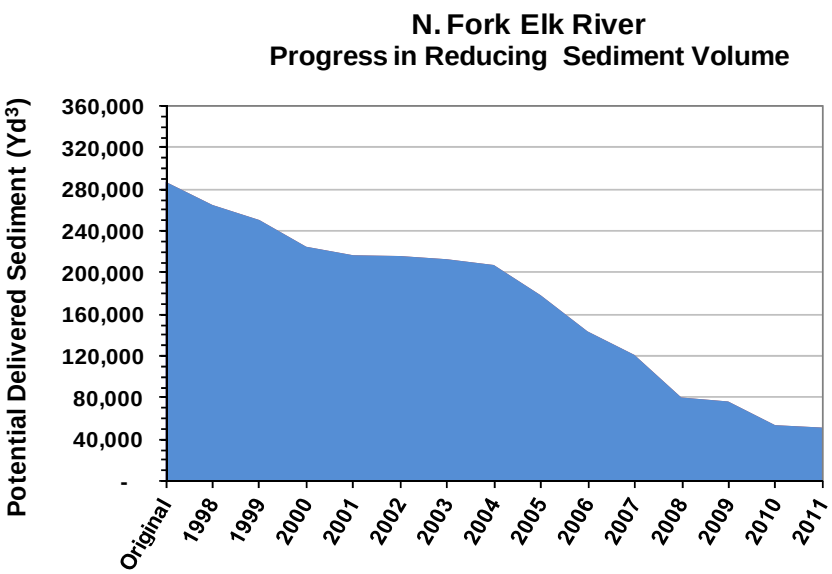
- Declining trend generally
- Monitoring begins with very big year RI-- 62 years
- 3 larger years– "channel forming events"
- Decreasing trend in those as well

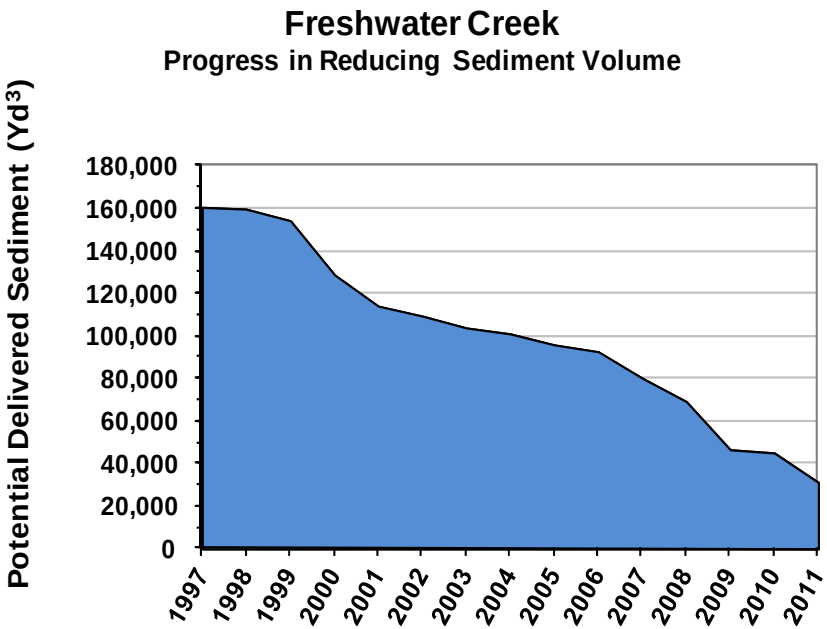
Formulating Hypotheses- Management Factors





Road Work


N. Fork Elk River
Progress in Reducing Sediment Volume
Potential Delivered Sediment (Yd³)
360,000
320,000
280,000
240,000
200,000
160,000
120,000
80,000
40,000
-
Original
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011


Freshwater Creek
Progress in Reducing Sediment Volume
Potential Delivered Sediment (Yd³)
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011

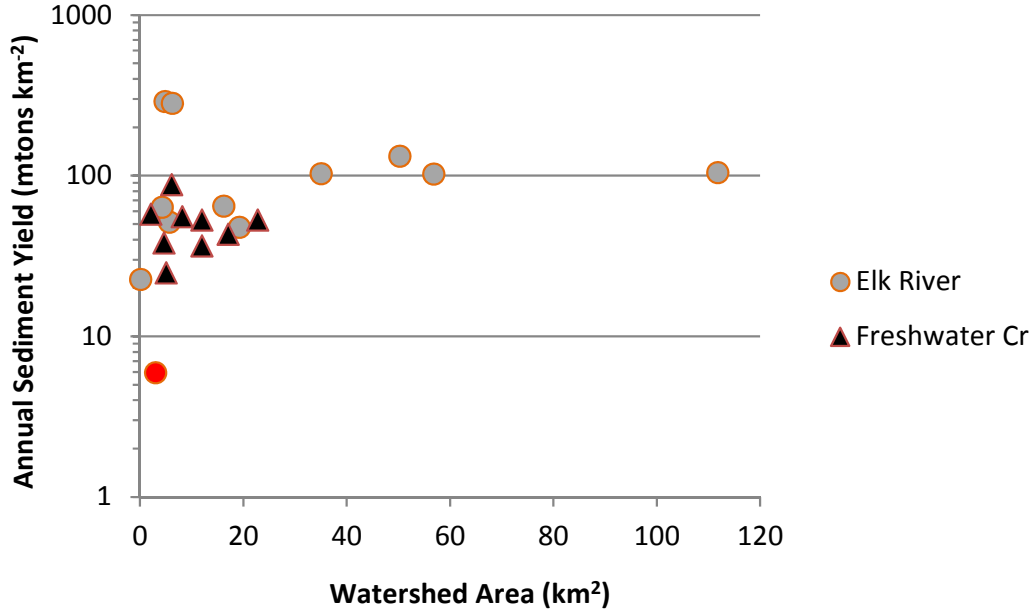
Multivariate Statistics

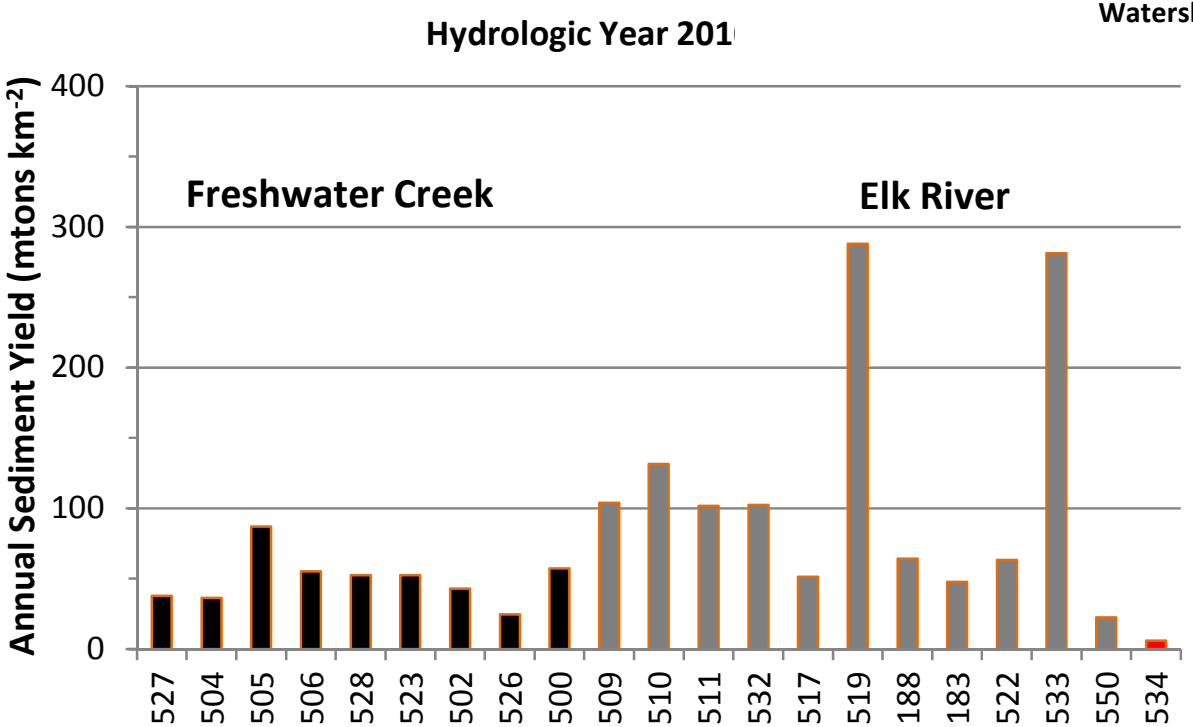
Characteristic	Parameters	Indicates
Sediment Response Variables	▪ **Annual suspended sediment yield (metric tonnes km^{-2})** ▪ 10% turbidity exceedance ▪ Percent of time exceeding 25 NTU ▪ Percent of time exceeding 70 NTU	▪ Total weight of suspended sediment exported from watershed each year ▪ Water quality defined relative to salmonid habitat
Independent Variables		
Watershed-related	▪ Basin area (km^2)	▪ Watershed size
Weather-related	▪ Annual Peak Q ($m^3 s^{-1} km^{-2}$) ▪ Erosivity Index (unitless)	▪ Flow ▪ Rainfall
Timber Harvest Activity	Equivalent clearcut area (ECA), % of watershed area ▪ Annual 1-yr harvest rate ▪ 2-yr harvest rate ▪ Previous 10-15 year harvest rate ▪ Previous 10 -year harvest rate	▪ Active harvest activity including harvest, road use, site preparation ▪ Historic harvest rate (suggested by Klein et al. 2012)
Roads	▪ Sediment Removal (cubic yards) ▪ Sediment Volume Remaining (cubic yards)	▪ Indicator of road construction/deconstruction disturbance ▪ Indicator of erodible material from untreated road crossing sites
Time	▪ Year	▪ Cumulative effects of HCP management practices

Overview of Analysis

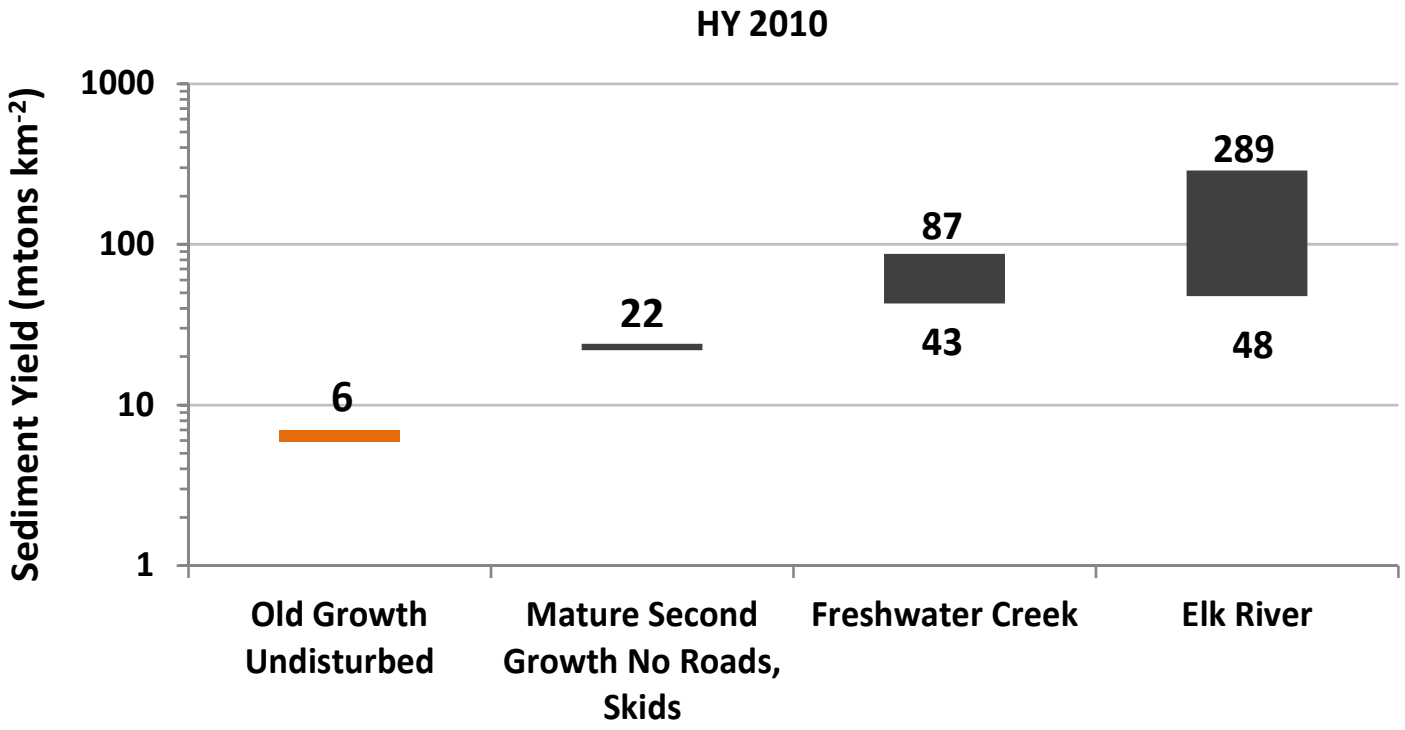
- **Spatial Patterns of Sediment Yield**
- **Temporal trends in sediment yield and turbidity**
- **Relationship of sediment budgets to sediment yield**
- **Relationship of management activities to observed sediment yield and turbidity**
  - Assess active and legacy effects
  - Review results relative to Klein et al. 2012
- **Legacy sediments**
- **Lower Elk River Deposition Zone**

Spatial Pattern of Sediment Yield

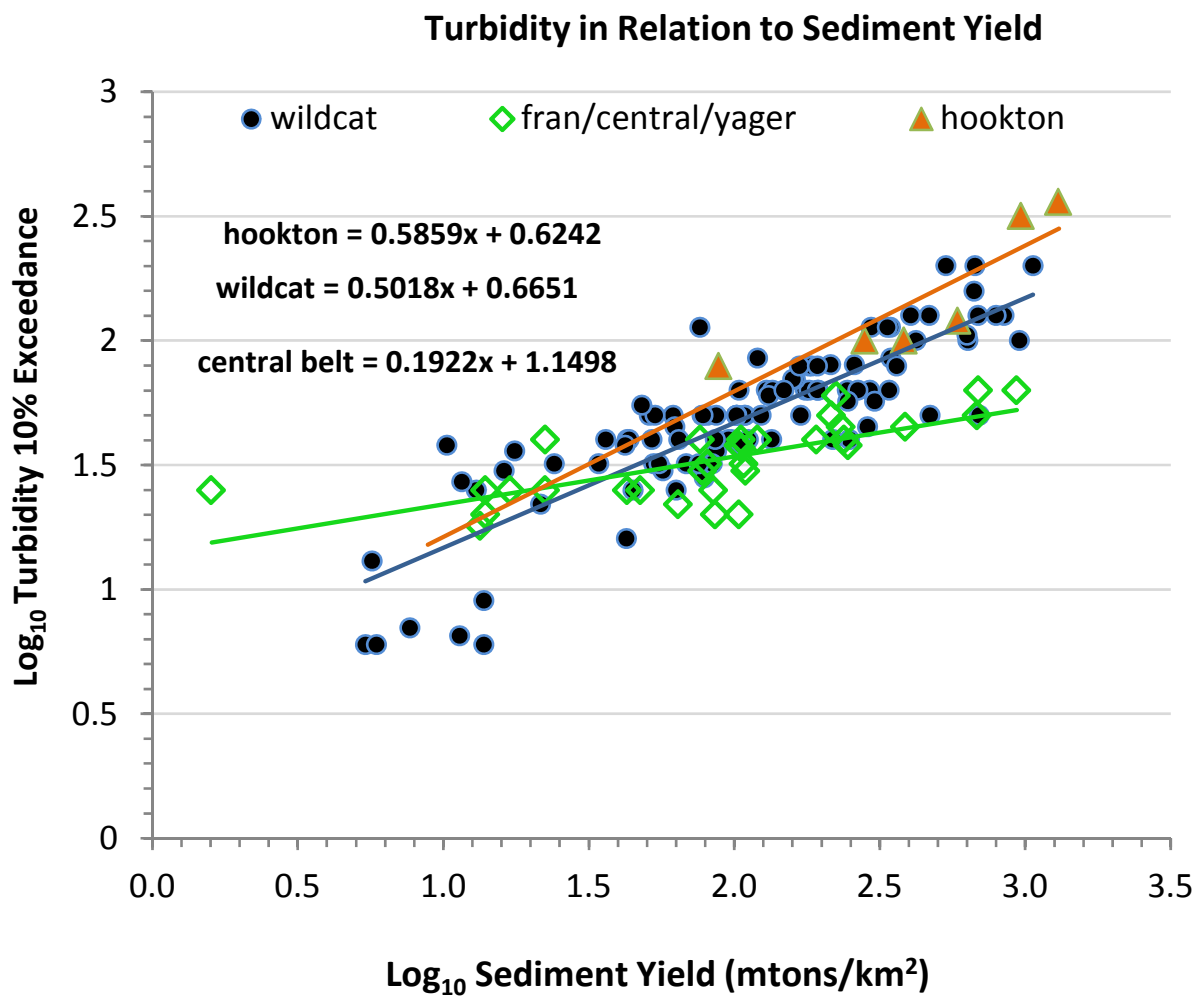




Grouped by General Management Category

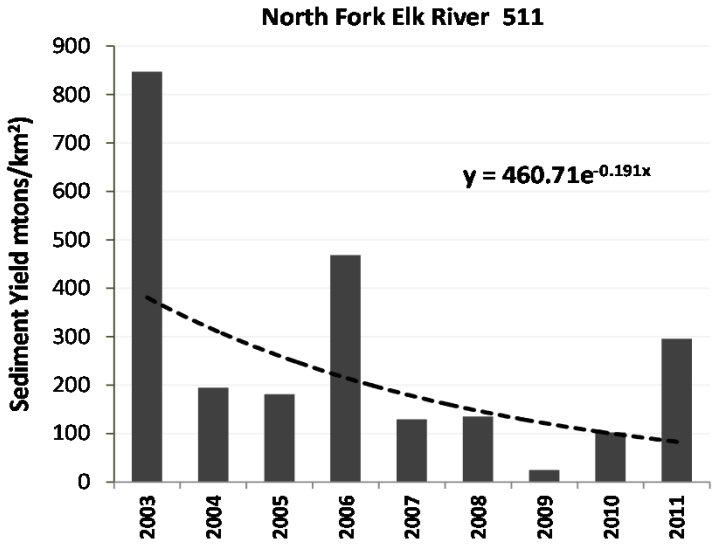


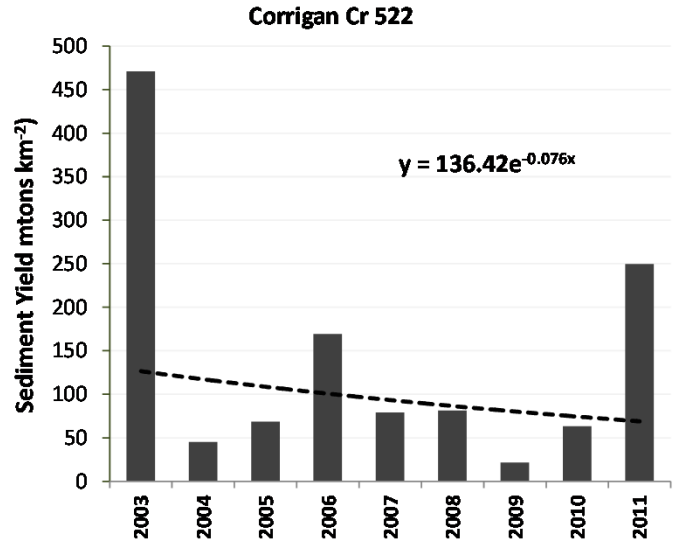
Geology influence on turbidity

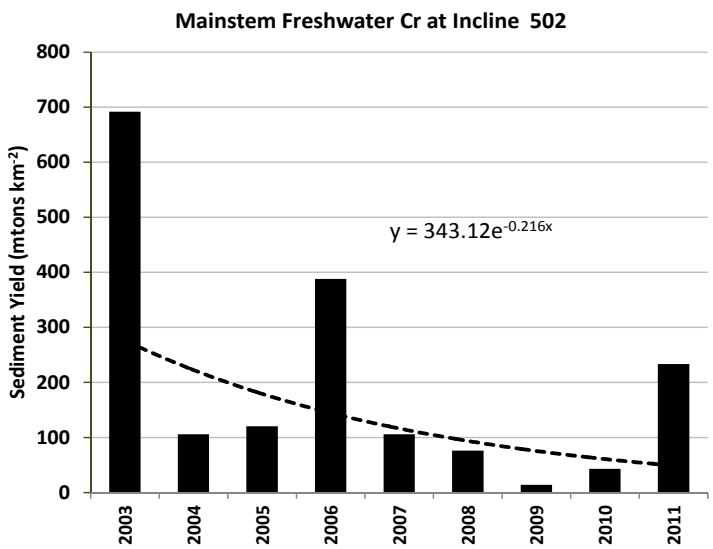


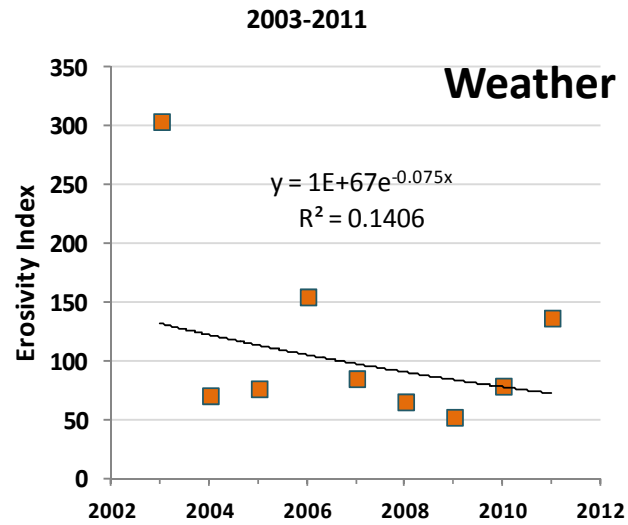
TEMPORAL TRENDS

Sediment Yield at 19 of 21 stations followed this pattern



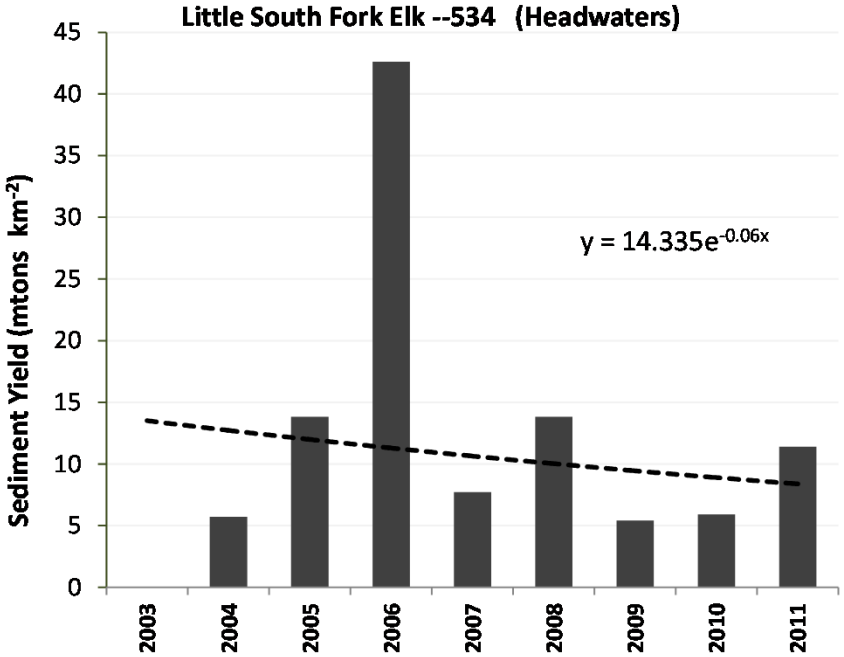


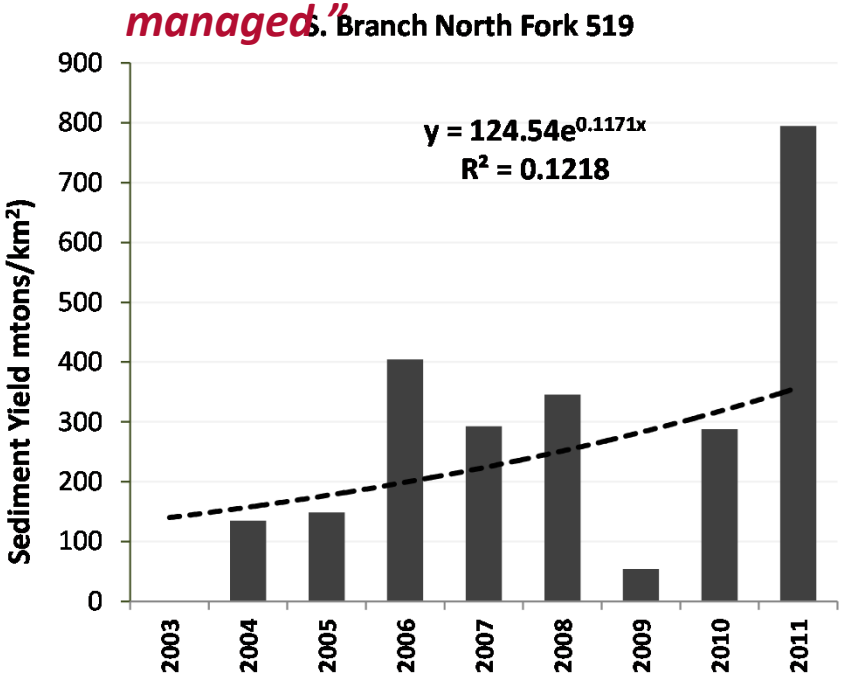




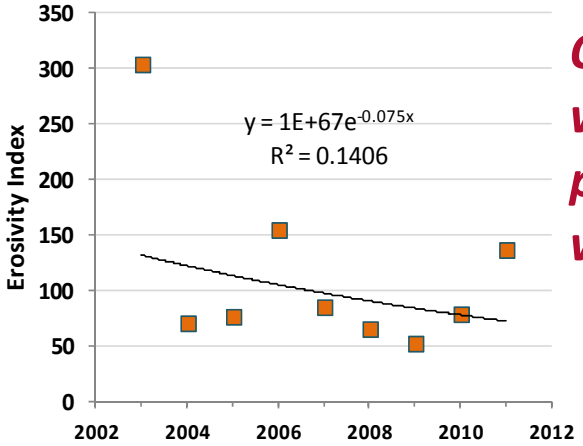
The other two sites

NCRWQCB uses as reference for "heavily managed."



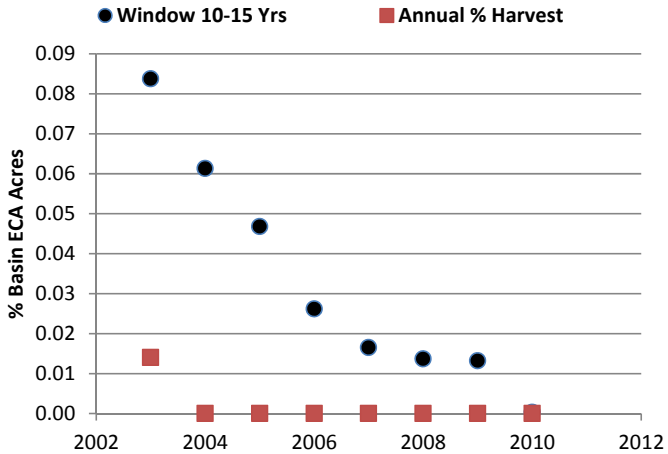


2003-2011

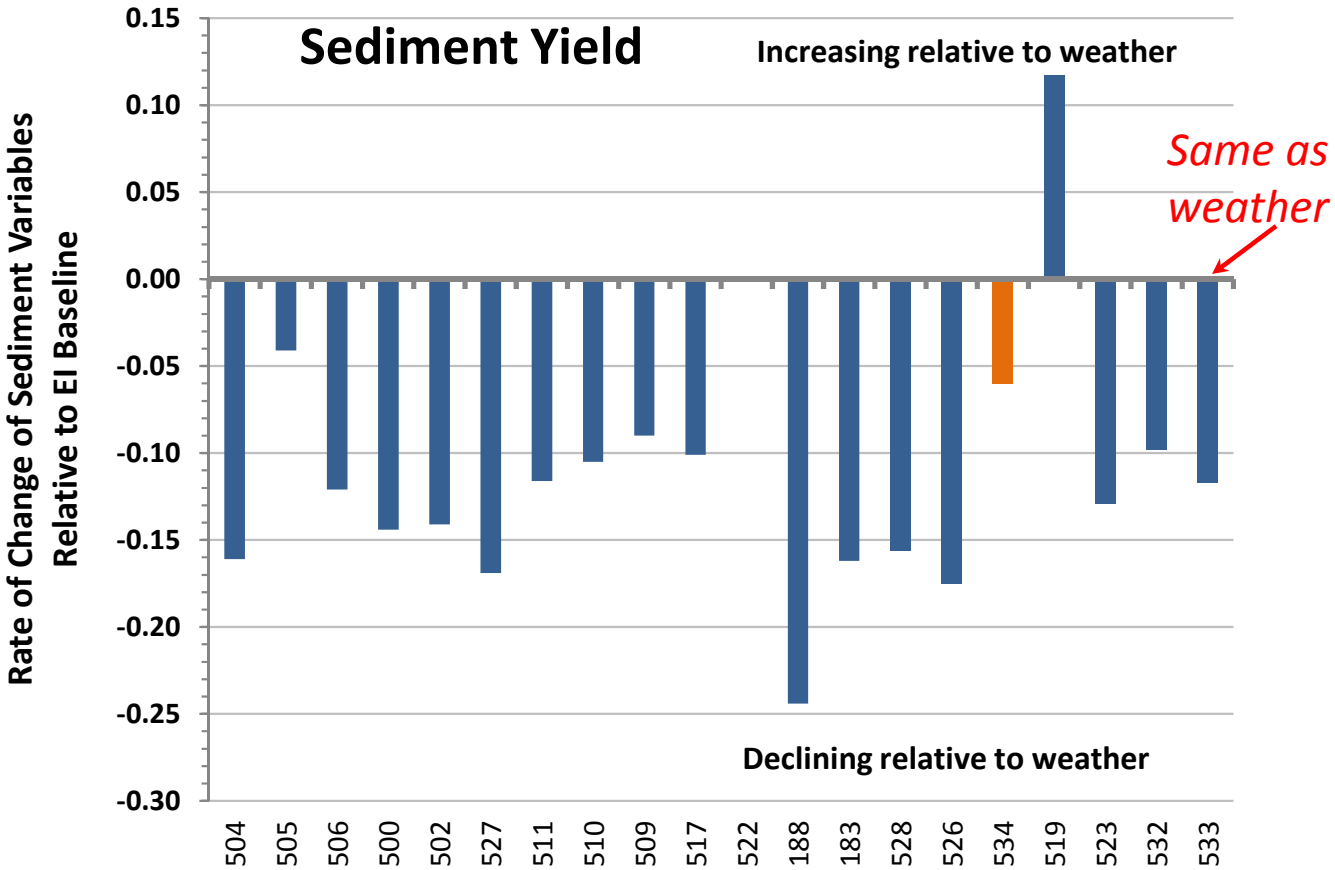


Old growth watershed pattern matched weather

Harvest History--S. Branch N. Fork Elk (519)



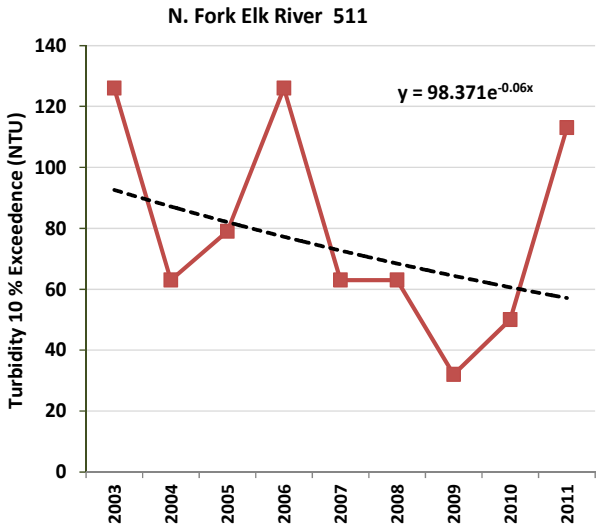
Relative change in sediment yield relative to erosivity index e^{-kt}

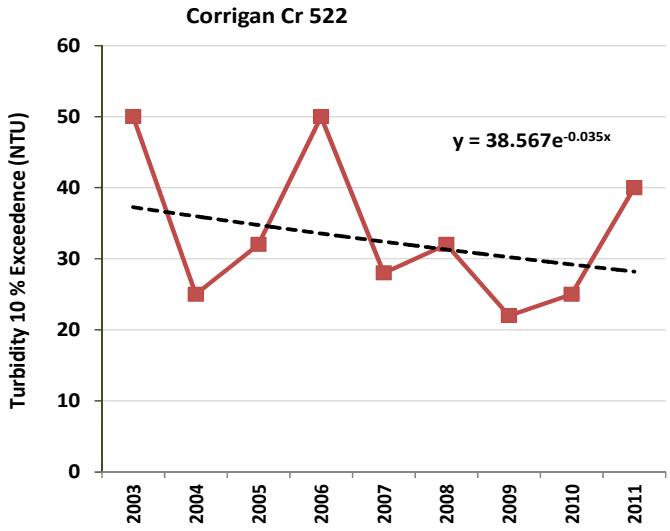


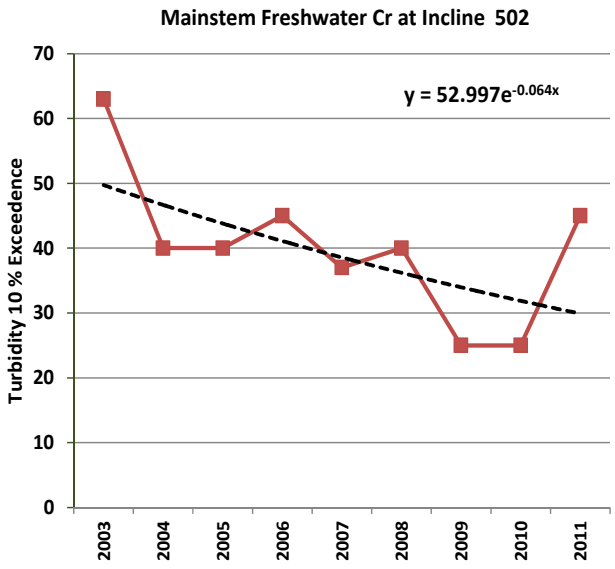
- Sediment yield generally declined during the period
- Average about 10% in this analysis
- A few exceptions

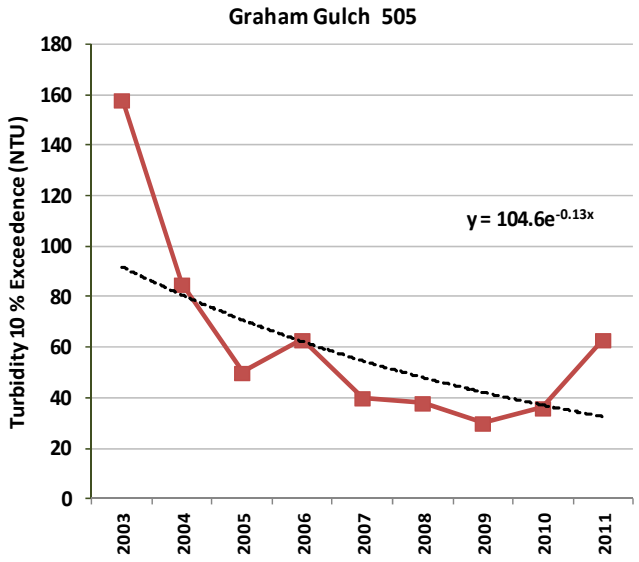
Site "k" – EI "k"

10% Exceedence Turbidity

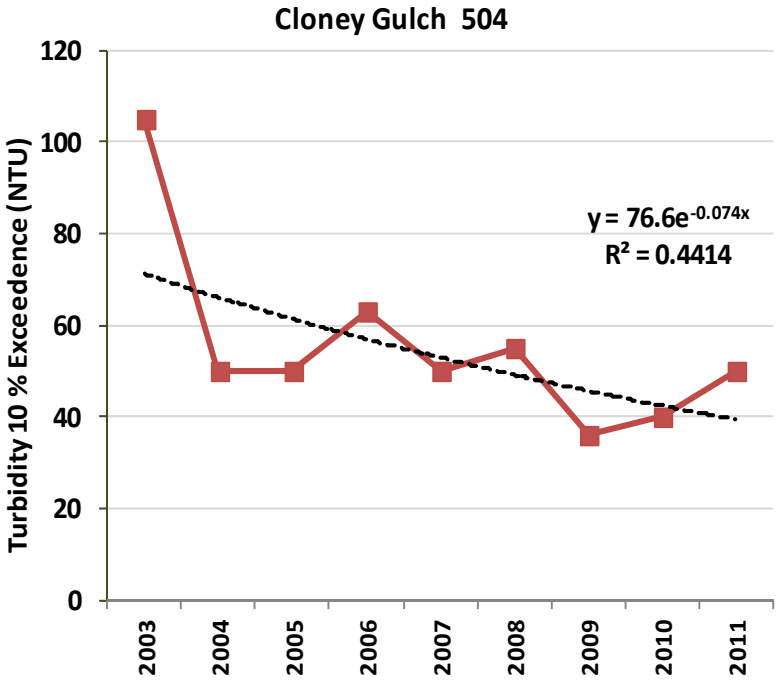


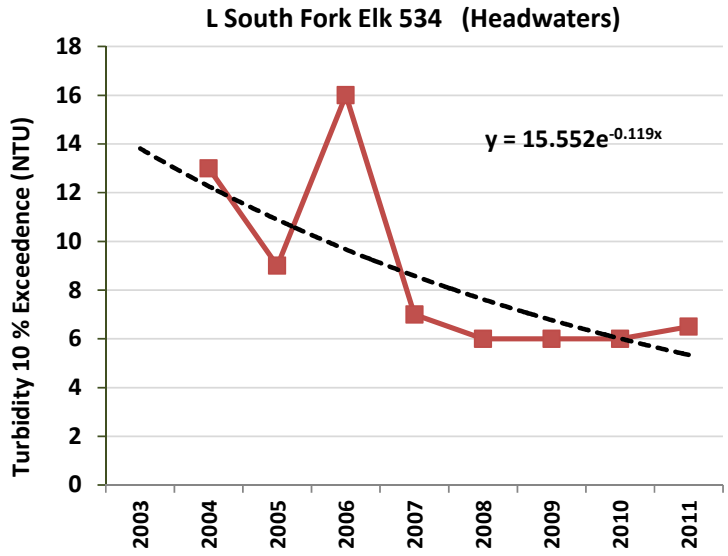


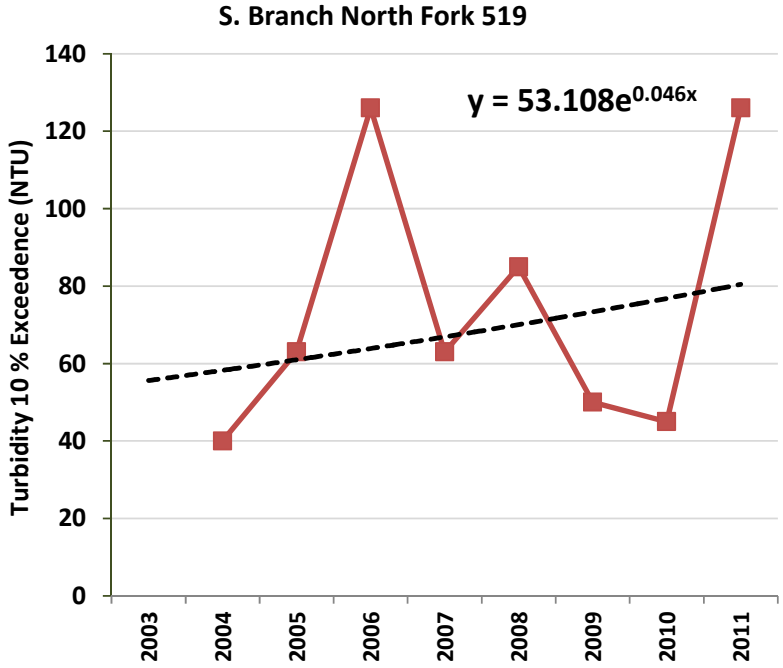




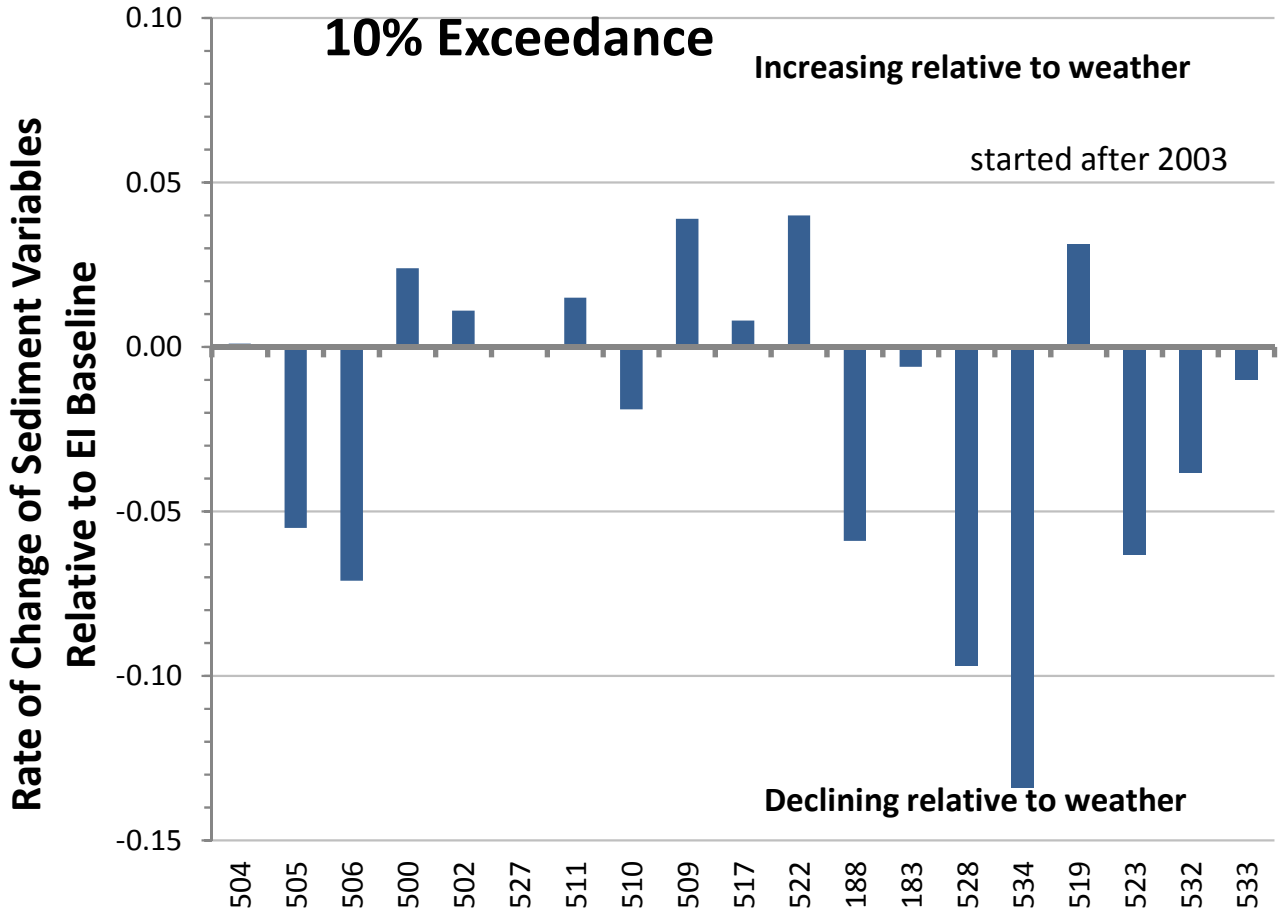
10% Turbidity Exceedence







10% Turbidity Exceedence



More subdued response generally

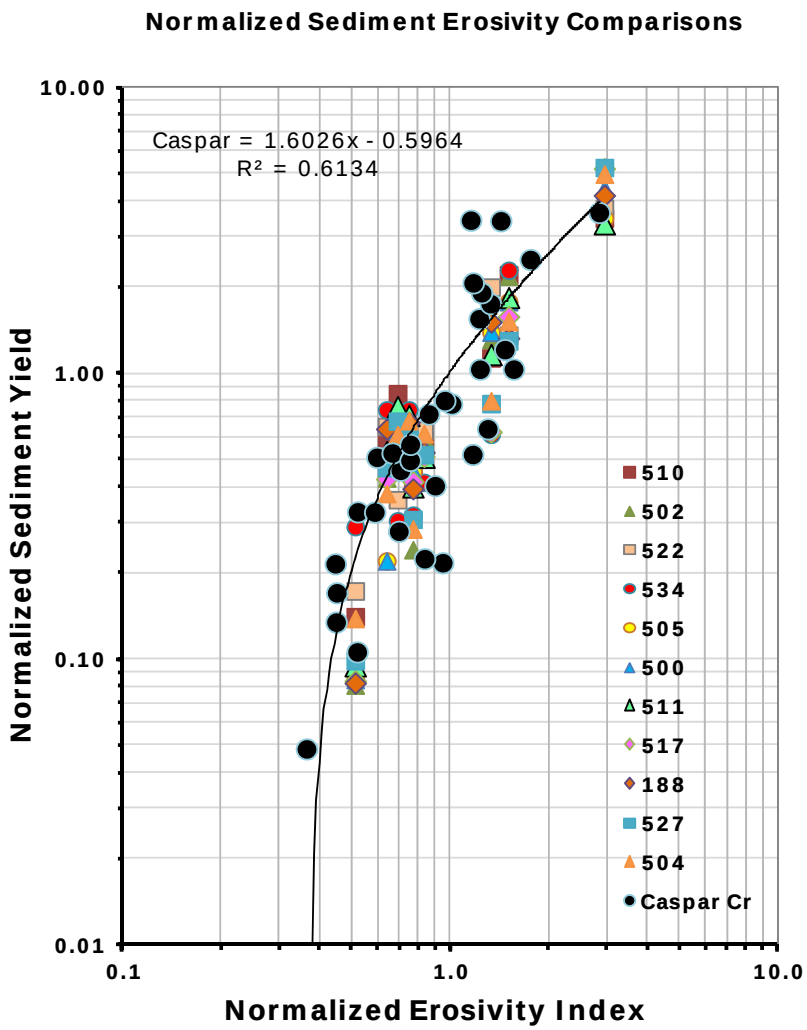
Turbidity probably has not declined significantly as a whole

Most strongly declining was old growth site

When rainfall erosivity is accounted for, North Coast streams appear to behave similarly

Normalized =

$$\frac{\text{Annual Value}}{\text{Long-term Average}}$$



Long-term Average Erosivity Index

Eureka (125 years)
102

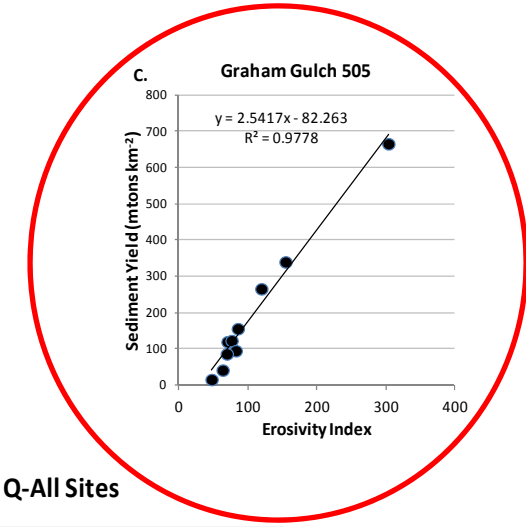
Caspar Cr (43 years)
146

Long-term Average Sediment Yield

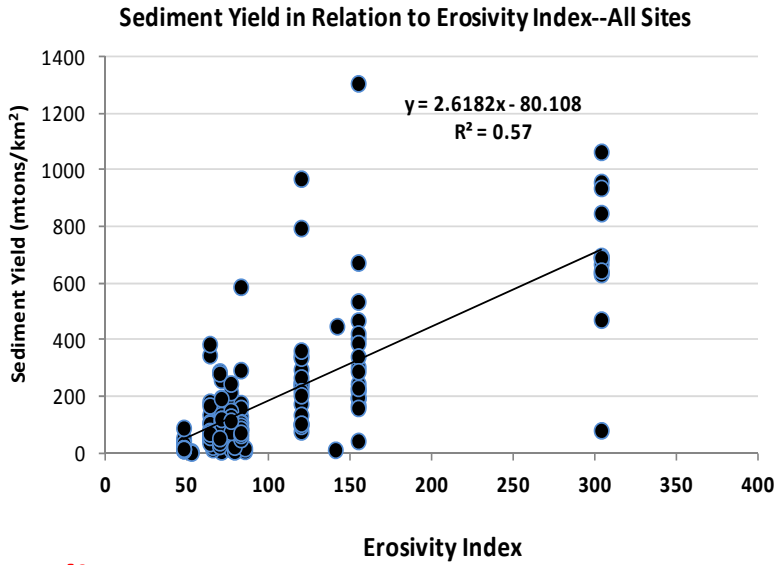
S. Fork Caspar
(excluding mgt yrs)
56 mtons km^2

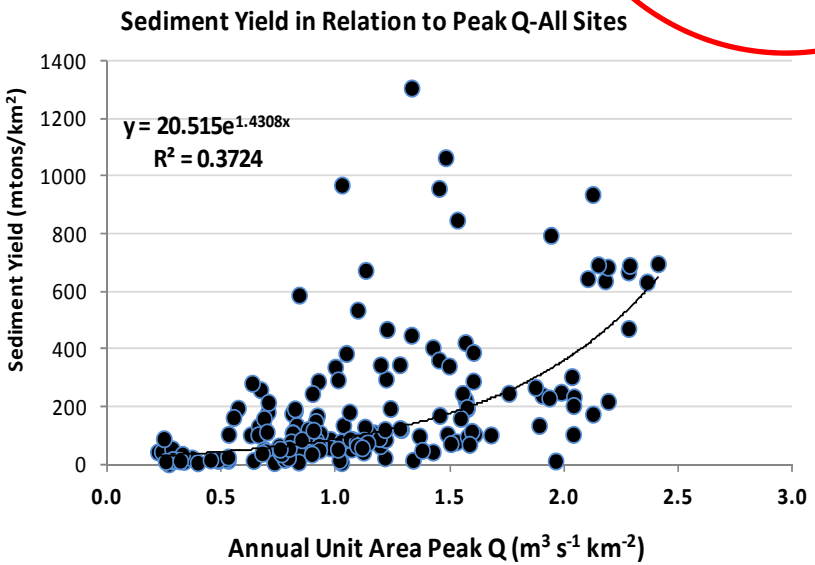
Weather Indices

At a site R^2= 0.70-0.98



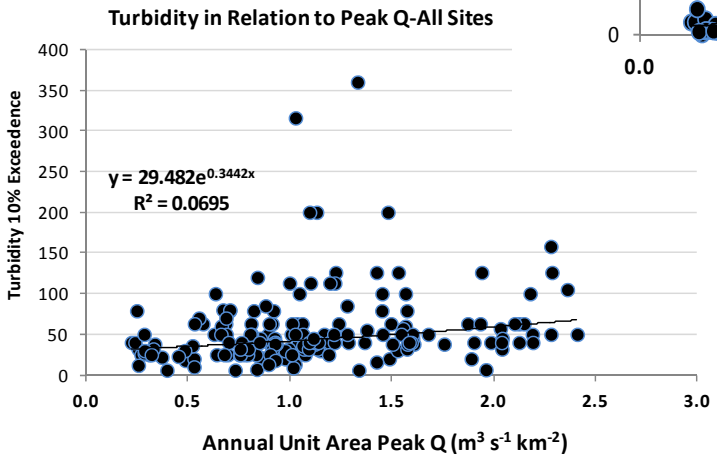
Indices do a good job explaining the relative difference from year to year at each site





Sediment sources determine the relative amount of sediment at each site

R^2 .07 -.57



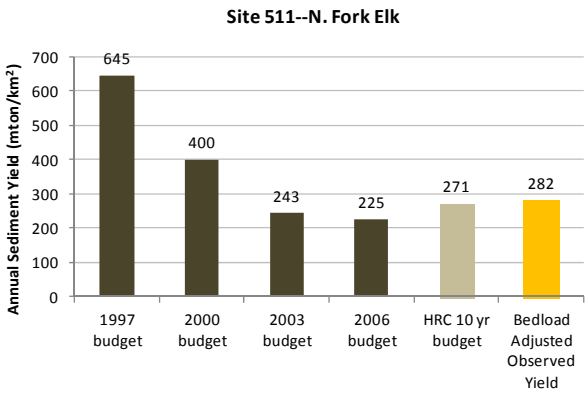
What do we know so far?

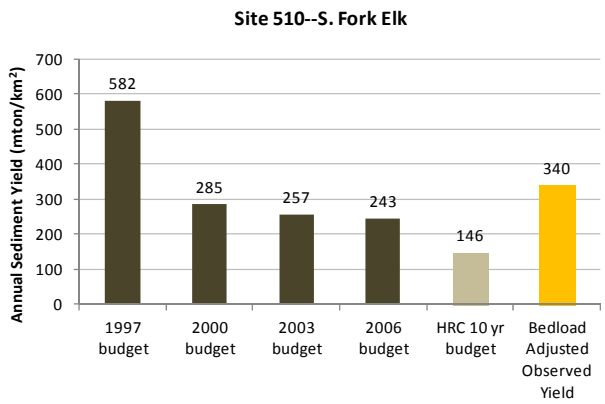
- **Considerable spatial variability in sediment yield, especially in Elk River**
- **Managed watersheds significantly higher than old growth reference**
- **During the short 9-year monitoring period, there has been a strong decline in sediment yield**
  - Largely explained by weather
  - But appears to be a stronger decline than fully explained
- **Turbidity measures have not declined to the same extent**
- **Weather index will be used to account for weather in subsequent statistical analysis**

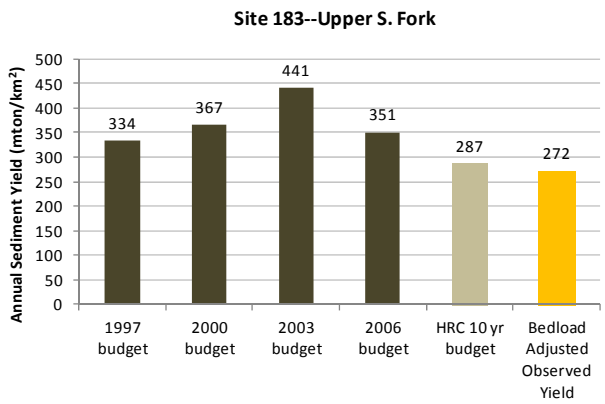
Relationship between Sediment Yield and Sediment Budgets

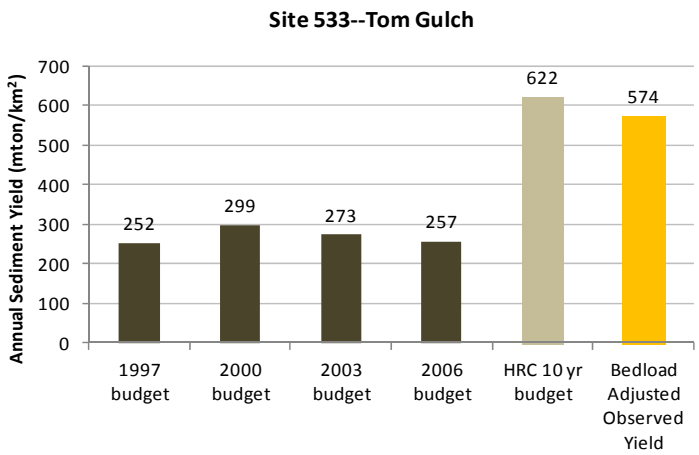
TRENDS

Elk River Sediment Budgets

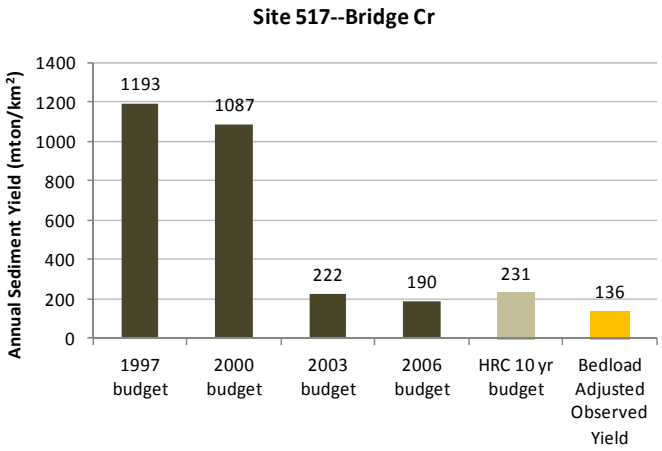


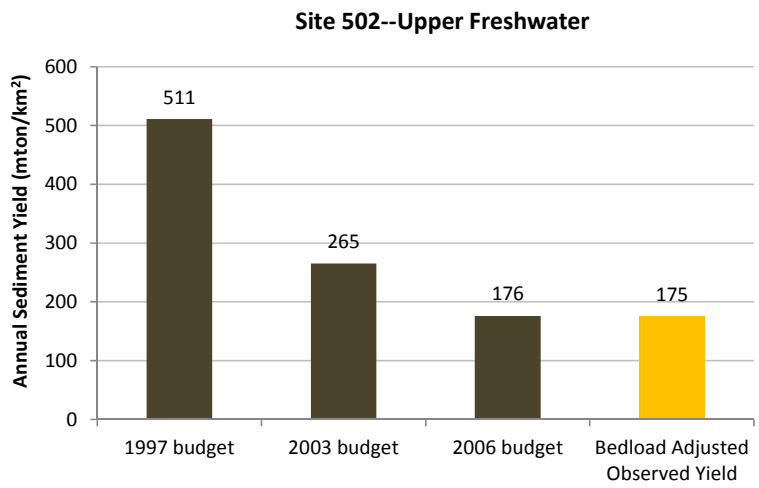




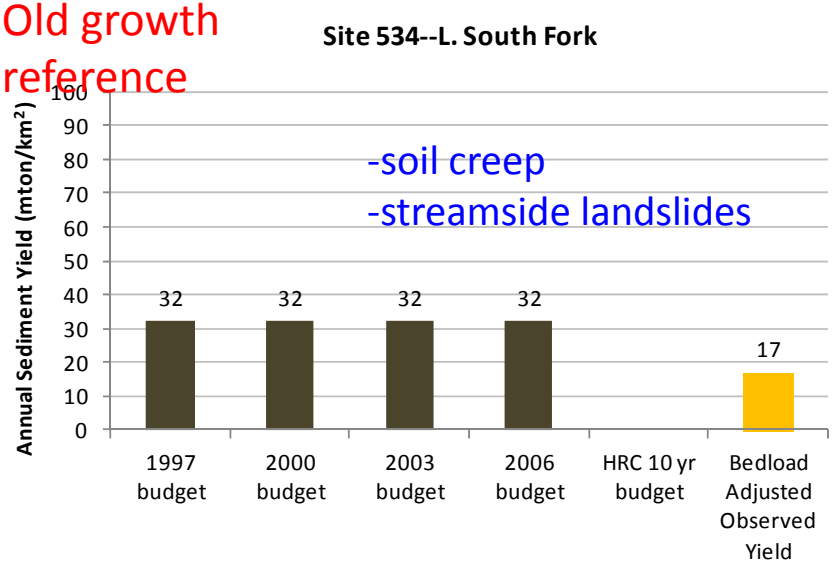


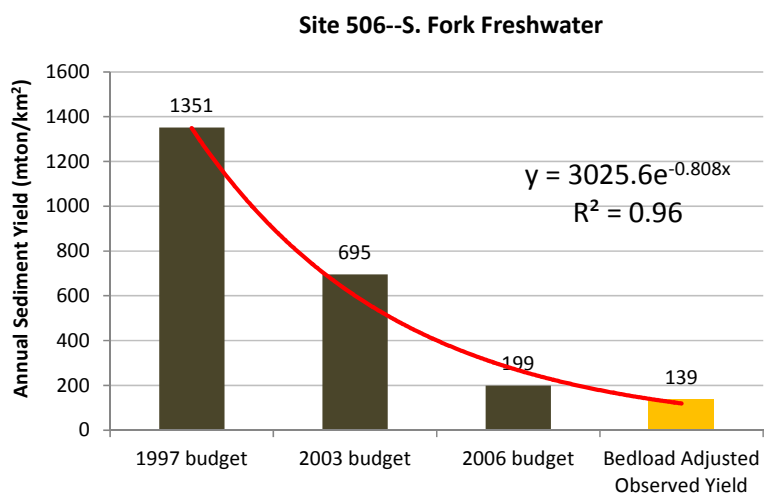
Elk River Sediment Budgets



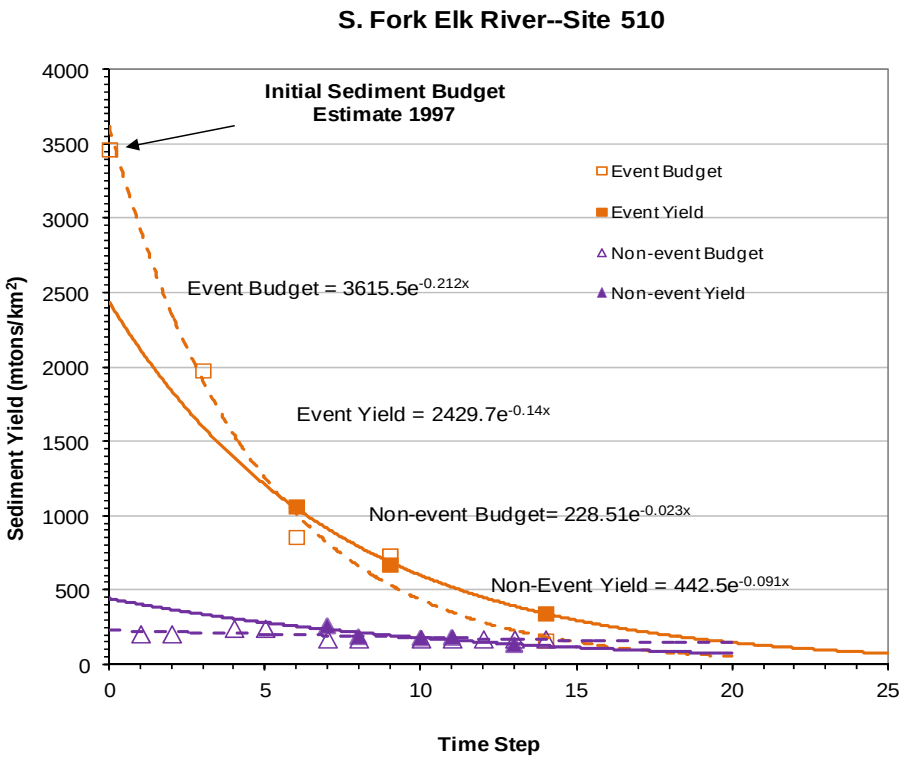


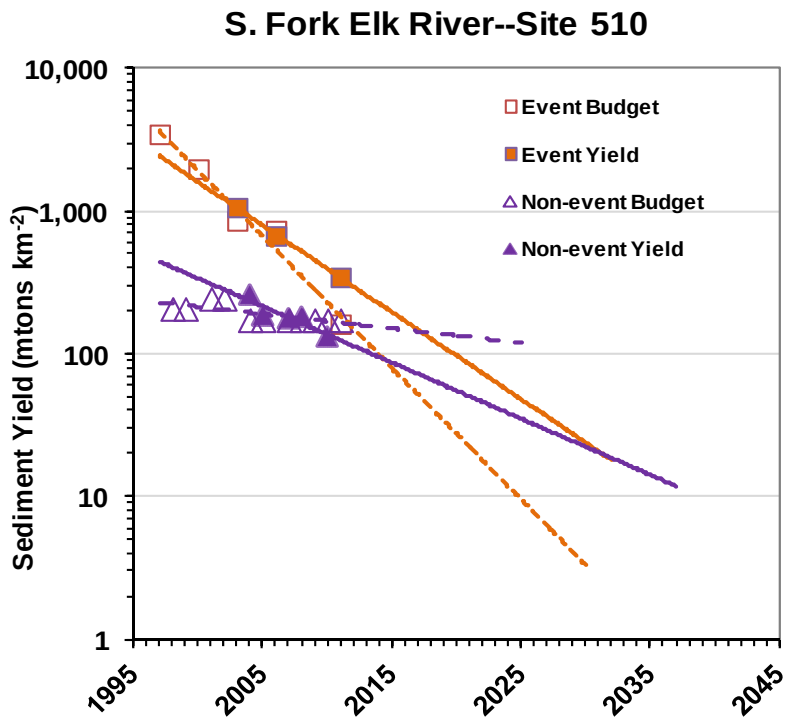
Old growth reference

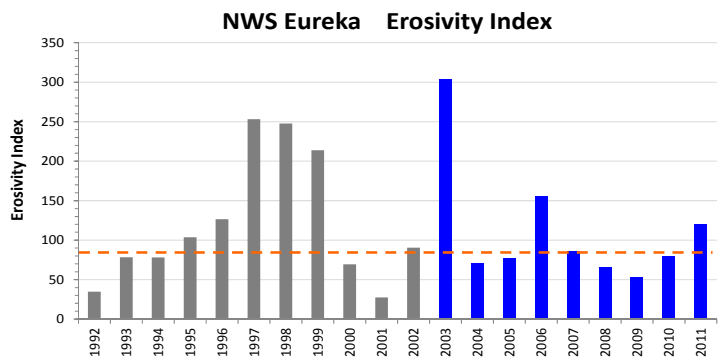




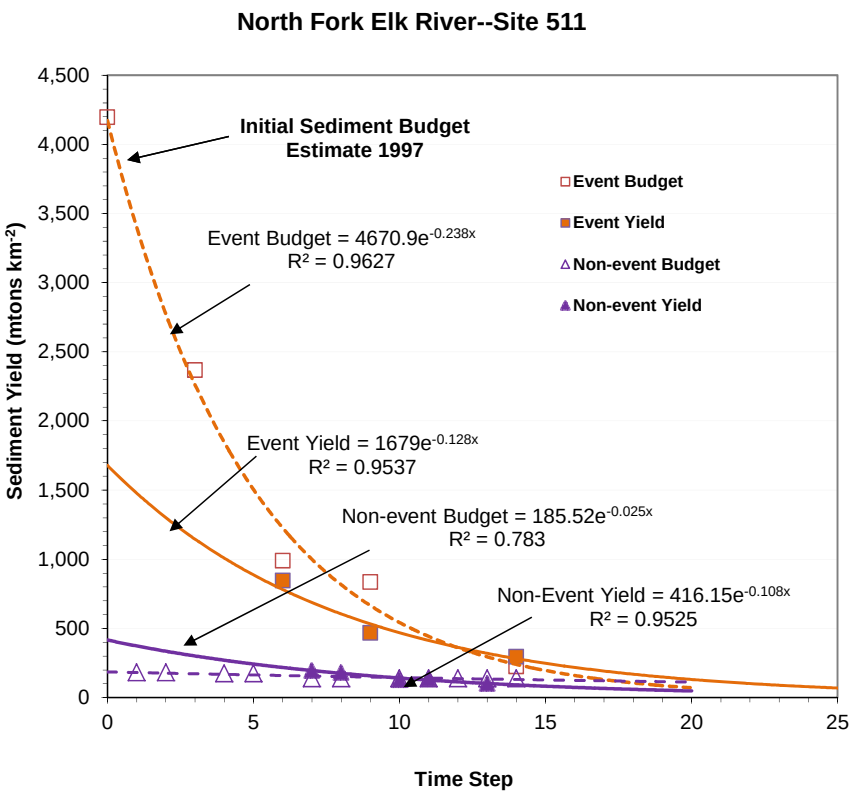
Event Years vs. Non-event years

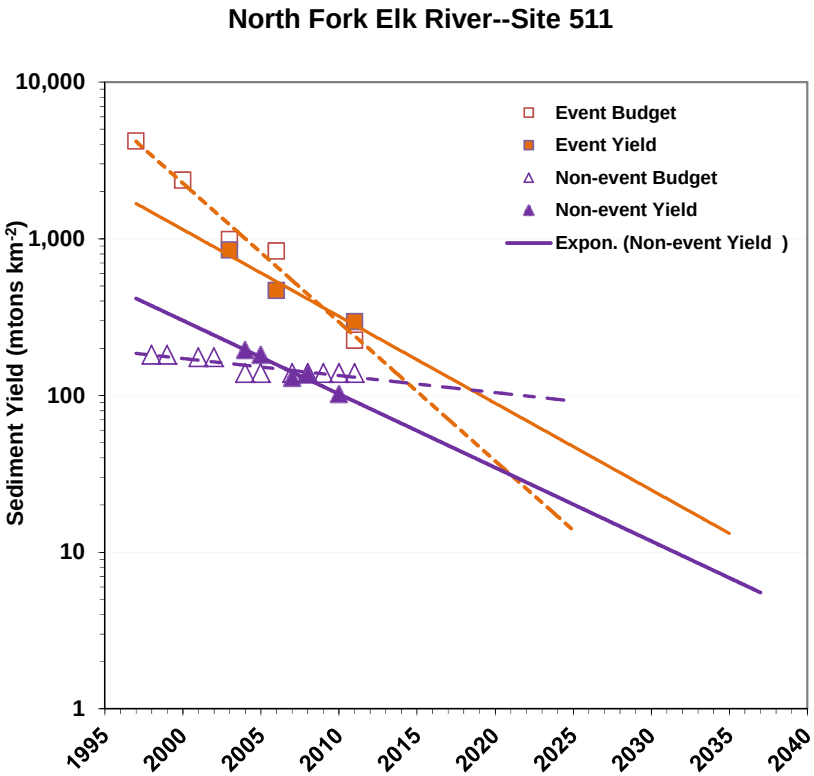


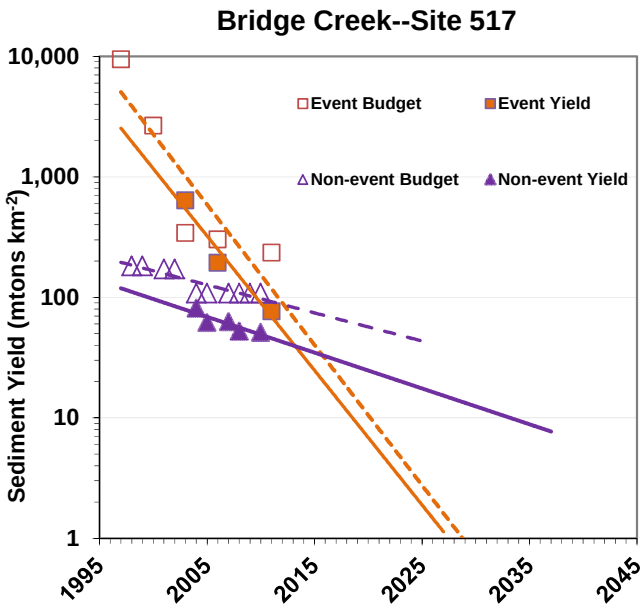


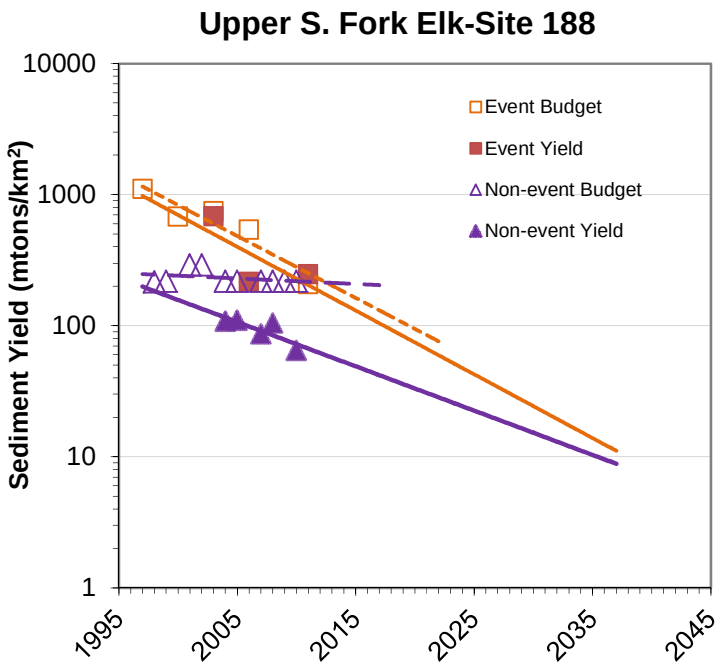


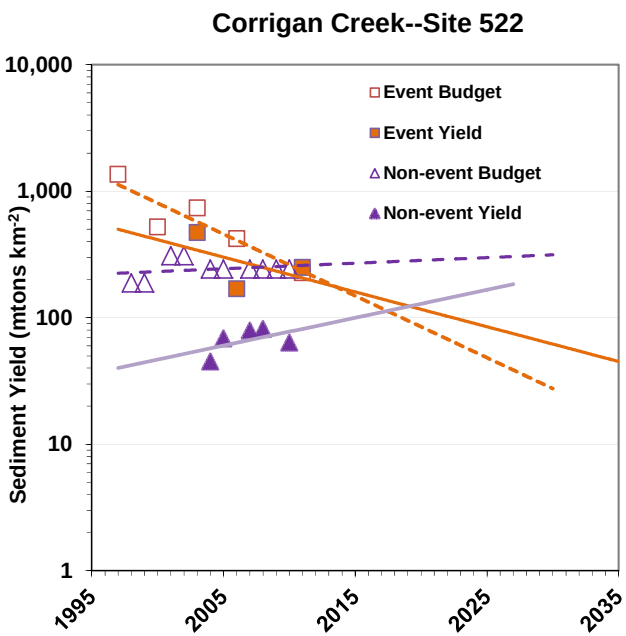
Event Years vs. Non-event years

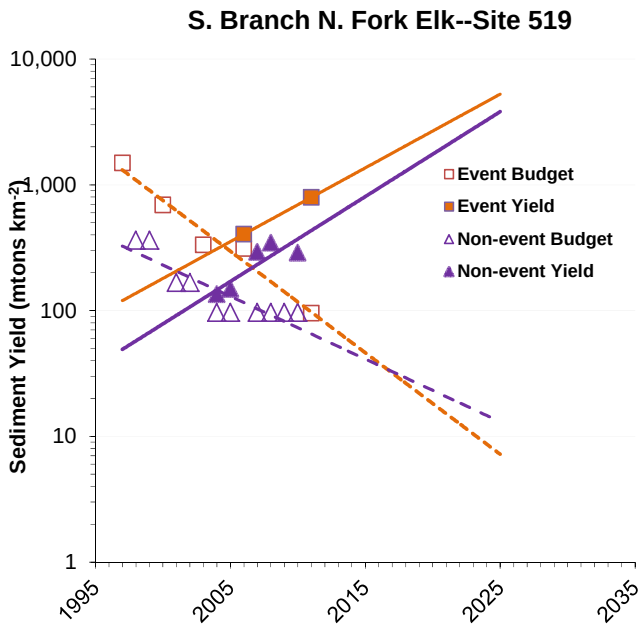


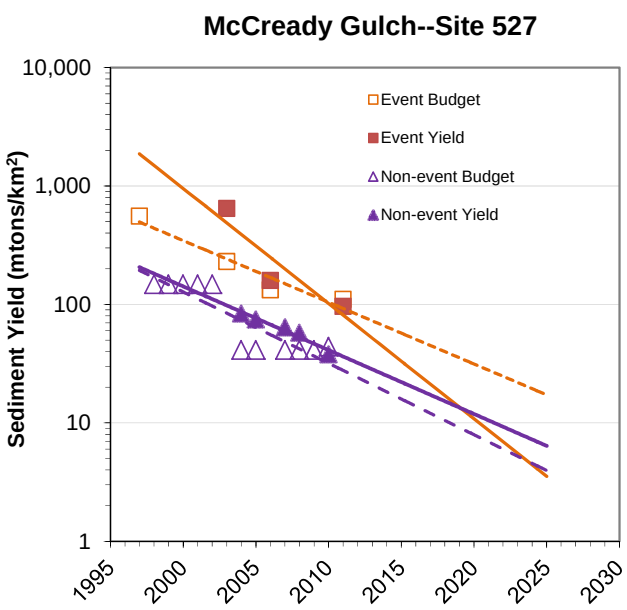


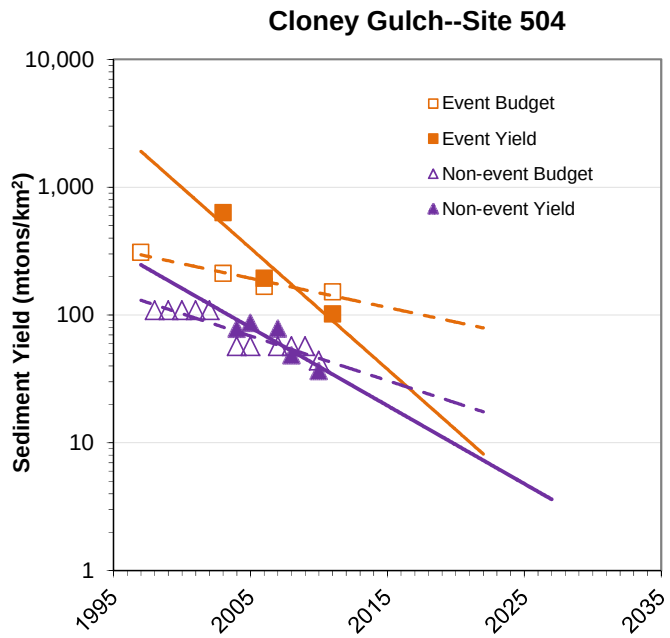

Bridge Creek--Site 517
Sediment Yield (mtons km-2)
10,000
1,000
100
10
1
1995
2005
2015
2025
2035
2045
Event Budget
Event Yield
Non-event Budget
Non-event Yield

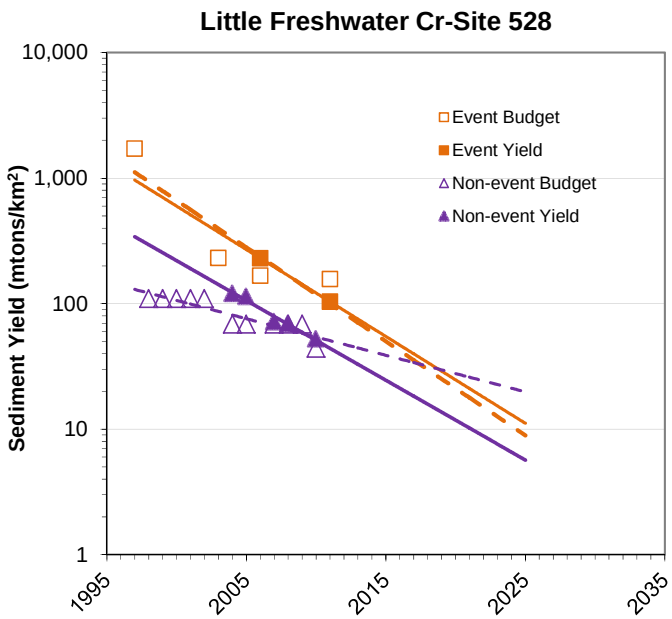

Upper S. Fork Elk-Site 188
Sediment Yield (mtons/km2)
10000
1000
100
10
1
1995
2005
2015
2025
2035
2045
Event Budget
Event Yield
Non-event Budget
Non-event Yield

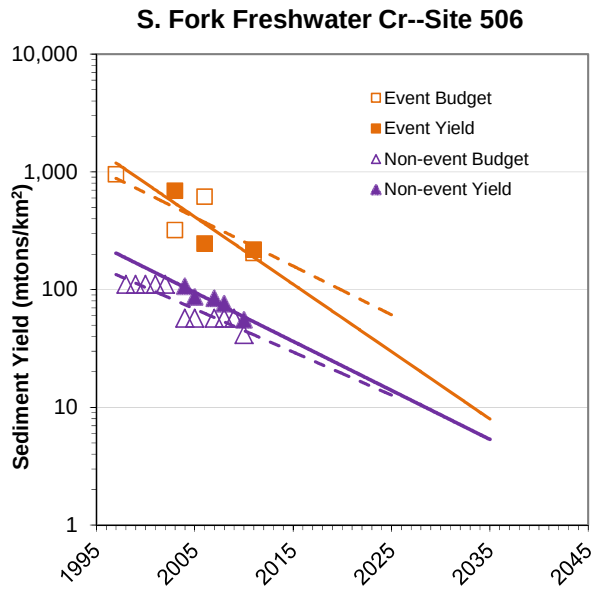

Corrigan Creek--Site 522
Sediment Yield (mtons km-2)
10,000
1,000
100
10
1
1995
2005
2015
2025
2035
Event Budget
Event Yield
Non-event Budget
Non-event Yield


S. Branch N. Fork Elk--Site 519
Sediment Yield (mtons km-2)
10,000
1,000
100
10
1
1995
2005
2015
2025
2035
Event Budget
Event Yield
Non-event Budget
Non-event Yield

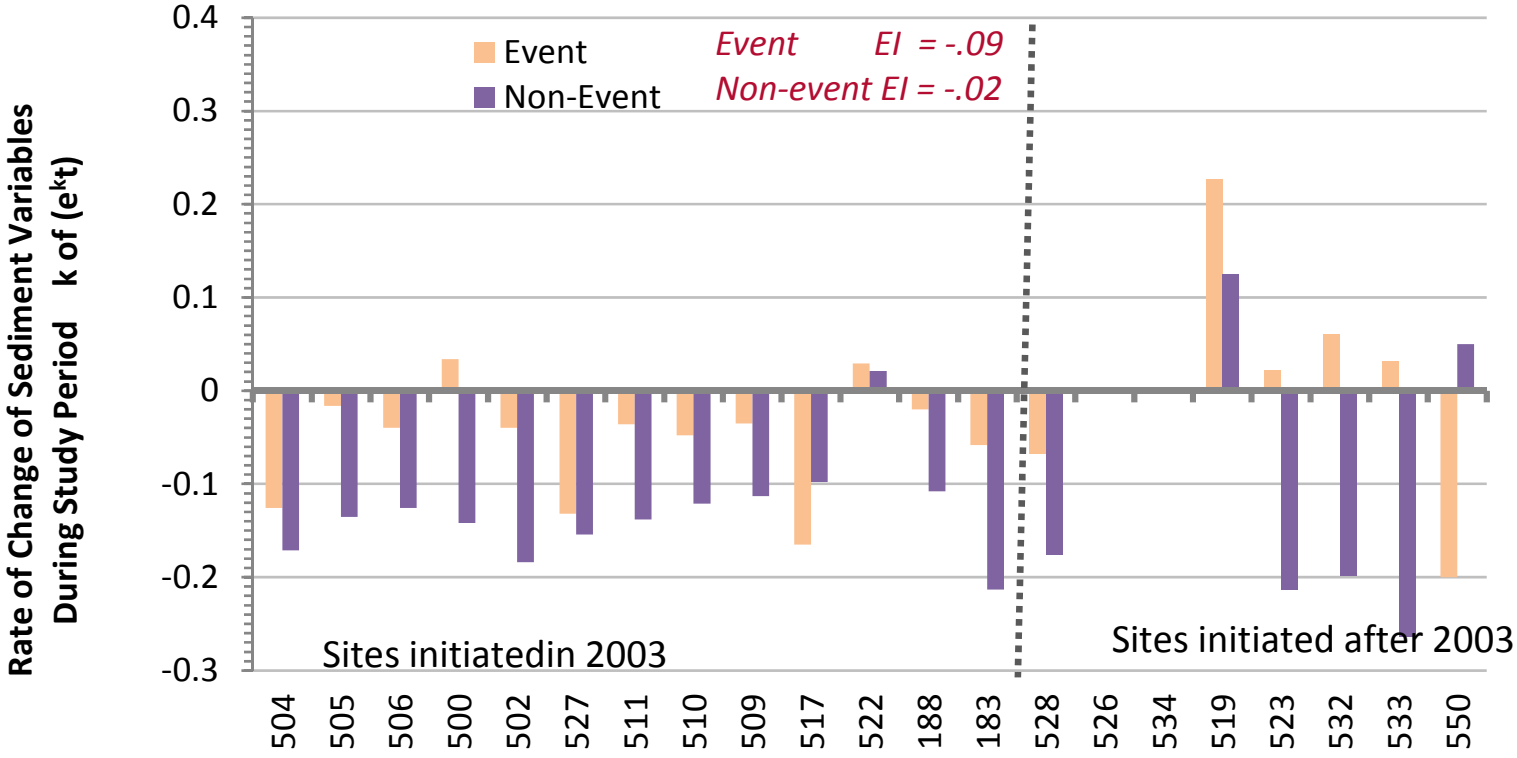

McCready Gulch--Site 527
Sediment Yield (mtons/km²)
10,000
1,000
100
10
1
1995
2000
2005
2010
2015
2020
2025
2030
Event Budget
Event Yield
Non-event Budget
Non-event Yield


Cloney Gulch--Site 504
Sediment Yield (mtons/km²)
10,000
1,000
100
10
1
1995
2005
2015
2025
2035
Event Budget
Event Yield
Non-event Budget
Non-event Yield


Little Freshwater Cr-Site 528
Sediment Yield (mtons/km²)
10,000
1,000
100
10
1
1995
2005
2015
2025
2035
Event Budget
Event Yield
Non-event Budget
Non-event Yield


S. Fork Freshwater Cr--Site 506
Sediment Yield (mtons/km²)
10,000
1,000
100
10
1
1995
2005
2015
2025
2035
2045
Event Budget
Event Yield
Non-event Budget
Non-event Yield

Rate of change compared to Erosivity Index



--Sediment yield is declining faster in non-event "average" years

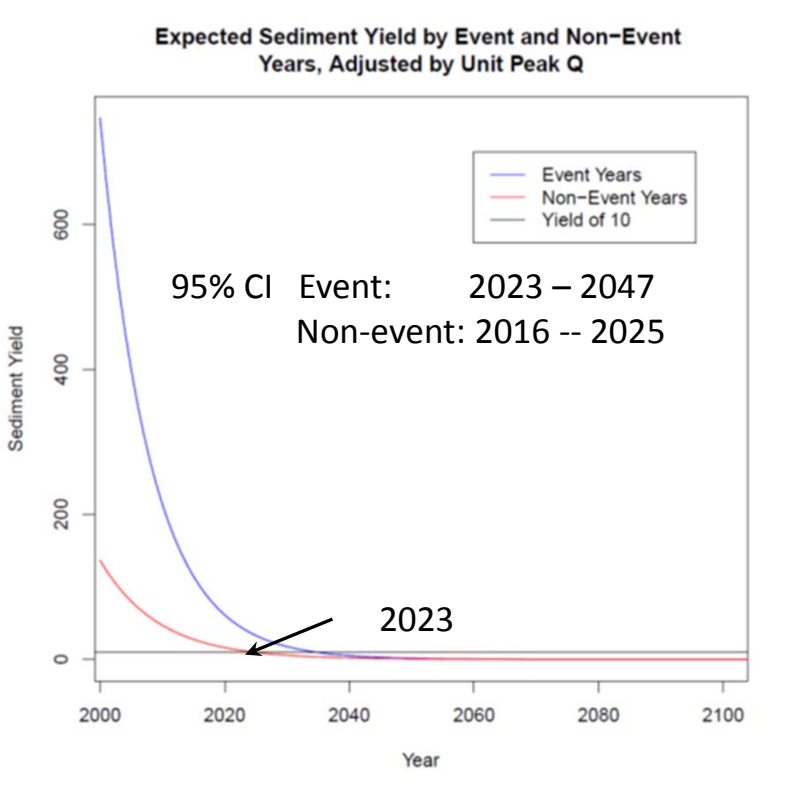
--Declining, but must less strongly, in "event" years

Multivariate Regression Trend with time

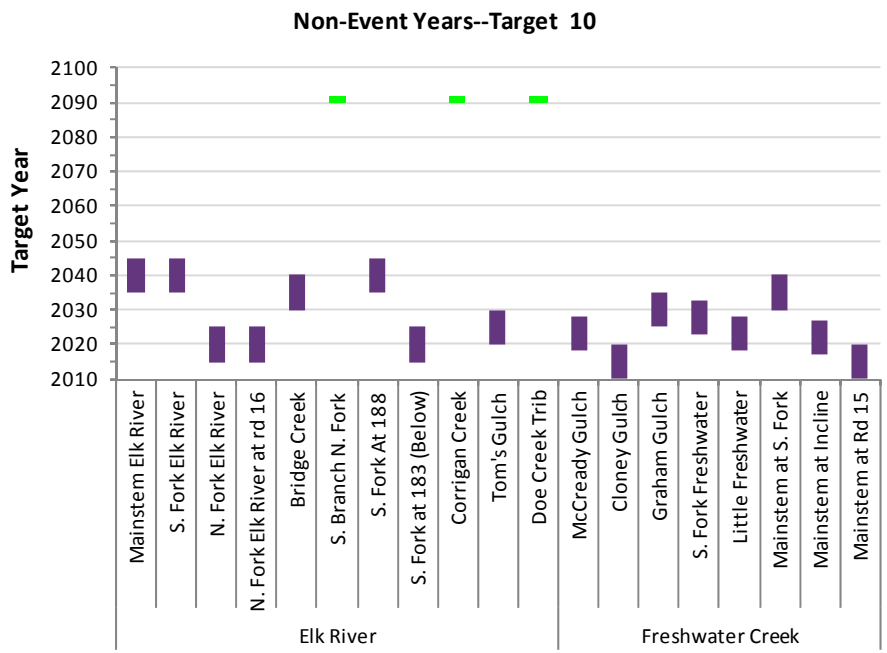
(unit peak Q used to account for weather)

Parameter	Event Status	n	YEAR Regression parameter B	Pr > |t|
Sediment Yield	Event	55	**-.125**	<.0001
	Non-event	120	**-.107**	<.0001
10% Turbidity Exceedence	Event	54	**-.059**	<.0001
	Non-event	120	**-.058**	<.0001

Event EI -.09
Non-event EI -.02



Non-event target



Modern and Legacy

MANAGEMENT EFFECTS

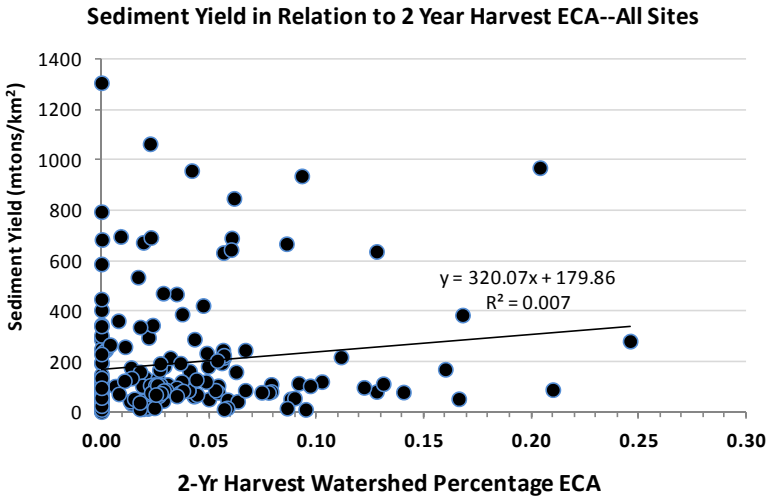
Management-Related Parameters

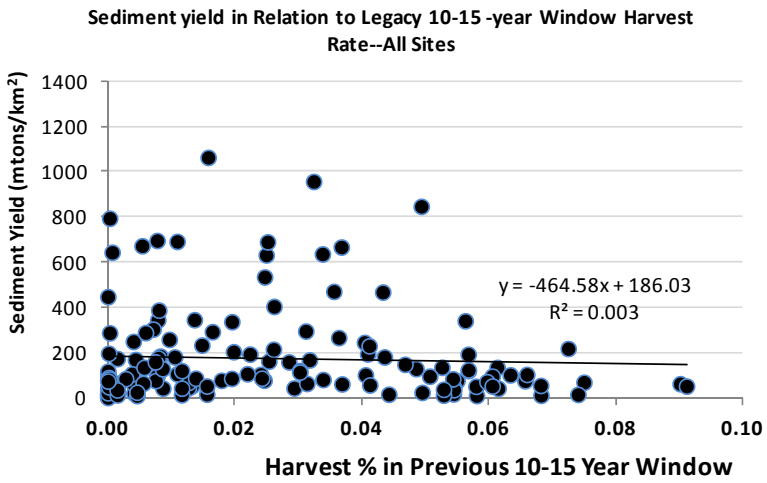
	Parameter	Range
Modern	**1-yr** ECA	0 to 20.4%
	2-yr ECA	0 to 20.6%
	Annual Sediment Removal	57,261 yd^3
Past Practices	Previous **10 to 15 Year** ECA	0 to 9.1%
	Previous **10 Year** ECA annual harvest	0 to 4.1%
Legacy	Legacy Sediment Volume	313,382 yd^3
Other Attributes	Basin Area	0.13- 118.3 (km^2)
	Erosivity Index	1 to 62 year Return Interval
	Year	2003 to 2011

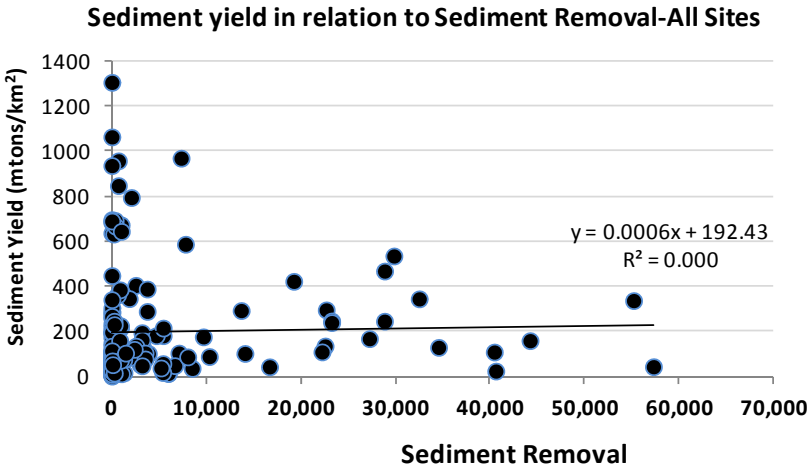
ECA = portion of watershed area harvested

Single Variables

Sediment Yield

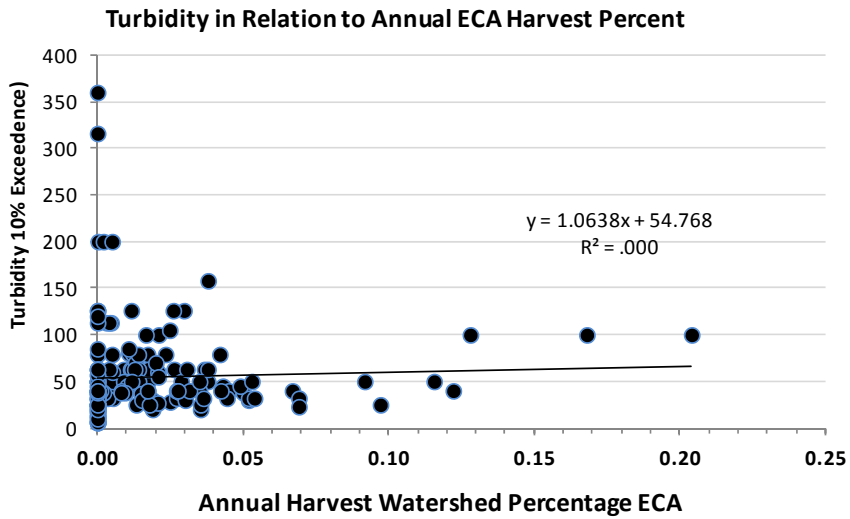


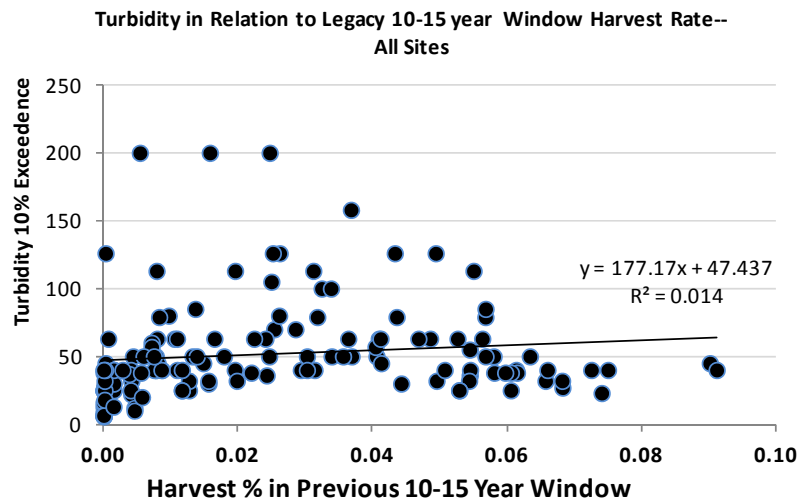


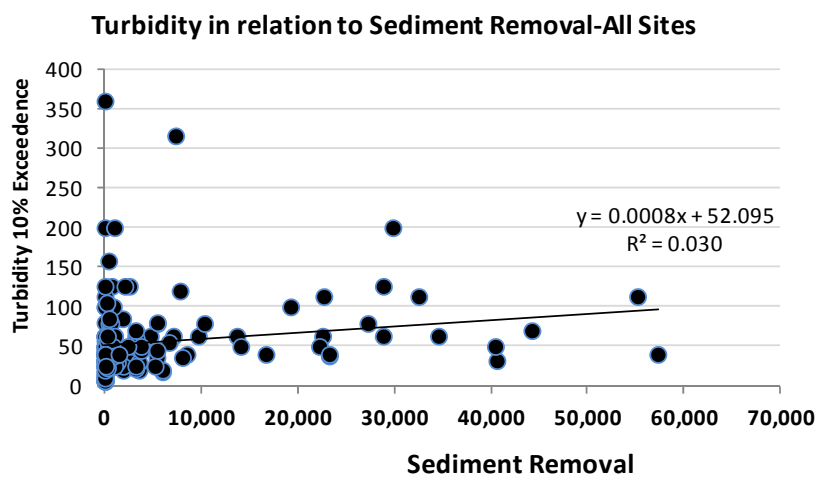


Single Variables

10% Turbidity







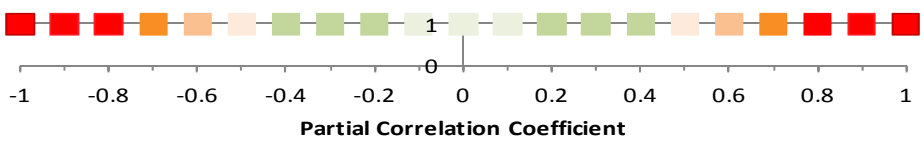
Multivariate Statistical Analysis

Parametric

- Model selection test
  - Used the Adjusted R^2 test
  - Similar to the AIIC test
- Normal multivariate regression performed on the “best fit” model
- P values for parameters, R^2 for total relationship
- Performed on total data set using SAS

Non-parametric

- Partial correlation analysis
- R = -1.0 to +1.0,



- Performed on total data set using SPSS

Sediment Yield

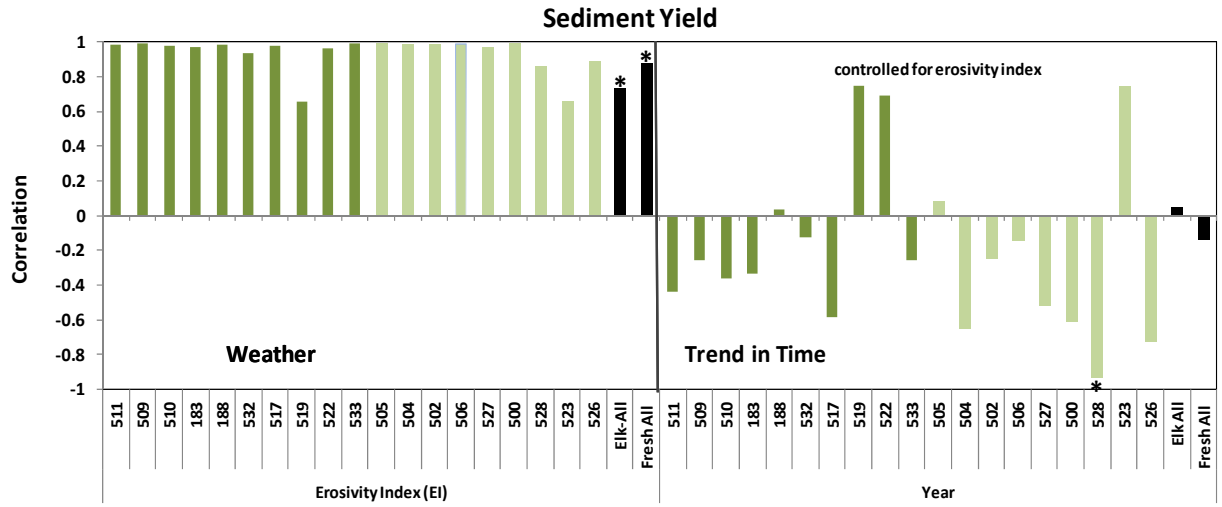
Adjusted R^2 model selection for management factors

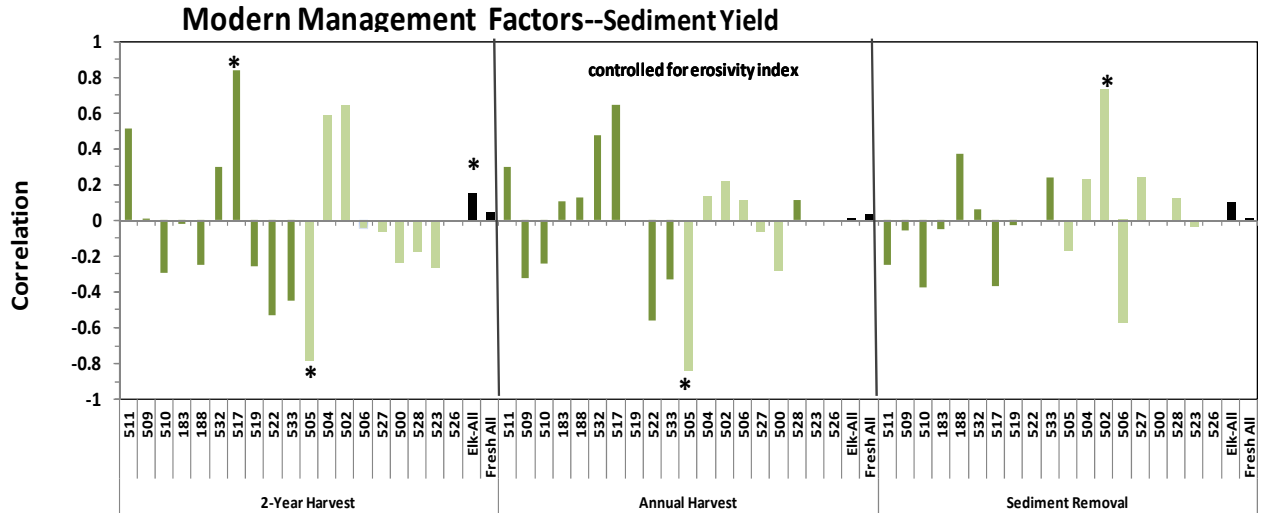
Number Params	Adjusted R-Square	Variables in Model
3	0.48	Unit_Peak_Q Sed_Removal _sed_removal_sq
4	0.48	Unit_Peak_Q Lag_1_yr_Harv_ Sed_Removal sed_removal_sq
4	0.48	Unit_Peak_Q Ann_Harvest__ Sed_Removal sed_removal_sq
4	0.48	Unit_Peak_Q Sed_Removal Window_10_15_Yr sed_removal_sq
4	0.48	Unit_Peak_Q X 2_Yr_Logging Sed_Removal sed_removal_sq
5	0.48	Unit_Peak_Q Ann_Harvest__ X2_Yr_Logging Sed_Removal sed_removal_sq
5	0.48	Unit_Peak_Q Ann_Harvest__ Lag_1_yr_Harv_ Sed_Remova sed_removal_sq
5	0.48	Unit_Peak_Q Lag_1_yr_Harv_ X2_Yr_Logging Sed_Removal sed_removal_sq

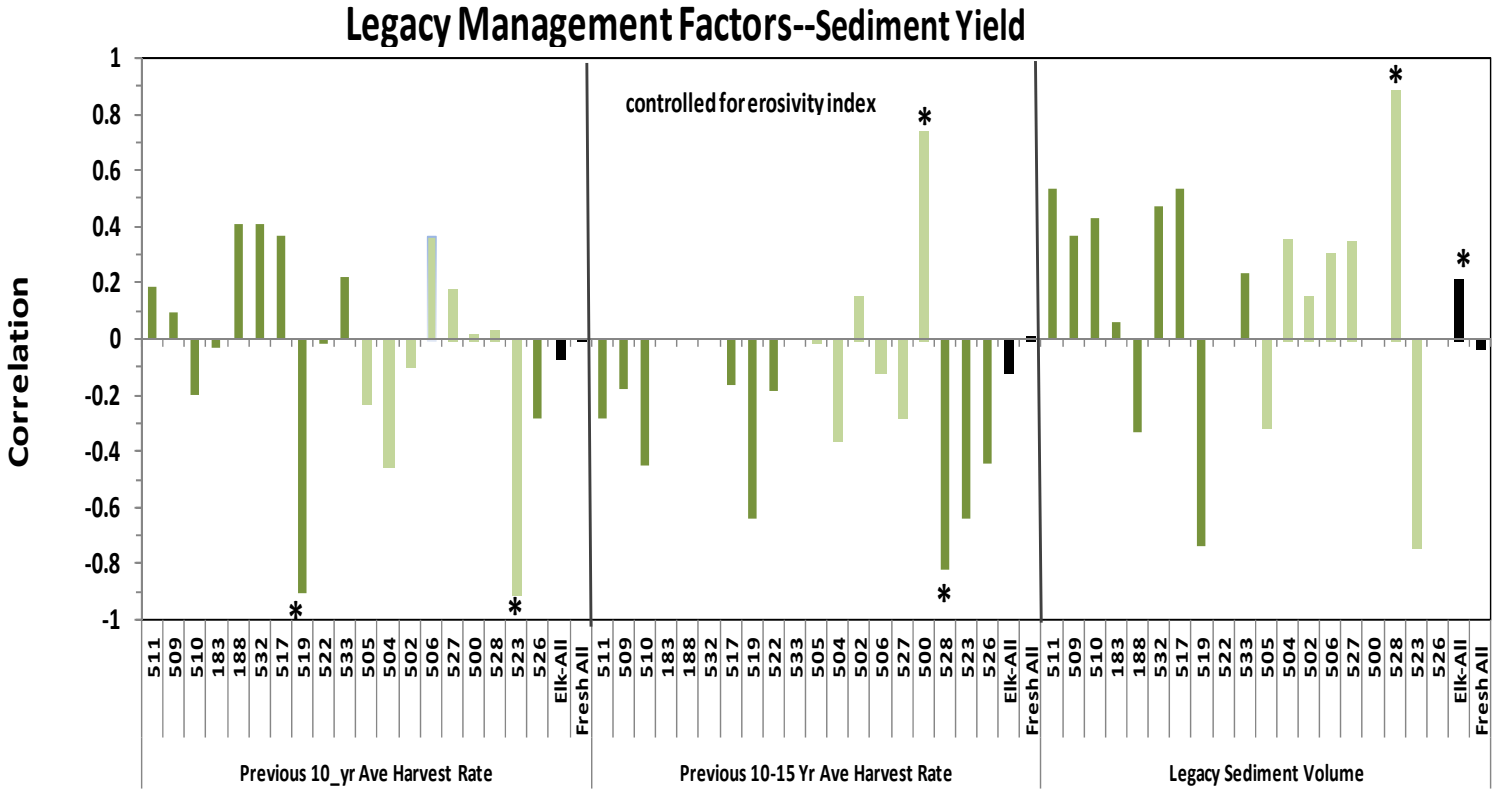
Normal linear mixed model

Solution for Fixed Effects

Effect	Estimate	Standard Error	t Value	Pr > |t|
Intercept	4.063	0.368	11.03	<.0001
Unit_Peak_Q	0.580	0.158	3.68	0.000
sed_removal_cs	0.053	0.075	0.71	0.476
sed_removal_cs_sq	-0.005	0.019	-0.25	0.805


Sediment Yield
Correlation
controlled for erosivity index
Weather
Trend in Time
Erosivity Index (EI)
Year
511 509 510 183 188 532 517 519 522 533 505 504 502 506 527 500 528 523 526 Elk-All Fresh All


Modern Management Factors--Sediment Yield
Correlation
controlled for erosivity index
2-Year Harvest
Annual Harvest
Sediment Removal
511 509 510 183 188 532 517 519 522 533 505 504 502 506 527 500 528 523 526 Elk-All Fresh All


Legacy Management Factors--Sediment Yield
Correlation
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
controlled for erosivity index
511 509 510 183 188 532 517 519 522 533 505 504 502 506 527 500 528 523 526 Elk-All Fresh All
Previous 10_yr Ave Harvest Rate
511 509 510 183 188 532 517 519 522 533 505 504 502 506 527 500 528 523 526 Elk-All Fresh All
Previous 10-15 Yr Ave Harvest Rate
511 509 510 183 188 532 517 519 522 533 505 504 502 506 527 500 528 523 526 Elk-All Fresh All
Legacy Sediment Volume

Turbidity 10% Exceedence

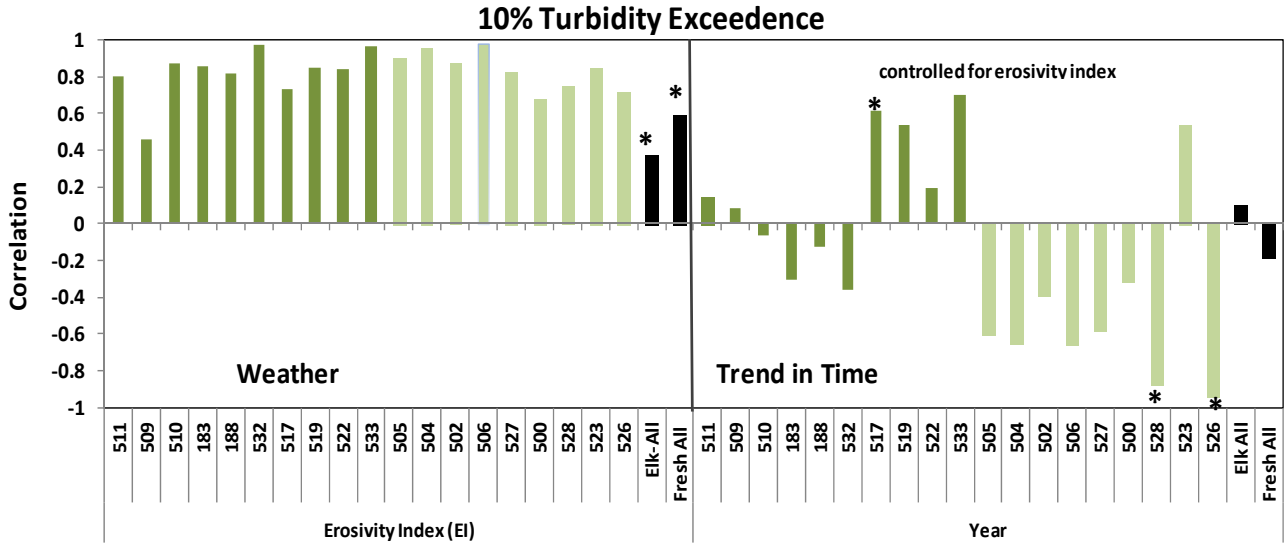
Adjusted R^2 model selection test for manage-ment factors

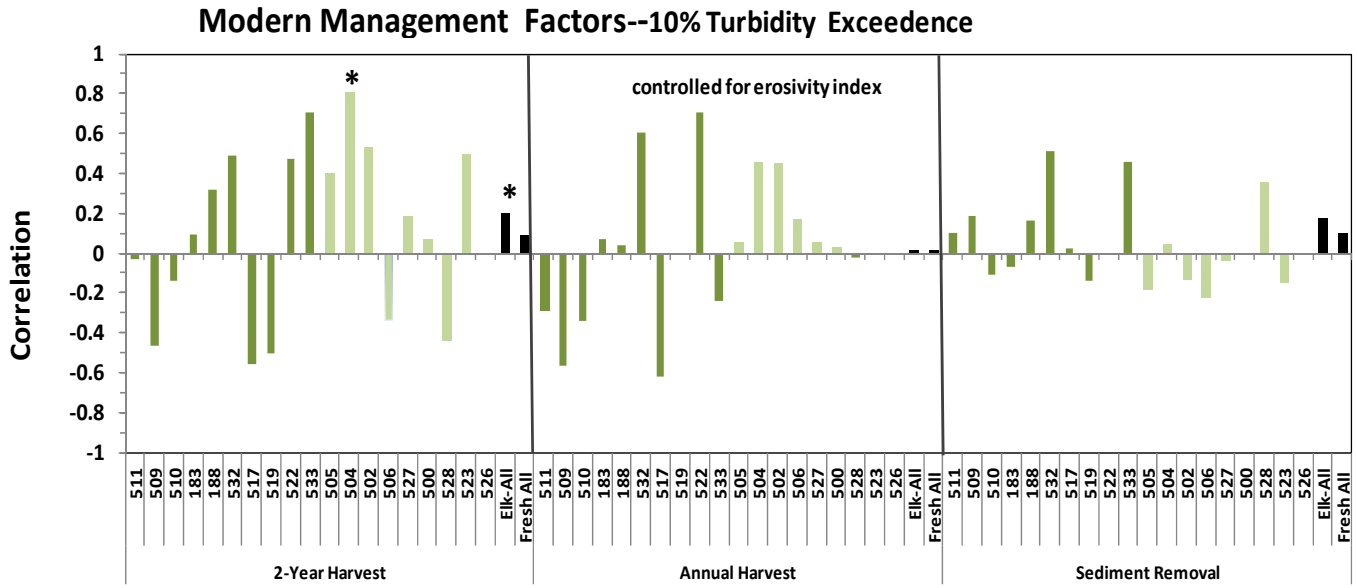
Number Params	Adjusted R-Square	Variables in Model
6	0.48	Unit_Peak_Q Sed_Removal Window_10_15_ Yrs sed_removal_sq Year
7	0.48	Unit_Peak_Q Lag_1_yr_Harv_ Sed_Removal Window_10_15_Yrs sed_removal_sq Year_Basin_Area
7	0.48	Unit_Peak_Q X 2_Yr_Logging Sed_Removal Window_10_15_Yrs sed_removal_sq Year Basin_Area
7	0.48	Unit_Peak_Q Ann_Harvest__ Sed_Removal Window_10_15_Yrs sed_removal_sq Year Basin_Area
8	0.48	Unit_Peak_Q Ann_Harvest__ Lag_1_yr_Harv_ Sed_Removal Window_10_15_Yrs sed_removal_sq Year Basin_Area

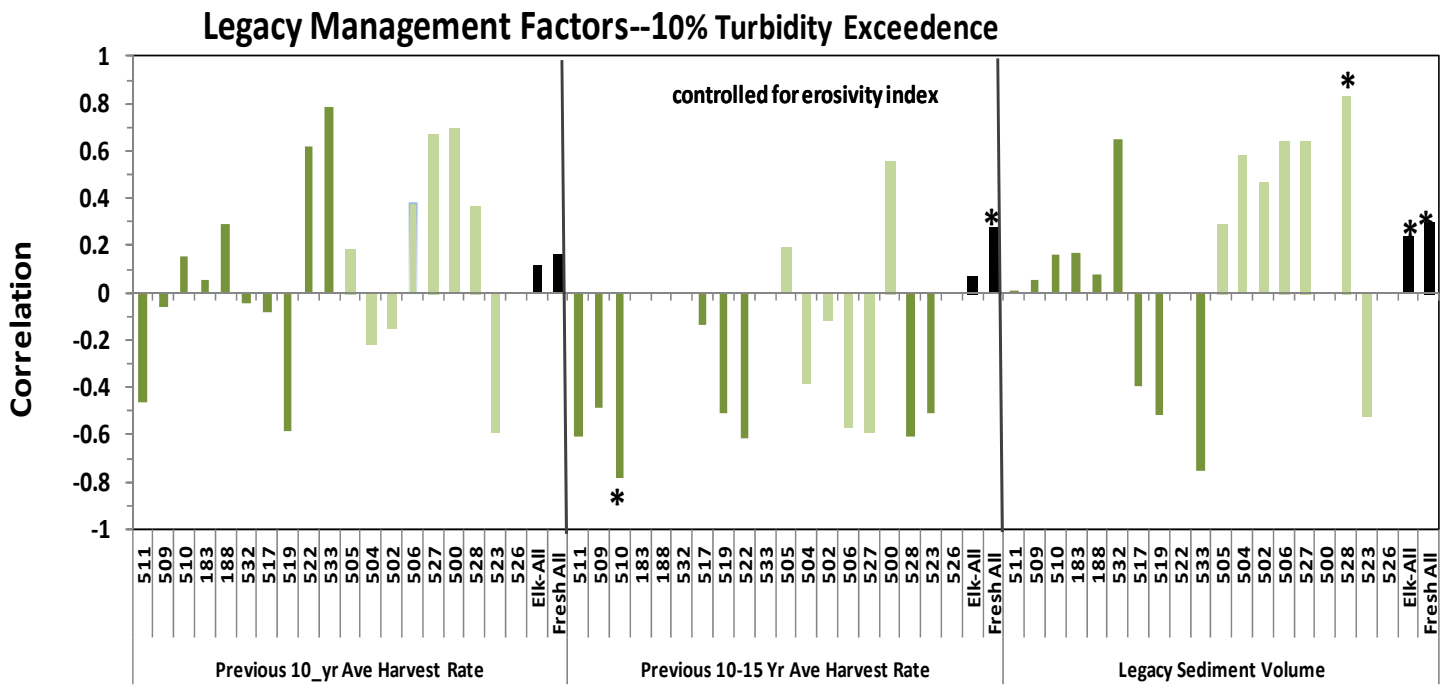
Normal linear mixed model

Solution for Fixed Effects

Effect	Estimate	Standard Error	t Value	Pr > |t|
Intercept	3.761	0.2566	14.66	<.0001
Unit_Peak_Q	-0.064	0.1095	-0.59	0.558
Sed_removal_cs	0.092	0.0642	1.43	0.156
Window_10_15_Yrs	-2.969	1.4704	-2.01	0.047
Sed_removal_cs_sq	-0.021	0.0152	-1.37	0.173
Basin_Area	0.0091	0.0048	1.90	0.060

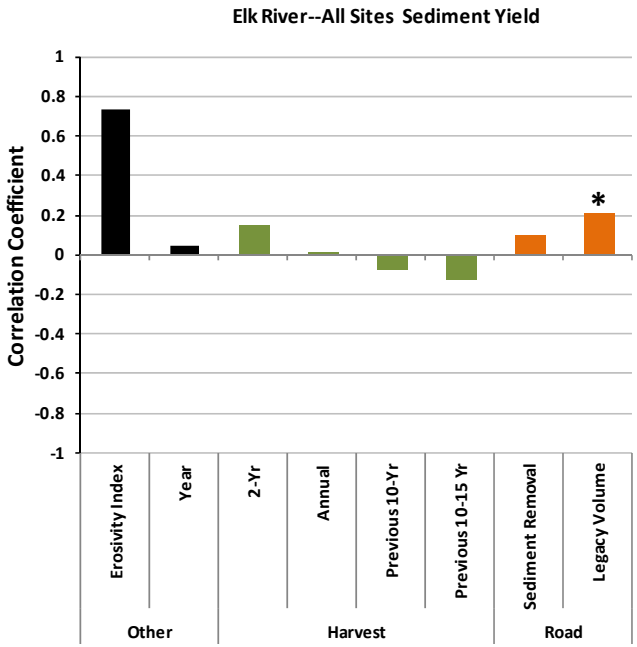

10% Turbidity Exceedence
Correlation
controlled for erosivity index
Weather
Trend in Time
Erosivity Index (EI)
Year

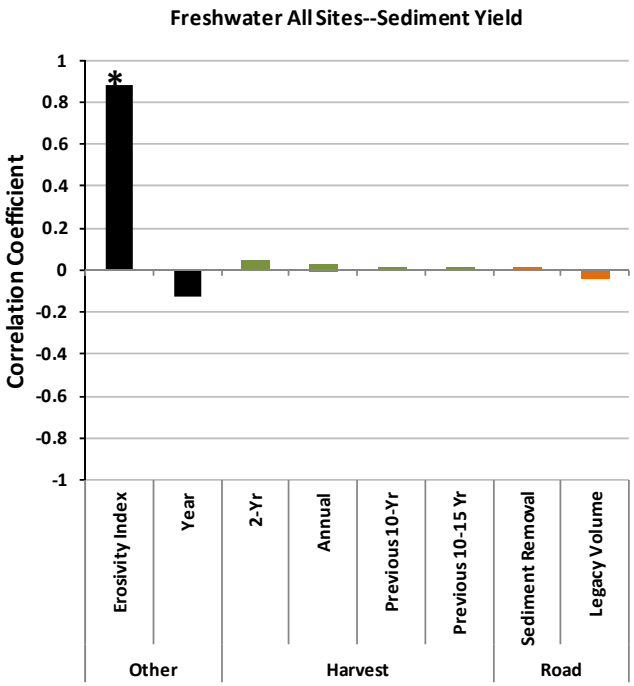

Modern Management Factors--10% Turbidity Exceedence
Correlation
controlled for erosivity index
2-Year Harvest
Annual Harvest
Sediment Removal


Legacy Management Factors--10% Turbidity Exceedence
Correlation
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
controlled for erosivity index
*
511 509 510 183 188 532 517 519 522 533 505 504 502 506 527 500 528 523 526 Elk-All Fresh All
Previous 10_yr Ave Harvest Rate
Previous 10-15 Yr Ave Harvest Rate
Legacy Sediment Volume

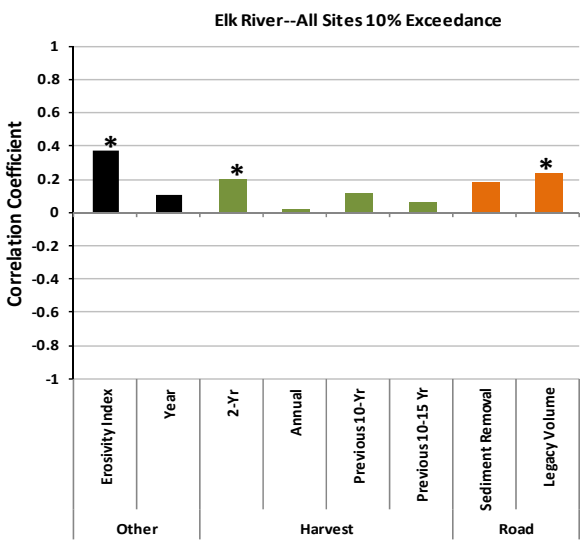
By Watershed

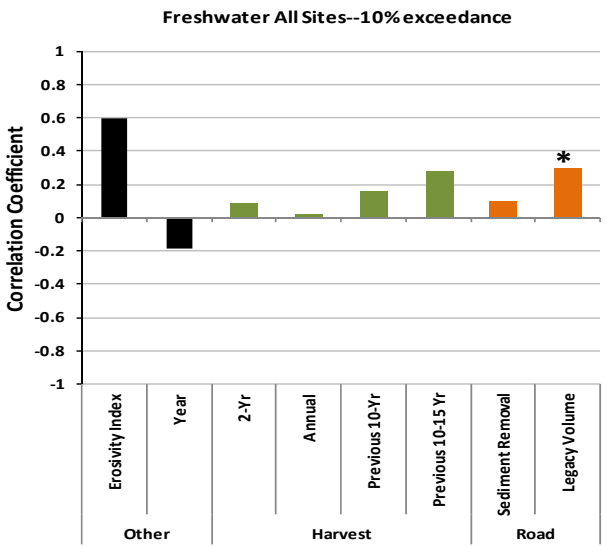
Sediment Yield



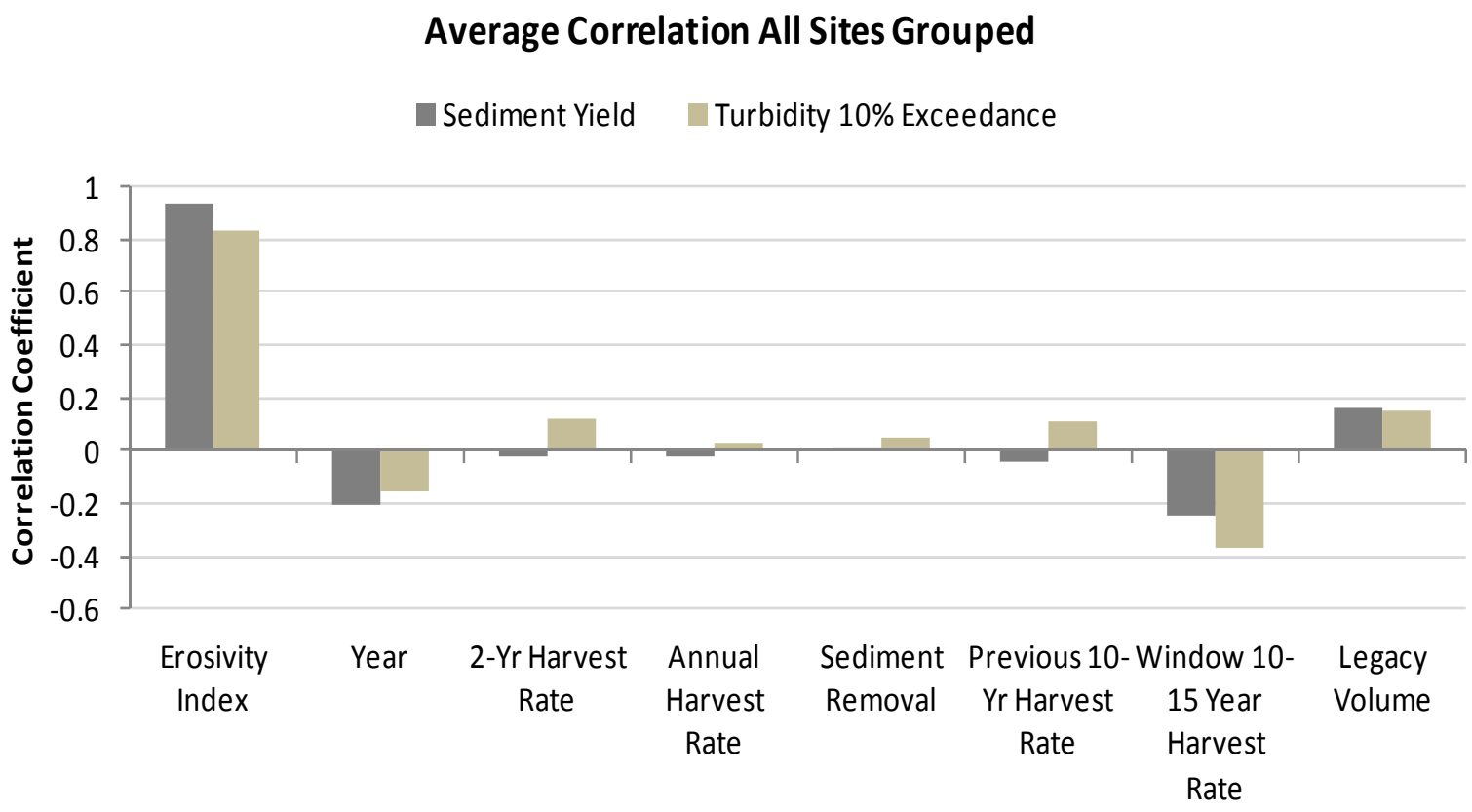


Turbidity

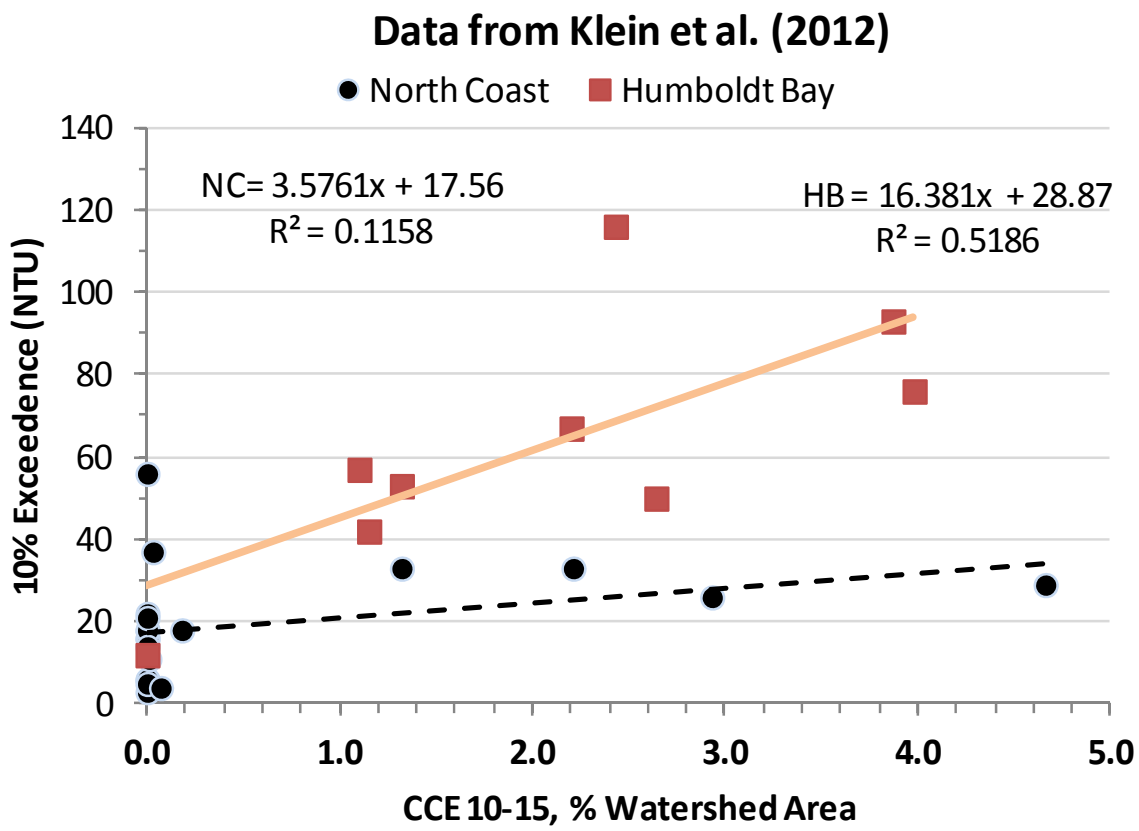




Summary of Partial Correlation Analysis



Comparison to Findings of Klein *et al*. 2012



Comparison to Findings of Klein *et al*. 2012

2005 Dependent variable: Turbidity 10% Exceedance

Variable	Parameter Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	25.828	4.334	14	5.96	<.0001
Basin Area	0.736	0.161	14	4.58	0.0006
Window 10-15 Yrs	440.67	146.99	14	3.00	0.0111

ALL YEARS 2003 to 2011

Dependent variable: Log transform Turbidity10%

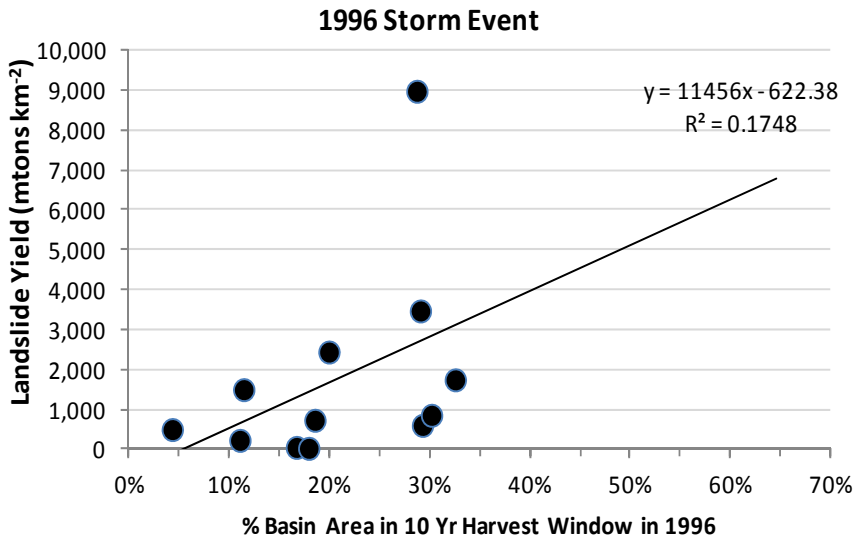
Variable	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	3.632	0.195	8	18.65	<.0001
Basin Area	0.01	0.005	116	2.24	0.027
Window 10-15 Yrs	-3.27	1.353	116	-2.42	0.017

Comparison to Findings of Klein *et al*. 2012

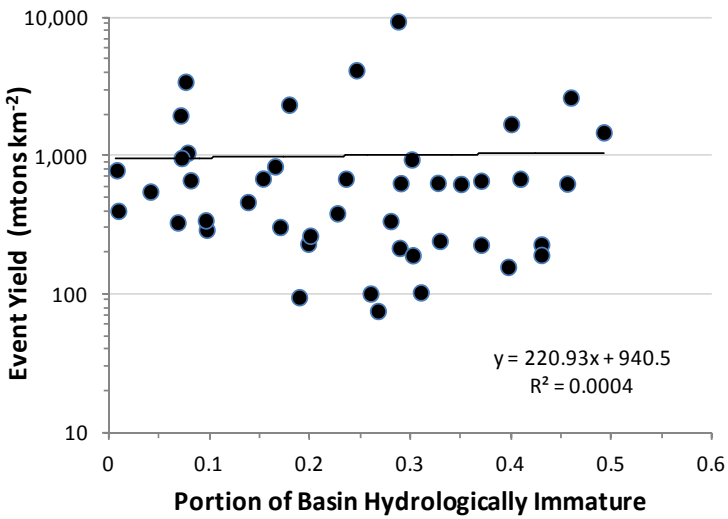
Year	Log transformed?	P Value	R^2
2003	log	0.362	0.213
2004	log	0.037	0.491
2005	untransformed	0.011	0.714
2006	log	0.105	0.575
2007	log	0.130	0.386
2008	log	0.284	0.268
2009	log	0.214	0.225
2010	untransformed	0.313	0.519
2011	log	0.421	0.272

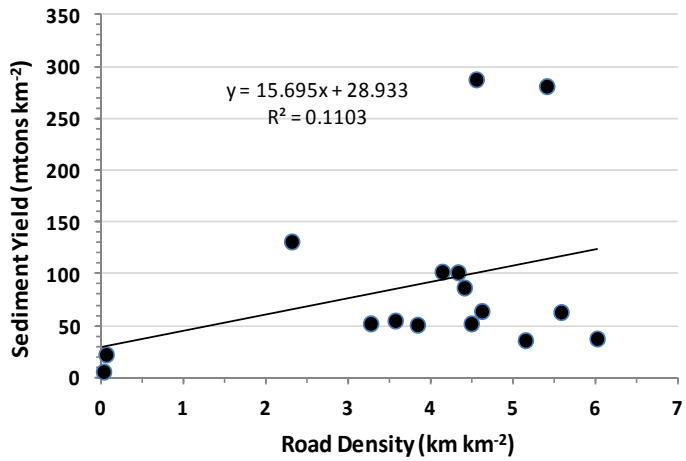
P value is significance of the harvest rate parameter

Why a significant correlation in 2005?



Represents 1990-1995





Management Effects--Summary

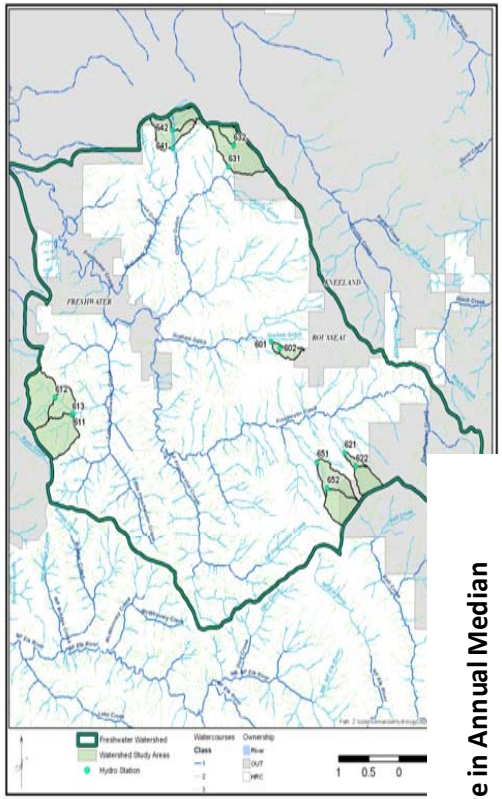
- **Weather parameters strongly explanatory**

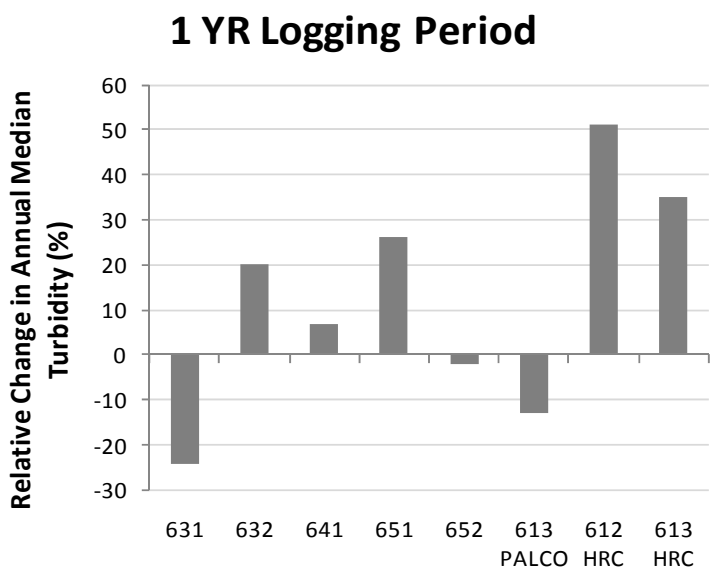
- **Modern and Legacy management factors influenced sediment yield and turbidity at individual stations, some significantly,**

But . . .

- **No consistent trends-- multivariate analysis found no strong predictive relationships**
  - Harvest rate (no)
  - Road upgrading/removal (no)
  - General progress on stormproofing roads (yes, to some extent)
- **Do these results make sense in light of previous studies?**

THP Turbidity Study

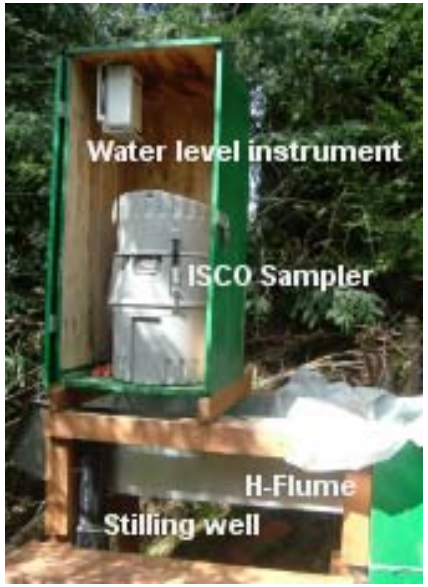


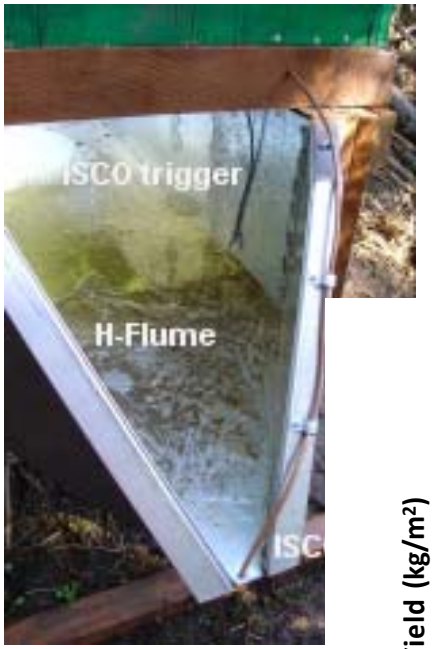


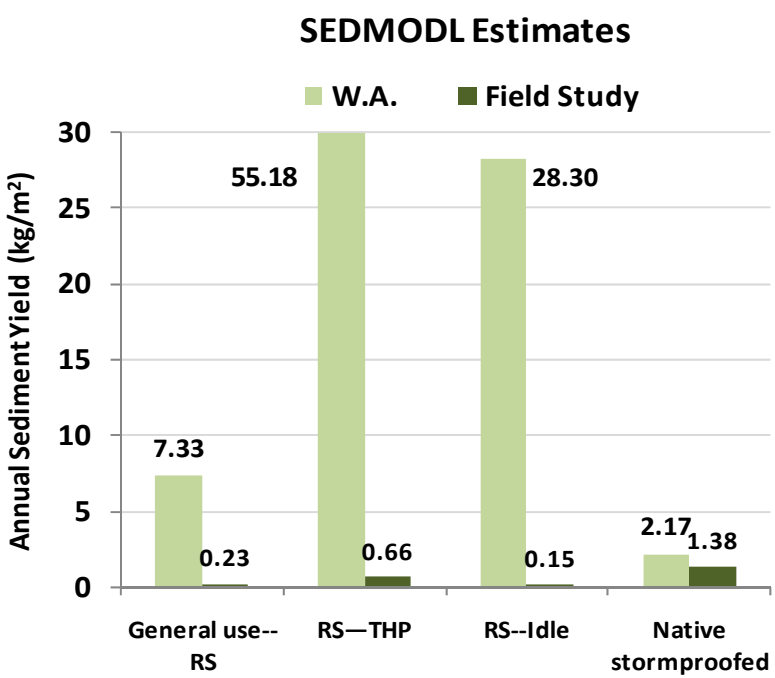
20 – 50% Increase

Increases documented during THP management, but low level and impacted area too small to affect turbidity at hydrostations

Road Surface Erosion







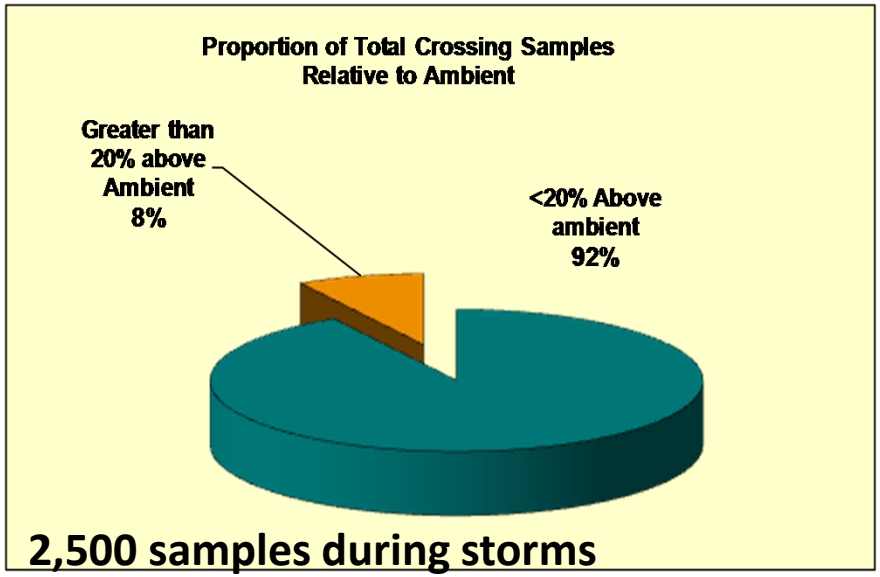
2- Year Intense road segment monitoring during storms and log truck use

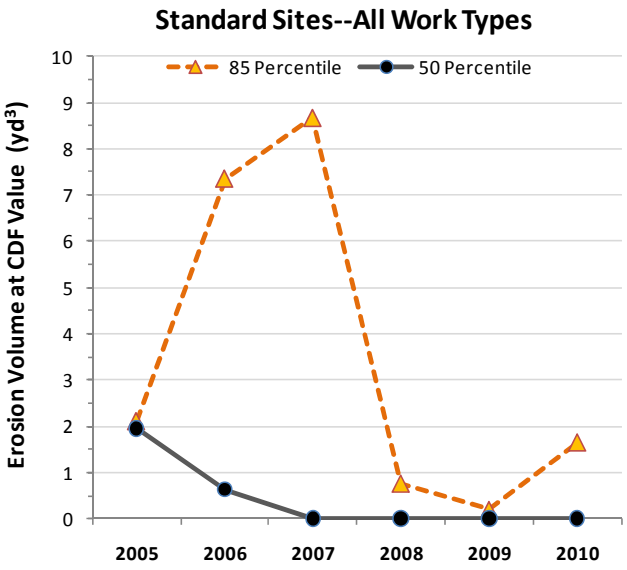
Road Inventory 400 miles of road

11% road surface delivered

Amount of road sediment generated significantly lower now than estimated before stormproofing

Synoptic Road Grab Sampling

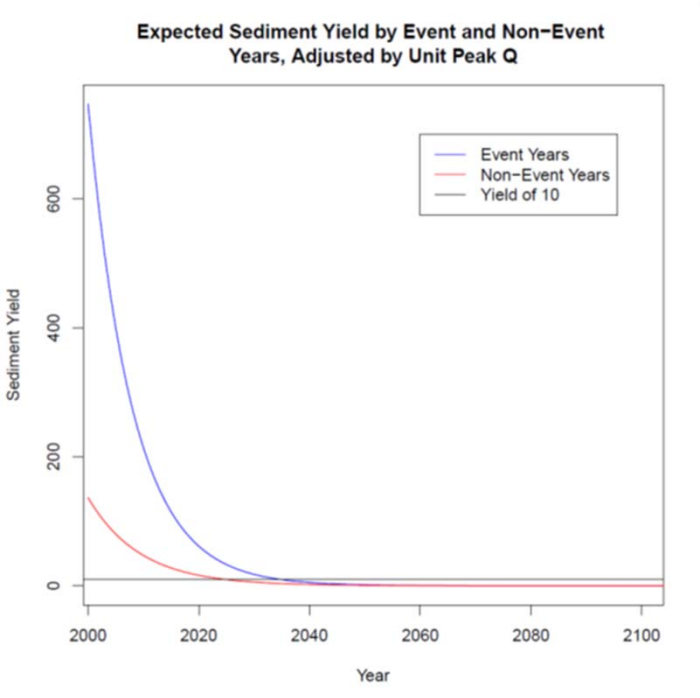


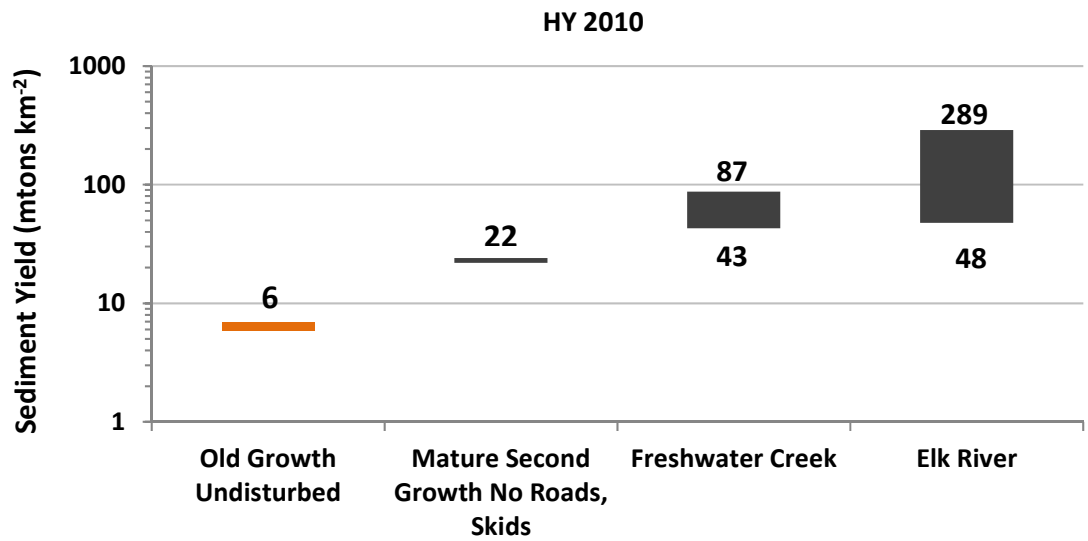


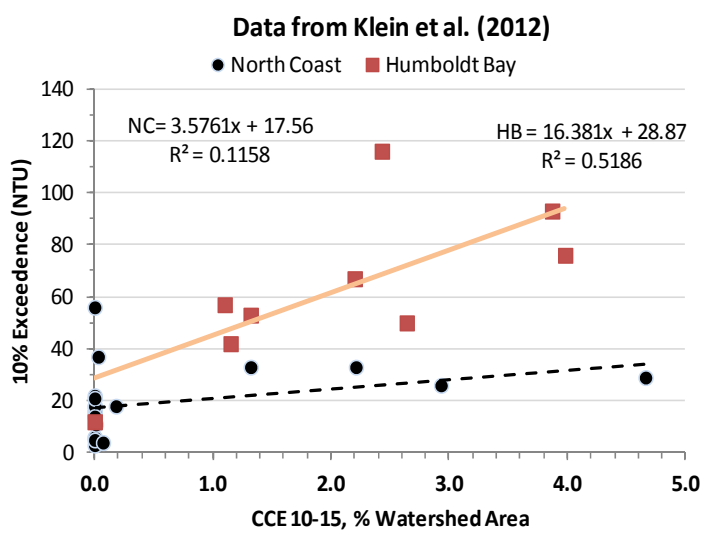
Post construction erosion

Median erosion loss = 0 cubic yards

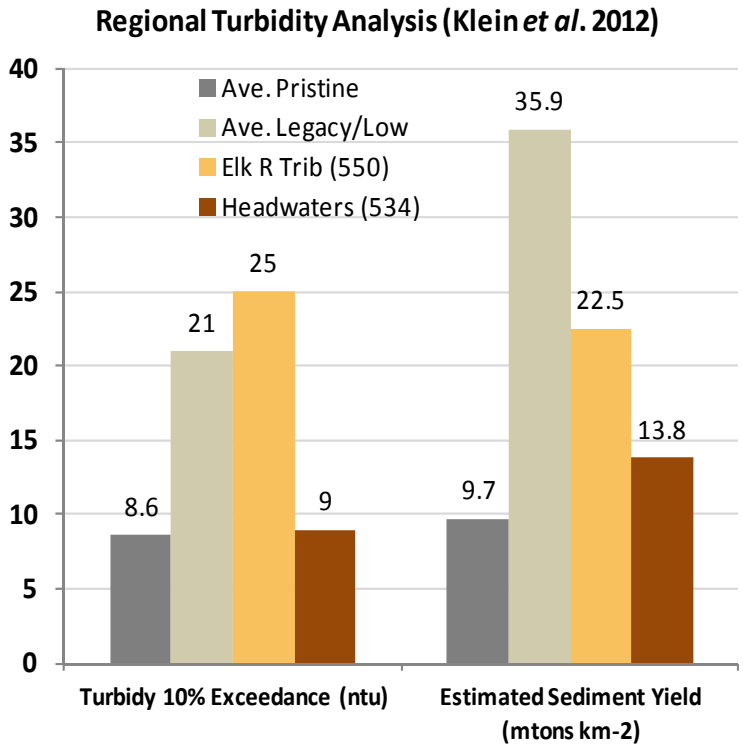
Will the sediments return to pristine levels of sediment yield and turbidity?







Legacy Sediments

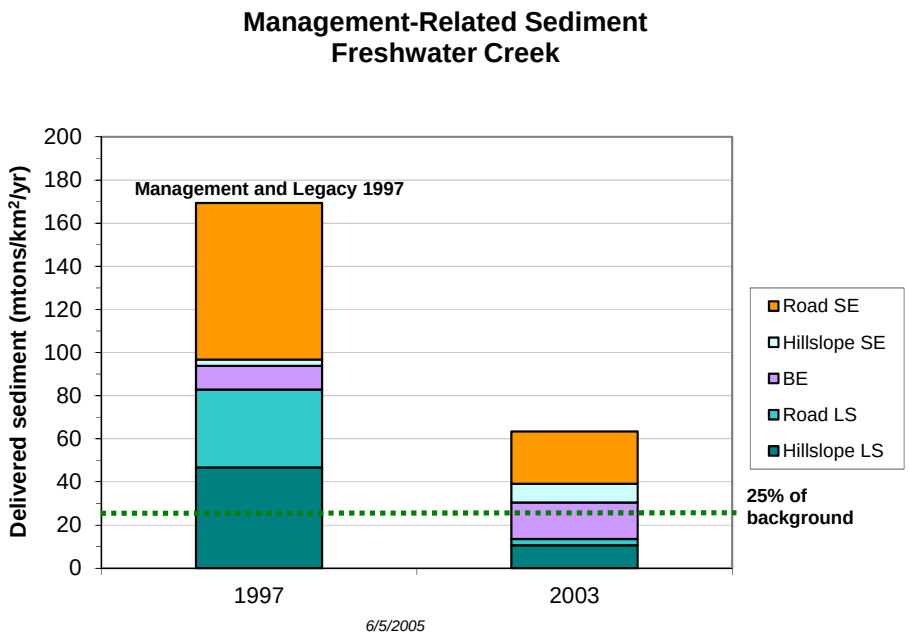


- **Elk River pristine = regional**
- **Elk River legacy = regional**

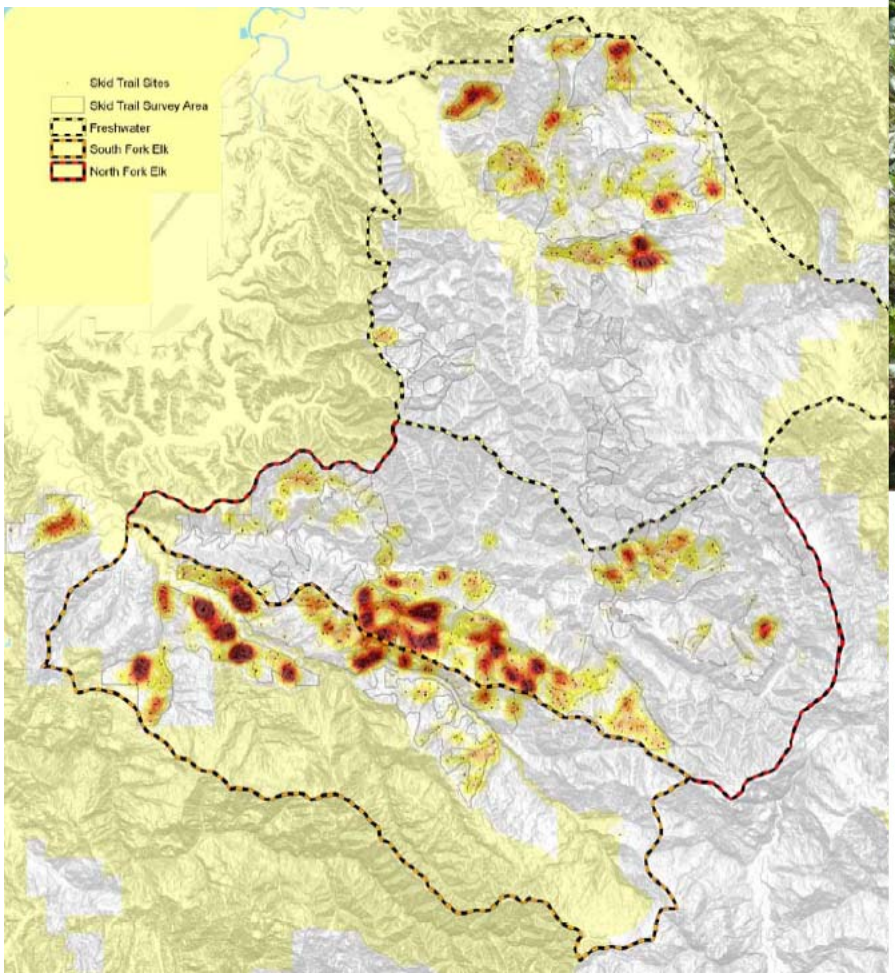
- **Indicates that there is an increase of about 15 ntu associated with "legacy" management**
  - Bank erosion 1st cycle logging
  - Skid trail crossings

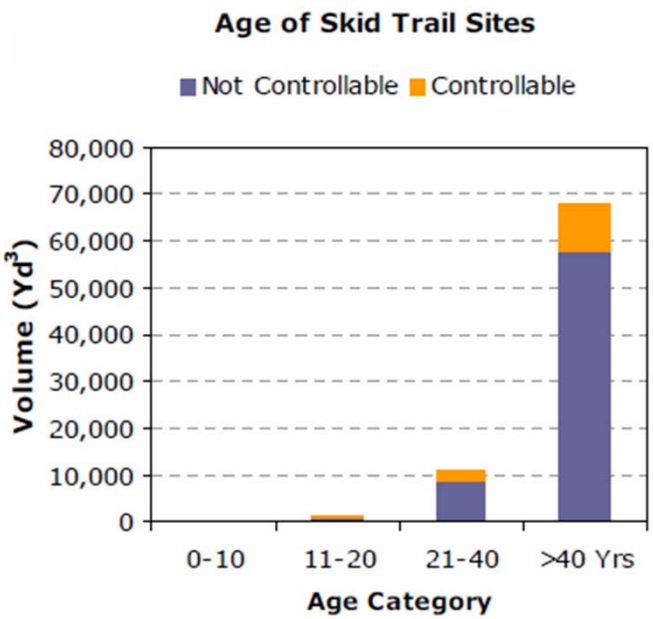
- **Indicates total 22 mtons/km^2 increase in sediment yield**
  - 9 BE
  - 14 Skid trail crossings ?

Active Management	Legacy Sources
• Road surface erosion • Harvest unit surface erosion • Bank erosion from low order channel headward migration • "Treatment" discharge	• Bank erosion from lower order valley fill following 1st cycle logging • Scour of tractor fill • Existing unimproved roads ("controllable" sites)

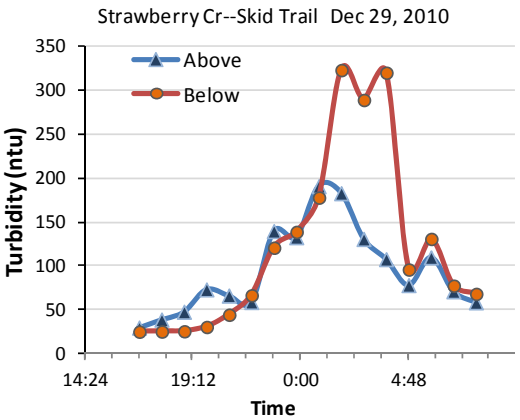


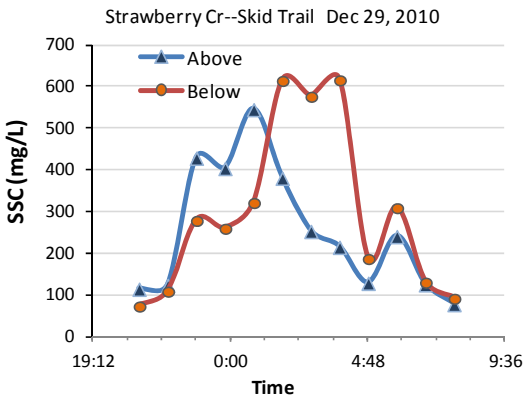
Skid Trail Impacts

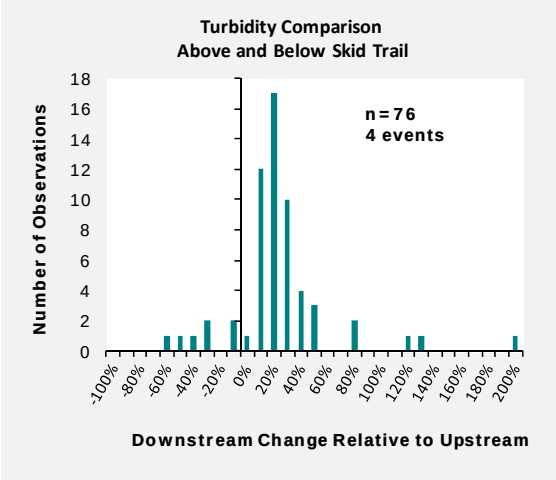


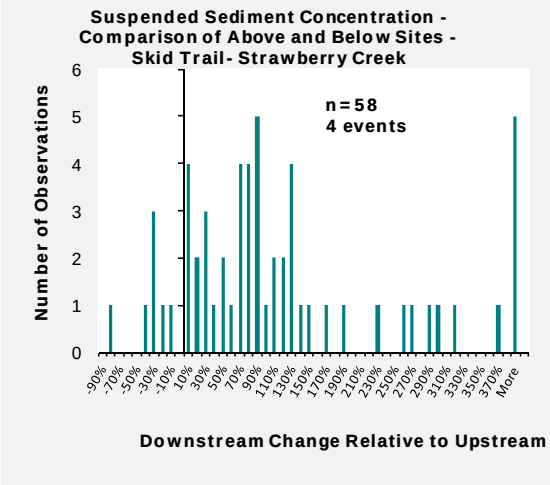


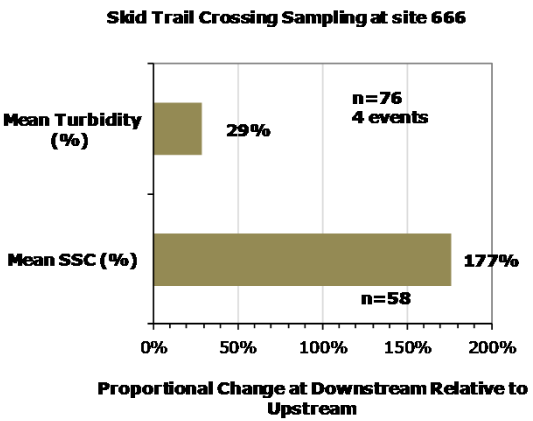
Site 1—Skid trail crossing



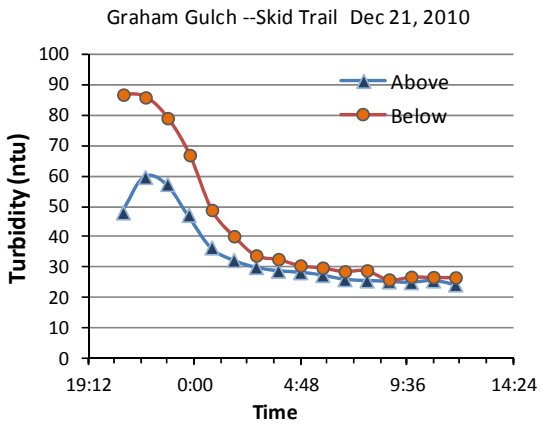


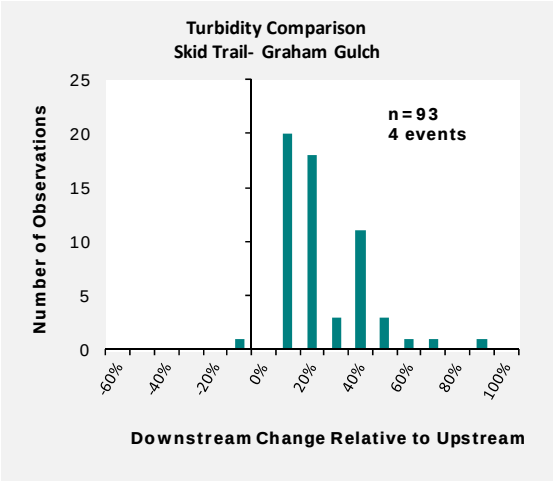


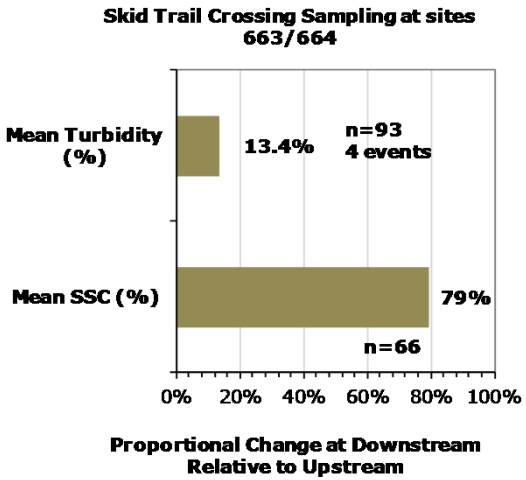


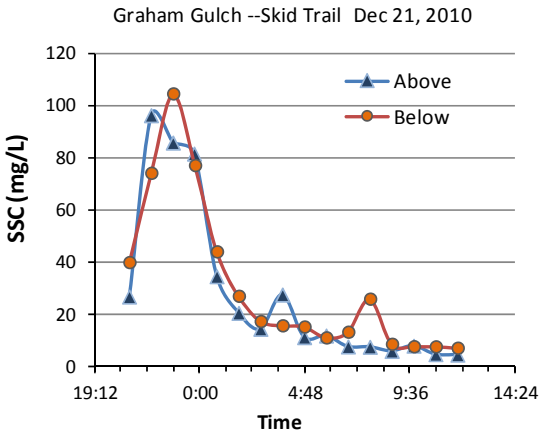


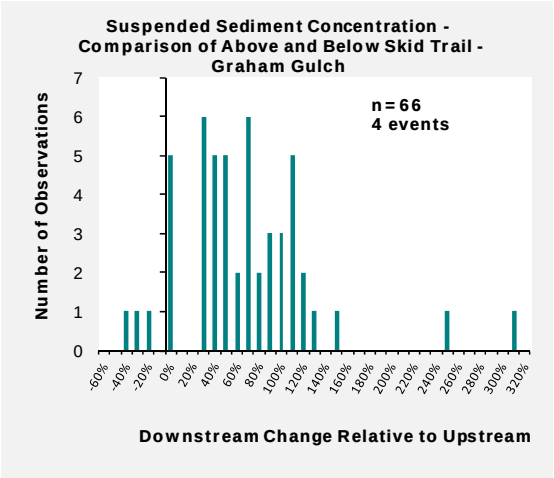
Site 2—Graham Gulch Skid Trail



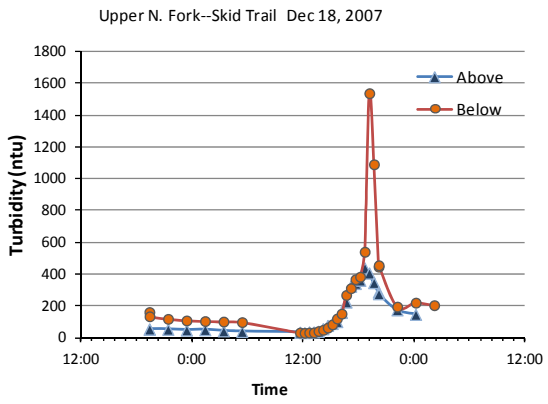


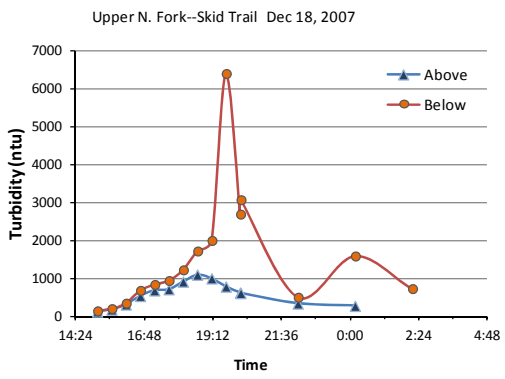


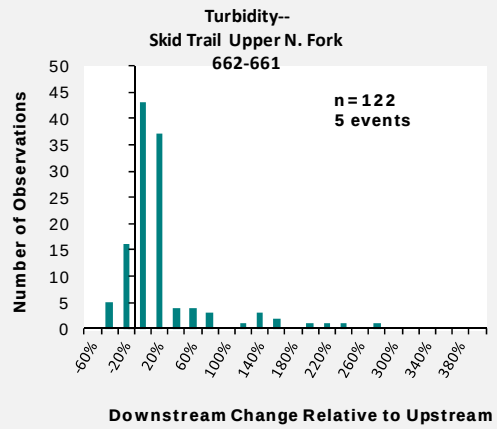


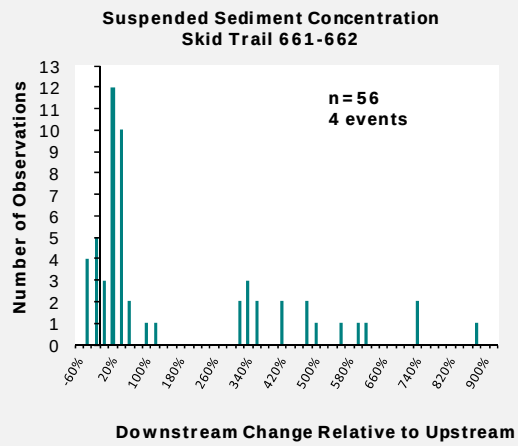


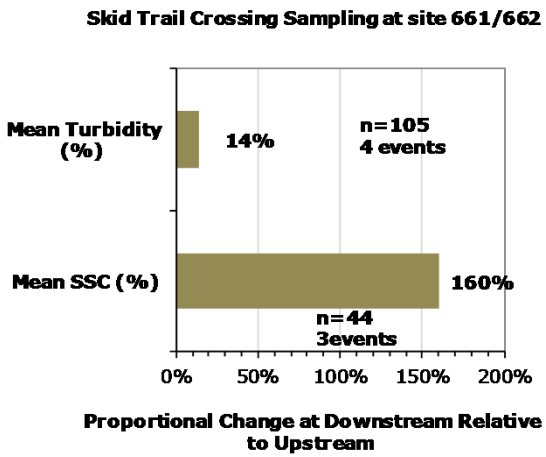
Site 3 Upper N. Fork Elk River –Skid trail



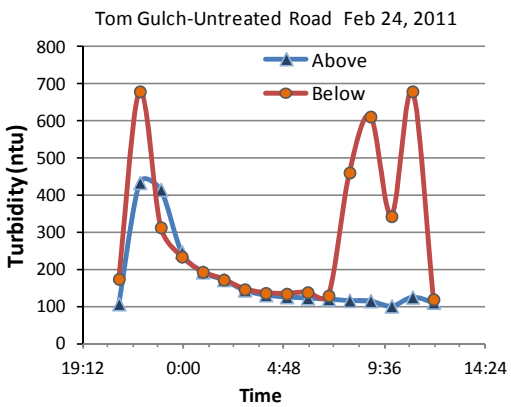


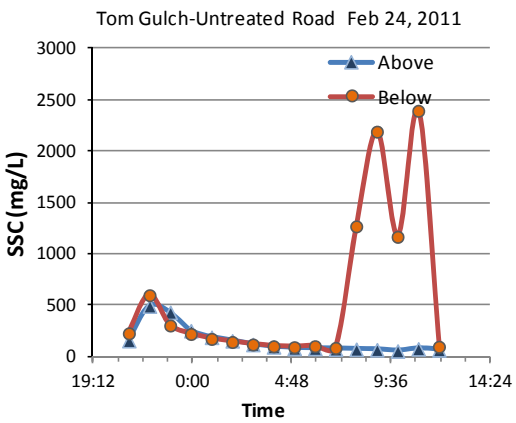


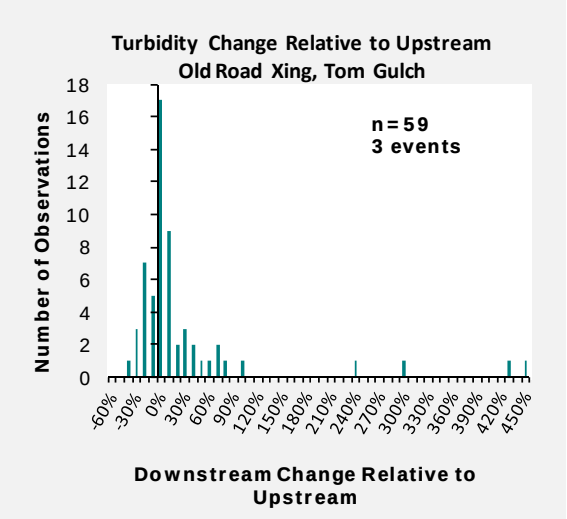


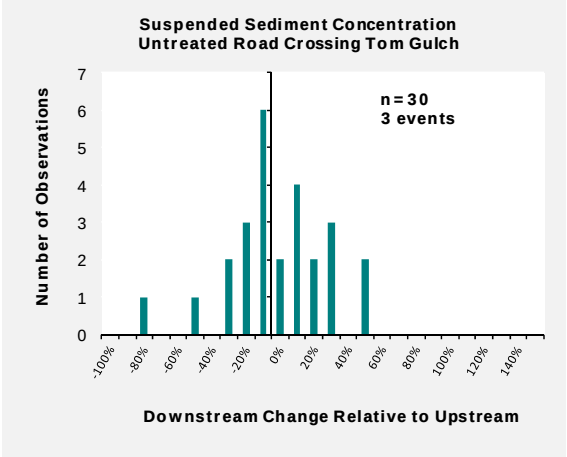


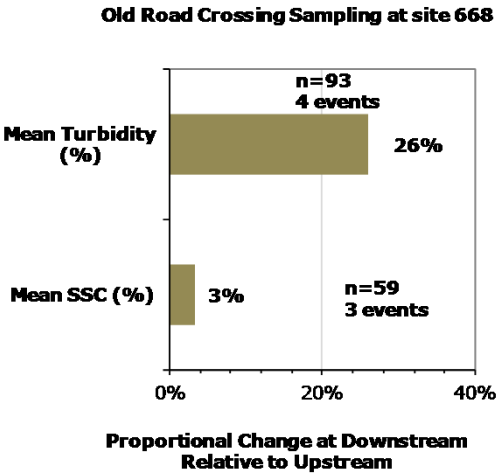
Site 4 Tom Gulch—Old road crossing





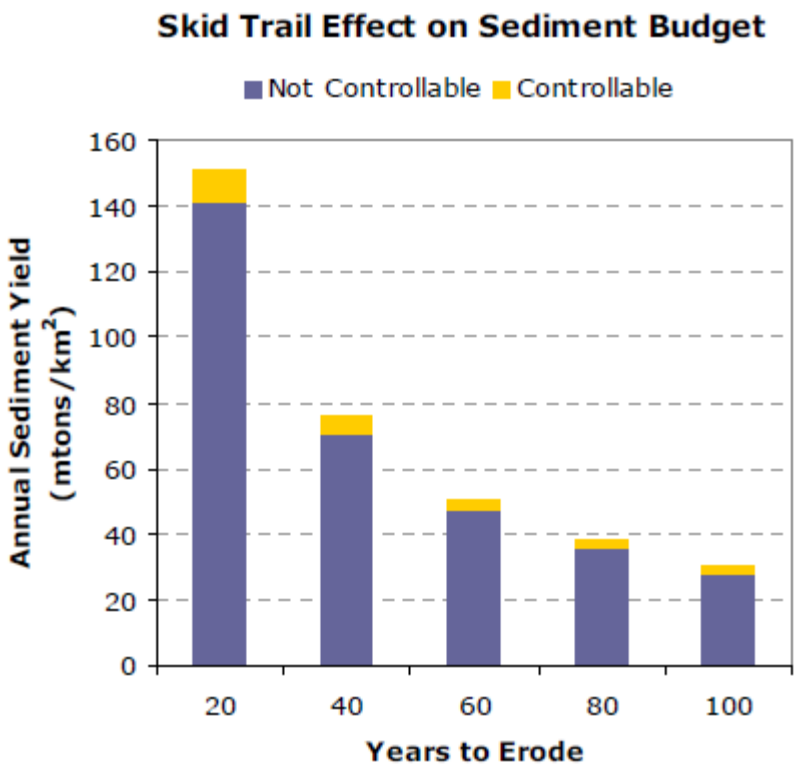






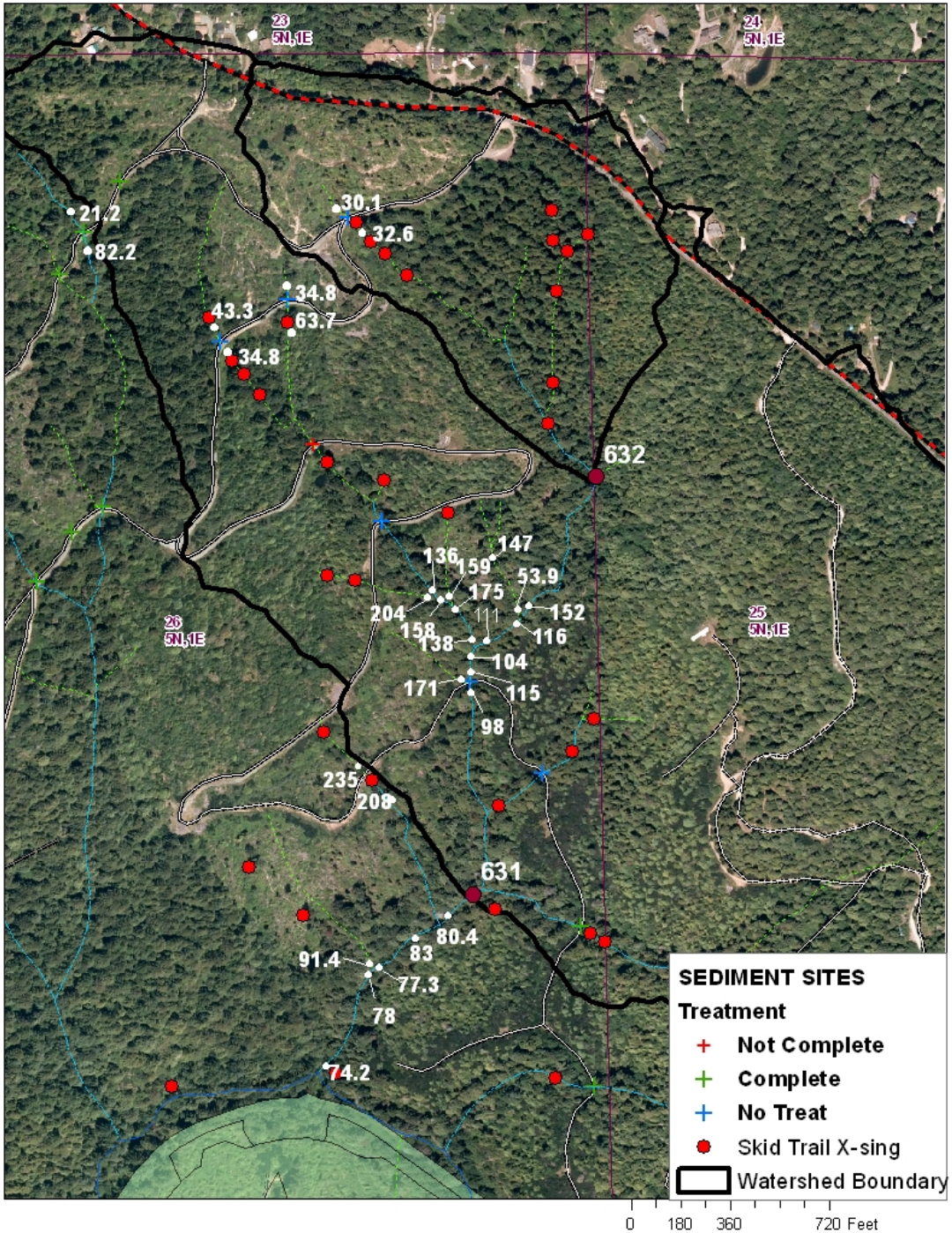
Legacy Skids

- **Every old skid trail crossing that was measured "leaks sediment" during routine storms**
  - Tends to be higher impacts on falling limb of the hydrograph
  - Suspended sediment concentration more than turbidity
- **Significant skid trail density in most of area ~ 25 per km^2**



Summary of Findings

- **Sediment yield has declined significantly during period**
  - Mostly due to weather
  - Some improvement due to cumulative effect of HCP management, especially road improvements
  - May reach target levels in 2030 or so, if all stays as is
  - Next several "events" will reveal whether staying on track
  - Modern practices have some impact, but not generally significant or consistent enough to predict
  - Likely not to reach targets due to legacy sources
- **Turbidity has not improved very much**
- **Salmon have experienced lower sediment due to favorable weather**


23
5N,1E
24
5N,1E
26
5N,1E
25
5N,1E
21.2
82.2
30.1
32.6
34.8
43.3
63.7
34.8
632
147
136
159
53.9
175
204
152
158
116
138
104
171
115
98
235
208
631
80.4
83
91.4
77.3
78
74.2
SEDIMENT SITES
Treatment
Not Complete
Complete
No Treat
Skid Trail X-sing
Watershed Boundary
0
180
360
720 Feet