Logging and Turbidity in the Coastal Watersheds of Northern California:

A regional analysis of watershed disturbance and water quality

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with
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Many Northcoast streams suffer from chronic turbidity: Why?

- Chronic turbidity is a condition of persistently turbid streamflow that can have serious impacts on fish. To answer this question, we:
- Undertook a study to identify the most important of causal factors affecting chronic turbidity.
- Used the turbidity level that was exceeded 10% of the time over the winter months (‘10%TU’) to index chronic turbidity.
- Regressed 10%TU on a set of natural and human-driven factors to try and answer the question.

Confluence of Prairie and Redwood Creeks, October, 1989

Severely eroded fill slope on Prairie Creek Bypass, October, 1989

Lower Jacoby Creek (JBW) at 20 NTU

Lower Jacoby Creek (JBW) at 200 NTU

Sampling boom for deployment of turbidity probe and pumping sampler intake in Upper Prairie Creek.

View inside stream gaging hut showing data logger box and pumping sampler. Sampler can take up to 24 samples between site visits.

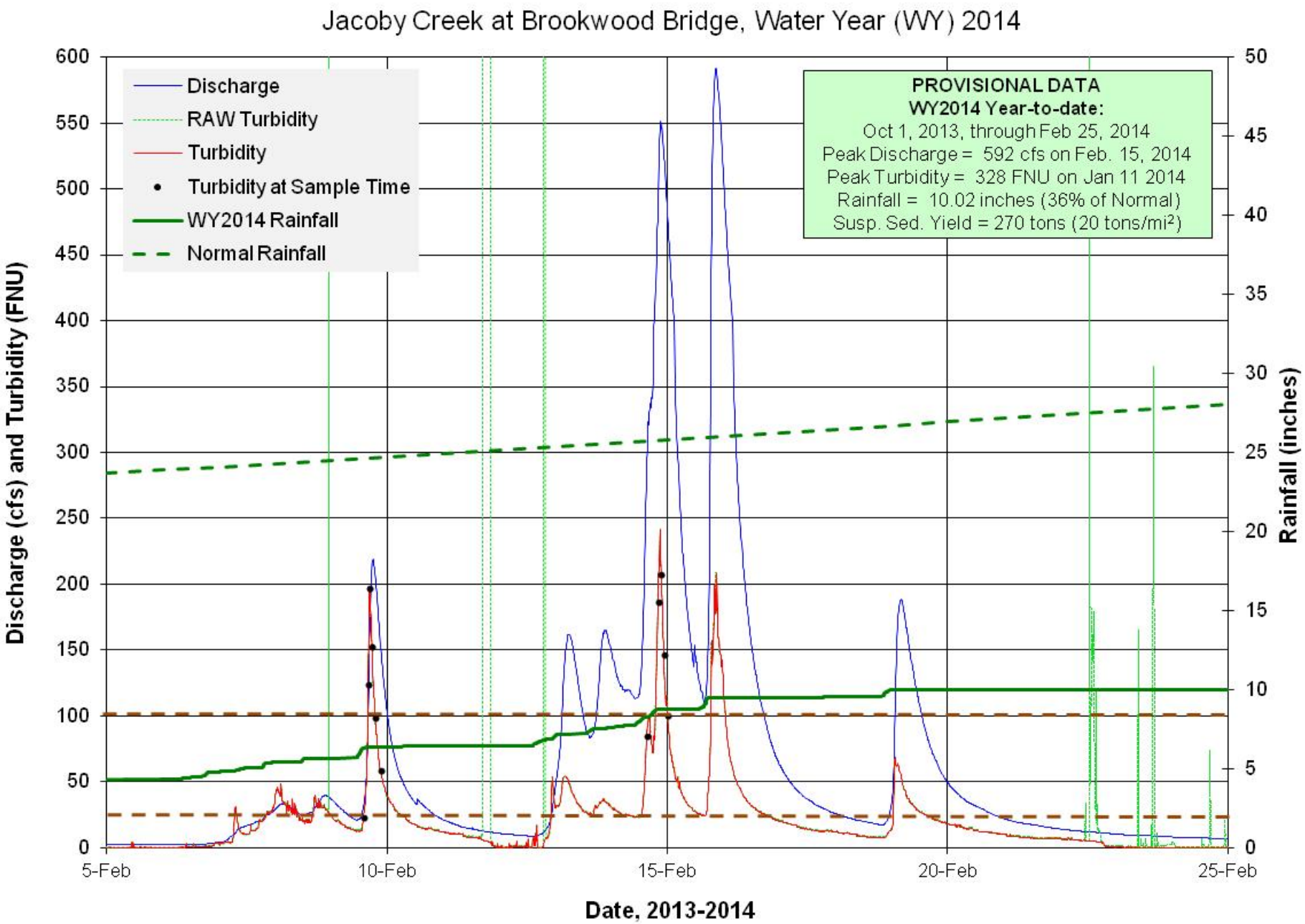
Sample times are determined by TTS (turbidity threshold sampling) protocols developed by Redwood Sciences Laboratory, Arcata, CA.

TTS protocols initiate sampling at pre-set turbidity levels and turbidity level changes.

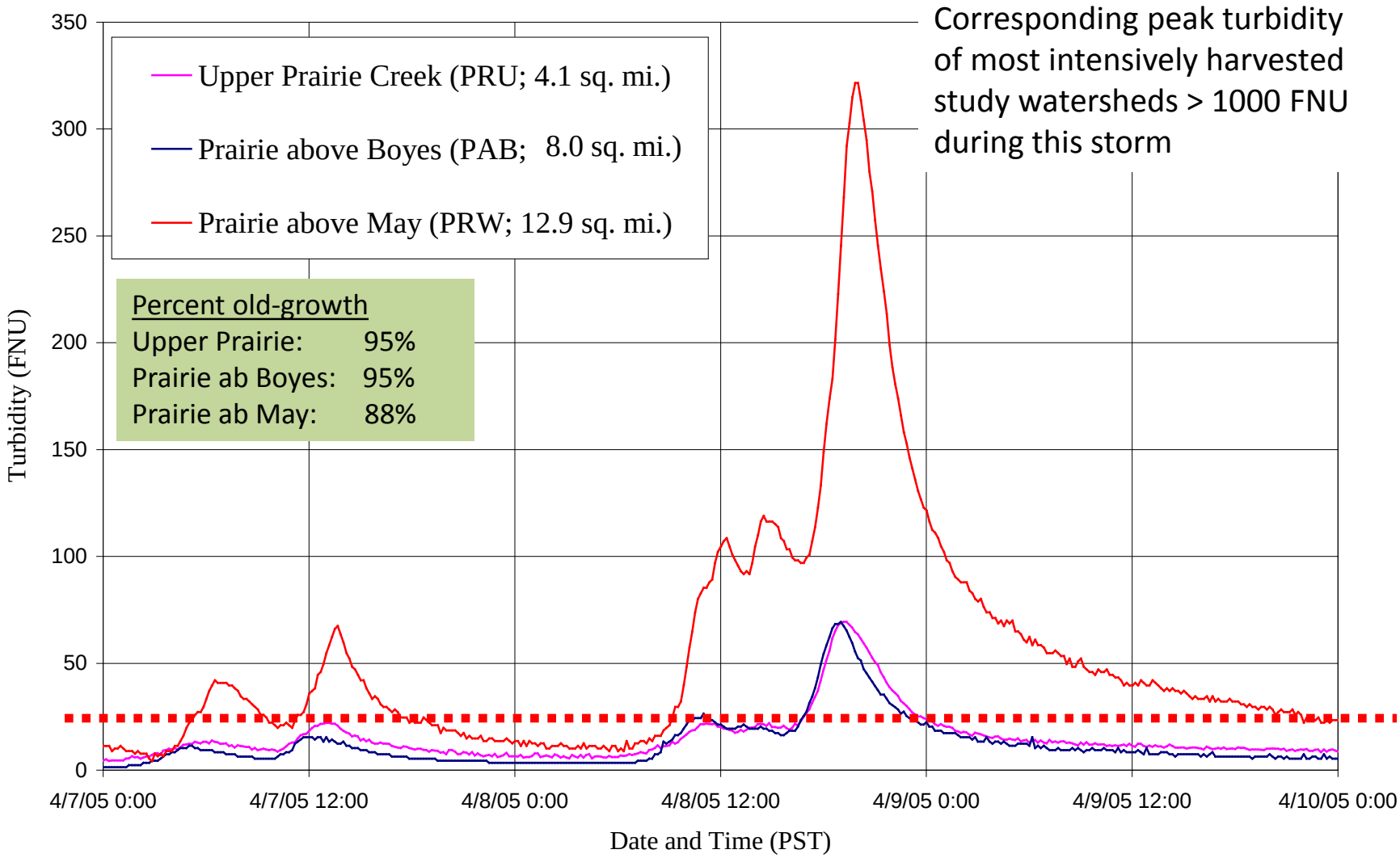
Samples are taken to laboratory for suspended sediment concentration (SSC) analysis.

Suspended load can be calculated by using turbidity (nearly continuous) as a surrogate for SSC during times when no samples were taken.

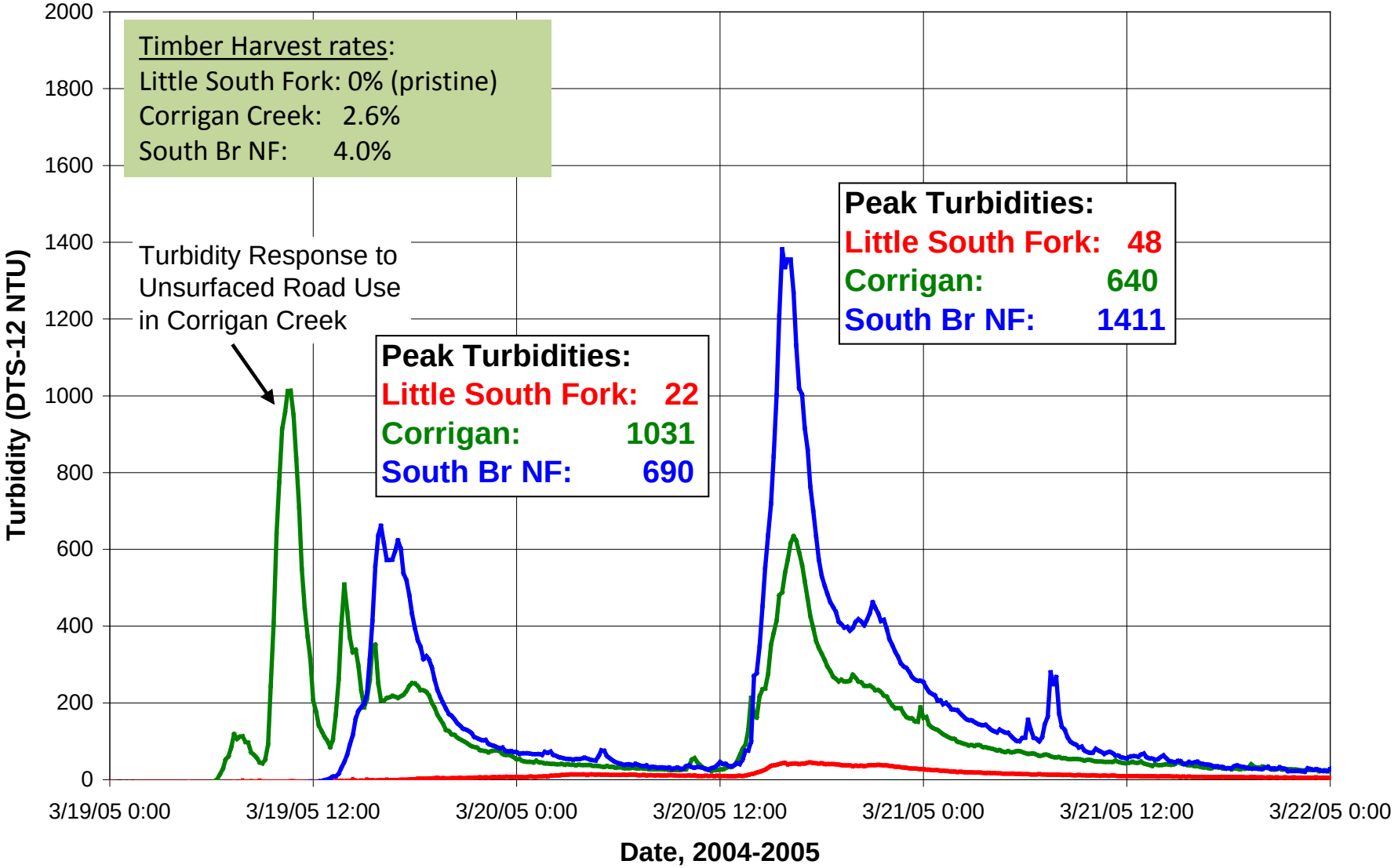
Turbidity (NTRU)


Jacoby Creek at Brookwood Bridge, Water Year (WY) 2014
Discharge
RAW Turbidity
Turbidity
Turbidity at Sample Time
WY2014 Rainfall
Normal Rainfall
PROVISIONAL DATA
WY2014 Year-to-date:
Oct 1, 2013, through Feb 25, 2014
Peak Discharge = 592 cfs on Feb. 15, 2014
Peak Turbidity = 328 FNU on Jan 11 2014
Rainfall = 10.02 inches (36% of Normal)
Susp. Sed. Yield = 270 tons (20 tons/mi²)
Discharge (cfs) and Turbidity (FNU)
Rainfall (inches)
Date, 2013-2014
5-Feb
10-Feb
15-Feb
20-Feb
25-Feb
0
50
100
150
200
250
300
350
400
450
500
550
600
0
5
10
15
20
25
30
35
40
45
50

Turbidity along Prairie Creek, April, 2005.



Upper Elk River turbidities, Mar. 19 and 20, 2005



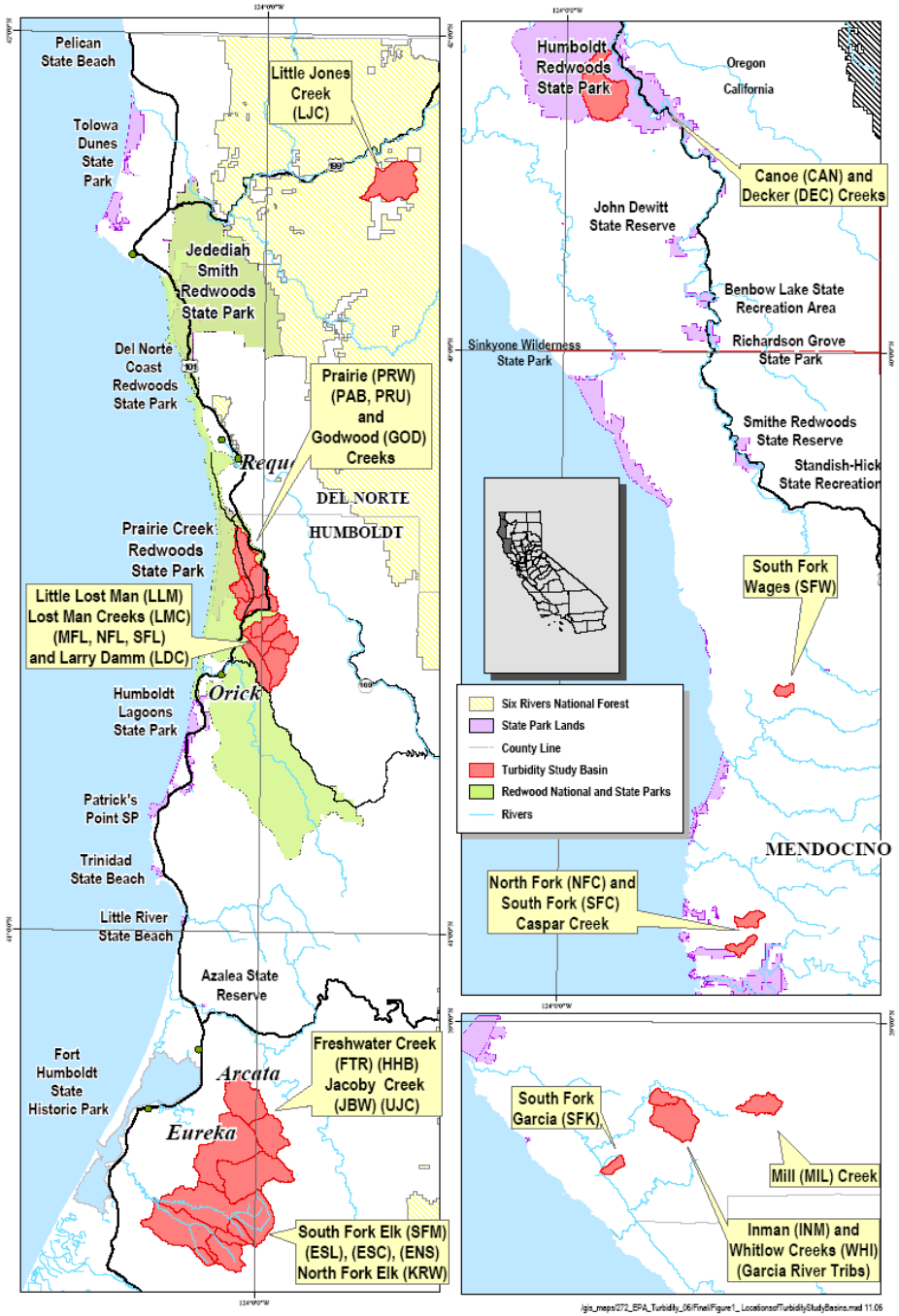


Figure 1. Locations of turbidity study basins, north coastal California.

Stream [a]	Site Code	Harvest Catergory	Drain-age Area (km^2)	Mean Basin Slope (%)	Basin Relief (m)	Mean Annual Precip.[b] (mm)	Data Period WY
Whitlow Creek	WHI	high	4.9	41	427	1400	2004-05
S Branch NF Elk River	*ENS*	high	4.9	31	518	1400	2004-05
North Fork Elk River	*KRW*	high	57.4	35	701	1400	2003-05
Inman Creek	INM	high	19.5	43	579	1400	2005
Corrigan Creek	*ESC*	high	4.1	33	396	1400	2004-05
South Fork Elk	*SFM*	high	50.0	30	610	1400	2004-05
North Fork Caspar Creek	NFC	high	4.8	36	244	1400	2003-05
Freshwater Cr at HH Bridge	*HHB*	high	72.8	32	671	1400	2005
Lower Jacoby Creek	*JBW*	low	35.1	32	640	1400	2003-05
Upper Jacoby Creek	*UJC*	low	15.1	38	488	1400	2003-05
Freshwater Creek at Roelofs	*FTR*	low	33.1	38	853	1400	2004-05
Mill Creek	MIL	low	9.4	39	305	1400	2004-05
SF Wages ab Center Gulch	SFW	low	2.9	58	488	1400	2004-05
South Fork Caspar Creek	SFC	low	4.1	33	305	1400	2003-05
South Fork Garcia R	SFK	low	3.5	45	579	1400	2005
Prairie Cr above May Cr	*PRW*	legacy	33.4	29	549	1650	2004-05
South Fork Lost Man Creek	*SFL*	legacy	10.2	39	610	1650	2003-05
Lost Man Creek at Hatchery	*LMC*	legacy	31.3	30	427	1650	2003-05
Middle Fork Lost Man Creek	*MFL*	legacy	5.8	36	518	1650	2004-05
North Fork Lost Man Creek	*NFL*	legacy	5.8	34	488	1650	2004-05
Larry Damm Creek	*LDC*	legacy	4.8	26	488	1650	2004-05
Little Jones Creek	LJC	legacy	22.3	51	945	2670	2003-05
Canoe Creek	*CAN*	legacy	26.2	43	975	2670	2004-05
Little South Fork Elk River	*ESL*	pristine	3.1	23	244	1400	2004-05
Godwood Creek	*GOD*	pristine	3.8	29	213	1650	2003-05
Little Lost Man Creek	*LLM*	pristine	9.1	29	640	1650	2003-05
Prairie Cr above Boyes Cr	*PAB*	pristine	19.9	31	427	1650	2004-05
Upper Prairie Creek	*PRU*	pristine	10.8	29	396	1650	2003-05

[a] Humboldt County subset streams appear in *italics*.

[b] From isohyetal maps at: http://frap.cdf.ca.gov/webdata/maps/statewide/rainmap.pdf

Watershed Regression Variables	Units	Code
Natural Watershed Variables		
Drainage area	km^2	DRA
Mean watershed slope	percent	AWS
Perrenial stream density	km/km^2	PSD
Intermittent stream density	km/km^2	ISD
Total stream density	km/km^2	TSD
SINMAP area with FS < 1	percent of area	SIN<1
SINMAP area with FS 1.0-1.1	percent of area	SIN 1.0
SINMAP area with FS 1.1-1.2	percent of area	SIN 1.1
SINMAP area with FS >1.2	percent of area	SIN>1.2
Hypsometric integral	n/a	HYP
Basin relief	meters	RLF
WY2005 Annual precipitation recurrence interval	years	ANP
WY2005 Max. 1-day precipitation recurrence interval	years	1DP
WY2005 Max. 2-day precipitation recurrence interval	years	2DP
WY2005 Max. 3-day precipitation recurrence interval	years	3DP
Basin-wide road characteristics		
Basin-wide road density: all roads	km/km^2	GRD
Basin-wide road density: lower slope roads	km/km^2	LSRD
Basin-wide road density: mid-slope roads	km/km^2	MSRD
Basin-wide road density: upper slope roads	km/km^2	USRD
Data from approved THPs [a]		
Clearcut equivalent area, 1990-2004	weighted % of area	CCE 0-15
Clearcut equivalent area, 1995-2004	weighted % of area	CCE 0-10
Clearcut equivalent area, 2000-2004	weighted % of area	CCE 0-5
Clearcut equivalent area, 1995-1999	weighted % of area	CCE 5-10
Clearcut equivalent area, 1990-1994	weighted % of area	CCE 10-15
Tractor yarded area, 1990-2004 (15-yr)	percent of area	TYA-15
Permanent roads constructed 1990-2004	km/km^2	PRC-15
Seasonal roads constructed 1990-2004	km/km^2	SRC-15
Temporary roads constructed 1990-2004	km/km^2	TRC-15
Temporary and seasonal roads constructed 1990-2004	km/km^2	TSR-15
All nonpaved roads constructed, 1990-2004	km/km^2	ARC-15

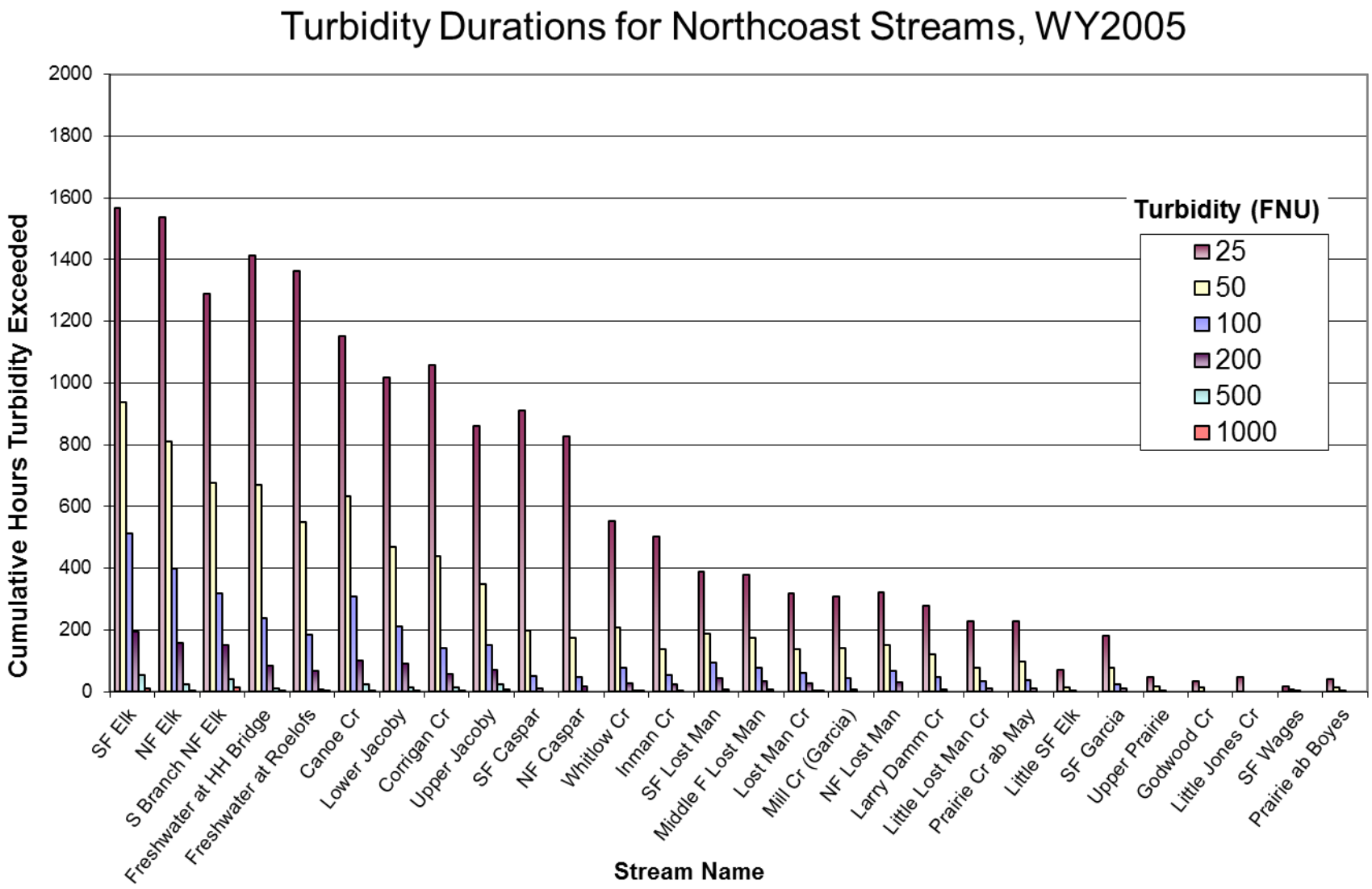
[a] THP data (road lengths, harvest, and yarding areas) are expressed on a per-unit area basis for the entire gaged watershed; clearcut equivalent area (CCE) variables are expressed on a mean annual basis.

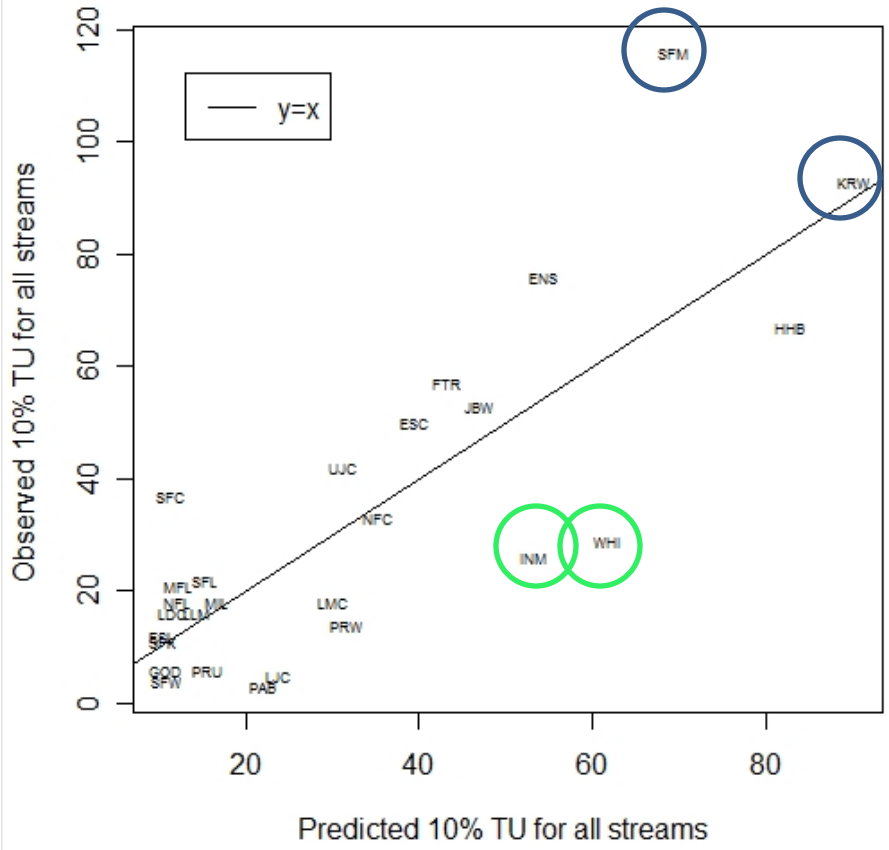
Silvicultural prescription	Weighting factor
Clearcut	1.00
Commercial thin	0.50
Group selection	0.50
Rehabilitation of understocked areas	1.00
Road right of way	1.00
Sanitation salvage	0.75
Shelterwood preparation cut	0.75
Shelterwood removal cut	0.75
Shelterwood seed cut	0.75
Selection	0.50
Seed tree removal cut	0.75
Seed tree seed cut	0.75
Alternative prescription	0.75
Variable retention	0.50

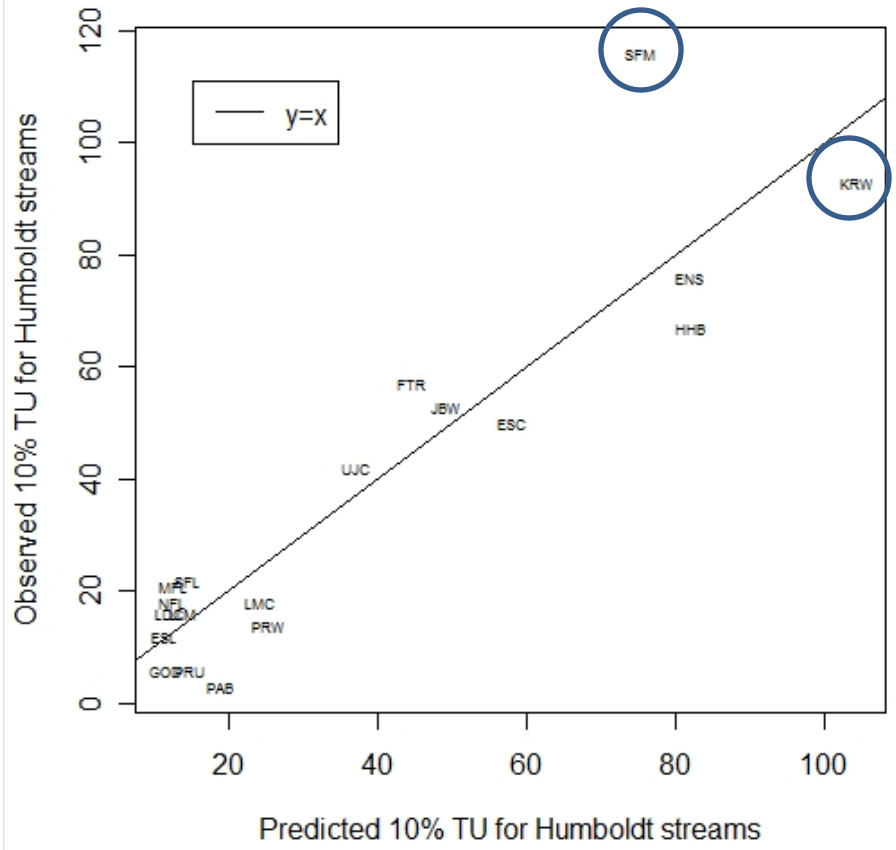
Water year (WY) 2005 Data

Site	Harvest rate	Turbidity (FNU) at specified exceedence					Cumulative hours above specified turbidity					
Code [a]	CCE10-15	0.1%	1%	2%	5%	10%	1000	500	200	100	50	25
SFM	2.43%	1245	551	370	185	116	11	54	195	513	936	1566
KRW	3.87%	766	376	271	161	93	1	25	157	399	810	1538
ENS	3.98%	1416	483	303	144	76	13	41	150	320	678	1290
HHB	2.20%	620	281	197	107	67	1	8	85	238	670	1413
FTR	1.10%	675	254	167	87	57	0	8	67	184	550	1363
CAN	0.00%	509	225	152	92	56	0	6	56	186	485	936
JBW	1.32%	794	307	205	96	53	1	14	90	211	470	1016
ESC	2.64%	785	249	148	78	50	1	14	56	140	440	1058
UJC	1.15%	1662	293	167	75	42	8	23	71	150	349	860
SFC	0.03%	258	110	77	48	37	0	0	10	52	197	909
NFC	2.21%	359	107	65	43	33	0	0	17	46	174	829
WHI	4.66%	416	149	92	48	29	0	2	26	78	209	552
INM	2.93%	327	127	64	40	26	0	0	24	53	138	504
SFL	0.00%	548	197	107	42	22	0	7	43	94	187	387
MFL	0.00%	590	157	87	40	21	0	8	32	76	172	379
LMC	0.00%	494	131	72	33	18	0	4	27	62	136	317
MIL	0.18%	235	99	73	34	18	0	0	6	43	140	308
NFL	0.00%	343	145	79	36	18	0	0	29	67	150	322
LDC	0.00%	213	106	66	31	16	0	0	7	48	120	278
LLM	0.00%	256	77	47	26	16	0	0	11	32	78	227
PRW	0.00%	290	94	55	26	14	0	0	11	38	98	229
ESL	0.00%	79	31	22	16	12	0	0	0	2	15	71
SFK	0.01%	259	71	45	20	11	0	0	10	24	76	180
PRU	0.00%	81	26	17	10	6	0	0	0	1	16	45
GOD	0.00%	66	23	16	9	6	0	0	0	0	12	34
LJC	0.00%	41	25	14	8	5	0	0	0	0	0	46
SFW	0.07%	60	15	10	6	4	0	0	0	0	7	16
PAB	0.00%	82	24	14	6	3	0	0	0	1	14	41

[a] see Table 1 for corresponding stream names; *italics* indicates Humboldt County streams; shaded cells are pristine sites.


Turbidity Durations for Northcoast Streams, WY2005
Cumulative Hours Turbidity Exceeded
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Turbidity (FNU)
25
50
100
200
500
1000
SF Elk
NF Elk
S Branch NF Elk
Freshwater at HH Bridge
Freshwater at Roelofs
Canoe Cr
Lower Jacoby
Corrigan Cr
Upper Jacoby
SF Caspar
NF Caspar
Whitlow Cr
Inman Cr
SF Lost Man
Middle F Lost Man
Lost Man Cr
Mill Cr (Garcia)
NF Lost Man
Larry Damm Cr
Little Lost Man Cr
Prairie Cr ab May
Little SF Elk
SF Garcia
Upper Prairie
Godwood Cr
Little Jones Cr
SF Wages
Prairie ab Boyes
Stream Name



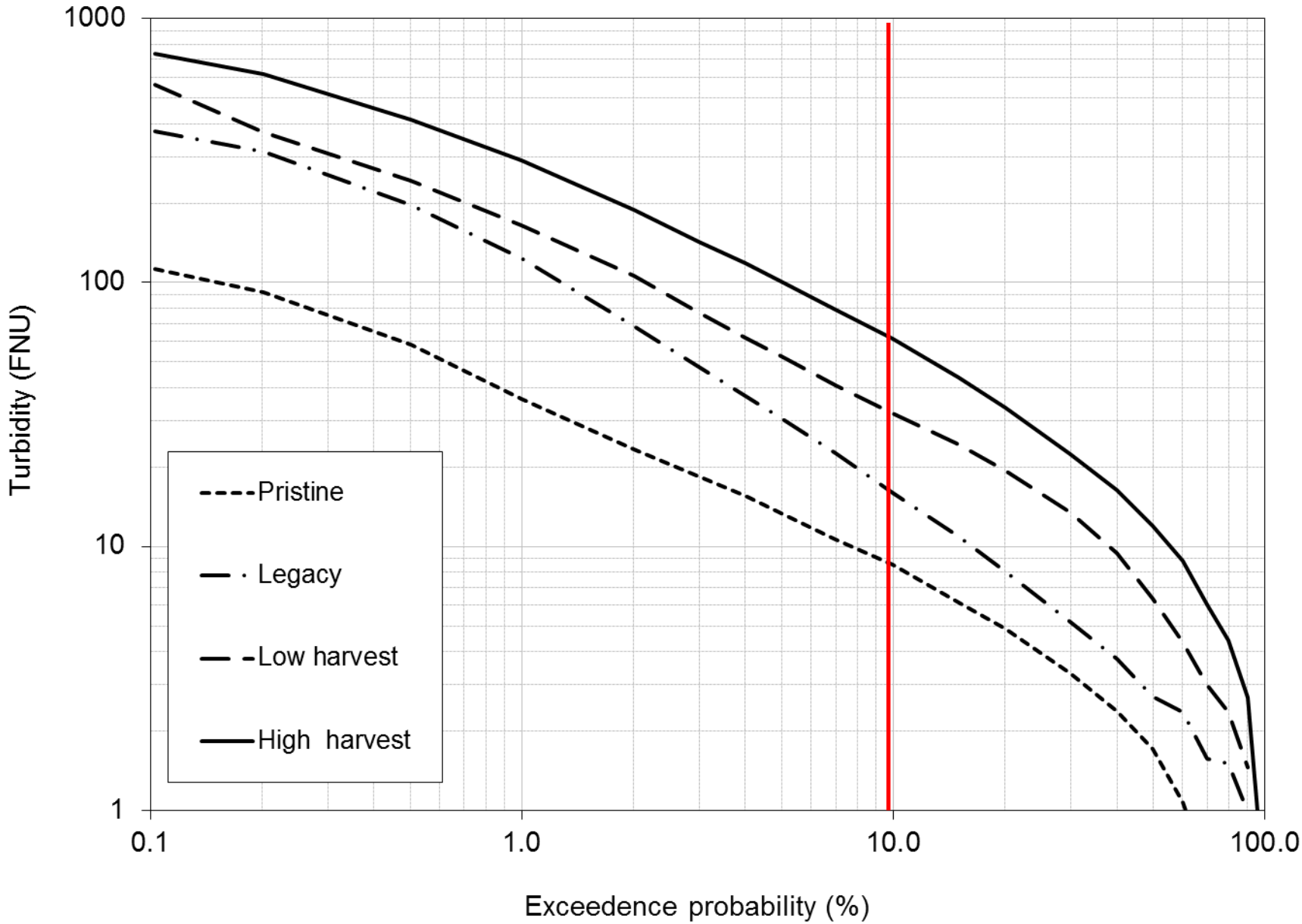


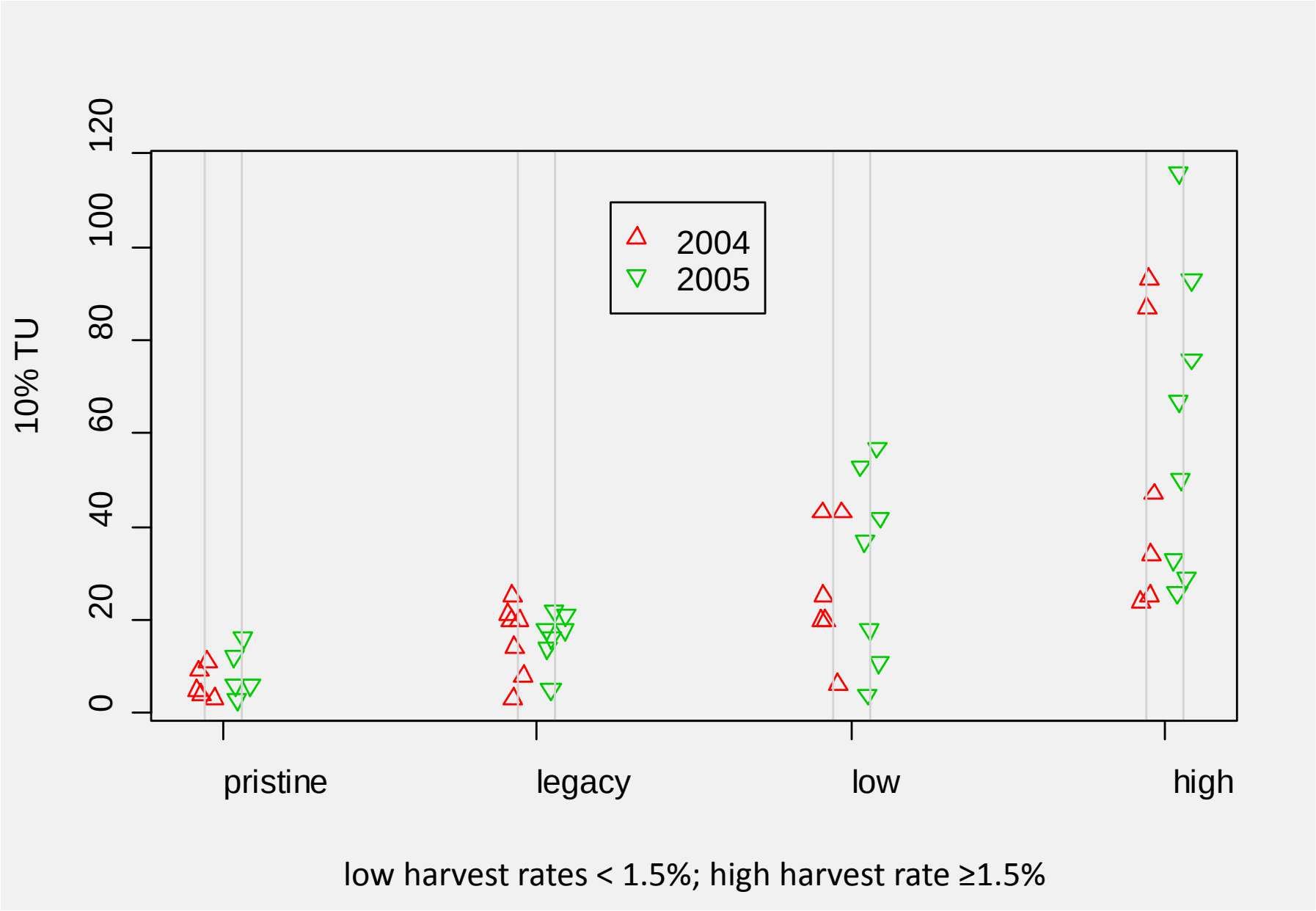
Regression with all streams (n = 27):
Predictors: CCE 10-15 and Drainage Area
Adjusted multiple r^2 = 0.63

Regression with HumCo streams (n = 19):
Predictor: CCE 10-15 and Drainage Area
Adjusted multiple r^2 = 0.82

WY2005 Multiple Regression Results				
Dataset	Predictor(s)	p-value(s)	Significance	Adj. Mult. r^2
All Sites	CCE%10-15	*p<0.0002*	highly significant	0.63
"	DRA	*p=0.0013*	highly significant	
HumCo	CCE%10-15	*p<0.0002*	highly significant	0.82
"	DRA	*p=0.018*	significant	

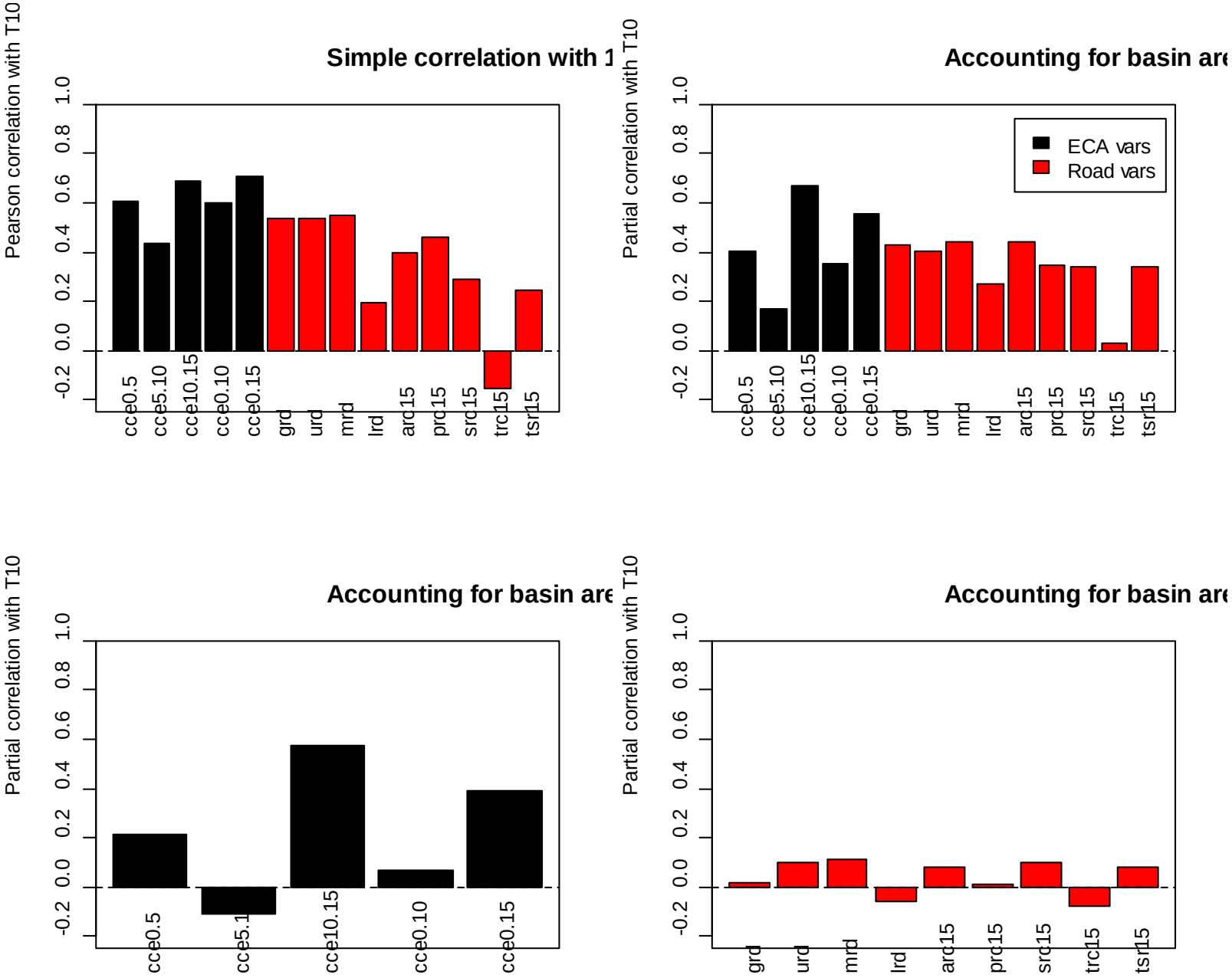
Former private timberland as it appeared in 1977:
now included in Redwood National and State Parks
LEGACY
LEGACY
LEGACY
LEGACY
LEGACY
LEGACY

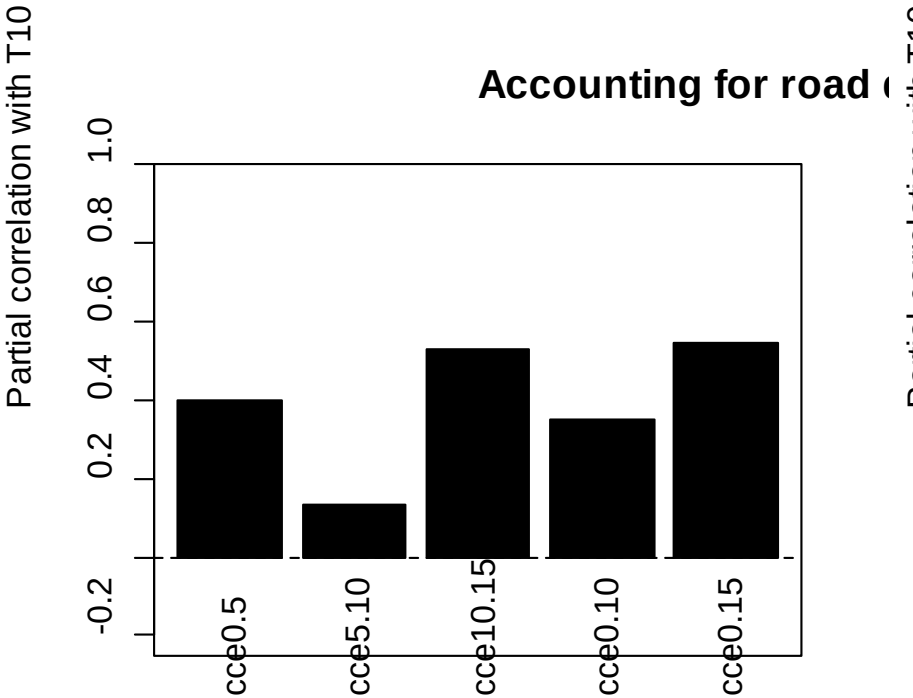

1000
100
10
1
Turbidity (FNU)
0.1
1.0
10.0
100.0
Exceedence probability (%)
Pristine
Legacy
Low harvest
High harvest

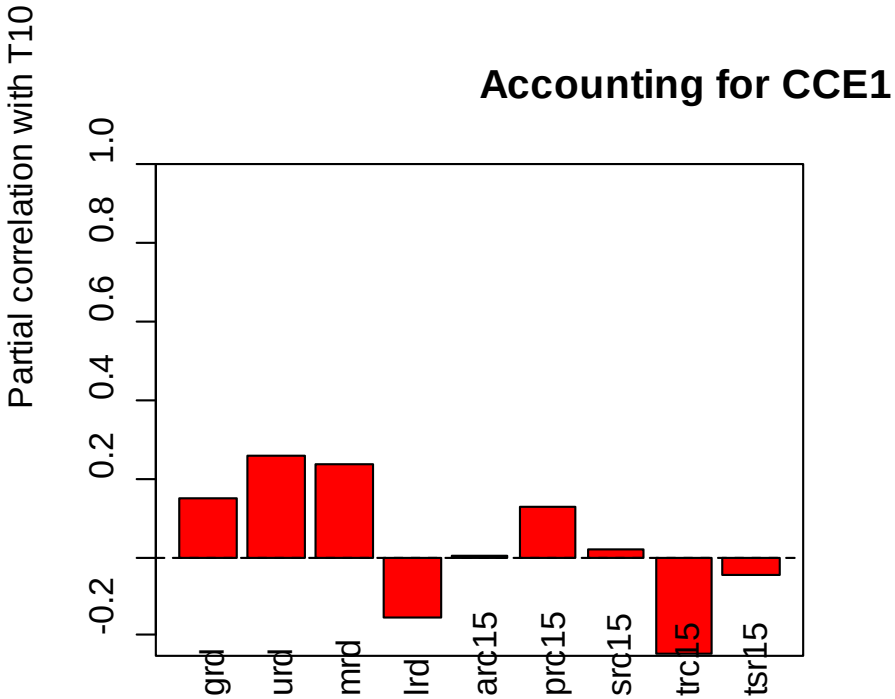

10% TU
0
20
40
60
80
100
120
2004
2005
pristine
legacy
low
high
low harvest rates < 1.5%; high harvest rate ≥1.5%

Permutation Test Results Comparing "Legacy" Streams with Other Harvest Categories					
Harvest Category	Harvest Rate	Drainage Area (km^2)	WY2005 10%TU (FNU)	WY2004 10%TU (FNU)	Permuta-tion Test p-value
High	3.1%	27.3	61	52	0.001
Low	0.6%	14.7	32	26	0.054
Legacy	0.0%	16.2	16	16	N/A
Pristine	0.0%	9.3	8	6	0.009

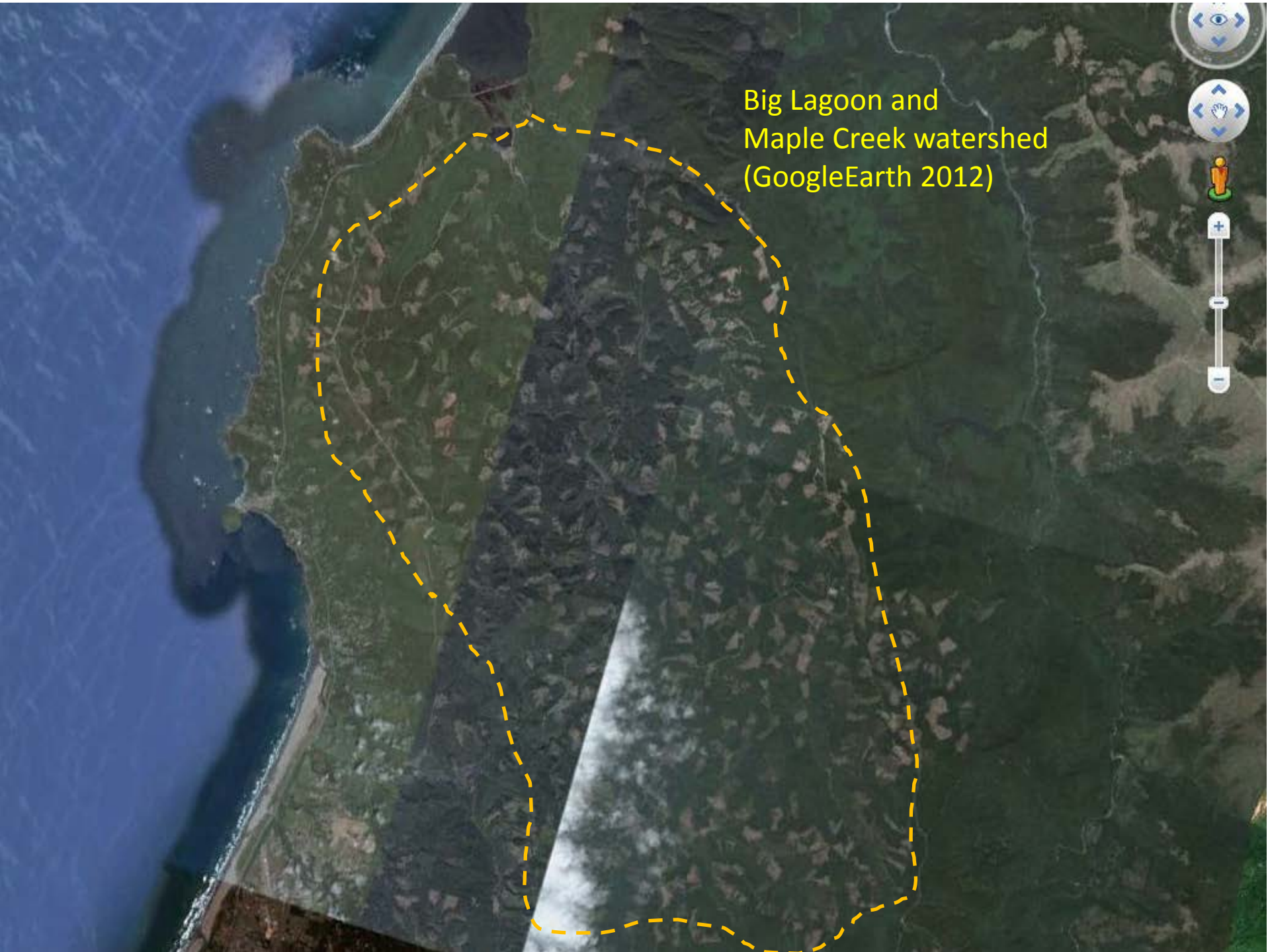
Road bed heavily eroded by streamflow diverted at plugged culverts.


Simple correlation with 1
Pearson correlation with T10
Accounting for basin are
Partial correlation with T10
ECA vars
Road vars
Accounting for basin are
Partial correlation with T10
Accounting for basin are
Partial correlation with T10
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
cce0.5
cce5.10
cce10.15
cce0.10
cce0.15
grd
urd
mrd
lrd
ard15
prd15
srd15
trc15
tsr15

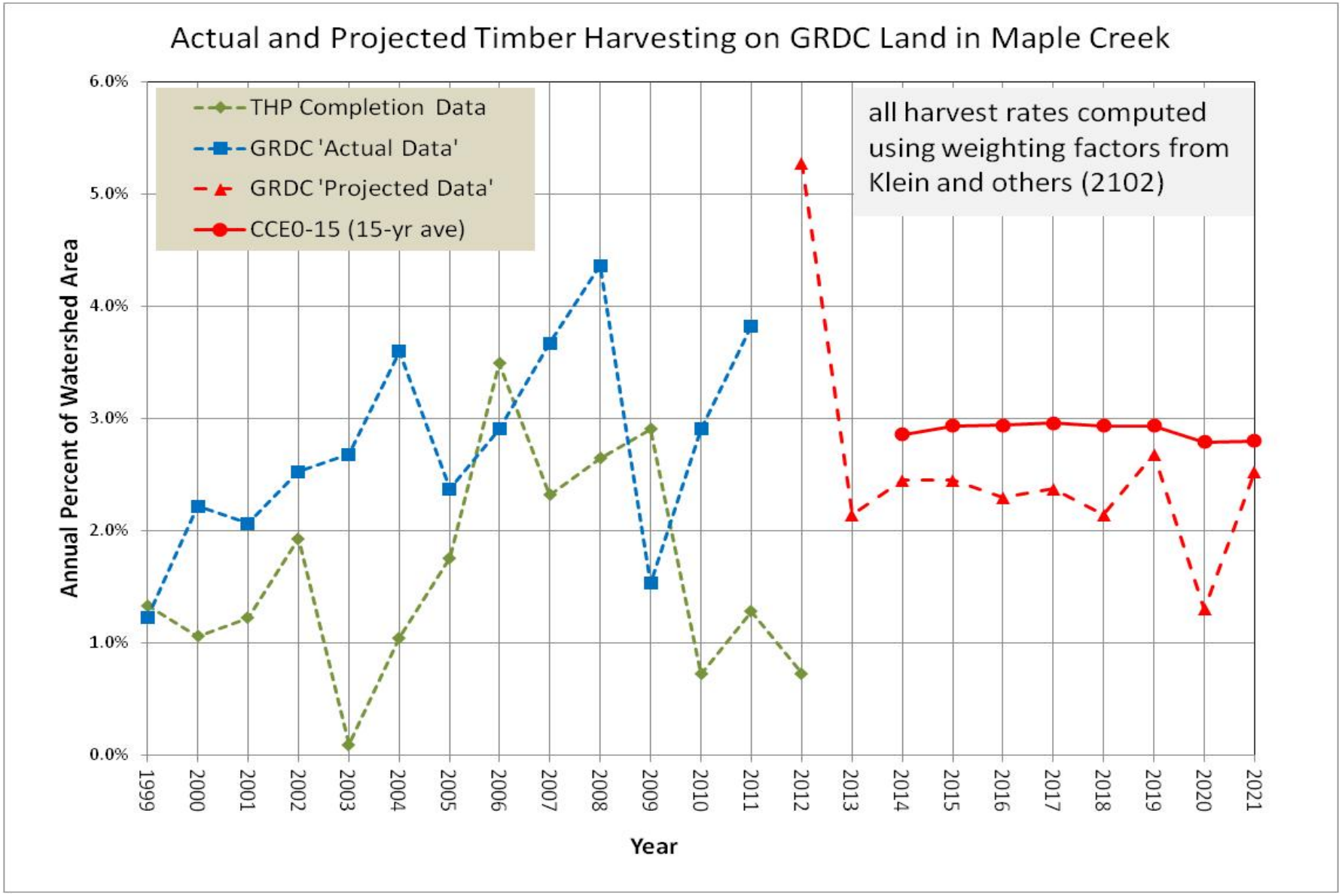




Toe-to-toe comparison of the value of harvest rate and road variables in explaining chronic turbidity differences among North Coast watersheds.


Big Lagoon and
Maple Creek watershed
(GoogleEarth 2012)

Big Lagoon and
Maple Creek watershed
(GoogleEarth 2012)



GRDC Data captured from Figure 1 in "*Review of Green Diamond Resource Company's Timber Harvest Operations and Forest Management Activities As They Relate to Rate of Harvest and Cumulative Watershed Effects*" GDRC June 2012. Weighting factors from Klein et al.,2012, applied.

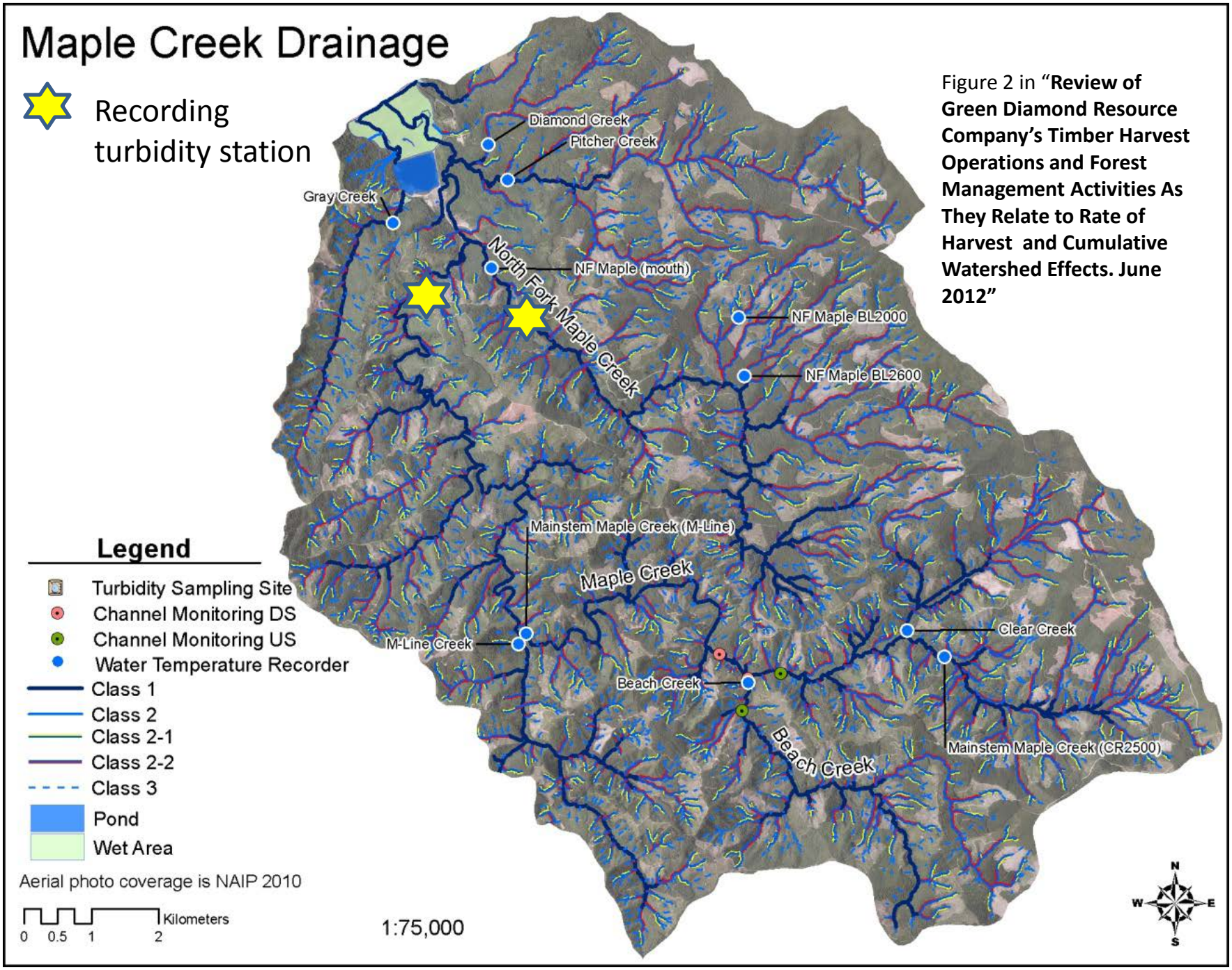
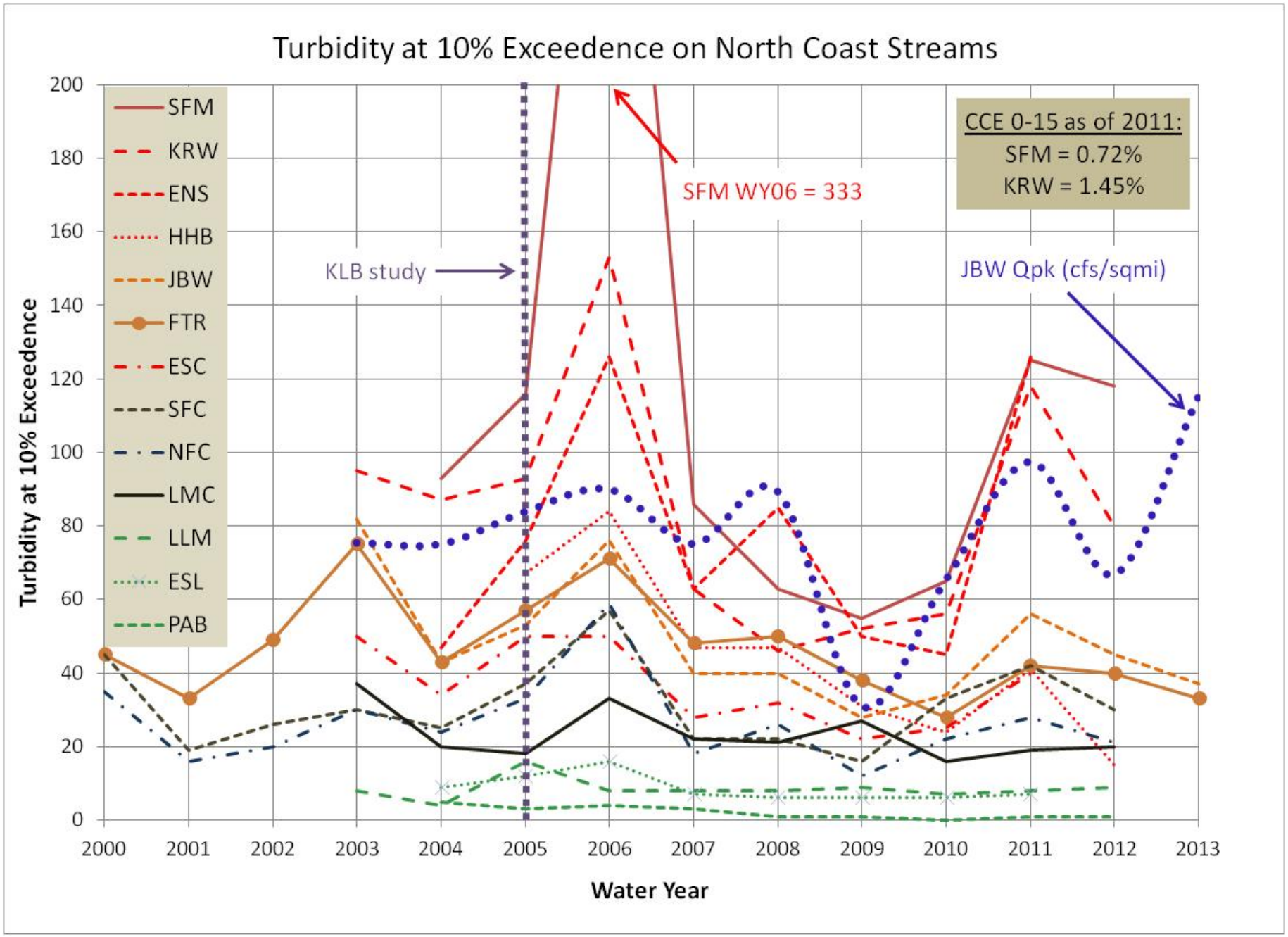
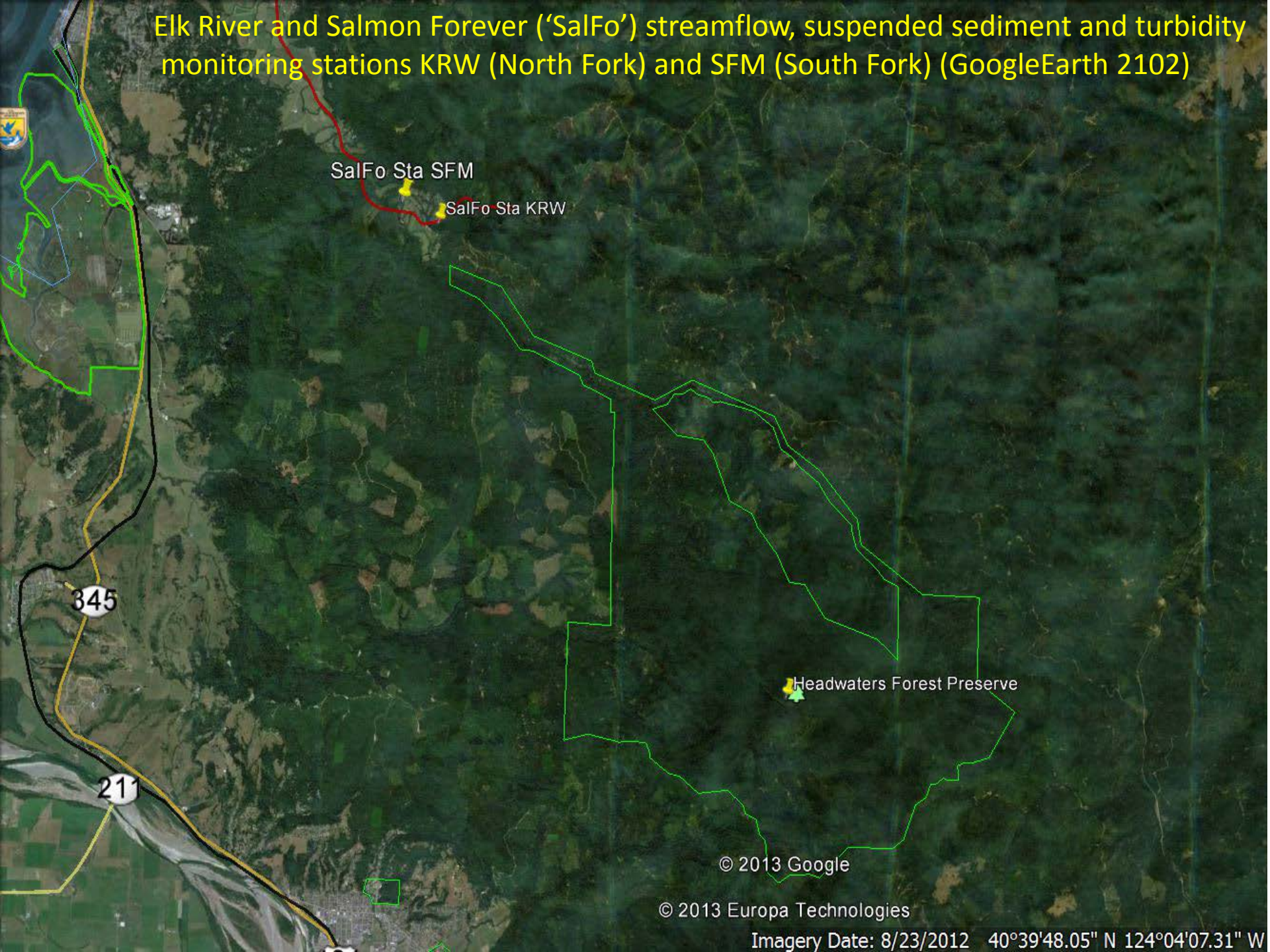


Figure 2 in "**Review of Green Diamond Resource Company's Timber Harvest Operations and Forest Management Activities As They Relate to Rate of Harvest and Cumulative Watershed Effects. June 2012**"


Turbidity at 10% Exceedence on North Coast Streams
Turbidity at 10% Exceedence
Water Year
SFM
KRW
ENS
HHB
JBW
FTR
ESC
SFC
NFC
LMC
LLM
ESL
PAB
KLB study
SFM WY06 = 333
JBW Qpk (cfs/sqmi)
CCE 0-15 as of 2011:
SFM = 0.72%
KRW = 1.45%
0
20
40
60
80
100
120
140
160
180
200
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

Elk River and Salmon Forever ('SalFo') streamflow, suspended sediment and turbidity monitoring stations KRW (North Fork) and SFM (South Fork) (GoogleEarth 2102)