A)

B)

Figure 10. Photos showing the association of historic terrace with historic railroad trestles remaining in the channel from the old-growth logging era. Dashed lines indicate approximate back edge of historic terrace. Photo A is from Area C and photo B is from Area B.

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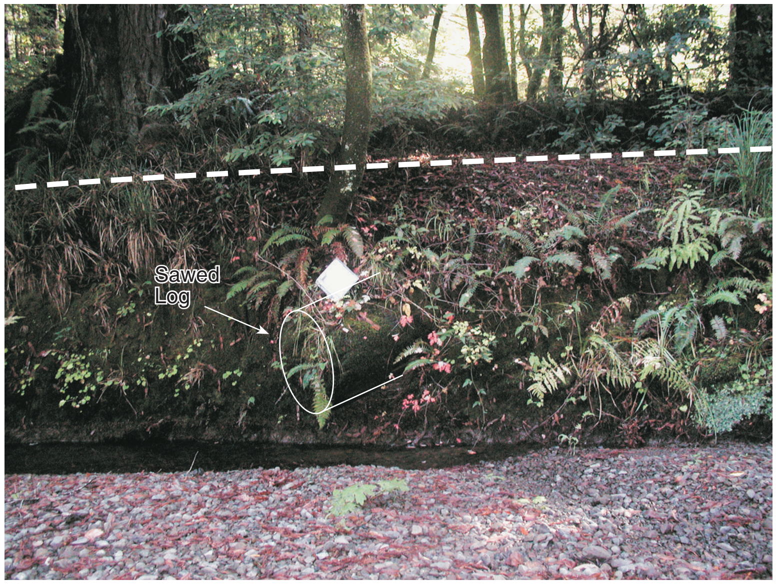
A)



B)

Figure 11. A) Photo showing sawed log embedded within historic terrace deposit in map Area D. Pre-historic terrace is visible in the background and gravel bar is in the foreground. Field map board is on embedded log for scale. B) Photo showing historic terrace deposit in Area C. In both photos, dashed line indicates approximate back edge of historic deposit.

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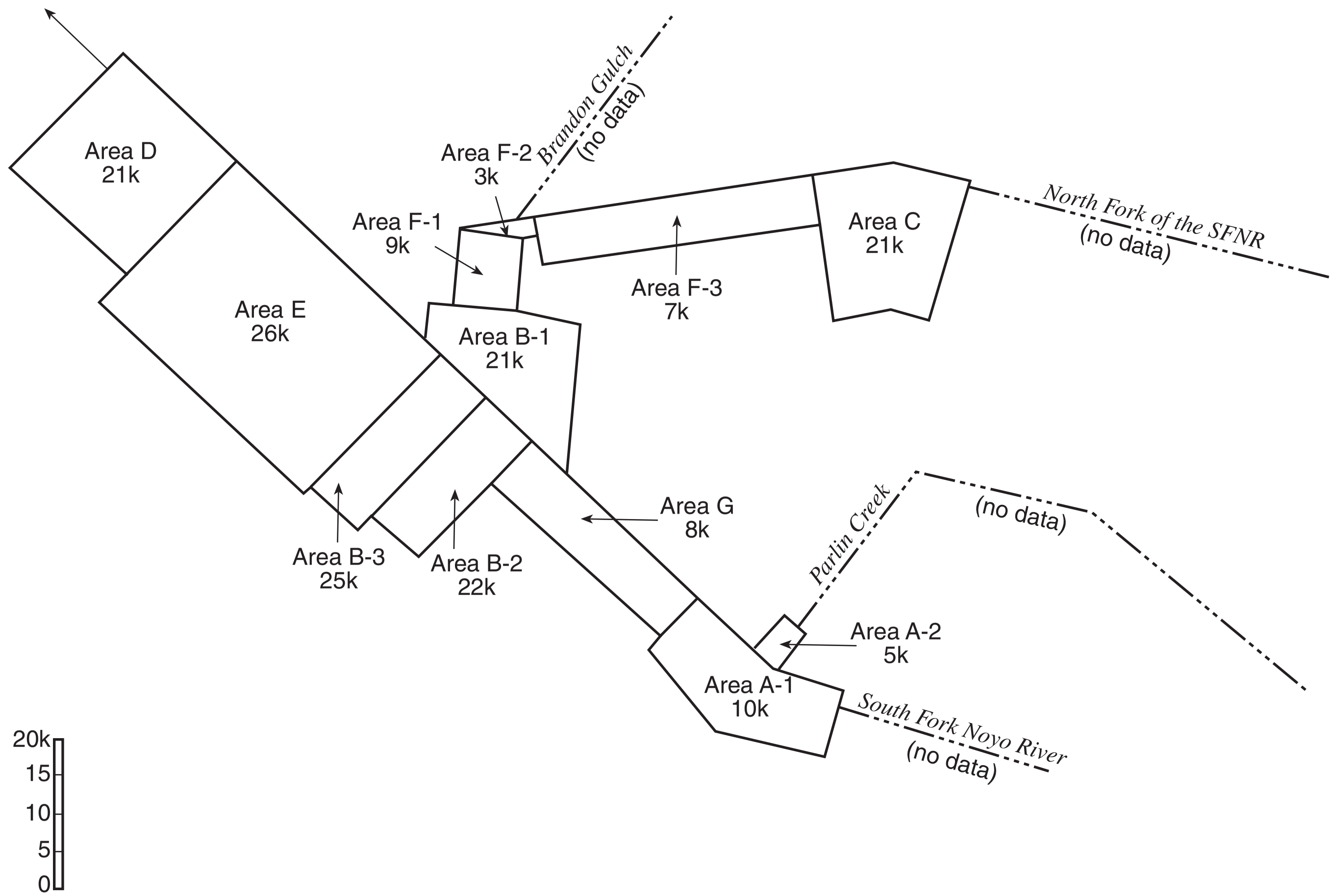

Figure 12. Box diagram showing total volume of active channel deposits per river mile in the South Fork Noyo basin. Box width is relative amount of sediment in yds^3/mile.

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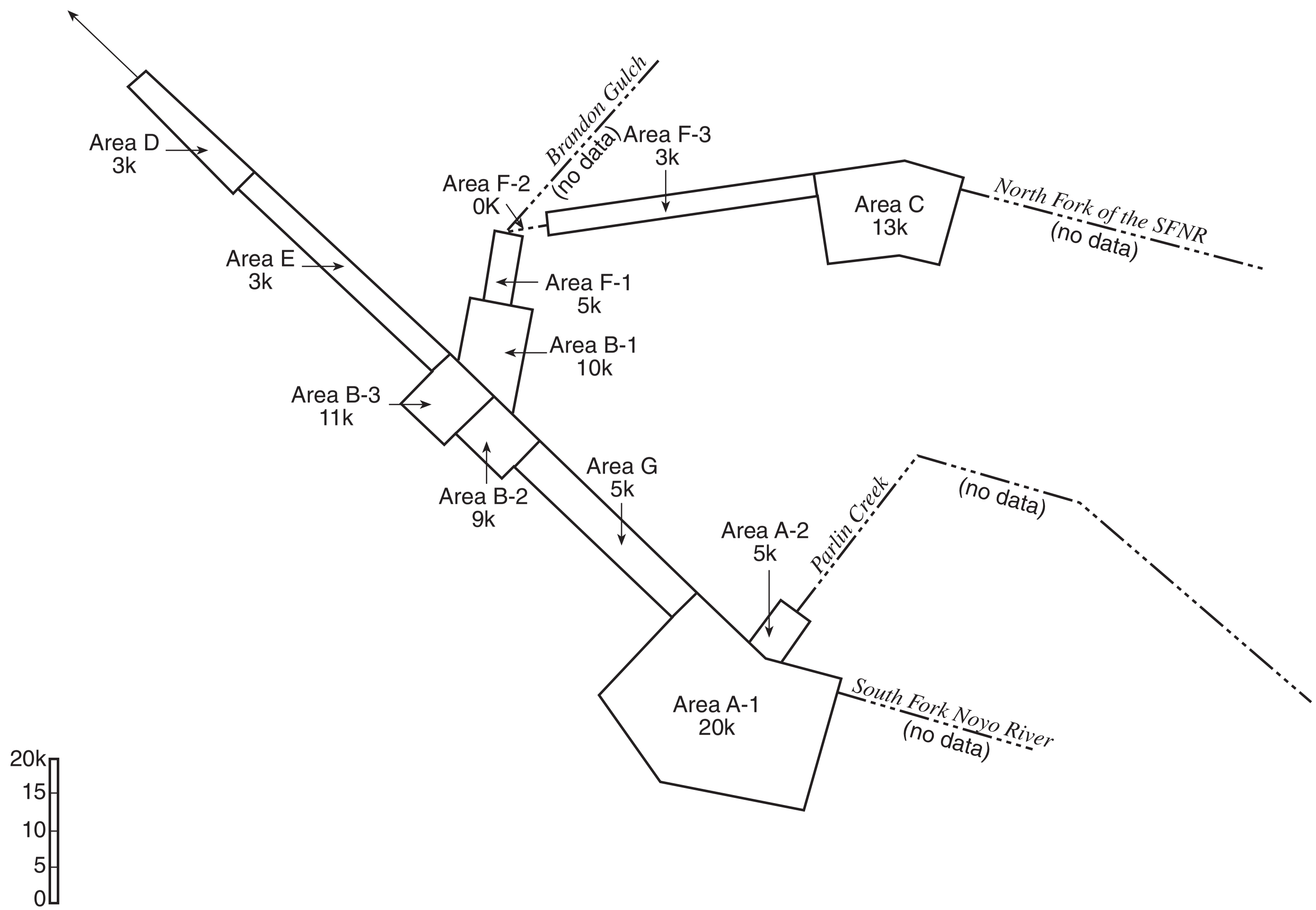

Figure 13. Box diagram showing total volume of historic terrace storage per river mile in the South Fork Noyo basin. Box width is relative amount of sediment in yds^3/mile.

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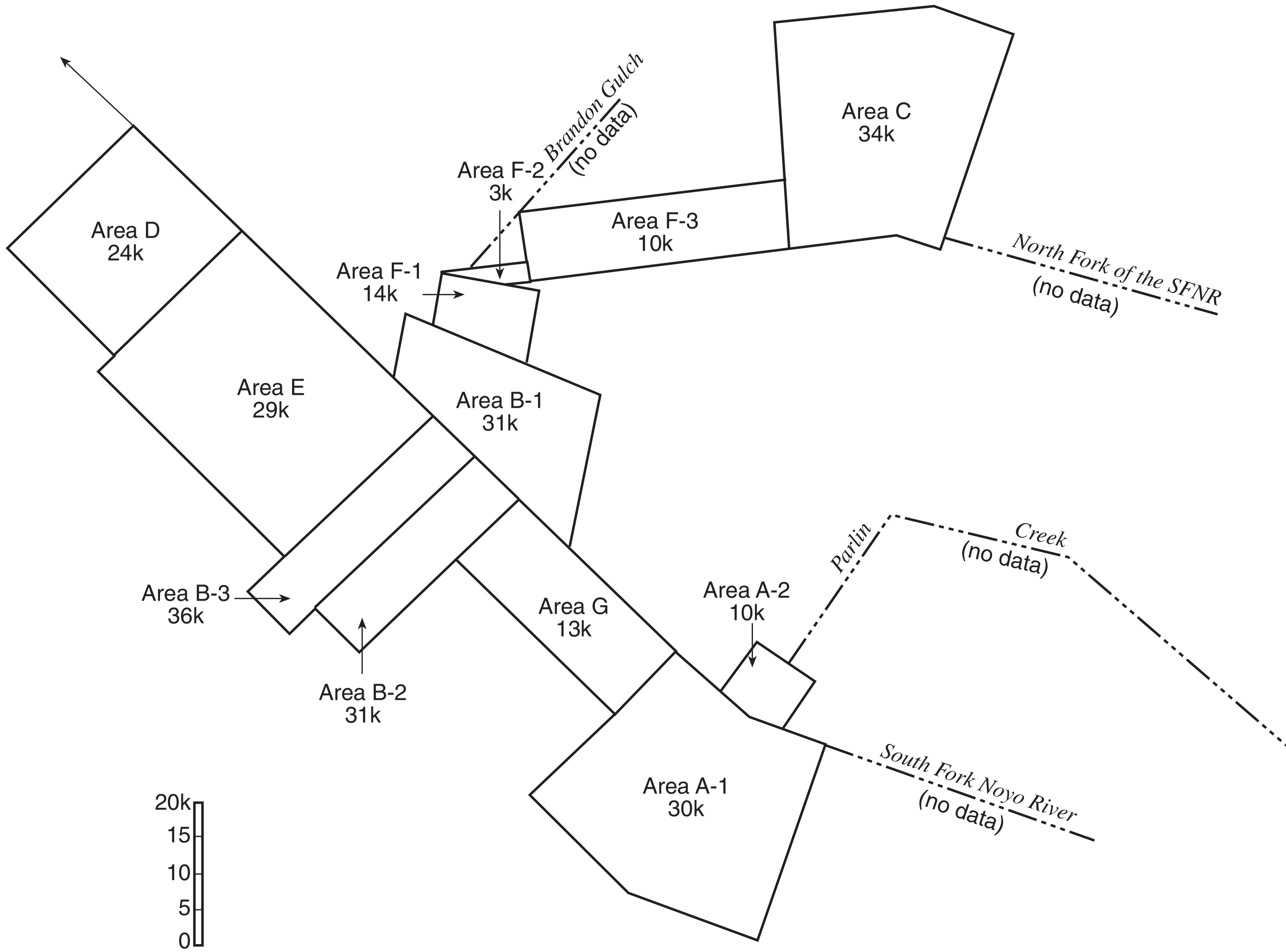

Figure 14. Box diagram showing total volume of post-logging sediment (active channel plus historic terrace deposits) in SFNR. Includes combined volume of channel and historic terrace sediment. Box width is relative amount of sediment per river mile (yds^3/mi).

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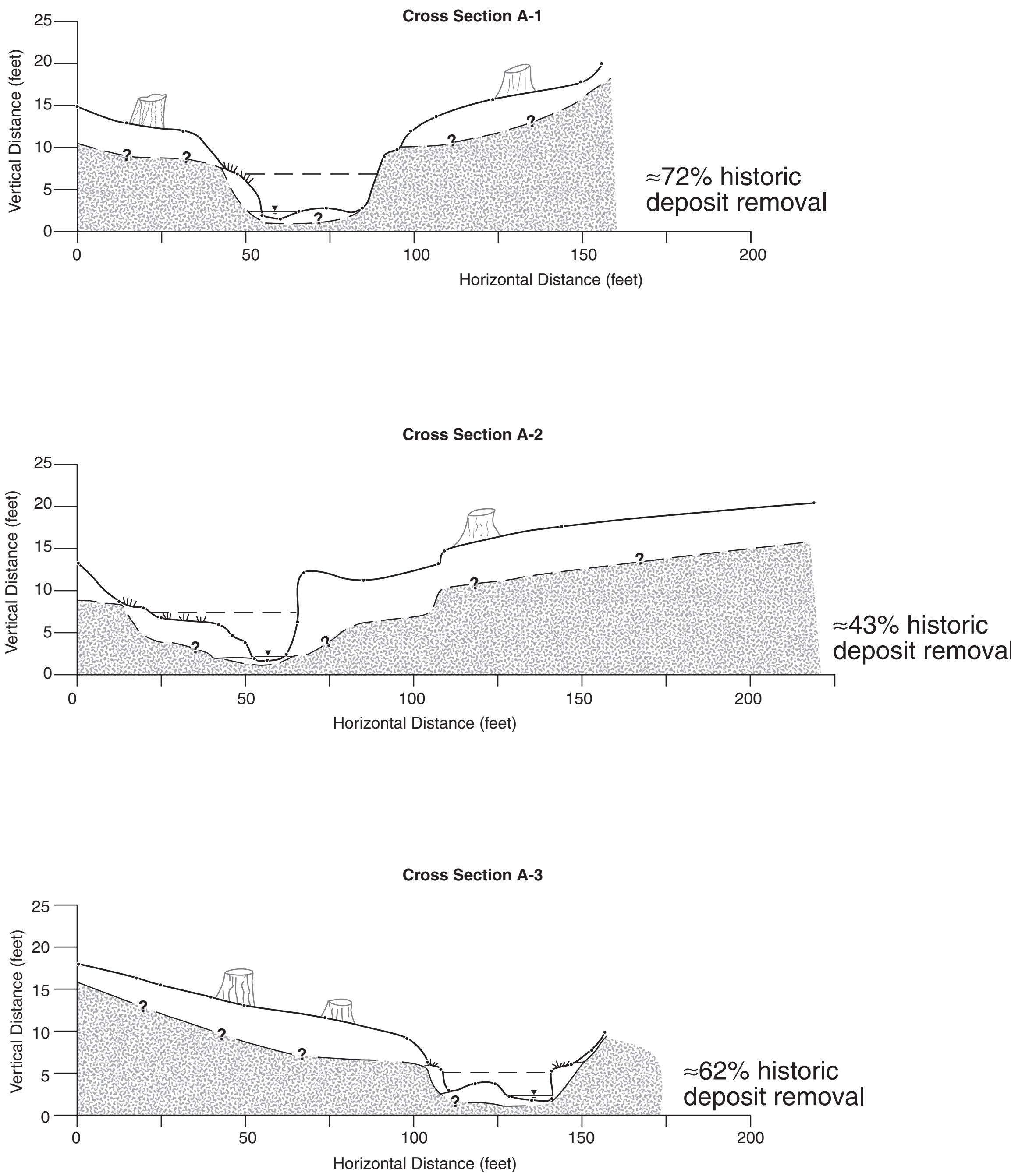

Figure 15. Surveyed cross sections A-1, A-2, and A-3. Dashed lines represent probable maximum thickness of historic aggradation used to estimate amount of material removed since time of terrace deposition.

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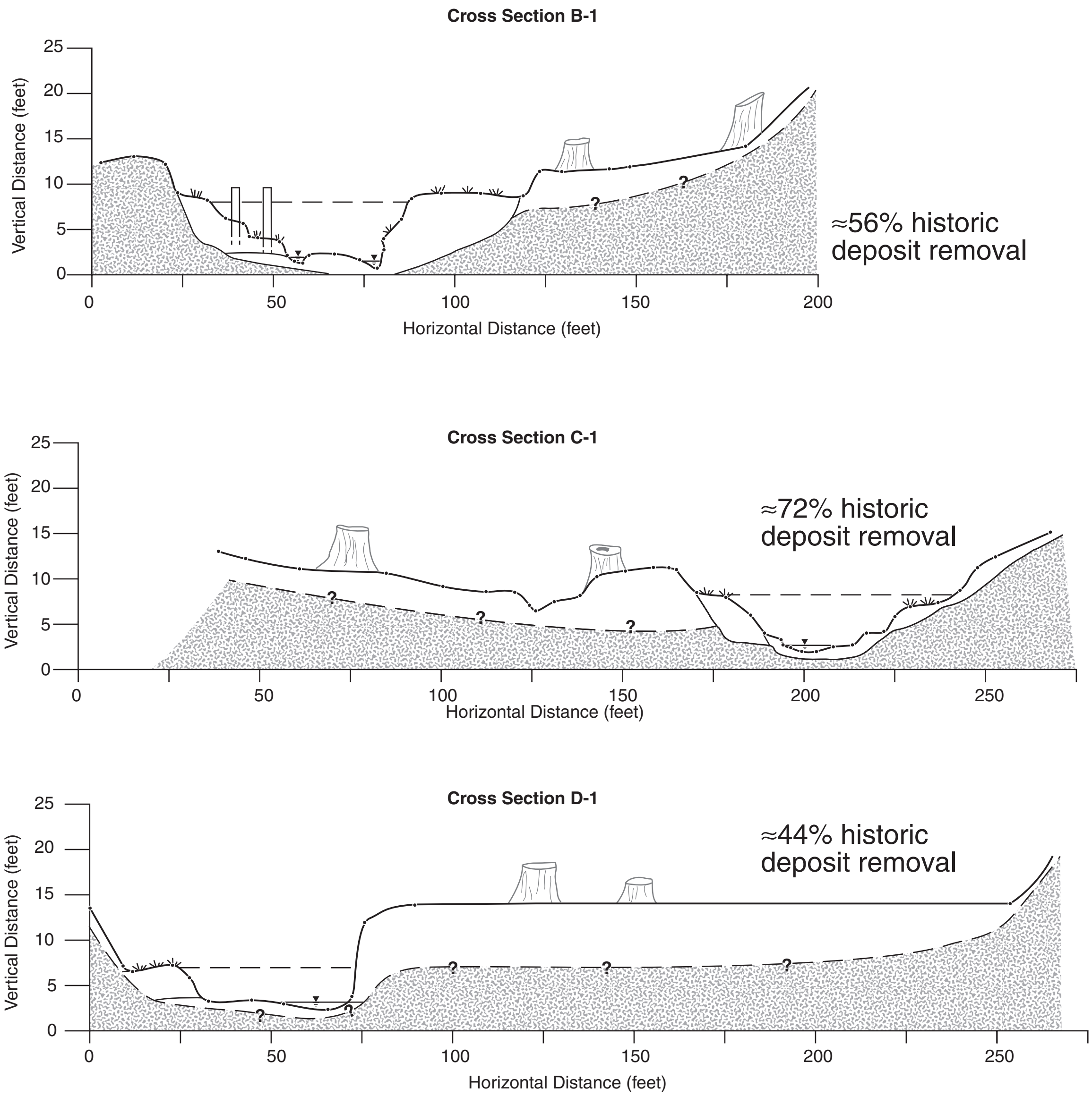


Figure 16. Surveyed cross sections B-1, C-1, and D-1. Dashed lines represent probable maximum thickness of historic aggradation used to estimate amount of material removed since time of terrace deposition.

Figure 17. Discharge Rating Curve #1 for the South Fork Noyo River above Parlin Creek. Begin Date: 2/1/01

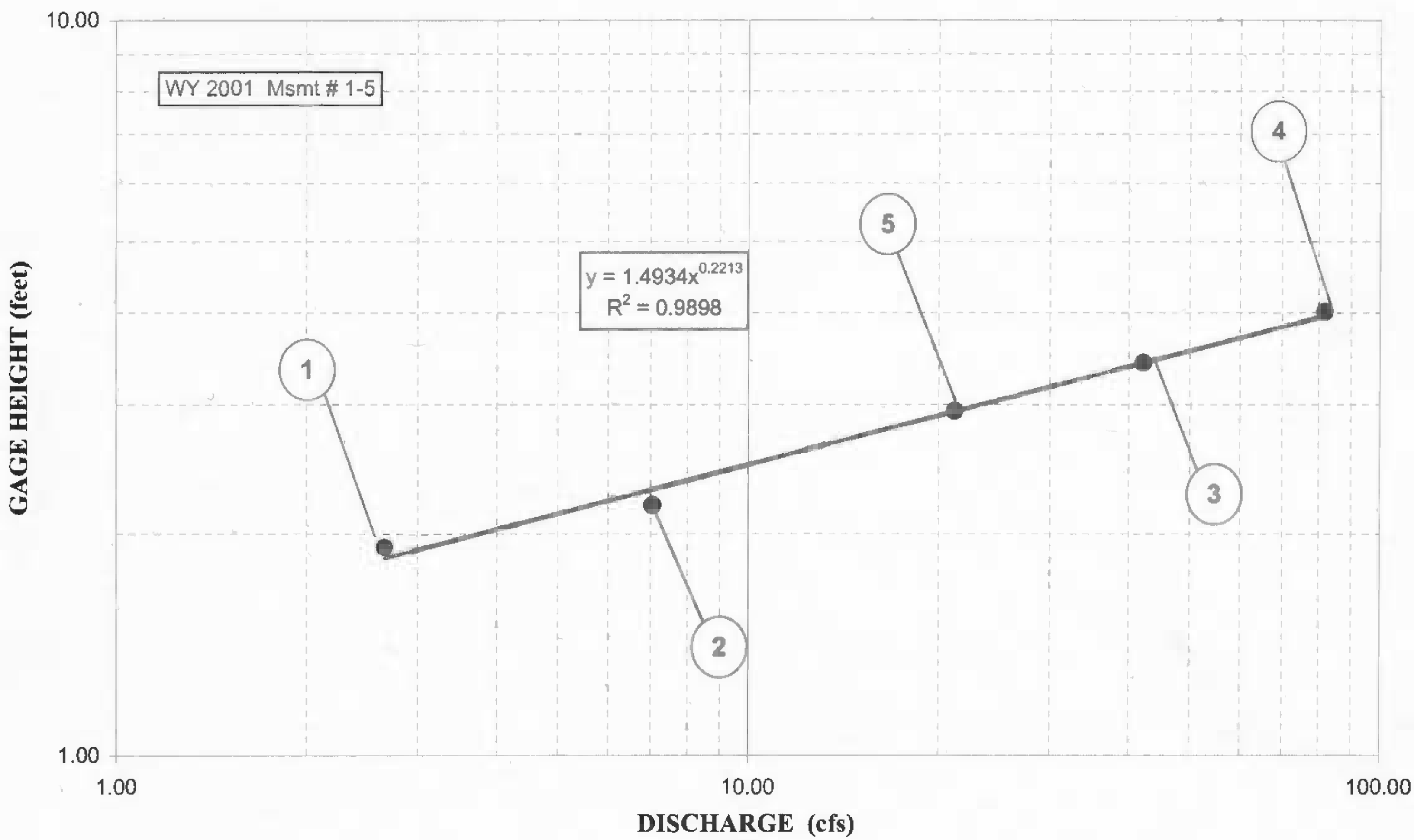


Figure 18. Discharge hydrograph for WY 2001 over the period of record South Fork Noyo River below Kass Creek.

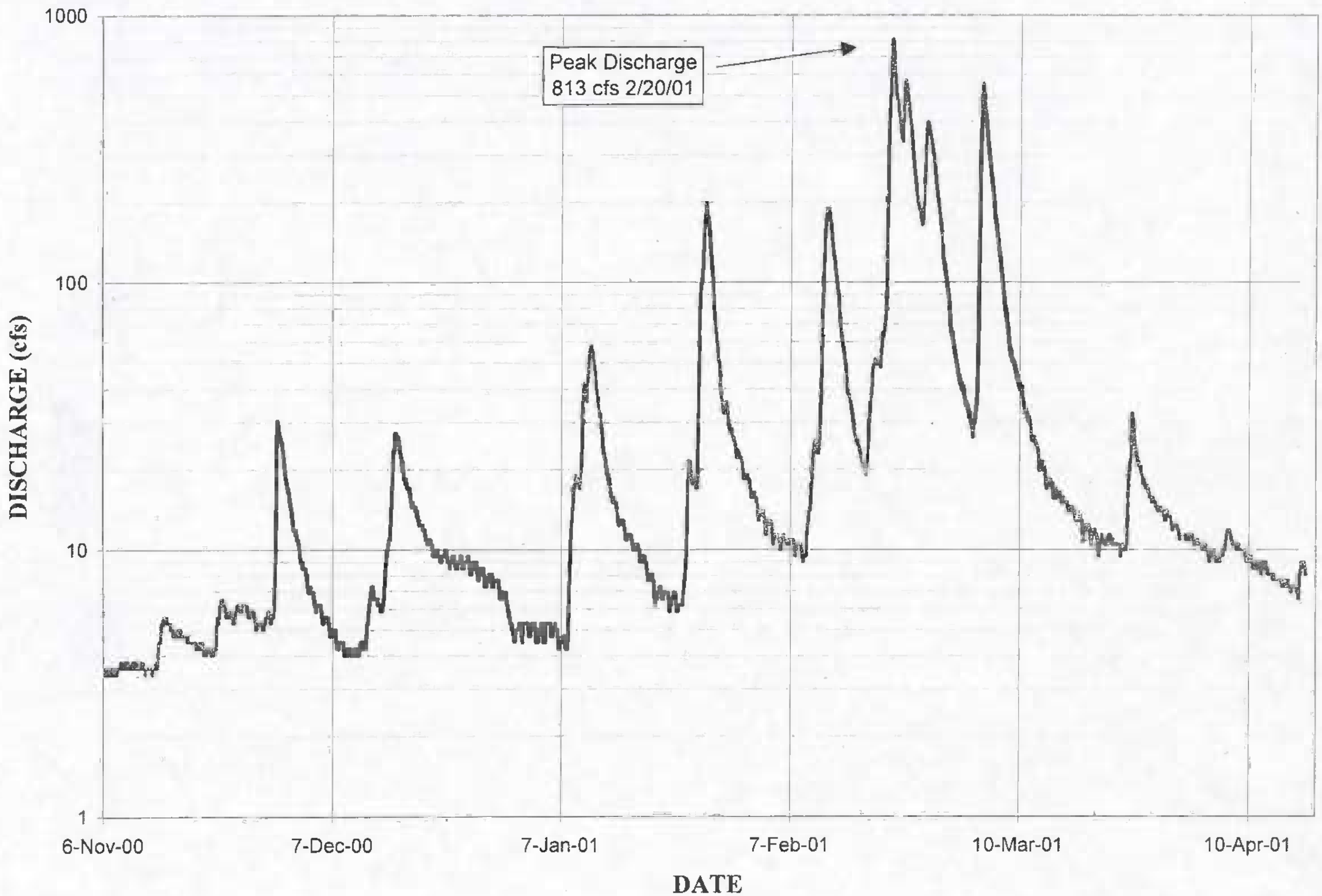
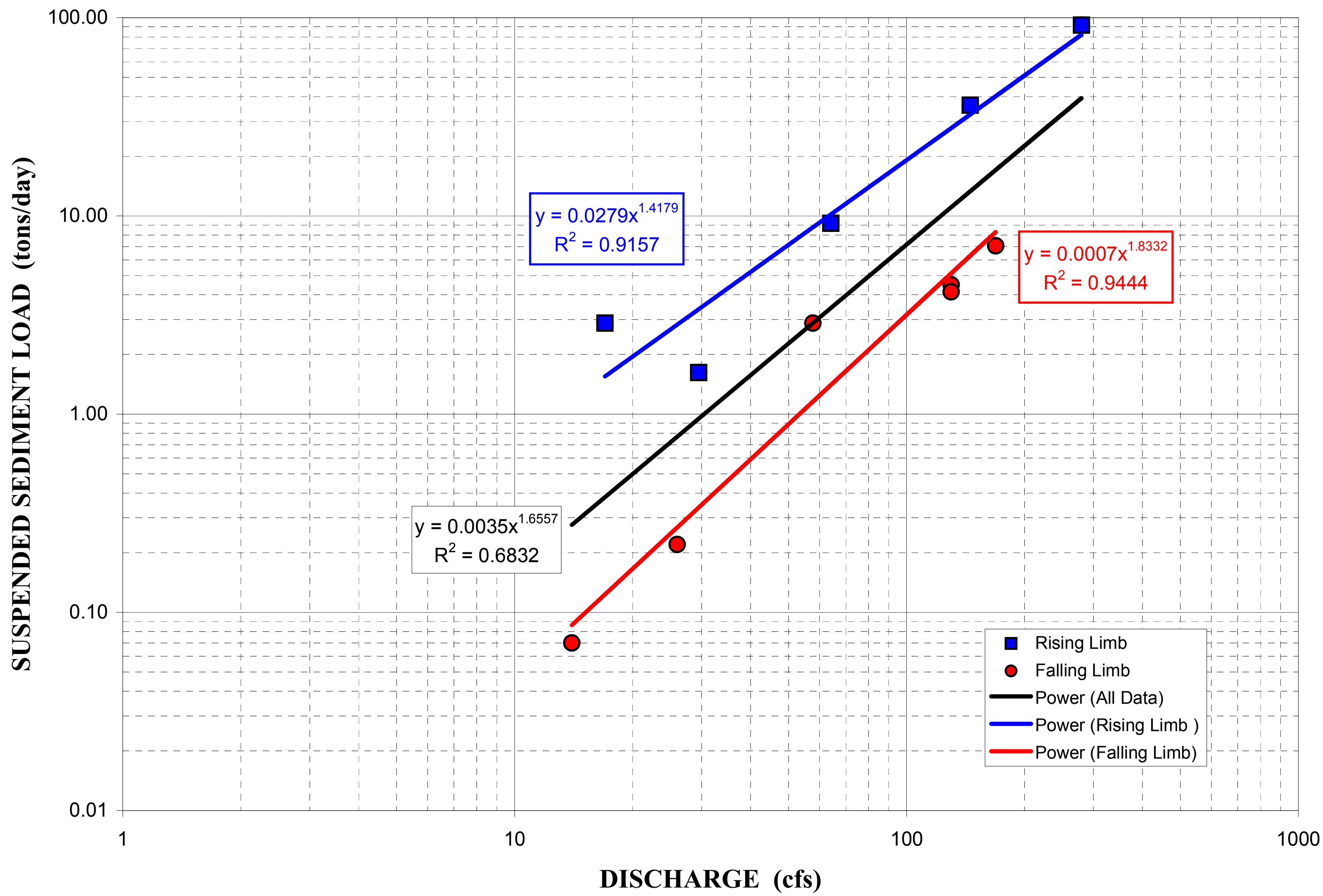


Figure 19. Analysis of WY 2001 data by hydrograph position, North Fork of the SFNR above SFNR



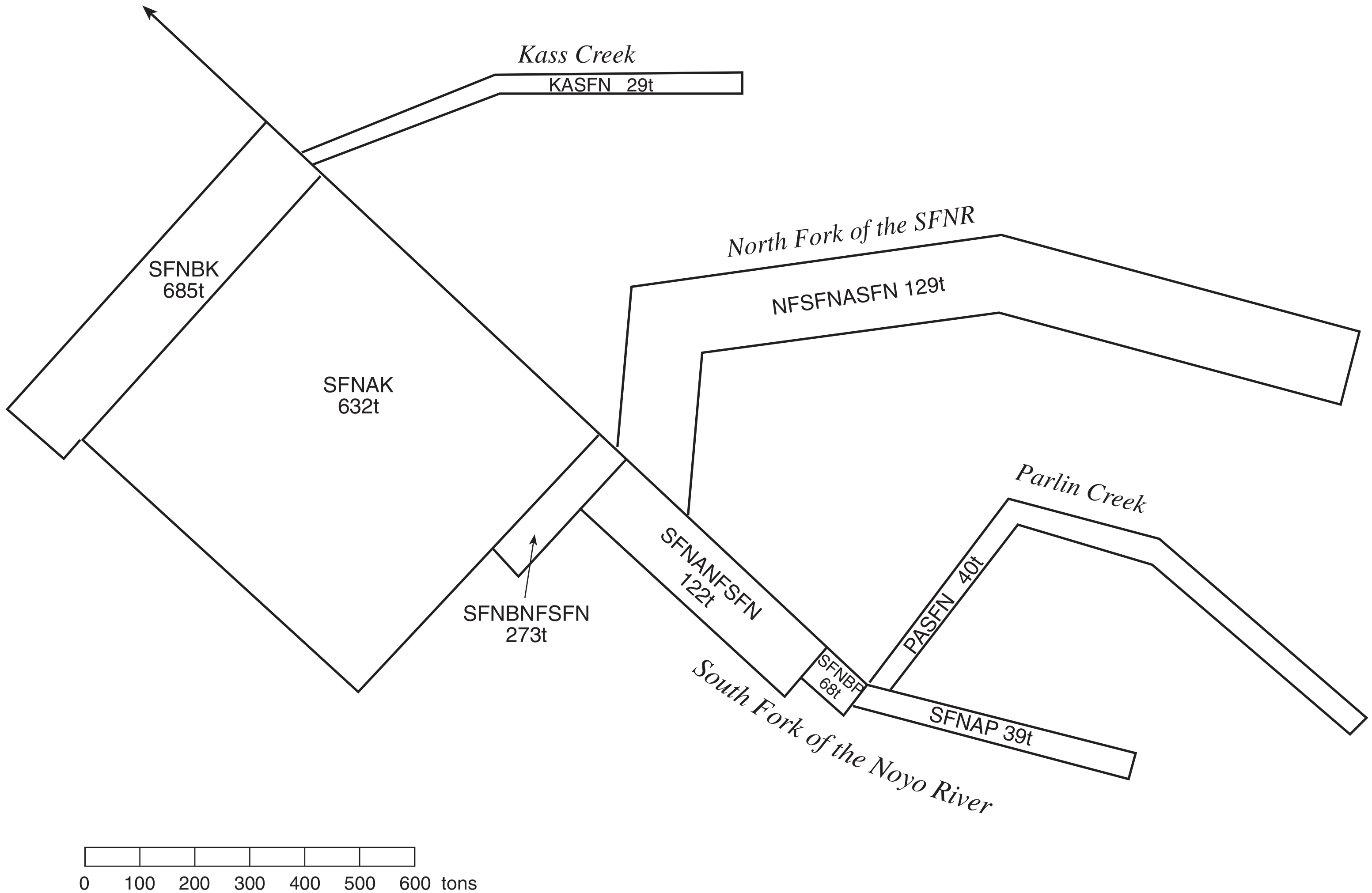


Figure 20. Box diagram showing total suspended sediment in tons for each sampling station.

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Figure 21. Suspended sediment concentration vs. turbidity rating curve, all data WY 2001, South Fork Noyo River watershed

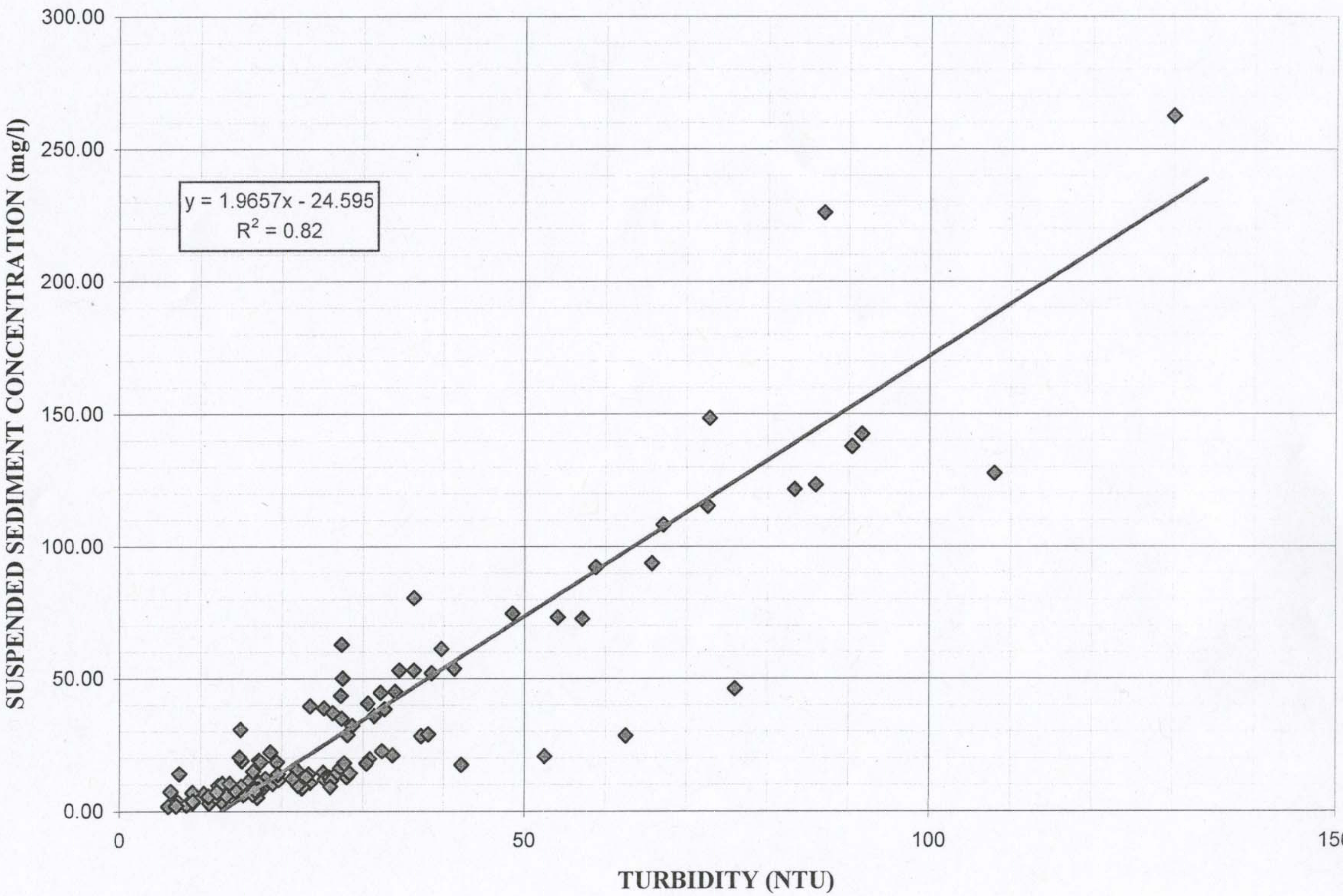


Figure 22. Turbidity vs. discharge rating curve, all data WY 2001
South Fork Noyo River watershed

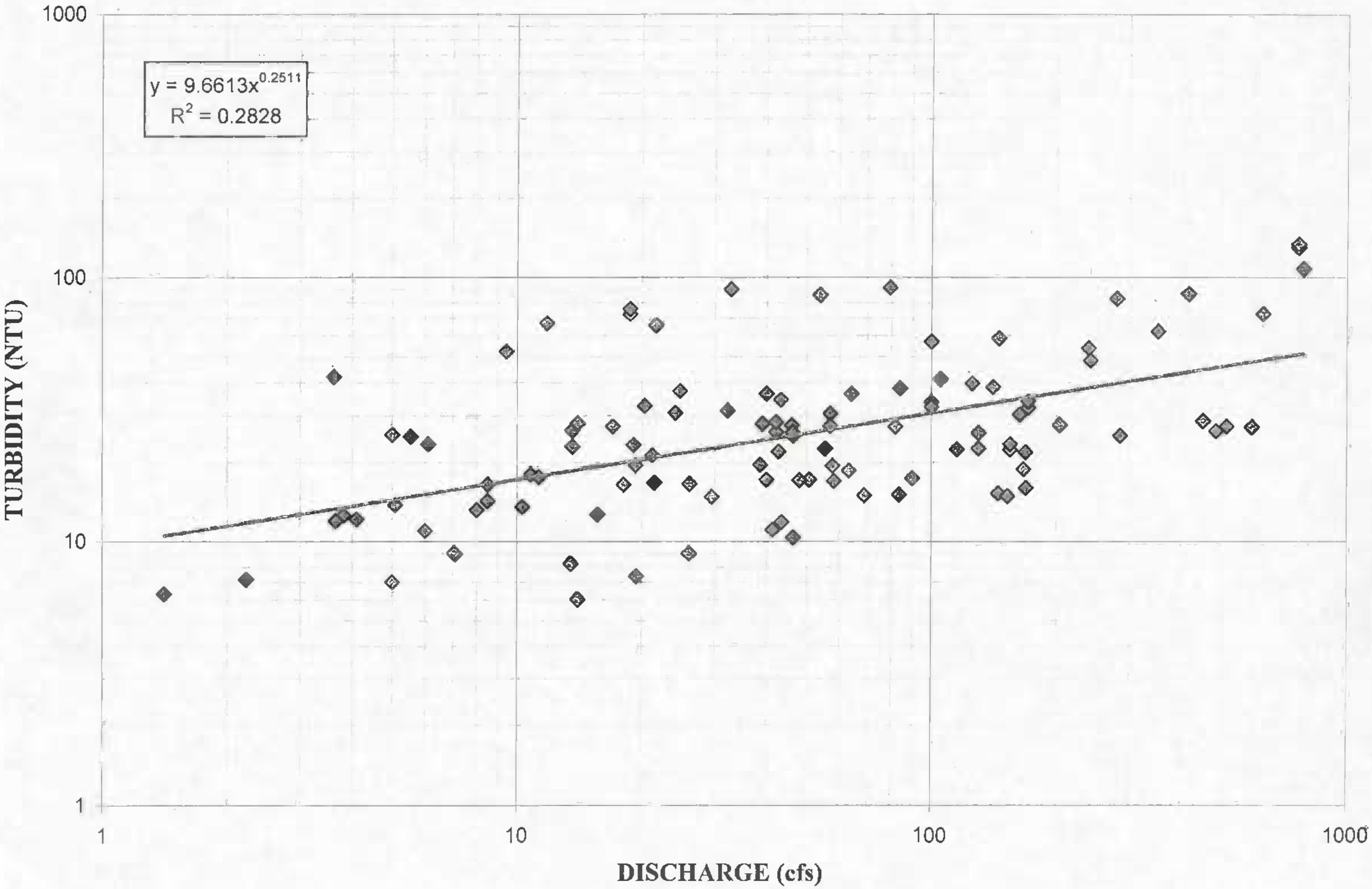


Figure 23. Suspended sediment concentration vs. discharge, WY 2001
South Fork Noyo River watershed

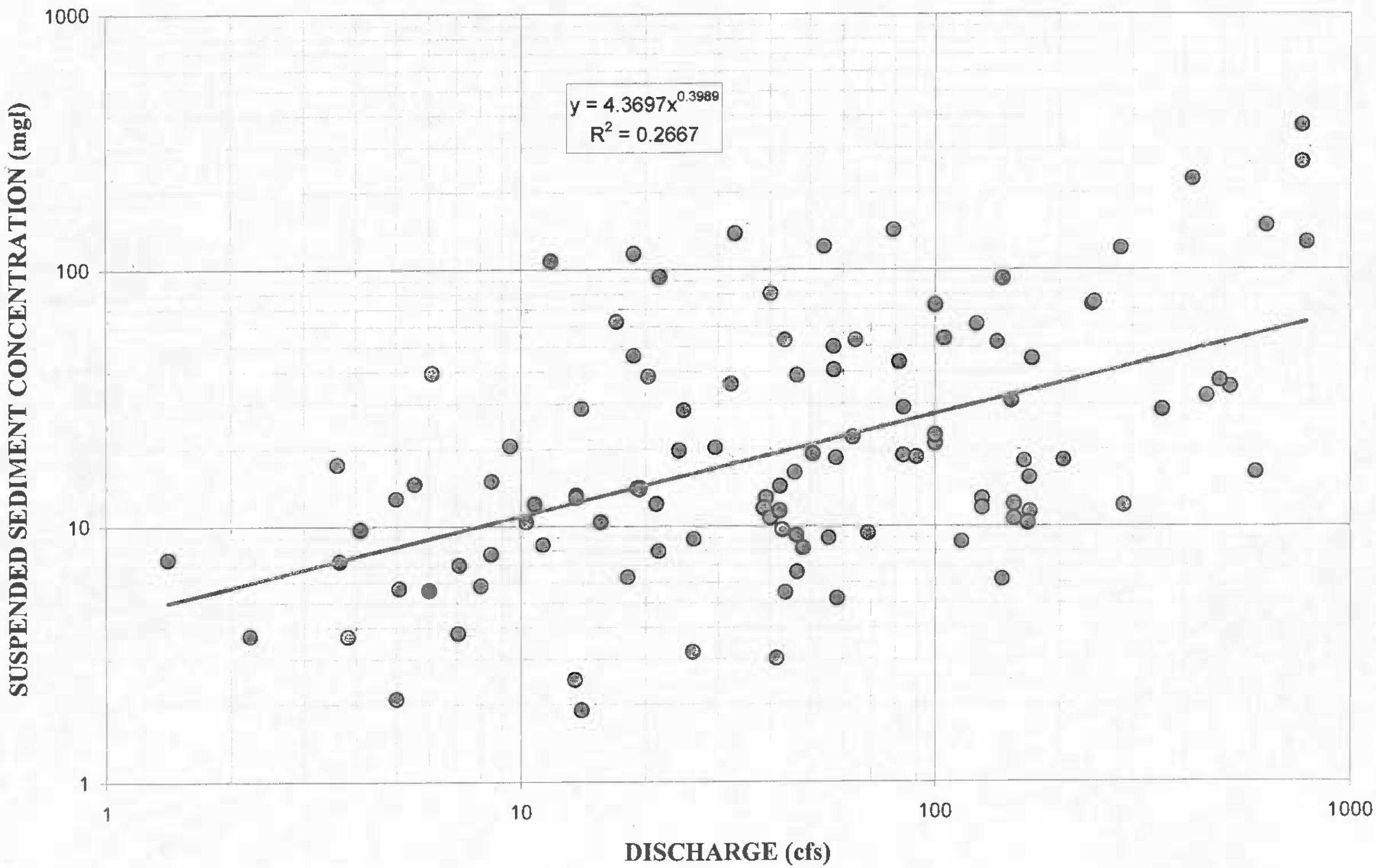


Figure 24. Suspended sediment load vs. discharge rating curve, all data WY 2001
South Fork Noyo River watershed

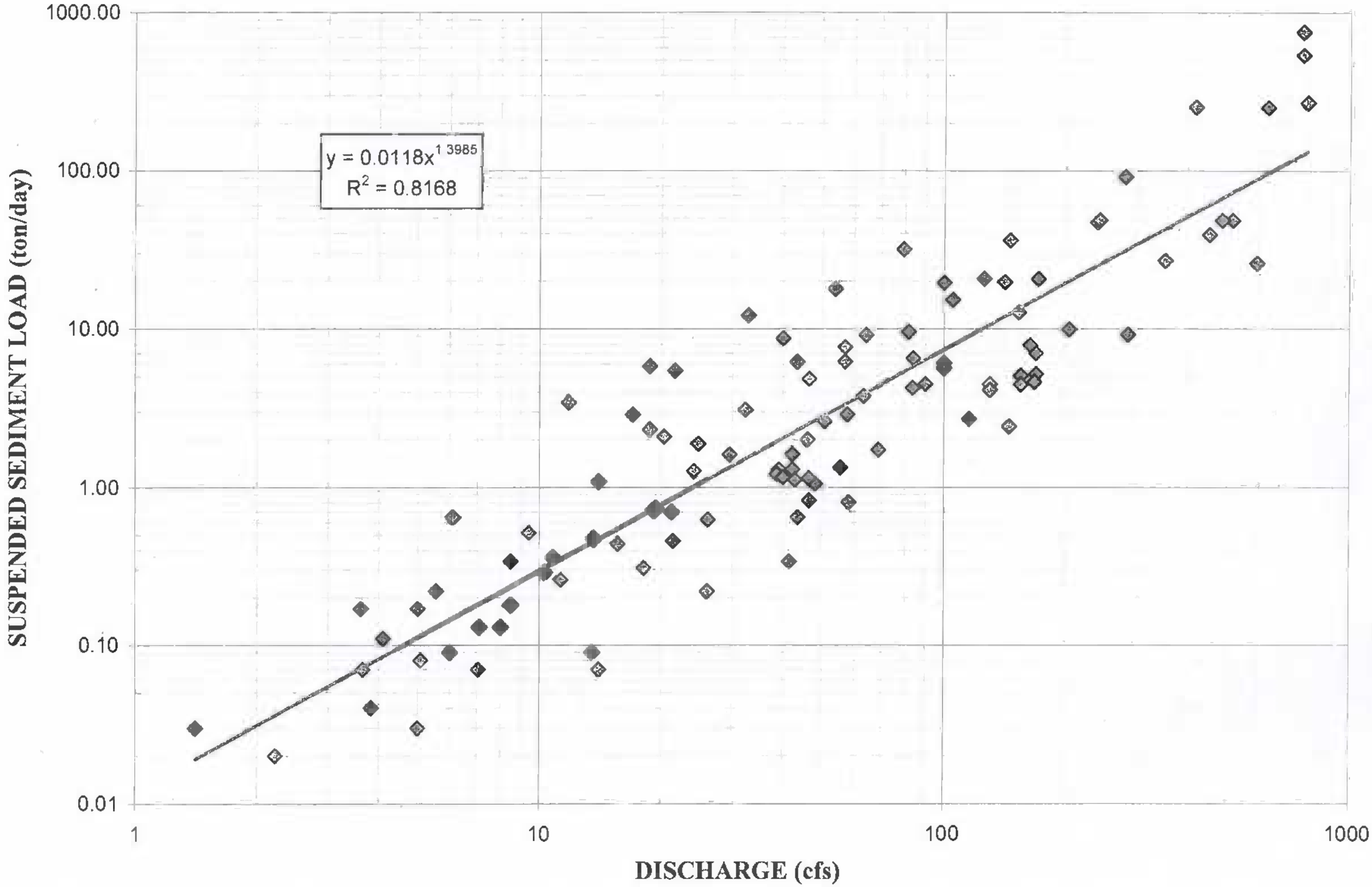


Figure 25. Suspended sediment load vs. discharge curve, data by site, WY 2001
South Fork Noyo River watershed

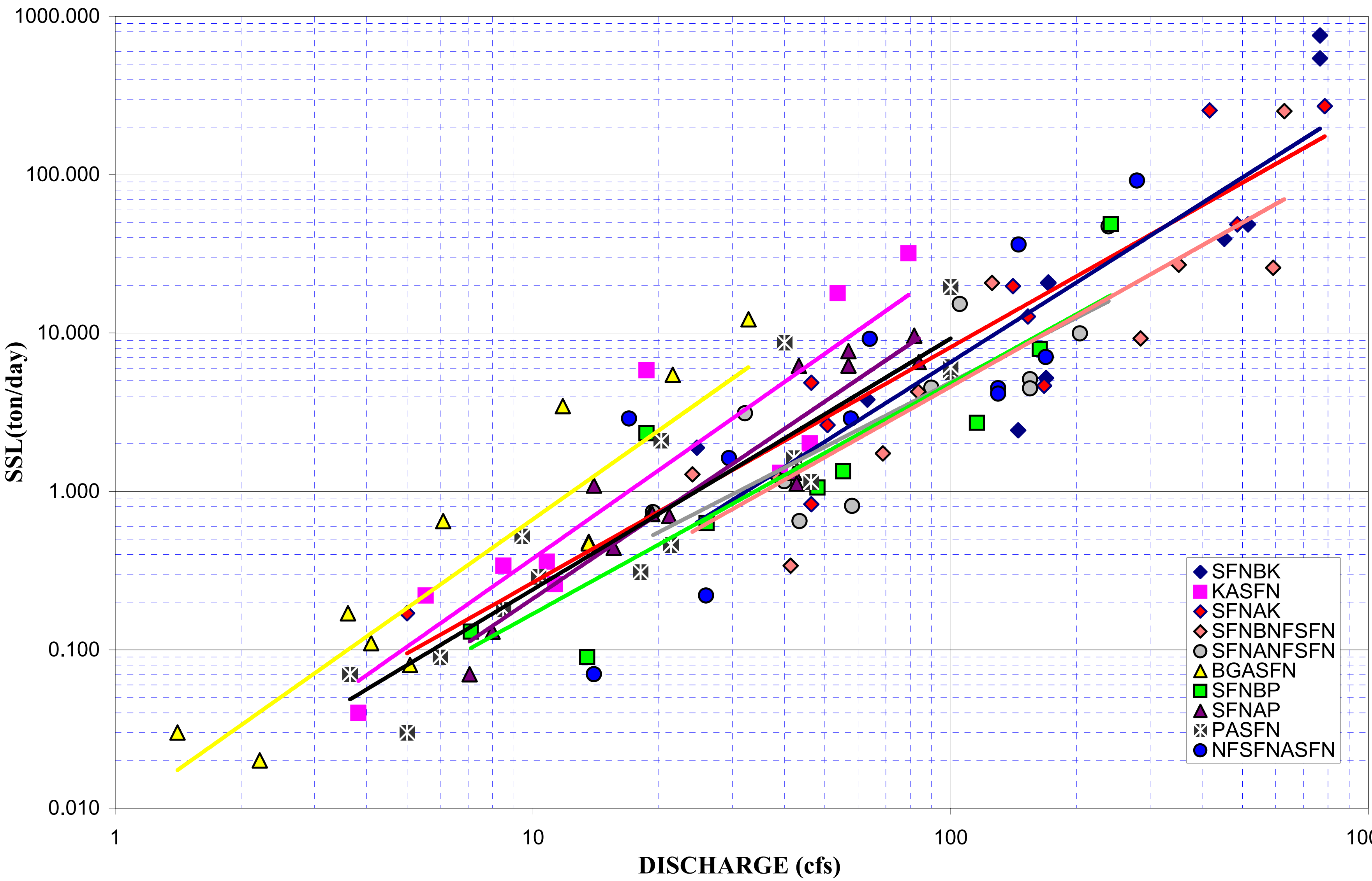


Figure 26. Suspended sediment load per watershed area vs. discharge per watershed area curve, all data
WY 2001
South Fork Noyo River watershed

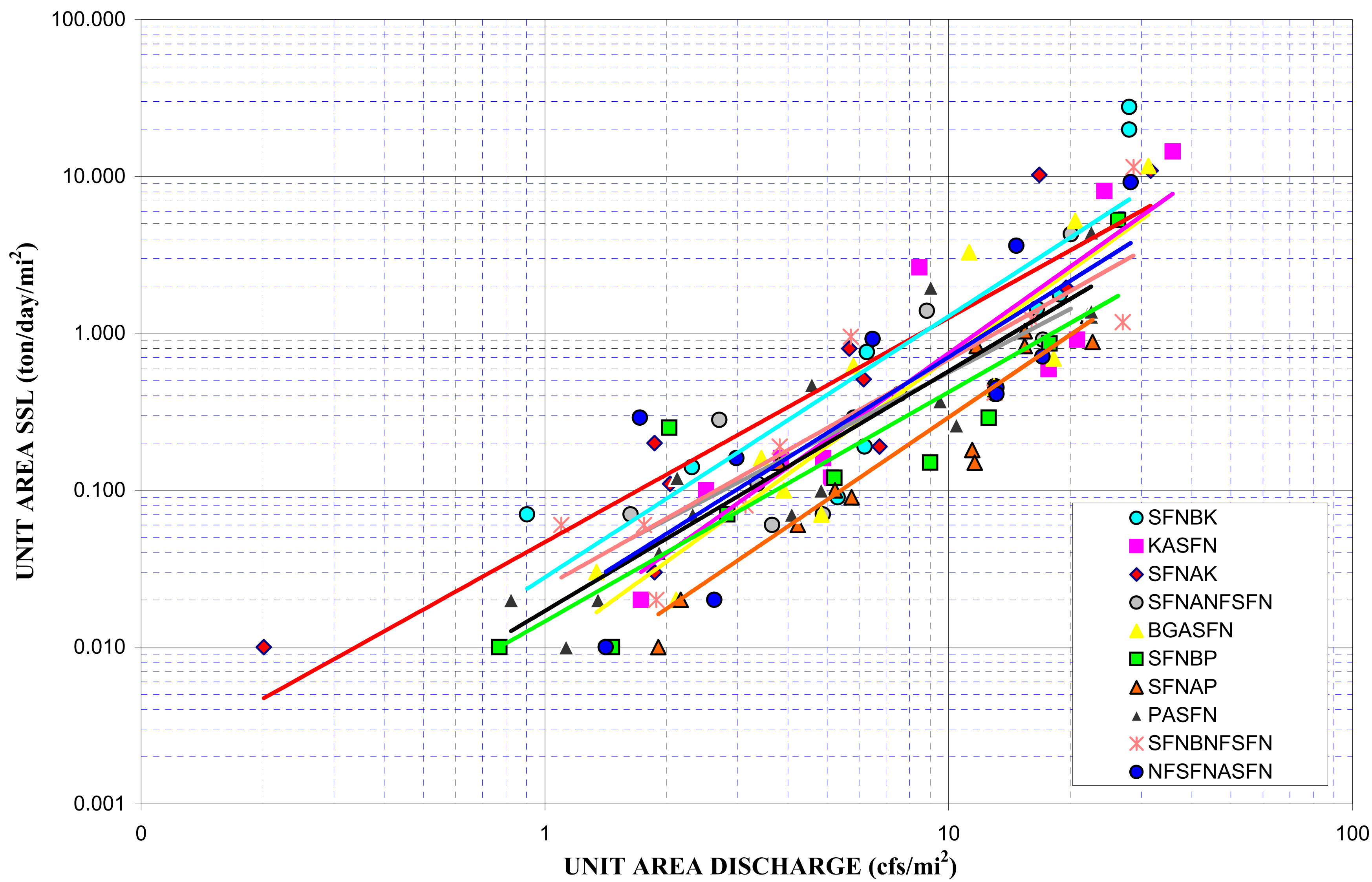


Figure. 27. Suspended sediment load vs. discharge rating curve, Regional and albion watershed data for WY2000-2001

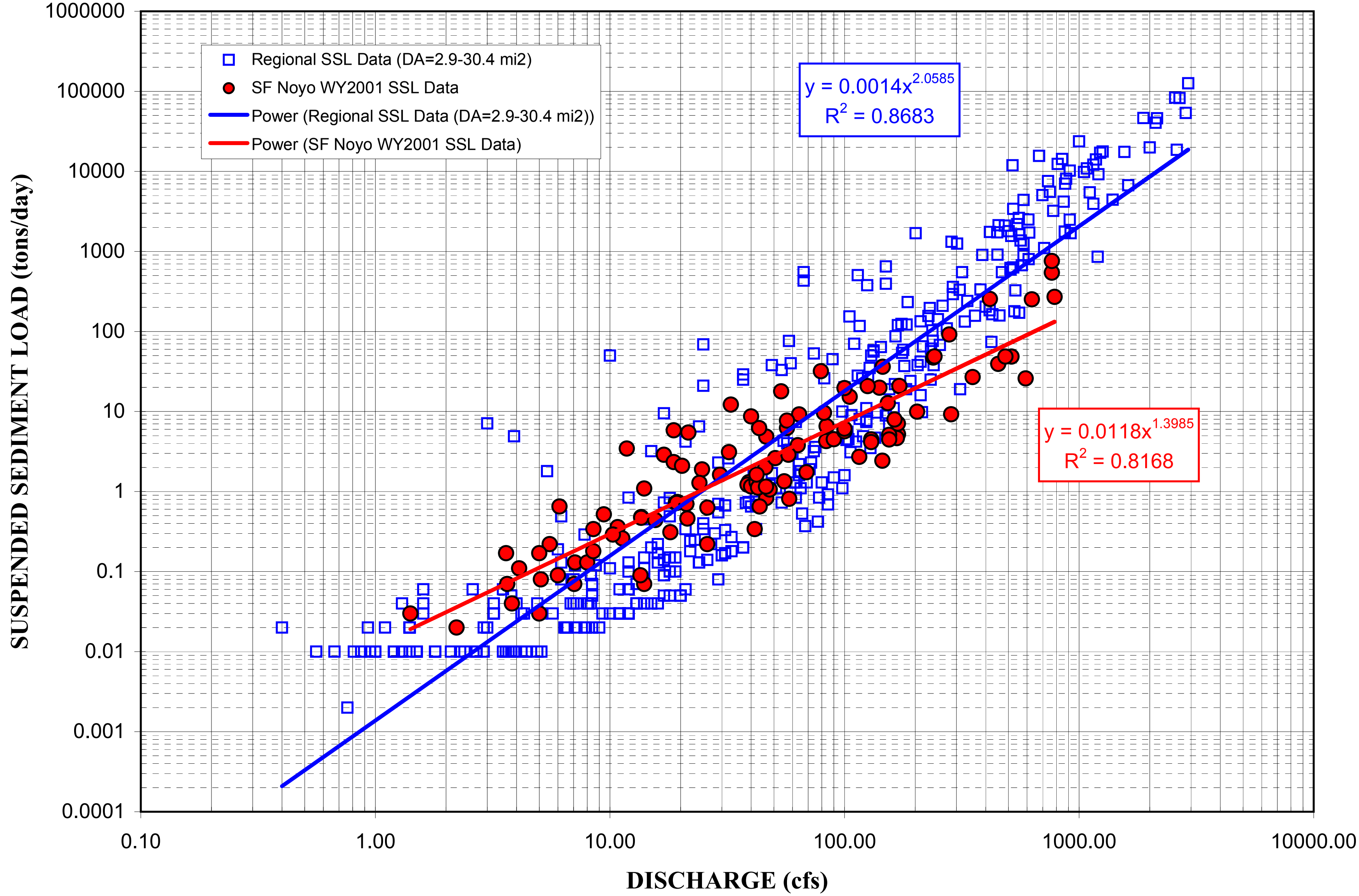


Figure 28. Drainage area vs. WY 2001 suspended sediment load, South Fork Noyo River watershed

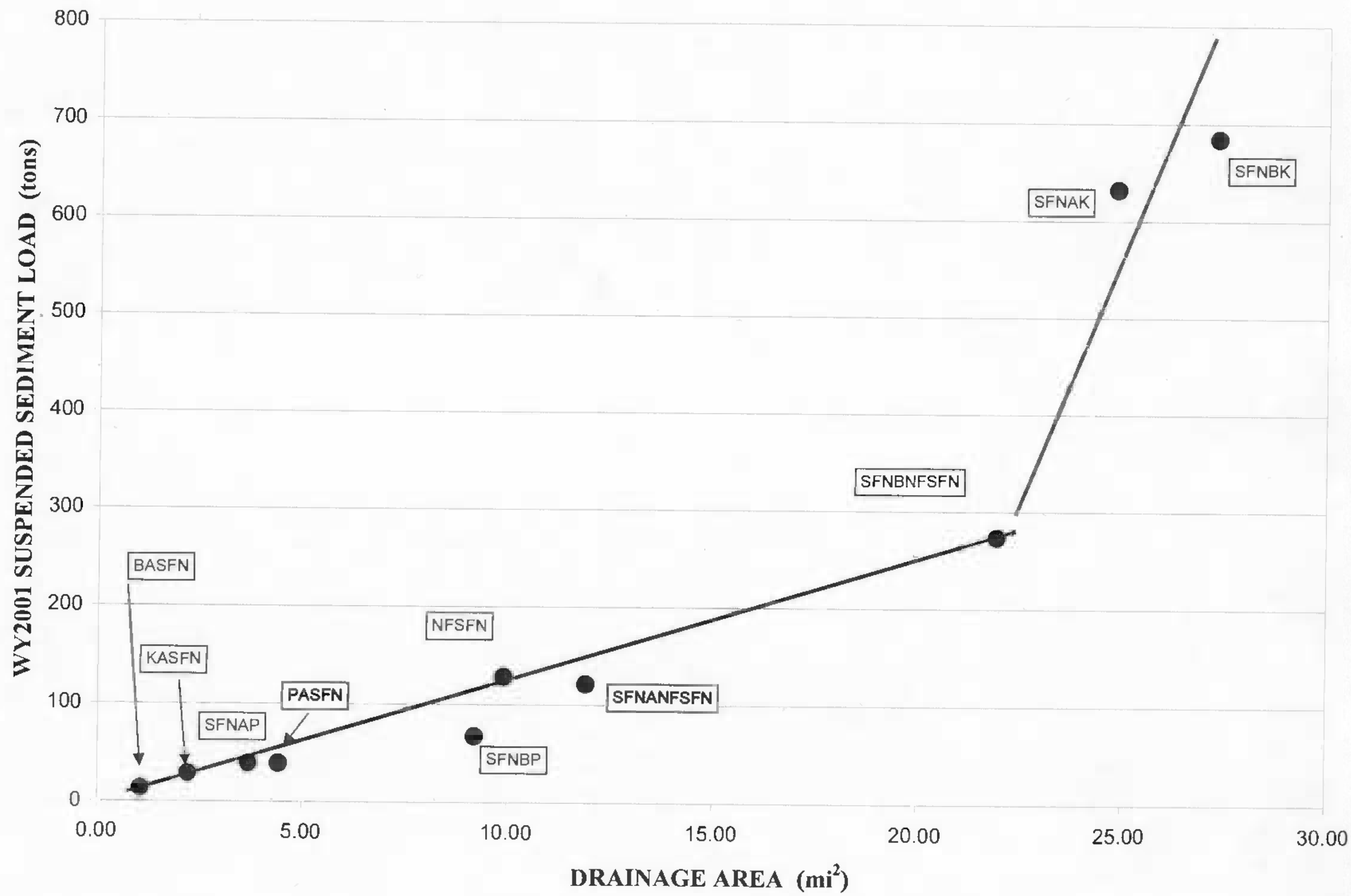


Figure 29. Relationship between drainage area and WY 2001 unit area suspended sediment load, South Fork Noyo River watershed

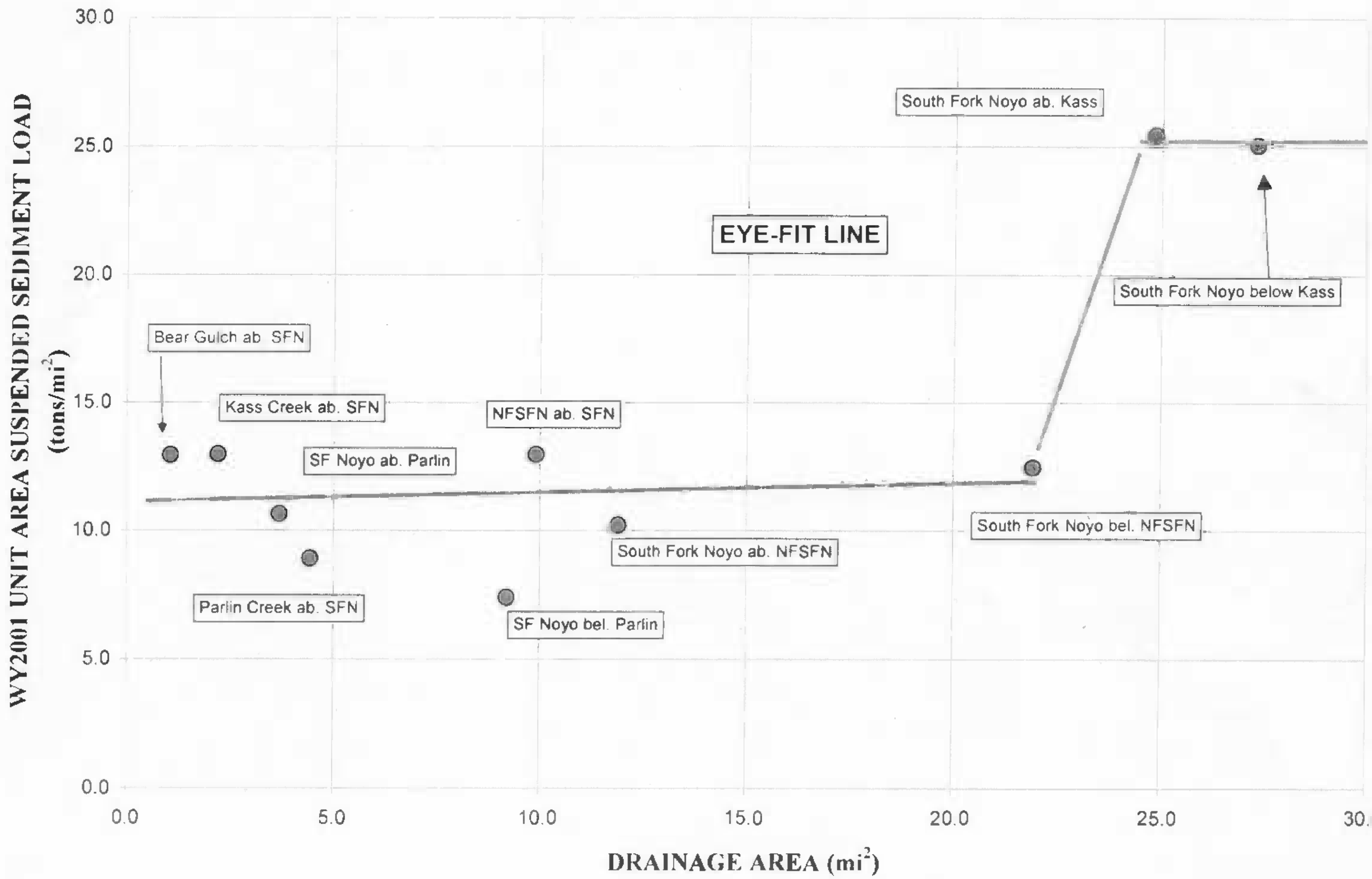
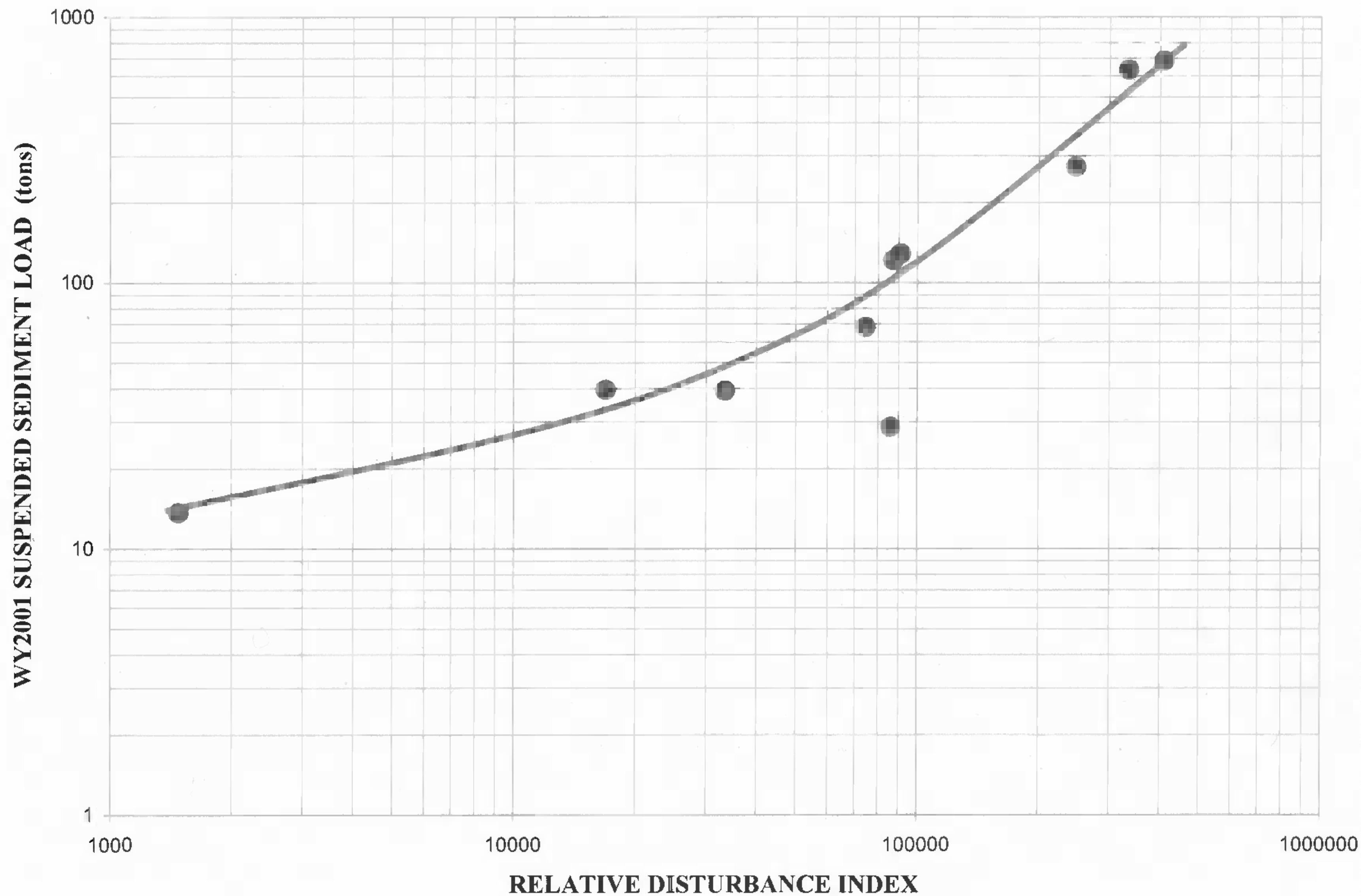


Figure 30. Relative disturbance index vs. WY 2001 suspended sediment load



Appendix A
Discharge Measurement Summary Sheet for the South Fork Noyo River Watershed, WY 2001

APPENDIX A
SOUTH FORK NOYO WATERSHED

DISCHARGE MEASUREMENT SUMMARY SHEET

WATER YEAR: 2001

Measurement Number	WY Msmt #	Date	Made By:	Width (feet)	Mean Depth (feet)	Area (ft2)	Mean Velocity (ft/sec)	Gage Height (feet)	Discharge (cfs)	Rating __1___ Shift Adj.	Percent Diff.	Method	No. of Msmt sections	Begin Time (hours)	End Time (hours)	Msmt Rating	Recorder level	Notes
LOCATION:	**SFNBK**																	
1	**2001-01**	1/11/2001	K Faucher	41.0	0.72	31.30	1.59	1.95	49.90			w	29	12:05	12:50	Good		
2	**2001-02**	1/23/2001	K Faucher	32.0	0.49	16.00	0.40	1.41	6.49			w	26	10:30	11:09	Good		
3	**2001-03**	2/20/2001	C.Pryor	48.2	4.00	193.00	4.13	4.98	798.00			c	13	14:59	16:30	fair		
4	**2001-04**	2/21/2001	C.Pryor	44.0	2.36	104.00	3.99	3.66	415.00			c	15	12:17	13:03	fair		
5	**2001-05**	3/6/2001	K Faucher	40.0	1.51	60.30	2.82	2.51	170.00			w	26	15:45	16:15	Good		
LOCATION:	**KASFN**																	
1	**2001-01**	1/23/2001	K.Faucher	5.5	0.21	1.38	0.60	1.47	0.83			w	13	11:36	12:00	f to g		
2	**2001-02**	2/17/2001	K.Faucher	7.2	0.46	3.34	1.70	1.82	5.69			w	20	18:38	19:05	good		
3	**2001-03**	2/20/2001	K.Faucher	19.0	1.14	21.60	3.67	3.23	79.30			w	21	16:49	17:20	good		
4	**2001-04**	2/21/2001	C. Pryor	9.8	1.12	9.87	3.96	2.60	39.10			w	18	13:58	14:21	f to g		
LOCATION:	**SFNSNFSFN**																	
1	**2001-01**	1/23/2001	K.Faucher	14.0	0.25	3.84	0.87	2.62	3.33			w	16	14:01	14:25	g to f		
2	**2001-02**	2/21/2001	C. Pryor	33.3	1.98	66.10	2.34	4.21	155.00			w	17	15:03	15:21	g to e		
3	**2001-03**	2/22/2000	C. Pryor	31.0	2.42	75.10	2.72	4.57	204.00			w	17	15:40	16:05	g to e		
4	**2001-04**	3/6/2001	K.Faucher	28.0	1.61	45.10	1.62	3.51	73.00			w	29	13:35	14:06	good		

APPENDIX A
SOUTH FORK NOYO WATERSHED

DISCHARGE MEASUREMENT SUMMARY SHEET

WATER YEAR: 2001

Measurement Number	WY Msmt #	Date	Made By:	Width (feet)	Mean Depth (feet)	Area (ft2)	Mean Velocity (ft/sec)	Gage Height (feet)	Discharge (cfs)	Rating __1___ Shift Adj.	Percent Diff.	Method	No. of Msmt sections	Begin Time (hours)	End Time (hours)	Msmt Rating	Recorder level	Notes
LOCATION:	**NFSFNASFN**																	
1	**2001-01**	1/23/2001	K.Faucher	15.5	0.39	6.60	0.54	1.19	3.54			w	17	15:11	15:41	g to f		
2	**2001-02**	2/21/2001	C.Pryor	28.0	1.72	48.10	2.70	2.50	130.00			w	20	15:58	16:21	good		
3	**2001-03**	3/6/2001	K. Faucher	33.0	0.86	28.50	2.15	2.06	61.30			w	34	7:51	8:38	good		
4	**2001-04**	3/8/2001	K. Faucher	32.0	0.55	17.50	1.41	1.66	24.60			w	22	16:05	16:45	good		
LOCATION:	**SFNAP**																	
1	**2001-01**	2/1/2001	K.Faucher	10.0	0.47	4.98	0.53	1.92	2.66			w	21	14:18	14:48	good		
2	**2001-02**	2/17/2001	K.Faucher	10.0	0.47	4.65	1.52	2.19	7.05			w	21	15:40	16:10	g to f		
3	**2001-03**	2/21/2001	C.Pryor	12.7	1.06	13.40	3.15	3.42	42.20			w	18	18:30	18:46	good		
4	**2001-04**	2/22/2001	C.Pryor	16.5	1.77	29.10	2.81	4.01	81.80			w	17	13:49	14:04	good		
5	**2001-05**	3/6/2001	K.Faucher	12.5	0.96	12.00	1.74	2.94	21.20			w	26	11:38	12:13	good		
LOCATION:	**PASFN**																	
1	**2001-01**	2/1/2001	K.Faucher	12.0	0.29	3.57	0.81	1.83	2.90			w	25	15:50	16:25	good		
2	**2001-02**	2/21/2001	C.Pryor	19.1	0.78	14.90	2.83	2.59	42.20			w	19	17:39	18:04	fair		
3	**2001-03**	3/6/2001	K.Faucher	13.5	0.68	9.22	2.32	2.39	21.40			w	28	10:40	11:07	good		
4	**2001-04**	3/8/2001	K.Faucher	10.5	0.61	6.40	1.61	2.10	10.30			w	26	17:48	18:15	good		

Appendix B
Suspended Sediment Summary Sheet for the South Fork Noyo River Watershed, WY 2001

APPENDIX B

SOUTH FORK NOYO RIVER WATERSHED

Suspended Sediment Summary WY 2001

Site	Date	Msmt No.	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	WSA	Q/WSA cfs/(mi^2)	SSL (ton/day)	SSLPA (ton/day/mi^2)	Note
SFNBK	1/10/2001	2	18.6	22.22	2.04	63.2	27.32	2.3	3.79	0.14	Q ESTIMATED FROM RATING
SFNBK	1/25/2001	3	37.2	28.31	1.72	24.7	27.32	0.9	1.89	0.07	Q ESTIMATED FROM RATING
SFNBK	2/20/2001	5	32.2	44.70	2.52	171.4	27.32	6.3	20.66	0.76	Q ESTIMATED FROM RATING
SFNBK	2/20/2001	6	34.0	45.10	2.52	171.4	27.32	6.3	20.85	0.76	Q ESTIMATED FROM RATING
SFNBK	2/20/2001	7	130.0	262.70	4.89	765.7	27.32	28.0	542.50	19.86	Q ESTIMATED FROM RATING
SFNBK	2/20/2001	8	134.0	367.10	4.89	765.7	27.32	28.0	758.10	27.75	Q ESTIMATED FROM RATING
SFNBK	2/21/2001	9	28.7	32.20	3.75	452.2	27.32	16.6	39.27	1.44	Q ESTIMATED FROM RATING
SFNBK	2/22/2001	10	27.4	34.90	4.00	515.0	27.32	18.9	48.47	1.77	Q ESTIMATED FROM RATING
SFNBK	2/24/2001	11	15.3	6.20	2.42	145.1	27.32	5.3	2.43	0.09	Q ESTIMATED FROM RATING
SFNBK	3/6/2001	12	16.0	11.40	2.51	169.2	27.32	6.2	5.20	0.19	Q ESTIMATED FROM RATING
KASFN	1/8/2001	1	12.6	3.68	1.69	3.8	2.21	1.7	0.04	0.02	ESTIMATED SYNTHETIC Q
KASFN	2/17/2001	3	25.1	14.60	1.82	5.5	2.21	2.5	0.22	0.10	ESTIMATED SYNTHETIC Q
KASFN	2/19/2001	4	18.0	12.20	2.04	10.8	2.21	4.9	0.36	0.16	ESTIMATED SYNTHETIC Q
KASFN	2/20/2001	5	72.6	115.30	2.27	18.7	2.21	8.5	5.82	2.63	ESTIMATED SYNTHETIC Q
KASFN	2/20/2001	6	85.9	123.40	2.86	53.7	2.21	24.3	17.87	8.09	ESTIMATED SYNTHETIC Q
KASFN	2/20/2001	7	91.6	142.40	3.29	79.3	2.21	35.9	31.88	14.42	Q MEASURED
KASFN	2/21/2001	8	28.0	12.90	2.58	39.1	2.21	17.7	1.31	0.59	Q MEASURED
KASFN	2/22/2001	9	27.6	16.20	2.72	46.0	2.21	20.8	2.01	0.91	ESTIMATED SYNTHETIC Q
KASFN	3/6/2001	10	17.6	8.46	2.06	11.3	2.21	5.1	0.26	0.12	ESTIMATED SYNTHETIC Q
KASFN	3/7/2001	11	16.5	15.00	1.95	8.5	2.21	3.8	0.34	0.16	ESTIMATED SYNTHETIC Q
SFNAK	1/10/2001	3	17.2	19.18	1.18	50.7	24.84	2.0	2.62	0.11	ESTIMATED SYNTHETIC Q
SFNAK	1/25/2001	4	25.5	12.81	0.98	5.0	24.84	0.2	0.17	0.01	ESTIMATED SYNTHETIC Q
SFNAK	2/19/2001	5	10.4	6.60	1.35	46.4	24.84	1.9	0.83	0.03	ESTIMATED SYNTHETIC Q
SFNAK	2/20/2001	6	38.5	52.10	1.78	141.0	24.84	5.7	19.81	0.80	ESTIMATED SYNTHETIC Q
SFNAK	2/20/2001	7	86.9	226.10	2.97	416.8	24.84	16.8	254.14	10.23	ESTIMATED SYNTHETIC Q
SFNAK	2/20/2001	9	108.0	127.70	3.98	786.3	24.84	31.7	270.79	10.90	ESTIMATED SYNTHETIC Q
SFNAK	2/21/2001	10	25.2	38.80	2.68	46.4	24.84	1.9	4.86	0.20	ESTIMATED SYNTHETIC Q
SFNAK	2/22/2001	11	26.3	37.00	3.06	485.6	24.84	19.5	48.46	1.95	ESTIMATED SYNTHETIC Q
SFNAK	2/24/2001	12	14.9	30.80	2.64	153.0	24.84	6.2	12.71	0.51	ESTIMATED SYNTHETIC Q
SFNAK	3/6/2001	13	18.9	10.30	1.71	167.3	24.84	6.7	4.65	0.19	ESTIMATED SYNTHETIC Q
SFNBNFSFN	1/10/2001	2	19.6	11.76	2.31	38.6	21.93	1.8	1.22	0.06	ESTIMATED SYNTHETIC Q
SFNBNFSFN	1/25/2001	3	30.8	19.74	2.18	24.1	21.93	1.1	1.28	0.06	ESTIMATED SYNTHETIC Q
SFNBNFSFN	2/19/2001	4	11.1	3.02	2.33	41.4	21.93	1.9	0.34	0.02	ESTIMATED SYNTHETIC Q
SFNBNFSFN	2/20/2001	5	39.7	61.26	2.67	125.6	21.93	5.7	20.75	0.95	ESTIMATED SYNTHETIC Q
SFNBNFSFN	2/20/2001	6	62.5	28.41	3.03	351.8	21.93	16.0	26.95	1.23	ESTIMATED SYNTHETIC Q
SFNBNFSFN	2/20/2001	7	72.8	148.46	3.30	629.0	21.93	28.68217054	251.85	11.48	ESTIMATED SYNTHETIC Q
SFNBNFSFN	2/21/2001	8	25.3	12.02	3.01	285.0	21.93	13.0	9.24	0.42	ESTIMATED SYNTHETIC Q
SFNBNFSFN	2/22/2001	9	27.2	16.21	3.23	592.0	21.93	27.0	25.88	1.18	ESTIMATED SYNTHETIC Q
SFNBNFSFN	2/24/2001	10	15.0	9.40	2.48	68.8	21.93	3.1	1.74	0.08	ESTIMATED SYNTHETIC Q
SFNBNFSFN	3/6/2001	11	15.1	18.90	2.54	83.6	21.93	3.8	4.26	0.19	ESTIMATED SYNTHETIC Q
SFNANFSFN	1/10/2001	2	17.2	10.79	3.20	40.0	11.90	3.4	1.16	0.11	Q ESTIMATED USING RATING
SFNANFSFN	1/25/2001	3	31.4	35.86	3.12	32.2	11.90	2.7	3.11	0.28	Q ESTIMATED USING RATING
SFNANFSFN	2/17/2001	4	7.4	14.10	2.94	19.4	11.90	1.6	0.74	0.07	Q ESTIMATED USING RATING
SFNANFSFN	2/19/2001	5	11.9	5.50	3.25	43.5	11.90	3.7	0.65	0.06	Q ESTIMATED USING RATING
SFNANFSFN	2/20/2001	6	41.3	53.80	3.76	105.2	11.90	8.8	15.26	1.39	Q ESTIMATED USING RATING
SFNANFSFN	2/20/2001	8	54.1	73.20	4.99	239.1	11.90	20.1	47.20	4.29	Q ESTIMATED USING RATING
SFNANFSFN	2/21/2001	9	22.4	12.20	4.20	155.0	11.90	13.0	5.10	0.46	Q MEASURED
SFNANFSFN	2/22/2001	10	27.7	18.10	4.57	204.0	11.90	17.1	9.96	0.91	Q MEASURED
SFNANFSFN	2/24/2001	11	17.0	5.20	3.43	58.1	11.90	4.9	0.81	0.07	Q ESTIMATED USING RATING
SFNANFSFN	3/5/2001	12	23.5	10.70	4.21	155.0	11.90	13.0	4.47	0.41	Q ESTIMATED USING RATING
SFNANFSFN	3/6/2001	13	17.4	18.60	3.59	90.0	11.90	7.6	4.51	0.41	Q ESTIMATED USING RATING

Appendix B. (Cont.)

Site	Date	Msmt No.	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	WSA	Q/WSA cfs/(mi^2)	SSL (ton/day)	SSLPA (ton/day/mi^2)	Note
NFSFASFN	1/10/2001	3	14.8	20.33	1.72	29.5	9.89	3.0	1.62	0.16	Q ESTIMATED USING RATING
NFSFASFN	1/25/2001	4	27.4	62.86	1.51	17.0	9.89	1.7	2.88	0.29	Q ESTIMATED USING RATING
NFSFASFN	2/17/2001	5	6.0	1.90	1.45	14.0	9.89	1.4	0.07	0.01	Q ESTIMATED USING RATING
NFSFASFN	2/19/2001	6	9.0	3.20	1.67	26.0	9.89	2.6	0.22	0.02	Q ESTIMATED USING RATING
NFSFASFN	2/20/2001	7	36.3	53.10	2.08	64.1	9.89	6.5	9.18	0.92	Q ESTIMATED USING RATING
NFSFASFN	2/20/2001	8	58.8	92.20	2.58	145.5	9.89	14.7	36.18	3.62	Q ESTIMATED USING RATING
NFSFASFN	2/20/2001	9	83.3	121.70	3.09	279.6	9.89	28.3	91.77	9.19	Q ESTIMATED USING RATING
NFSFASFN	2/21/2001	11	25.9	12.80	2.50	130.0	9.89	13.1	4.49	0.45	Q MEASURED
NFSFASFN	2/22/2001	12	21.9	15.50	2.69	168.9	9.89	17.1	7.06	0.71	Q ESTIMATED USING RATING
NFSFASFN	3/5/2001	14	22.6	11.80	2.50	130.0	9.89	13.1	4.14	0.41	Q ESTIMATED USING RATING
NFSFASFN	3/6/2001	15	19.4	18.50	2.02	57.7	9.89	5.8	2.88	0.29	Q MEASURED
BGASFN	1/8/2001	1	6.3	7.42	1.22	1.4	1.05	1.3	0.03	0.03	Q ESTIMATED USING RATING
BGASFN	1/25/2001	2	42.2	17.40	1.53	3.6	1.05	3.4	0.17	0.16	Q ESTIMATED USING RATING
BGASFN	2/17/2001	3	7.2	3.70	1.36	2.2	1.05	2.1	0.02	0.02	Q ESTIMATED USING RATING
BGASFN	2/19/2001	4	12.2	9.69	1.58	4.1	1.05	3.9	0.11	0.10	Q ESTIMATED USING RATING
BGASFN	2/20/2001	5	67.1	108.31	2.10	11.8	1.05	11.2	3.45	3.28	Q ESTIMATED USING RATING
BGASFN	2/20/2001	6	65.7	93.67	2.46	21.6	1.05	20.6	5.46	5.20	Q ESTIMATED USING RATING
BGASFN	2/20/2001	7	90.4	137.90	2.77	32.8	1.05	31.2	12.20	11.62	Q ESTIMATED USING RATING
BGASFN	2/21/2001	8	26.5	13.21	2.17	13.6	1.05	13.0	0.48	0.46	Q MEASURED
BGASFN	2/22/2001	9	23.3	14.05	2.38	19.1	1.05	18.2	0.72	0.69	Q ESTIMATED USING RATING
BGASFN	2/24/2001	10	13.8	5.70	1.67	5.1	1.05	4.8	0.08	0.07	Q ESTIMATED USING RATING
BGASFN	3/5/2001	11	23.0	12.90	2.17	13.6	1.05	13.0	0.47	0.45	Q ESTIMATED USING RATING
BGASFN	3/6/2001	12	23.5	39.60	1.75	6.1	1.05	5.8	0.65	0.62	Q MEASURED
SFNBP	1/8/2001	1	9.0	7.02	1.68	7.1	9.20	0.8	0.13	0.01	ESTIMATED FROM SYNTHETIC Q
SFNBP	1/10/2001	2	16.6	8.90	1.02	26.1	9.20	2.8	0.63	0.07	ESTIMATED FROM SYNTHETIC Q
SFNBP	1/25/2001	3	76.0	46.22	2.17	18.7	9.20	2.0	2.33	0.25	ESTIMATED FROM SYNTHETIC Q
SFNBP	2/17/2001	4	8.3	2.50	1.95	13.5	9.20	1.5	0.09	0.01	ESTIMATED FROM SYNTHETIC Q
SFNBP	2/20/2001	5	48.5	74.60	3.55	242.1	9.20	26.3	48.70	5.29	ESTIMATED FROM SYNTHETIC Q
SFNBP	2/22/2001	6	30.4	18.00	3.38	163.5	9.20	17.8	7.94	0.86	ESTIMATED FROM SYNTHETIC Q
SFNBP	2/24/2001	7	17.1	8.20	2.44	48.0	9.20	5.2	1.06	0.12	ESTIMATED FROM SYNTHETIC Q
SFNBP	3/5/2001	8	22.5	8.68	3.02	115.6	9.20	12.6	2.71	0.29	ESTIMATED FROM SYNTHETIC Q
SFNBP	3/6/2001	9	22.6	9.00	2.56	55.4	9.20	6.0	1.34	0.15	ESTIMATED FROM SYNTHETIC Q
SFNAP	1/10/2001	2	13.2	5.85	2.25	8.0	3.69	2.2	0.13	0.02	Q ESTIMATED FROM RATING
SFNAP	1/25/2001	3	28.1	28.75	2.60	14.0	3.69	3.8	1.09	0.15	Q ESTIMATED FROM RATING
SFNAP	2/17/2001	4	9.1	3.80	2.19	7.1	3.69	1.9	0.07	0.01	Q MEASURED
SFNAP	2/19/2001	5	12.7	10.40	2.68	15.6	3.69	4.2	0.44	0.06	Q ESTIMATED FROM RATING
SFNAP	2/20/2001	6	34.5	53.10	3.45	43.3	3.69	11.7	6.20	0.83	Q ESTIMATED FROM RATING
SFNAP	2/20/2001	7	30.6	40.60	3.73	56.9	3.69	15.4	6.23	0.83	Q ESTIMATED FROM RATING
SFNAP	2/20/2001	8	27.5	50.10	3.73	56.9	3.69	15.4	7.69	1.03	Q ESTIMATED FROM RATING
SFNAP	2/20/2001	9	38.1	29.00	4.04	83.9	3.69	22.7	6.56	0.88	Q ESTIMATED FROM RATING
SFNAP	2/21/2001	10	26.1	11.50	3.42	42.2	3.69	11.4	1.31	0.18	Q MEASURED
SFNAP	2/22/2001	11	27.3	43.60	4.01	81.8	3.69	22.2	9.62	1.29	Q MEASURED
SFNAP	2/24/2001	12	19.5	13.90	2.86	19.3	3.69	5.2	0.72	0.10	Q ESTIMATED FROM RATING
SFNAP	3/5/2001	13	22.0	9.67	3.44	42.8	3.69	11.6	1.12	0.15	Q ESTIMATED FROM RATING
SFNAP	3/6/2001	14	21.3	12.20	2.94	21.2	3.69	5.7	0.70	0.09	Q MEASURED
PASFN	11/29/2000	1	11.0	5.60	1.95	6.0	4.43	1.4	0.09	0.02	Q ESTIMATED FROM RATING
PASFN	1/8/2001	2	12.0	7.27	1.88	3.7	4.43	0.8	0.07	0.02	Q ESTIMATED FROM RATING
PASFN	1/10/2001	3	14.3	7.75	2.03	8.5	4.43	1.9	0.18	0.04	Q ESTIMATED FROM RATING
PASFN	1/25/2001	4	52.5	20.61	2.06	9.4	4.43	2.1	0.52	0.12	Q ESTIMATED FROM RATING
PASFN	2/17/2001	5	7.0	2.10	1.92	5.0	4.43	1.1	0.03	0.01	Q ESTIMATED FROM RATING
PASFN	2/19/2001	6	13.6	10.40	2.10	10.3	4.43	2.3	0.29	0.07	Q ESTIMATED FROM RATING
PASFN	2/20/2001	7	32.7	38.40	2.36	20.3	4.43	4.6	2.10	0.47	Q ESTIMATED FROM RATING
PASFN	2/20/2001	8	36.3	80.60	2.57	40.0	4.43	9.0	8.70	1.96	Q ESTIMATED FROM RATING
PASFN	2/20/2001	9	57.1	72.60	2.80	100.0	4.43	22.6	19.58	4.42	Q ESTIMATED FROM RATING
PASFN	2/21/2001	10	28.4	14.30	2.59	42.2	4.43	9.5	1.63	0.37	Q MEASURED
PASFN	2/22/2001	11	33.7	21.00	2.80	100.0	4.43	22.6	5.66	1.28	Q ESTIMATED FROM RATING
PASFN	2/22/2001	12	32.4	22.60	2.80	100.0	4.43	22.6	6.10	1.38	Q ESTIMATED FROM RATING
PASFN	2/24/2001	13	16.5	6.30	2.30	18.1	4.43	4.1	0.31	0.07	Q ESTIMATED FROM RATING

PASFN	3/5/2001	14	26.0	9.20	2.61	46.3	4.43	10.5	1.15	0.26	Q ESTIMATED FROM RATING
PASFN	3/6/2001	15	16.7	8.00	2.39	21.4	4.43	4.8	0.46	0.10	Q MEASURED

Mapping Prehistoric, Historic, and Channel Sediment Distribution, South Fork Noyo River: A Tool For Understanding Sources, Storage, and Transport[1]

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Abstract

The South Fork Noyo River (SFNR) watershed in coastal northern California contains large volumes of historic sediment that were delivered to channels in response to past logging operations. This sediment presently is stored beneath historic terraces and in present-day channels. We conducted geomorphic mapping on the SFNR valley floor to assess the volume and location of sediment associated with pre-historic terraces, historic terraces, and the active channel along four 1-mi-long stream reaches. Additionally, we established ten streamflow and suspended sediment sampling locations to monitor water and sediment discharges. We estimate 158,000 yds^3 of sediment stored in the active channel, and 68,000 yds^3 of sediment stored beneath historic terraces. These volumes are an order of magnitude less than the volumes estimated for pre-historic terraces. The present-day channel sediment is stored presently in large gravel bars and is mobilized primarily during winter flood events.

Based on channel mapping and hydrologic data, we infer that the largest suspended sediment loads are spatially coincident with the locations of the greatest amounts of stored channel sediment. Re-mobilized historic sediment appears to increase suspended sediment load, and may be a significant, previously unrecognized sediment source. Thus, accurately mapping and quantifying channel deposits is a critical step for assessing sediment budgets, especially in Total Maximum Daily Load (TMDL) studies attempting to relate upslope management to suspended sediment production.

Introduction

The South Fork Noyo River is a major tributary of the Noyo River, which drains to the Pacific Ocean at the town of Fort Bragg in coastal Mendocino County, California *(fig. 1)*. The watershed has been heavily impacted by widespread clearcut logging over the last century. As a consequence, large volumes of sediment have been delivered to watercourses within the basin. Management practices conducted following the 1973 Forest Practice Act have contributed to a decrease in the rate of sediment delivery, although, large volumes of sediment continue to affect the ecology of the watershed (USEPA 1999). Historically, large populations of coho salmon and steelhead reproduced in the river (Brown and others 1994). Drastically declining fish

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populations over the past several decades (CDFG 1995a, 1995b) have raised concerns over the cumulative impacts of sediment on water quality, fish habitat, and the aquatic environment.

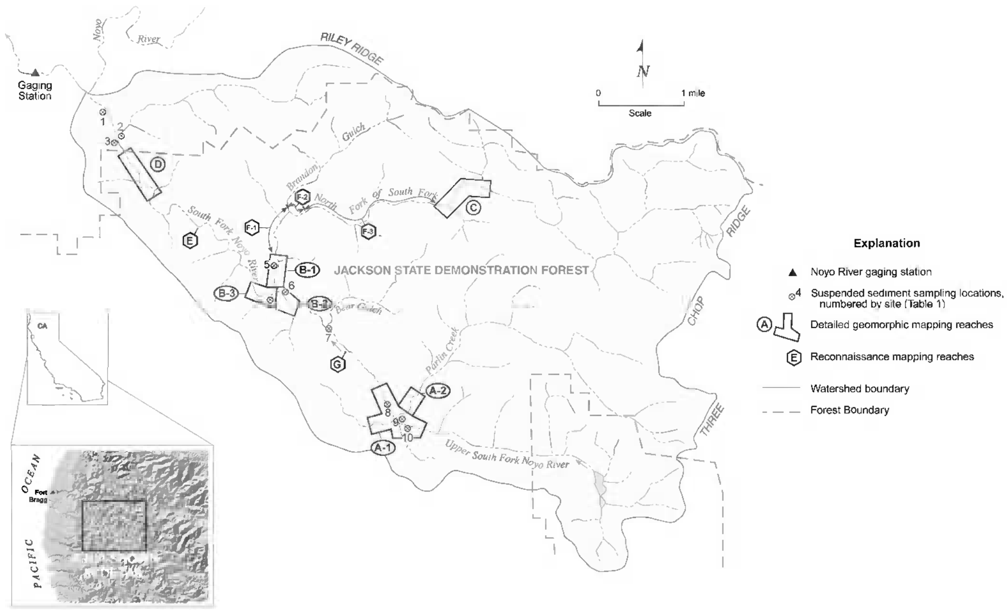

Figure 1—Drainage map of the South Fork Noyo River watershed showing detailed geomorphic mapping locations, reconnaissance mapping reaches, suspended sediment sampling locations, cross section locations, watershed boundary, and property boundary of Jackson State Demonstration Forest.

In response to these concerns, the Noyo River watershed was listed as a sediment impaired waterbody and included in the 1998 Section 303(d) list adopted by the State of California North Coast Regional Water Quality Control Board. In 1999, the Environmental Protection Agency (EPA) established the Noyo River TMDL for sediment, and identified sediment loading allocations aimed at improving water quality criteria for sediment. Accurately determining sediment loads for large watersheds is non-trivial, and office-based estimates are often associated with large uncertainties. The EPA acknowledges that large uncertainties in sediment input/storage estimates may be due to incompatibilities between field and office-based analyses (USEPA 1999). We believe that field-based sediment storage estimates are needed to improve office-based estimates. Thus, quantifying reasonable ranges of sediment input from, and storage in, these watershed sources is critical to understanding the sediment transport processes within the SFNR watershed, and to evaluating the long-term impacts of sediment transport within the SFNR ecological system.

The primary objectives of this assessment are to: (1) collect basic data on volumes of sediment stored and transported within the SFNR watershed over the past approximately 110 years, and (2) collect present-day stream flow and sediment transport data from the main stem SFNR and its major tributaries. These data provide information on long- and short-term storage and transport within the SFNR watershed and illustrate the importance of field-based information in sediment budget analyses.

Approach and Methods

We assessed the historic and current influences on channel morphology by conducting detailed geomorphic field mapping along four stream reaches (Areas A, B, C and D; *fig. 1*). Within these study reaches, we developed detailed geomorphic maps of current channel conditions showing the locations of fluvial terrace, gravel bar, and channel deposits. For field mapping, a string line painted at 25 foot intervals was tied tight along a straight line of sight in the channel thalweg. The compass bearing of the string line was plotted on the field map and tape and compass methods were used to map the dimensions of geomorphic units.

The field maps were converted into a Geographic Information System (GIS) format and used to calculate the area of all of the mapped deposits. These data were combined with field observations of deposit thickness to estimate the sediment volume for each deposit. Cumulative terrace and channel storage volume for each stream reach was calculated as a sum of individual terrace and channel deposits. Sediment thickness is the largest source of error in estimating storage volume.

Individual terrace and gravel bar deposit thickness was assumed to be the distance from the deepest scour in the active channel to the top of the surface. Field evidence used to determine the minimum thickness of channel storage included the depth of scour pools, depth measured at the downstream side of debris dams, the diameter of logs partially buried in the channel, and where available, the surface of bedrock. We infer that the estimates of the sediment volume associated with channel deposits represent minimum reasonable values. Additionally, because information usually is not available on the depth to bedrock beneath gravel bar or historic terrace deposits, we estimate thickness for these deposits as the sum of the sediment thickness estimated in the channel and the height of the respective surface. Because of this, estimates of the sediment volume associated with gravel bars and historic terraces combined represent minimum storage values associated with the active channel. In addition, sediment volume was quantified similarly in channel reaches between the detailed stream reaches (Areas E, F, and G; *fig. 1*), with the exception that surface area was estimated using pace measuring techniques.

To assess present-day hydrology and sediment transport within the major sub-watershed areas in the SFNR watershed, we established ten streamflow and suspended sediment sampling locations (numbered 1 to 10, *fig. 1*) and monitored these stations through WY2001. A standard staff plate and fence posts driven into the streambed were used to measure stream flow stage. Continuous stage recorders with pressure transducers were installed at four locations (Sites 1, 5, 9, and 10; *fig. 1*). Stream flow measurements were taken at all sites with a Price AA or Pygmy current meter and an AquaCalc 5000-Advanced Stream Flow Computer. Depth-integrated turbidity and suspended sediment sampling was performed at most locations. At locations where it was not possible to get a true depth-integrated sample, grab samples or modified depth-integrated samples were taken. The streamflow and sediment data were used to develop relations between stage, discharge, suspended sediment load, suspended sediment concentration, turbidity, and suspended sediment load per unit area (Koehler and others 2001). Total suspended sediment loads calculated for each sampling station were used to compare sediment loads between sub-watershed basins and to assess present-day sediment transport through the watershed.

Results

Locations and Amounts of Stored Sediment

Within each study area along the SFNR, we identified three distinct geologic map units, including deposits associated with pre-historic terraces, historic terraces, and the active channel *(fig. 2)*. Pre-historic terraces were identified by the presence of old-growth redwood stumps in growth position on the terrace surface. This map unit approximates the terrace configuration in the SFNR watershed prior to logging initiation in the late 1800s. Bedrock strath exposures along the channel margin indicate that the terraces are associated with three to eight feet of sediment, which probably is in permanent storage on the basis of deep incision (five to 20 feet). Historic terraces were delineated based on the presence of chainsawed logs within terrace deposits and an absence of old-growth stumps. Based on abundant logging debris only in historic terrace deposits, we infer that the historic terraces represent the maximum amount of channel aggradation that has occurred since the initiation of logging. Historic terraces are most common near the confluence of major tributaries *(fig. 1)*. The deposits associated with these terraces are approximately three to six feet thick. The terraces are a relatively constant height along the stream profile and are inset into pre-historic terraces and bedrock. Sediment stored in historic terrace deposits is subject to bank erosion but is trapped primarily in long-term storage.

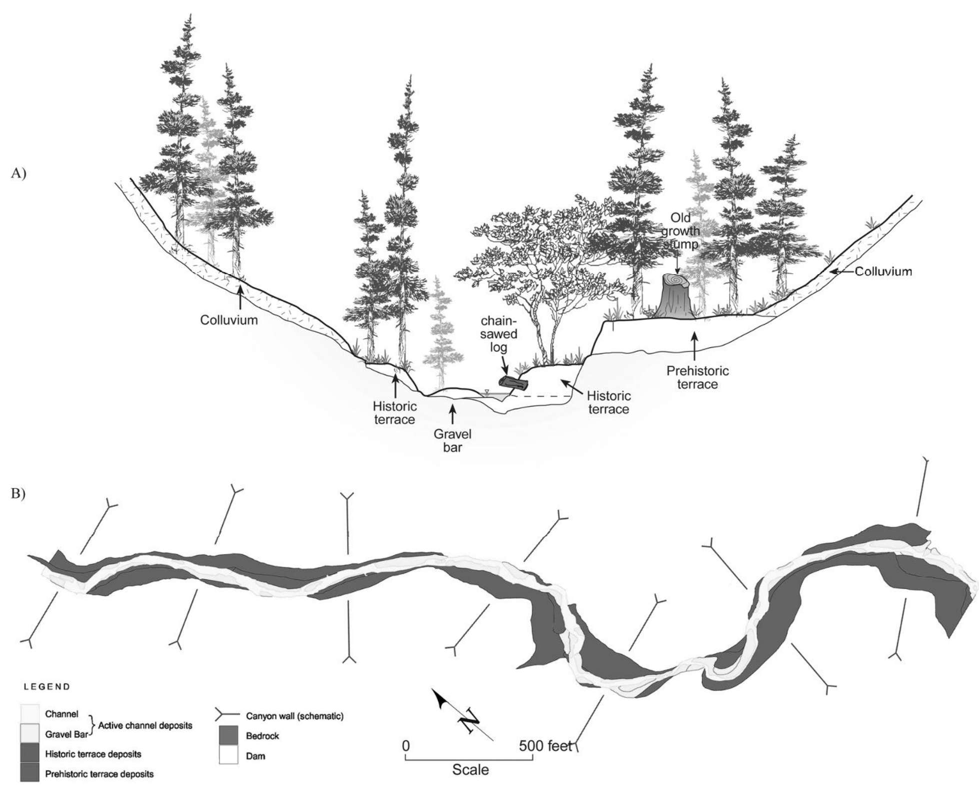

Figure 2—A) Schematic sketch of typical South Fork Noyo River channel showing valley margin, prehistoric terrace, historic terraces, gravel bar, and channel. Historic terrace deposits are observed on bedrock in some locations (left) and on channel deposits in other locations (right). Old growth redwood stumps are diagnostic of prehistoric deposits and embedded chain-sawed logs are diagnostic of historic deposits. Prehistoric terraces typically support second-growth redwood trees and ferns, historic terraces typically support alder trees and grasses. B) Detailed geologic map of mapping area D.

Active channel deposits exist throughout the study area, but are more extensive in downstream locations (Areas B, D, and E on *fig. 1*). These deposits are composed of both gravel bar and channel deposits. Channel deposits are submerged by the river throughout the year and range in thickness from approximately 0.5 to four feet, with occasional pockets as deep as 10 feet. Gravel bar deposits are submerged only during storm events, and range in thickness from approximately 0.5 to three feet. Based on the presence of chainsawed logs buried in the channel, we infer that the active channel deposits post-date the initiation of logging in the SFNR and represent transport of historic sediment.

Table 1 summarizes the total volume of each type of deposit within the detailed and reconnaissance mapping areas. Because individual mapping areas are different sizes, the total volume associated with each deposit in each stream reach is averaged over river distance for comparative purposes *(table 2)*. *Figure 3* shows active channel storage and historic terrace storage volumes for each stream reach. Map Areas A, F, and G have similar active channel storage (less than 13,300 yds^3/mile), whereas Areas B, C, D, and E have active channel storage of more than 20,000 yds^3/mile. Historic terrace sediment distribution is similar for areas D, E, F, and G (less than 5,000 yds^3/mile), however areas A, B, and C have considerably more stored historic terrace sediment *(table 3* and *fig. 3)*. Overall, the volume of sediment stored in the active channel is much more than the volume of the historic terrace deposits, with the exception of Area A. These data show that a large amount of the sediment in the SFNR watershed is stored along the main channel downstream of the North Fork of the SFNR. From these relations, we infer that there has been sufficient time since the logging operations and subsequent terrace deposition to erode the historic terrace deposits and redistribute this material downstream. We also infer that the combined volume of sediment stored in the active channel and historic terrace locations represents the minimum amount of material introduced to the South Fork Noyo river system by logging operations.

Table 3 shows the total post-logging sediment (in other words, active channel and historic terrace) remaining in the SFNR study area. The total post-logging sediment volume in storage over the entire study area is estimated at 225,000 yds^3 or approximately 22,000 yds^3/mile *(table 3)*. Areas F and G, which contain the least post-logging sediment, are located directly upstream of the confluence of the SFNR and the North Fork of the SFNR, and have bedrock exposed along much of their distance. The scarcity of historic terrace remnants and the low volume of active channel sediment within Areas F and G imply that much of the post-logging sediment has been transported downstream. This relationship may be related to the narrow confined valley (between pre-historic terraces) in Areas F and G and the comparatively wider valleys in Areas B, D, and E. Alternatively, the low sediment storage in Areas F and G may be related to a lesser amount of debris left by past logging operations. Notably, areas directly downstream from Areas F and G (in other words, Areas C and A, respectively) have considerably more post-logging sediment in storage than the stream reaches located directly upstream (Areas G and F, respectively). This probably is related to a wider channel in Area C, and a channel confluence in Area A.

Present-Day Hydrology WY2001

Streamflow measurements and sediment transport data included most of the significant storm events in WY2001, although few large storms provided relatively few opportunities to collect high-flow discharge measurements and sediment samples. One hundred and fifteen sediment transport measurements were made at the 10 sampling stations in WY2001 (Koehler and others 2001). *Table 4* shows the total suspended sediment load (tons) and the unit rate (tons/mi^2) for each sampling station, and *figure 3* shows the suspended sediment load distribution. Suspended sediment loads computed for each sampling station ranged from 14 tons at the mouth of Bear Gulch (Site 7, *fig. 1*) to 685 tons on the SFNR at the downstream end of the study area (Site 1, *fig. 1*). Total suspended sediment load increased downstream as the drainage area increased from Bear Gulch (Site 7) through the SFNR at Site 4. However, between this site and the mouth of Kass Creek suspended sediment load dramatically increased from 12.5 to 25.4 tons/mi^2, suggesting that a readily mobilized source of sediment exists within this stream reach. We infer that the source for this sediment is the large volume of sediment stored in the active channel that is remobilized during storm events.

Table 1—*Total volume of sediment stored in active channel deposits, historic terrace deposits, and pre-historic terrace deposits for each detailed mapping area (Area A-1 to Area D) and reconnaissance mapping area (Area E to Area G).*

Stream reach	River dist. (miles)	Active channel deposits (yds^3) *			Historic terrace deposits (yds^3) *	Pre-historic terrace deposits (yds^3) * ≠
		Gravel bar deposits (yds^3) *	Channel deposits (yds^3) Ø	Total active channel deposits (yds^3) *		
Area A-1	1	3,900	5,400	9,300	19,200	199,400
Area A-2	0.3	500	700	1,200	1,300	N.D. ∞
Area B-1	0.5	5,500	4,400	9,900	4,500	68,300
Area B-2	0.4	5,400	3,300	8,700	3,200	82,300
Area B-3	0.4	5,700	4,400	10,100	4,300	34,100
Area C	0.8	9,700	7,100	16,800	10,100	26,100
Area D	0.8	9,500	7,200	16,700	2,700	44,500
Area E	2.2	29,500	26,700	56,200	7,000	3,316,300
Area F-1	0.4	1,600	2,000	3,600	1,800	22,100
Area F-2	0.3	100	600	700	0	3,700
Area F-3	1.9	8,300	4,600	12,900	6,200	93,500
Area G	1.5	4,500	7,000	11,500	7,600	65,900
All areas	**10.27**	**84,200**	**73,400**	**157,600**	**67,900**	**3,956,200**

* Reported values represent minimum potential storage volume due to uncertainties in terrace thickness at the back edge of the deposit.
Ø Reported values represent minimum storage volume.
≠ Pre-historic terrace sediment volumes are based on an assumed 5 foot thickness except for Area A which is calculated based on 4 foot thickness determined from field observation. (Range of depth error is +/- 3 feet).
∞ N.D.; no data. Prehistoric terrace volume for Area A-2 is included in the volume calculated for A-1.

Table 2—*Sediment storage in active channel deposits, historic terrace deposits, and pre-historic terrace deposits averaged per river mile for each detailed mapping area (Area A-1 to Area D) and each reconnaissance mapping area (Area E to Area G).*

Stream reach	River dist. (miles)	Active channel deposits (yds^3/mile)*			Historic terrace deposits (yds^3/mile)*	Pre-historic terrace deposits (yds^3/mile)*
		Gravel bar storage (yds^3/mile)*	Summer channel storage (yds^3/mile)Ø	Total active channel storage (yds^3/mile)*		
Area A-1	1	3,900	5,400	9,300	19,200	199,400
Area A-2	0.3	1,600	2,300	4,000	4,300	N.D.∞
Area B-1	0.5	11,000	8,800	19,800	9,000	136,600
Area B-2	0.4	13,500	8,300	21,800	8,000	205,800
Area B-3	0.4	14,300	11,000	25,300	10,800	85,300
Area C	0.8	12,100	8,900	21,000	12,700	32,600
Area D	0.8	11,900	9,000	20,900	3,400	55,600
Area E	2.2	13,400	12,100	25,500	3,200	1,507,400
Area F-1	0.4	4,000	5,000	9,000	4,500	55,300
Area F-2	0.3	300	2,000	2,300	0	12,300
Area F-3	1.9	4,400	2,400	6,800	3,300	49,200
Area G	1.5	3,000	4,700	7,700	5,100	43,900
All Areas	**10.3**	**8,200**	**7,100**	**15,300**	**6,600**	**384,100**

* Reported values represent minimum potential storage volume due to uncertainties in terrace depth at the back edge of deposit.

Ø Reported values represent minimum storage volume.

∞ N.D.; no data, pre-historic terrace volume for Area A-2 is included in the volume calculated for A-1.

Table 3—*Total amount of post-logging sediment remaining in the South Fork Noyo River and tributaries by stream reach. The values represent the sum of sediment stored in the active channel and historic terrace deposits.*

Stream reach	River distance (miles)	Total volume of post-logging sediment (yds^3)*	Total volume of post-logging sediment averaged for river distance (yds^3/mi)*
Area A-1	1	28,500	28,500
Area A-2	0.3	2,500	8,300
Area B-1	0.5	14,400	28,800
Area B-2	0.4	11,900	29,800
Area B-3	0.4	14,400	36,000
Area C	0.8	26,900	33,600
Area D	0.8	19,400	24,200
Area E	2.2	63,200	28,700
Area F-1	0.4	5,400	13,500
Area F-2	0.3	700	2,300
Area F-3	1.9	19,100	10,100
Area G	1.5	19,100	12,700
All Areas	**10.3**	**225,500**	**21,900**

*Reported values represent minimum potential storage volume.

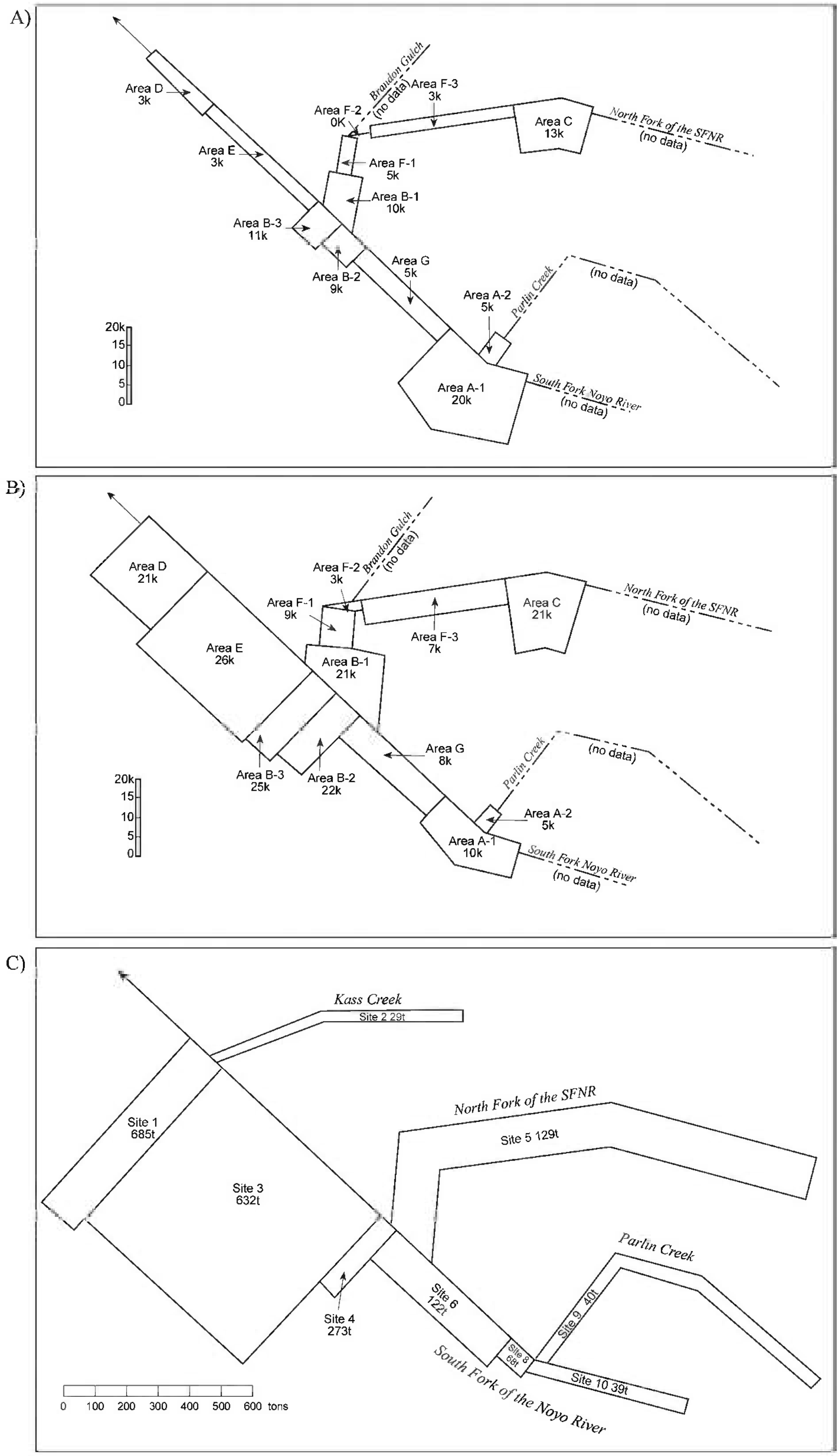

Figure 3—Schematic box diagrams of the South Fork Noyo River showing; A) total volume of historic terrace storage in yds^3/mile, B) total volume of active channel deposits in yds^3/mile, and C) total suspended sediment for each sampling station in tons.

Table 4—*WY 2001 total suspended sediment load (SSL) in tons and tons per square mile for each sampling station.*

Station Number	Area (mi^2)	SSL (tons)	Unit SSL (tons/mi^2)
1	27	685	25
2	2.21	29	13
3	25	632	25
4	22	273	13
5	9.9	129	13
6	12	122	10
7	1	14	13
8	9.2	68	7
9	4.4	40	9
10	3.7	39	11

Discussion

Our detailed channel mapping identified 158,000 yds^3 of sediment stored in the active channel and 68,000 yds^3 of sediment stored in historic terraces *(table 2)*. This sediment likely is mobilized during winter storm flows. The greatest amount of active channel storage occurs between Kass Creek and the mouth of the North Fork SFNR (Areas B, D, and E). In contrast to upstream areas, suspended sediment measured in this area showed a dramatic increase in the volume of sediment produced, where approximately 360 tons of suspended sediment were delivered from only 2.9 mi^2. Thus, the greatest amount of stored channel sediment is spatially coincident with the location of the largest amount of suspended sediment load *(fig. 3)*.

The source for this suspended sediment is most likely sediment stored in the active channel that is re-mobilized during storm events, rather than eroded from historic terrace deposits. The volume of sediment stored in historic terraces along this reach (Areas B, D, and E; *figs. 1* and *3*) is less than along reaches upstream, suggesting that suspended sediment eroded from historic terraces by bank erosion is a minor component of the total suspended sediment load. We interpret that other possible sources of suspended sediment load (in other words, landslides, road erosion) are minor contributors, based on scarcity of slides along the channel margin and adjacent side slopes, and the consistent road density in the area. Thus, land management practices probably do not cause the relatively high suspended sediment load in Areas B, D, and E.

Short-term sediment budgets, evaluated over decadal time scales, generally rely on the assessment of sediment inputs determined from inspection of multiple sets of aerial photographs and limited field observation. The office-based sediment budget approach for the Noyo River TMDL, which included the SFNR, states that fluvial-induced alluvial storage change is a relatively minor term in the overall sediment budget (USEPA 1999). However, the TMDL notes that the discrepancy between inputs and outputs in the Noyo River watershed may be a result of sediment input volume errors or time lags from sediment delivery to transport through the system. In contrast to previous assumptions, our sediment storage and transport study shows that the amount of sediment stored in the SFNR for various lengths of time has a major influence on the assessment of the present-day sediment transport and the short-term sediment budget.

The addition of suspended sediment eroded from active channel deposits to watercourses appears to result in a dramatic increase in the overall suspended sediment load. Areas that contain large amounts of sediment stored in active channels likely are large contributors to the suspended sediment measured during present-day high-discharge events. Therefore, this research has demonstrated that the amount of sediment in long-term storage is a significant contributor to short-term suspended sediment load. Clearly, a distinction must be made between the amount of sediment introduced to the system over the short-term and the amount of sediment re-introduced to the system from long-term channel storage locations.

Future field-based sediment budget analyses for watersheds in the North Coast will benefit from accurate mapping and quantification of channel deposits. An understanding of the volume and timing of sediment stored in the channel is necessary to relate upstream management practices to suspended sediment production and to evaluate cumulative effects. By not addressing long-term sediment storage and relying solely on present-day suspended sediment sampling, suspended sediment load entering the watercourse by modern management practices can be substantially over-estimated.

Conclusions

We assessed the volume of past and present sedimentation within the SFNR by quantifying the volume associated with pre-historic terraces, historic terraces, and the active channel in four detailed mapping reaches and three reconnaissance surveys. Additionally, we assessed present day streamflow and sediment transport throughout the SFNR watershed by establishing and monitoring a stream gauge network for WY 2001.

Total post-logging sediment volume (active channel and historic terrace) in storage over the entire study area is estimated at 225,000 yds^3 or approximately 22,000 yds^3/mile. Comparison of the volume associated with historic terraces and the volume associated with the active channel indicates that a large portion of the sediment originally deposited in historic terraces has been eroded and transported downstream. A significant portion of this sediment presently is stored in the lower SFNR channel between its confluence with the North Fork of the SFNR and the mouth of the SFNR.

Suspended sediment loads computed for each sampling station ranged from 14 to 685 tons. Overall, most sites produced sediment at a fairly consistent rate with discharge, although a large increase in sediment transport occurred between the mouth of the North Fork SFNR (Site 4) and the site upstream of Kass Creek (Site 3). This implies that significant sources of readily accessible sediment are located in this reach. This readily accessible sediment is most likely the active channel sediment stored in Areas B, D,and E.

The detailed maps and hydrologic data produced in this research provide a snap-shot of the distribution of stored sediment and present day sediment transport within SFNR. These data represent a baseline datum from which to monitor future channel recovery and assess the effects of upslope management practices. This research suggests that past logging practices contributed many thousands of cubic yards of sediment to channels in the SFNR watershed, and that the river has the ability to transport this material downstream. This research also demonstrates the need for an understanding of in-channel sediment storage and transport for relating upslope forest management practices to suspended sediment load.

Acknowledgments

This research was supported by the State Forest Research and Demonstration Program (RFP # 8CA99038) of the California Department of Forestry and Fire Protection (CDF). We thank Tim Robards (CDF-Sacramento) and Bill Baxter (CDF-Fort Bragg) for logistical support throughout the project.

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The Garcia River Instream Monitoring Project

Final Report to

California Department of Forestry and Fire Protection

April 2001

Report Preparation by Michael Maahs and Teri Jo Barber

For

Mendocino County Resource Conservation District

With Baseline Conditions Reported by:

McBain and Trush

O'Connor Environmental

Ridge to River

Linda Vance

Salmon Trollers Marketing Association

Photo by Rixanne Wehren

DEDICATION
TO
MICHAEL MAAHS

On March 11, 2000, Michael Maahs was killed in a fishing accident at sea. Michael served as the Garcia River Watershed Project Manager for the Mendocino County Resource Conservation District for over seven years. His project management skills were responsible for seeing this and other projects through in a manner respected by landowners as well as his peers and colleagues. He cared about fisheries and watershed health and understood the issue from many sides -- as a commercial fisherman, from his decades of experience trouncing around creeks as a youthful trout fisherman, as a scientist, and as a concerned human being. He will be greatly missed. This document is dedicated to his life and accomplishments in the Garcia River Watershed.

ACKNOWLEDGMENTS

The Garcia River Instream Monitoring Project was implemented based on an instream monitoring plan written in 1998 by Forest Soil and Water (Dr. Fred Euphrat and Kallie Kull), along with O'Connor Environmental (Dr. Matt O'Connor) and East-West Forestry (Tom Gaman). The Mendocino County Resource Conservation District and its staff and subcontractors arranged landowner access to 12 tributaries, negotiated compromises between the Plan and the budget, and implemented the plan during 1998 and 1999. Linda Vance of UC Davis established the sample plots and study reaches, cross-sectional and thalweg profiles, and collected water temperature and canopy data. Dr. Matt O'Connor, O'Connor Environmental, completed the large woody debris inventory with the assistance of Charlotte Morrison Ambrose and Louisa Morris. Mr. Michael Maahs and the Salmon Trollers Marketing Association carried out the spawning survey. Mr. Darren Mierau, McBain and Trush, completed the assessment of gravel composition and permeability, and Teri Jo Barber, Ridge to River, carried out the Sediment Transport Corridor investigation. Dr. Tim Lewis and David Lamphear of the Forest Science Project provided a detailed analysis of the water temperature data collected in 1999.

Report writing began in early 2000, with Michael Maahs and Teri Jo Barber co-authoring the first draft of the final report. Since Michael's accidental death earlier this year, Teri completed the first draft, incorporated editing suggestions, and produced the final report. The spawning survey of Garcia River tributaries was the last of those designed and supervised by Fisheries Biologist Michael Maahs, whose work has been referenced in many of the rivers and streams of Mendocino County. Mapping and GIS services were provided by Suzanne Lange of CDF and Rixanne Wehren, Cartographer with Coast GIS.

Comments on the first draft of the Garcia River Instream Monitoring Project were received from CDF's Pete Cafferata and John Munn, Craig Blencowe, consulting forester and MCRCD Board Member, Dr. Matt O'Connor of O'Connor Environmental, and Chris Surfleet of Mendocino Redwood Company. Additional words of advice were obtained from Michael J. Furniss of the USFS, Pacific Northwest Research Station (formerly Six Rivers National Forest), Dr. Tim Lewis, EPA (formerly Director of the Forest Science Project), David Hines, Fisheries Biologist for the National Marine Fisheries Service (formerly Campbell Timberlands Management), and Charles Crayne of the MCRCD. As promised, in October 2000, the second draft was circulated to landowners participating in the monitoring program or granting access, and to Friends of the Garcia (FROG) with a 30-day comment period. No comments were received.

EXECUTIVE SUMMARY

The Garcia River Instream Monitoring Project was a pilot cooperative project that documented current channel conditions and established baseline monitoring data for a North Coast timber-producing watershed with anadromous fish. The project was conducted in two phases. The first phase was a watershed assessment and instream monitoring plan (1997-1998), and the second was implementation of the instream monitoring plan (1998-1999). The objective of the project was to document current instream channel conditions in Garcia River tributaries that could serve as a baseline, which could later be revisited to determine the effectiveness of California's Forest Practice Rules in protecting salmonid habitats. The utility of the Instream Monitoring Project is intended to develop with time, as monitoring stations are revisited and information is collected and compared to that collected in the baseline inventory. In this way, trends may be identified to indicate whether channel conditions are improving or declining, both within and among the surveyed tributaries.

Twelve sub-basins within the Garcia River (Figure 1) were monitored. Parameters measured included water temperature, gravel composition, gravel permeability, large woody debris (LWD), channel cross-sections, thalweg profiles, riparian canopy and shading, sediment transport corridors, a spawning survey, and to a very limited degree, turbidity. Five separate contractors conducted the sampling for these parameters. Four plots were established for the 12 tributary reaches, with plot length defined by estimated bankfull width. Spawning survey information was the only information available to characterize the population levels of Garcia River salmonids. Out-migrant trapping of juvenile fish would have provided a better indication of current habitat conditions, but available funding was not sufficient for this level of monitoring.

Water temperature data was collected at the upper and lower ends of study reaches, and a complete set of data was collected from mid-May to mid-October 1999 in flowing water to reflect average water conditions. Maximum weekly average mean and maximum weekly average maximum summer water temperatures were determined for each tributary. Maximum weekly average temperatures (MWATs) exceeding 17.4^{o} C, calculated with the highest 7-day moving average of maximum daily temperatures, were found on 6 of the 12 tributaries monitored. All of the six coastal tributaries were below this threshold. A recently developed MWAT model developed for predicting presence/absence of coho salmon based on temperatures in thermal refugia was applied to the data set. The model predicted coho in all the coastal tributaries evaluated, while none of the inland tributaries were predicted to have coho present. Canopy cover data was found to be correlated with maximum water temperatures ($r^2 = 0.60$ for all 12 tributaries). Average Garcia River canopy density was found to be 64%, while average shading determined with a Solar Pathfinder was reported as 71% in July.

Spawning gravel composition and gravel permeability was measured in 10 of the 12 tributaries. The relationship between permeability and the bulk samples explained 45% of the variability ($r^2 = 0.45$), with the remainder of the variability hypothesized to be due the packing of substrate particles. The basin average for percent fines (<0.85 mm) was found to be 8.2% utilizing the dry sieving method. Earlier work in the Garcia River watershed produced a much higher average for fine sediment with wet sieve data (for example, the Garcia TMDL lists the percentage as 20.6% with wet sieve data). Mean gravel permeabilities were approximately 3,000 cm/hr, with means for the various tributaries ranging from approximately 1,700 to 5,000 cm/hr. These values are generally considered to be in the lower portion of the moderate range for permeabilities. It was concluded that permeability showed the potential to define variability in spawning gravel quality with better resolution and lower cost than McNeil bulk samples—but the relationship between permeability and egg survival has yet to be established and quantified.

For the Garcia as whole, LWD loading was estimated to be 385 m^3/ha (compared to an average of 220 m^3/ha in second growth redwood/Douglas-fir watersheds, and 1,200 m^3/ha for old growth stands). Over half the LWD was found in accumulations or larger jams; approximately 60% was redwood and 25% hardwood. Most LWD was sound and mildly weathered and about 25% of the pieces were pool related. The recruitment rate was estimated to be 3.7 m^3/ha/yr, compared to 5.3 m^3/ha/yr documented at North Fork Caspar Creek. The recruited wood was a mix of hard and softwood classes with average diameters smaller than 0.5 meters. In contrast, long-lasting, geomorphically significant instream pieces are most often redwood with large diameters.

Sediment transport corridors (STCs) are visible corridors allowing sediment to enter stream channels and provide linkages to current sediment generating mechanisms on hillslopes. STCs were evaluated for the plots located within the 12 tributaries. Delivery potential, restoration priority, and possible machine restoration were rated. Most of the surveyed STCs were road and crossing related landslides and gullies. Many were failed crossings that diverted tributaries down roads, and most sites were judged to be inaccessible to heavy equipment due to crossings being washed out.

Spawning surveys were continued in the Garcia basin. Approximately 29 km (18 mi) of the upper mainstem and 12 of its tributaries were surveyed, for a total of 134 km (83 mi). No live coho or coho carcasses were observed during the winter of 1998-1999. Approximately two steelhead redds/mile and about one live fish/mile were observed. Turbidity measurements were attempted with a very low budget approach. Spawning surveyors collected grab samples at established cross sections, but there were difficulties in relating stage to discharge and the sample size in individual tributaries was very small. Because of these problems, little can be concluded regarding turbidity.

A schedule for re-evaluation of the 12 tributary reaches is included. It is suggested that parameters including LWD loading, channel cross-sections, and thalweg profiles be remeasured following geomorphically significant flood events, while other parameters such as water temperature, fish surveys, and turbidity be measured more frequently.

To determine how forest practices are related to changes in channel conditions, addition of the BOF's Hillslope Monitoring Program in the 12 study reaches of the Garcia River Instream Monitoring Project is recommended. Without this added component, the baseline may be used to determine whether channel conditions are trending toward target conditions, which would reflect on the Forest Practice Rules as a whole. But to connect impacts of timber operations, problems documented with hillslope monitoring need to be traced to channels. Without this understanding, it will be difficult to identify changes in the FPRs that are needed to prevent adverse impacts to downstream channels.

Several recommendations for future cooperative projects are provided. These include: 1) utilizing hillslope monitoring in watersheds with instream monitoring reaches to relate upslope impacts to instream channel conditions, 2) gaining full landowner access prior to project implementation, 3), collecting data so that measurement units are comparable to numeric targets set by agencies, 4) defining an acceptable rate of change toward targets for selected parameters prior to instream monitoring—not after, 5) monitoring the fish themselves to estimate populations, and 6) providing more feedback to landowners regarding techniques and locations for controlling sediment entry.

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Garcia River large woody debris instream monitoring (O'Connor Environmental)

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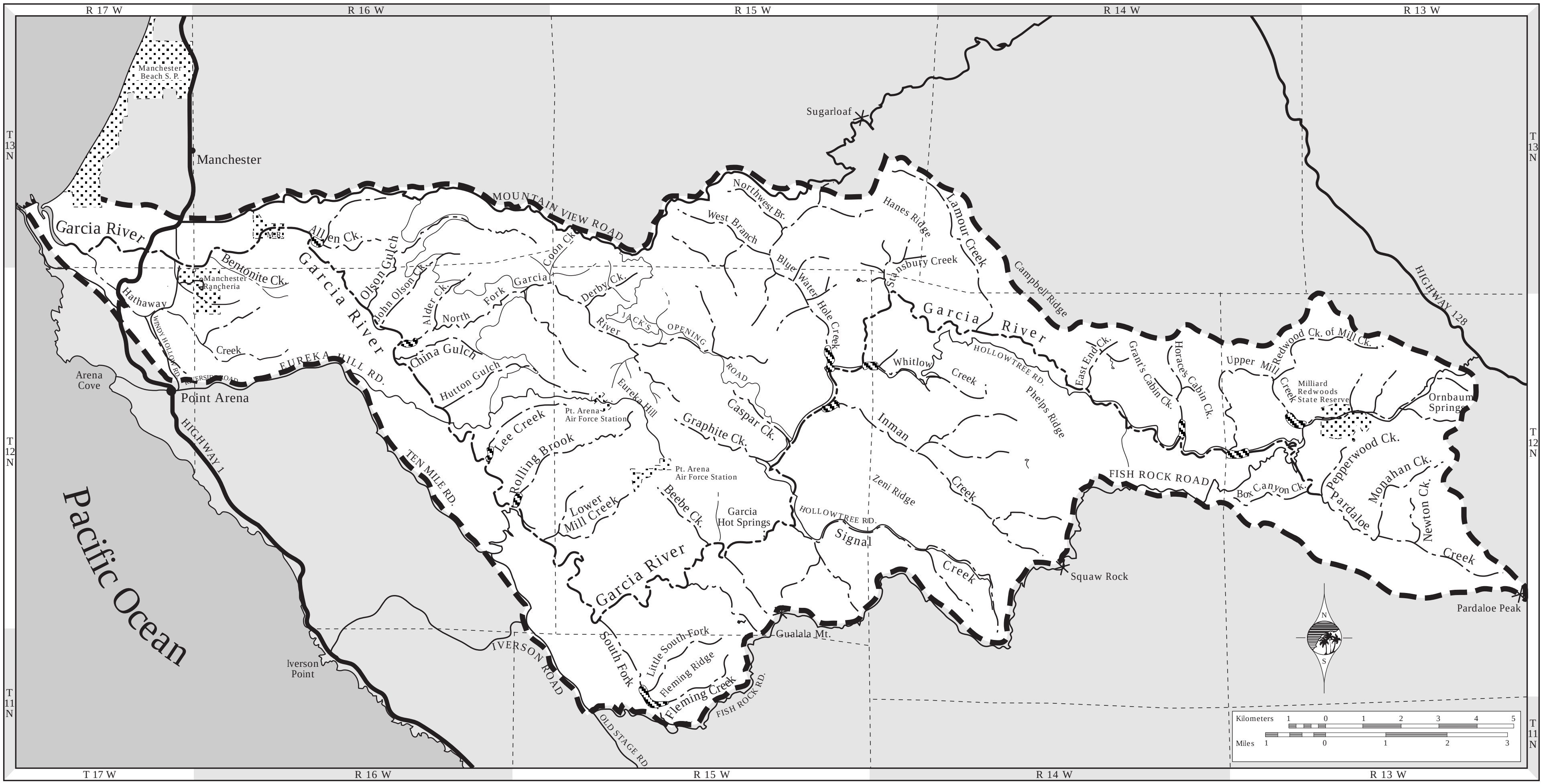
Sediment transport corridors (Barber, Ridge to River)

Study site map to reaches and plots (L. Vance)

These individual reports are not included in the Final Report. The reports in bold print, as well as this document, are either provided online at the Board of Forestry and Fire Protection's Monitoring Study Group website (www.fire.ca.gov, click on Board of Forestry and Fire Protection, click on Monitoring Study Group), or will be in the near future. For additional information on the project, contact Pete Cafferata, CDF, Sacramento, at pete_cafferata@fire.ca.gov.

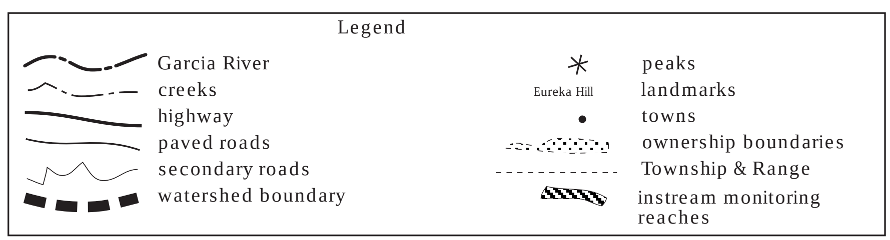


Garcia River Watershed

Mendocino County, California

Figure 1: instream monitoring reaches

Map source materials: USGS 1:100,000 topographic quadrangle Point Arena, Calwater Hydrologic Planning Unit maps, Garcia River Watershed Enhancement Plan work site maps, Blue Waterhole / Stansbury Subbasin Stabilization Project location map, local informants.



Rixanne Wehren
Cartographer

INTRODUCTION

This report documents results of a cooperative Instream Monitoring Project on the Garcia River, conducted by the Mendocino County Resource Conservation District (MCRCD) on behalf of the California Department of Forestry and Fire Protection (CDF). This pilot Instream Monitoring Project compliments the Board of Forestry and Fire Protection's (BOF's) Hillslope Monitoring Program. Taken together, the instream and hillslope components form the BOF's Long-Term Monitoring Program, which is charged to assess the effectiveness of the Forest Practice Rules (FPRs) in protecting the beneficial uses of water following timber harvesting activities on non-federal lands in the state.

Preliminary investigations were funded by CDF and agency partners in the early 1990s to determine how to monitor whether FPRs protect anadromous fishes (Knopp, 1993; BOF, 1993; Tuttle, 1995; Rae, 1995; Spittler, 1995). The Garcia River Watershed was chosen to implement the pilot instream monitoring project because the cooperative landowner-agency monitoring outlook appeared conducive. Additionally, anadromous fish issues are a significant concern in the Garcia River basin. Coho salmon have not been observed in the Garcia River basin since their population was estimated at seven to nine adults basin-wide in 1997, while coho continue to be observed in other Mendocino County watersheds (Maahs, 1999).

Site-specific investigations were accomplished in three phases, allowing the development of the final Garcia River Instream Monitoring Project (GRIMP): 1) collection of existing data regarding water quality and fish utilization, 2) preparation of a watershed assessment, and 3) utilization of these materials to develop a long-term Instream Monitoring Plan. Collection and processing of instream monitoring data began in 1998 and continued through 1999.

The following specific objectives were stated in the Garcia River Instream Monitoring Plan: "The primary objective of the this plan is to test the capability and effectiveness of the California Forest Practice Rules to protect determined beneficial uses, in this case, the salmonid fishery of the Garcia River. A secondary objective is to create a long-term monitoring data set whereby the Garcia River can be compared to other neighboring rivers in the development of a regional standard. The third, and perhaps most important objective, is to understand the Garcia River watershed and reduce its overall sediment load through adaptive management" (Euphrat et al., 1998).

The Garcia River Instream Monitoring Project selected 12 permanent study reaches in second and third order tributaries on managed forestlands where access was granted to establish baseline habitat conditions. Selection of monitoring parameters and experimental design were guided by the Watershed Assessment and Cooperative Instream Monitoring Plan for The Garcia River by Forest Soil and Water (Euphrat et al., 1998). Within each study reach, three or four sample "plots" were established. Each of these plots was 250 feet to 400 feet in length. Sampled monitoring parameters included channel morphology (cross sections and longitudinal thalweg profiles), large woody debris (LWD) and potential LWD recruitment, canopy and shading, stream temperature, spawning gravel composition and permeability, spawning surveys, sediment transport corridors, and to a very limited extent, turbidity.

Two experimental design approaches have been recommended by the authors as a means to compare the baseline conditions established during the 1998-99 GRIMP with results of subsequent monitoring. The first approach is to compare baseline instream conditions to “target instream conditions” recommended in the Garcia River Water Quality Attainment Action Plan (California Regional Water Quality Control Board, 1998) or new targets as they are developed. Target conditions were developed over the course of the Garcia River TMDL (total maximum daily load) issued by EPA to control the introduction fine sediments to the river. A second recommended approach is to associate instream conditions with FPR-related hillslope disturbances. The linkage or “cause and effect” approach lets landscape conditions traced to the channel lead to the determination of whether and to what extent FPRs change instream conditions. This second approach requires further investigation of hillslope conditions and should direct investigators to the practices producing channel degradation.

Testing California’s FPRs for capability and effectiveness at protecting salmonids is a complex task. Recently, a consensus group of specialists termed the Scientific Review Panel concluded that the FPRs do not ensure protection of anadromous salmonid populations (SRP, 1999). Taking the fish out of the equation and framing the question around habitat makes the test difficult to administer using this instream monitoring plan because: (1) CDF’s hillslope monitoring component did not coincide geographically with this instream monitoring project, such that linkages from recent timber operations to the channel remain unknown in the Garcia River (Poff, 1996). (2) A recent Hillslope Monitoring Program summary states in its conclusions that the effects of upslope conditions on channel conditions were not tested (BOF, 1999). (3) The instream conditions measured in Garcia River tributaries reflect “legacy”conditions (pre-forest practice rules) as well as post-modern FPR conditions, but post-modern FPR activities (the ones being tested) cannot be easily or accurately extricated from legacy conditions (Knopp, 1993). (4) Without identifying causal links and tracing their path to channel conditions, we are left with assessing the net instream measured channel condition against channel form targets that oversimplify "adequately protected salmonid habitat" (SRP, 1999; Michael J. Furniss, USFS-Six Rivers National Forest, Eureka, personal communication; Dr. William Trush, Humboldt State University, Arcata, CA, personal communication). (5) Effectively protecting threatened species implies achieving a sustainable population, but sustainable population sizes are not currently known (SRP, 1999).

Establishing baseline conditions for a long-term monitoring data set according to the instream monitoring plan was accomplished. A variety of problems were encountered while attempting to implement the plan, most being consequences of issues that did not fully arise until after implementation had begun, such as landowner access and budget constraints. The issue of landowner access was especially thorny, because one landowner directly experienced a situation in which data collected as a result of allowing government employees on the land was used against them. In order to gain access, a preliminary agreement entrusted MCRCD to "code" tributaries instead of associating commonly recognized names. Even with the privacy agreement, one large industrial landowner refused access. Eventually, the landowners that participated in the project allowed the coded tributaries to be descrambled.

Private landowners should be involved early on in setting up the monitoring program, in the selection of unbiased organizations and personnel gathering data, establishing conditions on how the information will be utilized, and whether and to what extent data will be made available to the public. With involvement comes care, pride and overall improvement to the quality of the project.

BACKGROUND INFORMATION

PREVIOUS INVESTIGATIONS INTO MONITORING CALIFORNIA'S FPRS

Prior to the Garcia River Instream Monitoring Plan, several investigations were funded by CDF, along with the North Coast Regional Water Quality Control Board (NCRWQCB) and the California Department of Fish and Game (DFG), to determine how best to monitor the effects of Forest Practice Rules on salmonids and other beneficial uses of water quality (Knopp, 1993; BOF, 1993; Lisle, 1993; Rae, 1995; Tuttle, 1995; Spittler, 1995; Dresser, 1996). These documents describe different suites of indicator variables appropriate to the task. For example, the need for monitoring a combination of hillslope and instream parameters was clearly stated in the recommendations in BOF (1993) and Rae (1995), yet this was not incorporated into the Garcia plans. Knopp (1993) categorized upslope watershed conditions as index, moderately disturbed, or highly disturbed, and used ANOVA (Analysis of Variance) to test the sensitivity of a suite of instream monitoring variables to the upslope disturbance classes. Conclusions stated that differences in instream conditions measured in "legacy" watersheds (highly disturbed in the pre-modern FPRs era) were not significantly different than conditions measured in highly and moderately disturbed watersheds, indicating these legacy effects are long-lasting and do exert some control on channel conditions found today.

BOF 's Hillslope Monitoring Program

In 1999, an interim report summarizing data collected from 1996-1998 as part of BOF 's Hillslope Monitoring Program was written (BOF, 1999). One hundred fifty timber harvesting plans (THPs) were sampled statewide, with 46 from within Mendocino County. An office review, a field review of on-site conditions, and an evaluation of Rules were conducted for each THP. Results for California as a whole were summarized by roads, logging operations, landings, watercourse crossings, watercourse and lake protections zones (WLPZ), and large erosion events (BOF, 1999). The BOF and CDF's Hillslope Monitoring Program is ongoing, but does not include a component that ties hillslope conditions to instream conditions monitored. The interim results from the BOF report are briefly summarized in the following paragraph.

Data collected as part of the Hillslope Monitoring Program has shown that roads and their associated crossings have the greatest potential for sediment delivery to watercourses. "Major departures were assigned when sediment was delivered to watercourses or when there was a substantial departure from the Rule requirements. Minor departures were assigned for slight Rule departures where there was no evidence that sediment was delivered to watercourses (e.g., WLPZ width slightly less than that specified by the Rule)." Problems were identified at about 40% of the evaluated crossings. Common deficiencies included fill slope erosion, culvert plugging, scour at the outlet, and diversion potential. Similarly, a substantial percentage of road-related rule requirements had poor implementation ratings, but generally had less impact on water quality than poorly implemented crossing Rules. Road Rules most frequently cited for poor implementation were waterbreak spacing and the size, and number and location of drainage structures. For both roads and crossings, implementation of FPRs that specify design, construction, and maintenance needs improvement. Erosion problems noted on randomly selected skid trails and landings were much less frequent and produced much lower impacts to water quality. Average canopy and ground cover remaining following harvesting in WLPZs were found to exceed Rule requirements (greater than 70 and 85%, respectively). Erosion events originating from current timber operations in WLPZs were found to be rare. Overall, erosion problems related to timber operations were almost always associated with improperly implemented Rule requirements.

As stated above, the Hillslope Monitoring Program results, however, do not allow conclusions to be drawn about whether the existing FPRs are providing properly functioning habitat for aquatic species, since evaluating the biological significance of the current Rules is not part of this program. Sample size and confidentiality of data preclude the ability for the public to associate site-specific findings to discrete watersheds or subwatersheds. The authors recommend a Garcia-specific study associating hillslope conditions with instream conditions and forest practices.

PREVIOUS GARCIA RIVER INVESTIGATIONS

Garcia River TMDL

The Garcia River was determined by EPA (Environmental Protection Agency) as impaired by non-point source sediment in 1998 (U.S. Environmental Protection Agency, 1998). EPA had previously funded a sediment source analysis from the work of Forest Soil and Water and O'Connor Environmental (PWA, 1997). Key elements needed to develop the Garcia River Watershed Water Quality Attainment Strategy were the reestablishment of the Watershed Advisory Group (WAG), a data gathering process, a limiting factors assessment, and a sediment source analysis (Mangelsdorf and Lundborg, 1997). In December 1998, the North Coast Region of California Water Quality Control Board adopted Resolution 98-66 to its North Coast Basin Plan, thereby establishing a TMDL (Total Maximum Daily Load) for sediment and a sediment reduction strategy for the Garcia River. On September 21, 2000, the State Water Quality Control Board approved the amendment, thereby placing Garcia's TMDL and Attainment Strategy into the North Coast Region's Basin Plan (see further information about the Garcia River TMDL at http://www.swrcb.ca.gov/rwqcb1/download/GarciaActionPlan.pdf).

Garcia River Limiting Factors Assessment

In October 1996, the North Coast Regional Water Quality Control Board (NCRWQCB) began meeting with agency and timber industry personnel to develop a limiting factor assessment. Stream habitat and fisheries information was sorted by subdivisions of the basin based on CALWATER planning watersheds. A four-volume set of information was distributed to a ten member Limiting Factors Assessment Team composed mainly of agency personnel. In March 1997, this group met to discuss the available data and to develop an office-based "limiting factors" assessment. The group discussed issues such as stream temperature, pool volume, gravel quality, large woody debris, migration barriers, flow rates, competition for water, channel geometry for maintaining gravel, pool cover, canopy, predation, food availability, and poaching, as well as population controlling factors such as carrying capacity versus productivity. A second meeting in April 1997 resulted in a report listing the factors in the freshwater environment that were likely to be limiting to salmonids by planning watershed within the Garcia basin (Mangelsdorf, 1997). A list of Target Conditions is reported in Attachment B of California Water Quality Control Board's Resolution 98-66 amending the North Coast Basin Plan (California Water Quality Control Board, 1998). A report titled "Reference Document for the Garcia River Watershed Action Plan for Sediment" provides clarification on how the numeric targets were obtained. References are made to research in the literature and to government agencies with respect to instream conditions preferred by coho, chinook salmon, and steelhead. Similar conclusions drawn by multiple researchers that quantify instream conditions were used to set the numeric target conditions adopted by the NCRWQCB. In the current report, discussions regarding limiting factors and target conditions are presented in the section entitled "Revisiting the GRIMP Objectives."

Garcia River Watershed Assessment

The MCRCD agreed to prepare a watershed assessment for CDF pertaining to portions of the basin having inadequate analysis, especially for geologic composition and dominant soils. Watershed assessments prepared by industrial timberland owners for a large portion of the basin as part of their draft Sustained Yield Plans (SYPs) were expected to be available. An additional goal was to select third or fourth order tributaries where comprehensive instream monitoring would be used to test the effectiveness of California's FPRs. The NCRWQCB and major landowners were expected to cooperate in this assessment effort.

The MCRCD Scope of Work called for the development of a watershed assessment using the mass wasting, surface erosion, and synthesis modules from the Washington State Department of Natural Resources assessment manual entitled Conducting Watershed Analysis Version 3.0 (Washington Department of Natural Resources, 1995). The remaining five modules were to be completed by a team of agency personnel. The final aspect of work included development of an instream monitoring plan.

Forest Soil & Water (FSW) was awarded the contract in April 1997. The FSW proposal called for a "Level I" watershed assessment, as described in the Washington Forest Practice Board's manual. This "office-level" approach utilized aerial photos, geologic maps, existing data, and reports to conduct the watershed assessment. Fieldwork was limited to areas that could not be interpreted from maps, photos, or existing reports.

Access issues developed early in the assessment because industrial timber companies were reluctant to allow access to their lands or data due to concerns that certain members of the FSW team might be hired by an environmental organization to review their company's Sustained Yield Plan. Timberland owners also wanted a guarantee that they would have an opportunity to review the MCRCD documents before they became final. These concerns were addressed in a meeting between the consultant, the MCRCD, and timber company representatives in May 1997.

In November 1997, FSW submitted a draft report and presented findings to the Garcia River WAG. The draft plan was modified based on comments from the WAG, public agencies, and timber industry representatives, and the final Watershed Assessment and Cooperative Instream Monitoring Plan for The Garcia River (Euphrat et al., 1998) was approved by the MCRCD in March 1998.

The mass wasting and surface erosion modules provide estimated historic erosion and sedimentation rates. Aerial photos from 1965, 1978, and 1996 covering 12 CALWATER planning watersheds were examined and identified mass wasting sites were classified as shallow rapid landslides, debris torrents, and persistent deep-seated landslides according to size classes. Aerial photo analysis identified 447 mass wasting sites. Of these, 85% were shallow rapid slides, 11%

were debris torrents, and 4% were persistent deep-seated features. The analysis suggests mass wasting rates decreased significantly after 1978.

The surface erosion module provided development of rough estimates of past and present road and skid trail erosion for the Garcia River watershed. The assessment relied heavily on a Geographic Information System (GIS) that was developed and maintained by CDF from existing THP maps. This GIS was used to compute the length of road in each planning watershed and then to estimate erosion potential based on inherent erodibility of parent material, protection from erosion provided by vegetation and road surfacing materials, and the proportion of roaded area that delivers drainage and sediment to stream channels. A similar method was used to estimate erosion for skid trails. Natural background levels of erosion were also estimated and included in estimates of total surface erosion in the Garcia River basin. Estimated erosion rates and methodologies for determining surface erosion in the basin are provided in Euphrat et al. (1998).

Garcia River Instream Monitoring Plan

History and Development

The Garcia River Instream Monitoring Plan (GRIMP) was developed by Forest Soil and Water to guide implementation of a pilot project for instream monitoring that would compliment CDF's Hillslope Monitoring Program. "The primary objective of this plan is to test the capability and effectiveness of the California Forest Practice Rules to protect determined beneficial uses, in this case, the salmonid fishery of the Garcia River" (Euphrat et al., 1998). Establishing a baseline condition and long-term database of uniform protocols across ownerships and assisting landowners with cost-effective sediment reductions were secondary objectives.

Landowner Issues

The GRIMP was designed to be a cooperative effort between landowners, agencies, and the MCRCD; it was imperative to get landowner support for the project, not just for access to monitoring sites, but also by incorporation of GRIMP protocols into their own monitoring programs. During the development of the GRIMP, it was realized that each landowner was using its own set of monitoring protocols and that the data sets were rarely compatible. Landowners were invited to participate in a series of meetings to discuss access, monitoring protocols, and data collection/ distributions issues. The first of these meetings was conducted in March 1998, a period of transition in the Garcia basin during the sale of Louisiana-Pacific Corporation and Coastal Forestlands, Inc. timberlands, which made access commitments uncertain. Key issues of concern to landowners were the use of raw data and preventing uninterpreted data from being distributed to the general public. At this meeting "coding the data" was agreed by those present as a technique that would satisfy data-privacy concerns of landowners while still affording the ability to publish findings and make them available to the public.

To alleviate landowner concerns, agreements were written to insure that data, when released, would not be linked to collection sites. This condition satisfied landowners, CDF, and environmental groups. Soon, LP (now Mendocino Redwood Company), GP (now Hawthorne Timber Company managed by Campbell Timberland Management), and the Maillard Ranch granted access. However, Pioneer Resources (the new owners of the Coastal Forestland property) did not. Eventually all the landowners participating in the project agreed to allow the tributary codes to be descrambled (see Table 1).

At the first meeting of the landowners, MCRCD, and FSW, there was little agreement on any issue. Concerns were raised that assessing the effectiveness of the FPRs through an instream monitoring program was not feasible. It was agreed that the current project could only document baseline conditions, and future measurements would be required to determine long-term trends related to FPR effectiveness. However without investigating links between channel conditions and upslope timber harvests, the task of assessing the effectiveness of FPRs may have been oversimplified.

Subcontracts for Implementation

The Garcia River Project Manager, Michael Maahs, acted as primary coordinator for the GRIMP. Most fieldwork was conducted by resource professionals who had considerable expertise with the selected monitoring protocols—without additional training. Five separate contractors were hired by the MCRCD to implement monitoring parameters listed in the GRIMP.

Selection of Tributaries for Monitoring

The GRIMP called for establishing study reaches in 12 Garcia River tributaries. The plan recommended Mill, Grant's Camp, Whitlow, Stansbury, Blue Waterhole, Inman, Signal, Graphite, and Fleming Creeks, Rolling Brook, and the North and South Forks of the Garcia River (see map, Figure 1). However, Signal, Graphite and Stansbury Creeks were not included in the final study reaches because the landowner would not allow access and Stansbury Creek was too remote to make monitoring practical. Study reaches in Pardaloe, Lee and Allen Creeks were established to replace these streams.

The GRIMP called for temperature monitoring on a slightly different set of 12 Garcia River tributaries: Horace's Cabin (also known as Grant's Cabin) Creek, Larmour Creek, Whitlow Creek, Stansbury Creek, Inman Creek, Signal Creek, Graphite Creek, Beebe Creek, SF Garcia, Fleming Creek, Rolling Brook, and the North Fork of the Garcia River. Access exclusion eliminated Signal, Beebe, Whitlow, and Graphite Creeks, as well as Blue Waterhole (during 1998). In addition, temperature monitoring in Pardaloe and Mill Creeks, which was expected to be conducted by the Mendocino County Water Agency, did not occur in 1998. The MCRCD Board of Directors decided 12 tributaries would be monitored for the full compliment of habitat conditions. The final list of 12 tributaries were Mill, Pardaloe, Horace's (or Grant's) Cabin Creek, Blue Waterhole, Inman, Whitlow, Lee, Fleming, Allen, Rolling Brook, and the North and South Forks of the Garcia River (Figure 1). North Fork Garcia and Rolling Brook were not monitored in the spawning survey because access would have required crossing the Garcia mainstem on foot during high flows. In addition, Rolling Brook and Lee Creek were deleted from the gravel component due to budget limitations.

Selection of Habitat Conditions for Monitoring

The GRIMP (Euphrat et al., 1998) offered the following list of candidate habitat conditions for monitoring and their utility in measuring fishery values (Table 2). Budget limitations required focusing on a refined subset. Those omitted included V*, summer fish counts, aerial photography, and dissolved oxygen monitoring. Other protocols were only partially completed, such as spawning substrate data collection in 10 of the 12 study reaches, and turbidity. The indices presented in **BOLD** were measured over the sampling period beginning in August 1998 and ending in fall 1999.

Table 1. Garcia River tributary names and corresponding codes.

Tributary Code	Tributary Name
1	Whitlow Creek
2	Lee Creek
3	North Fork of the Garcia River
4	Mill Creek
5	Pardaloe Creek
6	Horace's/Grant's Cabin Creek
7	Allen Creek
8	Inman Creek
9	South Fork of the Garcia River
10	Blue Waterhole Creek
11	Fleming Creek
12	Rolling Brook

Table 2. <u>Summary of Planned Measurement Parameters and Fisheries Values.</u>

Class / Index	Measurement	Fishery Value
Water quality		
turbidity	suspended sediment, sources	incubation, rearing
dissolved oxygen	oxygen saturation	incubation, rearing
temperature	heat, oxygenation	incubation, rearing
Gravel quality		
percent fines	substrate composition	spawning, incubation, emergence
permeability	interstitial flow	spawning, incubation, emergence
Channel		
cross-section	bed mobility, transport	juvenile rearing
V*	pool depth	summer refugia
LWD	stream complexity	summer, winter rearing/refuge
thalweg profile	bed complexity	summer, winter rearing/refuge
Riparian		
canopy	shade, allochthenous food	juvenile rearing/food
Causal mechanism		
STCs	sediment sources	sedimentation over habitat
turbidity	suspended sediment sources	incubation, rearing
Fish productivity		
spawning survey	escapement	productivity
summer fish counts	utilization of habitat	productivity, age class

HABITAT CONDITIONS MONITORED

STUDY REACHES

Study reaches within the 12 selected tributaries were chosen by the contractor hired for channel morphology work to be representative of managed timberlands and accessible for monitoring. Study reaches are mapped within the basin on Figure 1. Plot ends and cross-sections were marked with a combination of flagging, metal tags, and driven painted rebar, expected to endure for long-term relocation. The meander length criterion was difficult to apply to the third order streams selected because they are controlled more by bedrock than by alluvial deposits that generally form meanders. As such, a length equivalent to 20 bankfull widths was substituted as the criterion for desired length of a study reach.

CHANNEL MORPHOLOGY

Longitudinal thalweg profiles were measured over the length of each plot in all study reaches, recording relative elevations along the deepest parts of the channel. This technique captured rises and falls in elevation characteristic of pools and riffle crests. Graphs of these profiles provide a visual representation of the bed in terms of elevational changes along the channel length (thalweg profile) or width (cross-sectional profile). Cross sections were taken at a frequency of at least one per plot to measure channel complexity and the rise and fall of thalweg, bed, bars, banks, and floodplain. Longitudinal and cross section profiles are presented as a channel morphology unit.

WATER TEMPERATURES

Stowaway™ temperature data loggers recorded water temperature at half-hour intervals. Temperature loggers were calibrated at room temperature before deployment to insure that variability was within the manufacture's specifications (less than 0.5 degrees Celsius). These units were installed at both the upper and lower ends of study reaches. The contractor also recommended a temperature monitoring site in the mainstem Garcia River, as well as at least one air station. Only the mainstem station was implemented. Due to the complexities in gaining access and in contract negotiations, only five tributaries were monitored for summer water temperature in 1998, beginning in mid-August. A complete set of 12 tributaries were monitored for summer water temperature from mid-May to mid-October in 1999.

RIPARIAN CANOPY AND SHADING

Two different measurement techniques were recommended in the GRIMP to measure canopy and shading. The Solar Pathfinder was recommended as a means of determining the total amount of solar radiation blocked by vegetation or topography (referred to as shade in this document). To measure the amount of overhanging vegetation, or canopy cover, a spherical densiometer was recommended. For each of these instruments, measurements were recommended at the beginning, middle and end of each plot, for a total of 12 readings per study reach. Canopy was measured on only five tributaries in 1998, ceasing as the autumn leaves began to fall. All 12 creeks were monitored in 1999 by mid-August before leaf-fall.

LARGE WOODY DEBRIS AND RECRUITMENT TREES

Assessing the amount of large woody debris (LWD) was a major component of the GRIMP. Large wood (logs and root wads) within the wetted channel width create suitable fish cover, increase channel complexity, store and route spawning gravel, act as streambed grade control structures, and stabilize stream banks. To assess the amount of wood in streams, the GRIMP specified implementing the protocol described in the Timber Fish Wildlife manual (Shuett-Hames et al., 1994) in sample plots.

Because recruitment of new LWD into the channel is important, the GRIMP also recommended assessing the rate at which new LWD is recruited into the stream channel over time. To conduct the assessment of recruitment trees, the GRIMP recommended using the Washington Forest Practices Board (WFPB, 1995) methodology that called for on-the-ground assessment, as well as use of aerial photography. An assessment methodology developed by the Fish, Farm and Forests Communities Forum (Taylor, 1998) was also reviewed.

A meeting between landowners, CDF, MCRCD, and the LWD Contractor occurred where the various protocols were discussed. As a result of this meeting, a modified version of the WFPB protocol was adopted. Other competing protocols had desirable elements such that a hybrid protocol was developed at this meeting. Due to budget considerations, only the on-the-ground assessment of potential recruitment trees was conducted in conjunction with the LWD assessment. In addition to the WFPB approach, riparian stand assessments were also conducted according to California Wildlife Habitat Relationships (WHR) criteria (CDF, 1988). So while many features of recommended protocols were adopted, the final LWD survey incorporated features from other protocols to satisfy the objectives of landowners, the surveyor, CDF, and MCRCD representatives.

Riparian stand condition evaluation included 170 feet of horizontal distance from each streambank. The proportion of conifer to hardwood was reported for this zone, as well as whether the canopy cover was dense or sparse. For the LWD survey, the minimum size of wood counted required a midpoint diameter of 4 inches (10 centimeters). Data reported included whether the wood measured was redwood, other conifer or hardwood; a log, rootwad, or log with rootwad; in a single piece, an accumulation of up to 10 pieces, or a jam composed of more than 10 pieces; and whether the wood was freshly recruited, sound, or decayed. Other comments indicated the input mechanism, the manner in which stability was afforded against downstream forces, and whether the wood was associated with pools.

SPAWNING GRAVEL COMPOSITION AND PERMEABILITY

Two methods were recommended in the GRIMP to assess and monitor the quality of the spawning gravel. One method involved determining particle size distributions in the subsurface spawning gravel substrate, while the other method measured gravel permeability. A meeting was held in Fort Bragg in April 1999 with the MCRCD, Garcia River landowners, and the contractor to demonstrate the permeability pump and discuss sampling protocols. After considerable negotiations over protocols and budget, gravel condition measurements began in mid-May and were completed by the end of June 1999. For budgetary and logistical reasons, these measurements were completed on only 10 of the 12 tributaries.

TURBIDITY

The GRIMP specifically recommended hiring a helicopter or plane to conduct overflights during rainstorm events to locate turbidity sources. This would have included color airphoto sets of the entire basin. In addition, a collection of grab samples was recommended where various MCRCD cooperators could collect samples at gauged sites to make simultaneous flow and turbidity data available.

Due to budget limitations and foreseen long winter shadows, no aerial overflights were conducted. Secondly, information collected by such aerial surveys was not considered to be comparable or helpful in evaluating long-term changes without relating the observed conditions to streamflow discharge.

As plans for spawning surveys were being developed, it was apparent that grab samples could be collected during winter months at little to no extra cost to the project in the course of the spawning survey. To conduct this work, staff gauges were to be installed in each study reach. Spawning surveyors carried with them numbered sample bottles that they filled by: (1) submerging to approximately two-thirds the depth of the water column, and (2) tipping to allow water entry into the bottle. This was to be done at the time they encountered the staff gauges so that water stage could be recorded at the same time. Once samples were collected and sample bottle number recorded on spawning survey data sheets, the bottles were submitted to the MCRCD. Turbidity was determined with a Hach Portalab Model 16800 Turbidimeter.

It was originally intended that spawning surveyors would also determine current velocity at staff gauges where the stream profile had been determined. With known velocities, cross-sections, and staff gauge heights, stream flow could be estimated for each sample. With enough trips to the Garcia River at different flow conditions, a useful stage-discharge relationship (discharge rating curve) could be developed for estimating streamflow discharge for any gauge height. Staff gauge installation at measured cross sections, however, was incomplete when the spawning surveyors completed their fieldwork.

Ultimately, the level of commitment to turbidity monitoring was insufficient to produce a useful product. In this case, creativity and over-optimism spawned a partial effort that was doomed by lack of budget, lack of volunteers, and problems in the stream gauging plan.

SEDIMENT TRANSPORT CORRIDORS (STCs)

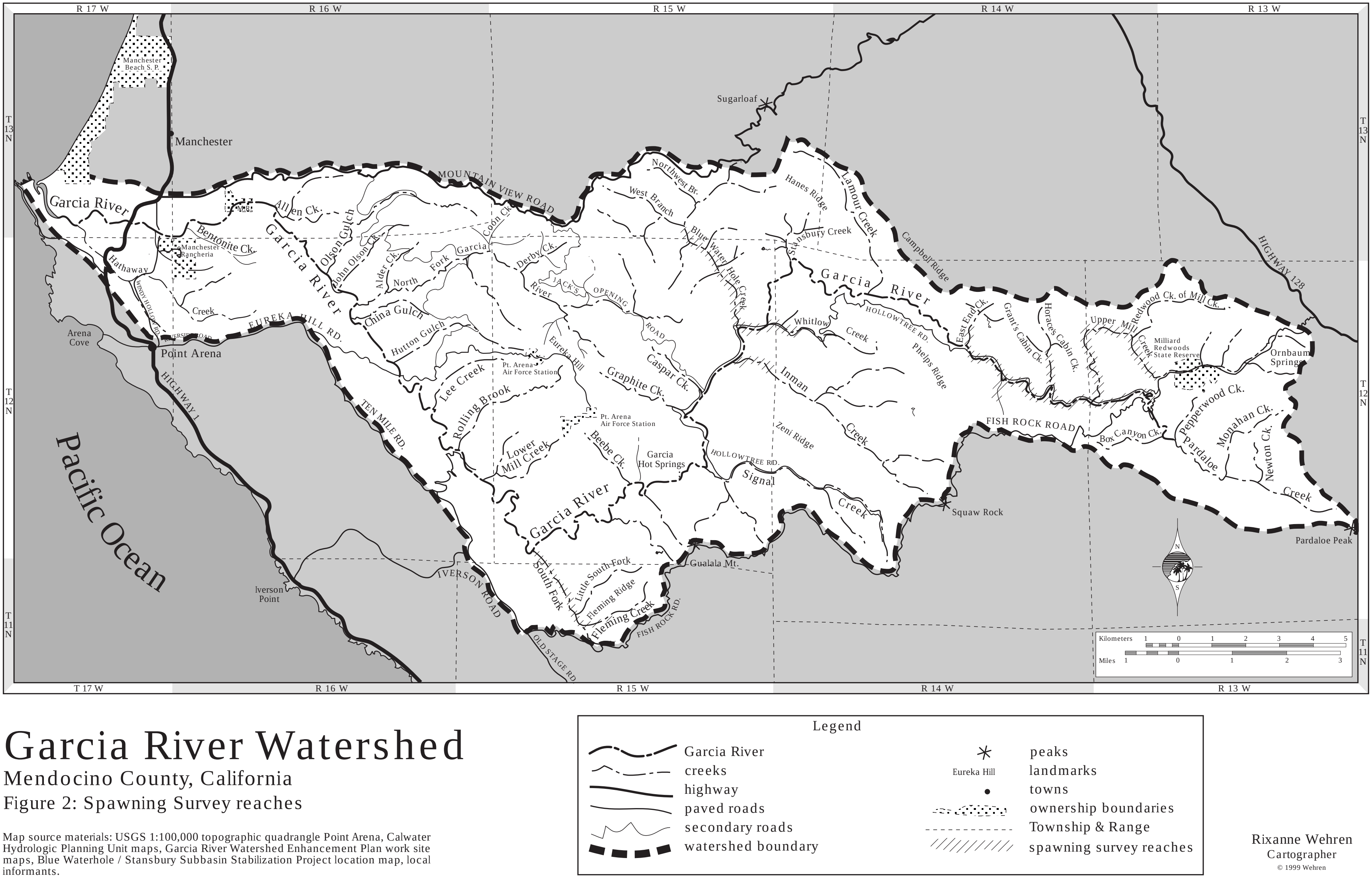
Sediment delivery pathways linking hillslope conditions, erosion source areas, and sediment entering a stream channel were considered in the GRIMP to be an important means of evaluating sediment production from erosion related to forest practice activities. This protocol offered the only link between forest practices and channel conditions in the Instream Monitoring Project. While sediment deposition signals were not always present, features such as landslides, gullies and bank failures were frequently identified as STCs. The lack of deposits can be partially explained in that second order tributaries are often transport reaches, not depositional reaches.

ANADROMOUS FISH PRODUCTIVITY

The GRIMP recommended that past fish stock assessment be continued. The two primary data sets available were salmon and steelhead spawning surveys, as well as late summer/early fall standing crop assessment utilizing electrofish surveys. Electrofishing was not pursued due to concerns of potential damage to fish. A spawning survey over much of the basin was conducted (see Figure 2). Data from some important spawning grounds, such as upper Inman Creek, Signal Creek and the North Fork Garcia could not be obtained due to landowner access issues.

The survey began in early December 1998 and continued through March 1999. Spawning surveys were not conducted on the North Fork, Rolling Brook, and Inman Creeks because they required crossing the mainstem Garcia by foot under unsafe winter flow conditions. Surveys were not conducted on Allen Creek because the landowner did not want conditions reported for fish, and Lee Creek, due to lack of spawning gravel.

Spawning survey results are reported by area. This was required by the permit obtained from National Marine Fisheries Service (NMFS), which specified that any data must be submitted to NMFS and the distribution of fish reported. Special permission was granted by landowners to conduct these surveys. This survey was the last of several spawning surveys developed and supervised by Michael Maahs in the Mendocino County area.



Garcia River Watershed

Mendocino County, California

Figure 2: Spawning Survey reaches

Map source materials: USGS 1:100,000 topographic quadrangle Point Arena, Calwater Hydrologic Planning Unit maps, Garcia River Watershed Enhancement Plan work site maps, Blue Waterhole / Stansbury Subbasin Stabilization Project location map, local informants.

Rixanne Wehren
Cartographer

SUMMARY OF BASELINE CONDITIONS MEASURED

A wide variety of habitat data was collected during the GRIMP implementation, the results of which are presented in the original reports prepared by the subcontractors hired by the MCRCD (see the list of these reports in the Table of Contents). Figure 1 shows the tributaries monitored in the Garcia River Basin. Figure 2 shows the extent of the spawning surveys, which in some cases excluded tributaries that required crossing on foot in high flows, and in other cases extended beyond the established study reaches. This chapter summarizes habitat conditions by monitoring element and attempts to coalesce results to generalize the basin wide condition. The analyses presented build on contributions by the subcontractors.

SAMPLE REACHS AND PLOTS

The sampled 12 tributaries include Horace's Cabin, Mill, Pardaloe, Fleming, Allen, Lee, Inman, Whitlow and Blue Waterhole Creeks, Rolling Brook, and the North and South Forks of the Garcia River (Figure 1). Streams are represented by codes; see Table 1 for corresponding tributary names. There are four surveyed plots per stream reach in all tributaries but one, where there are three plots. Table 3 provides a descriptive summary of each monitored tributary's drainage area, calculated stream length and bankfull width based on the San Francisco Region's Channel Geometry relationships (Dunne and Leopold, 1978; Linsley et al., 1975), measured plot lengths and widths, summed plot lengths (reach lengths) and variation in measured and estimated bankfull widths. Estimations of bankfull width were made from channel geometry tables in Dunne and Leopold (1978) to evaluate differences in the field estimates of bankfull width made by subcontractors Vance and O'Connor. These differences of opinion are discussed further in the QUALITY ASSURANCE AND QUALITY CONTROL section. Strahler stream orders are presented in Table 4.

Table 3. Plot and Reach Size in Surveyed Tributaries of Garcia River and Variations in Bank Full Widths.

Tributary code #	Drainage Area (acres)	Drainage Area (ha)	Plot length (m)	Reach length (m)	R Stream Length (m)	R % stream length (plots)
1	1221	494	87	351	3320	10.48
2	573	232	70	278	2108	13.28
3	6554	2652	111	445	9098	4.88
4	4846	1961	144	579	7591	7.59
5	5626	2277	173	692	8302	8.34
6	684	277	119	477	2345	20.3
7	862	349	39	156	2694	5.79
8	5481	2218	98	391	8173	3.6
9	2768	1120	117	467	5443	8.6
10	4750	1922	113	451	7500	6.03
11	667	270	118	474	2310	20.43
12	1690	684	112	446	4035	11.1
Tributary	**Bankfull Width Estimates**			**# bankfull widths per plot, reach**		
code #	**by S1(m)**	**by S2 (m)**	**by R (m)**	**plot S1**	**reach S1**	**plot S2**
1	4	11.4	26.8	21.8	88	8
2	4	11.4	21.3	0	70	6
3	9	29.8	15.2	12.3	50	4
4	6.5	13.1	27.1	22.2	89	11
5	6.5	17.2	32.3	26.6	106	10
6	6.7	7.5	21.6	17.6	71	16
7	4.3	21.3	11	9.2	36	2
8	7.4	15.4	16.2	13.2	53	6
9	6.7	10.9	21.3	17.5	70	11
10	9.1	15.2	15.2	12.4	50	8
11	6.2	9.5	23.2	19.1	76	12
12	4.9	17.2	27.7	22.8	91	7
S2 = based on measurements by Matt O'Connor						
S1 = based on measurements by Linda Vance						
R = based on average channel dimensions for drainage area in San Francisco Region,						
annual rainfall = 30" (Dunne and Leopold, 1978)						

Study reaches consist of three to four clustered sample plots, with a target representation of a 15% sampling intensity on each surveyed tributary. The desired statistical approach was to create a stratified, systematic sampling of plots (experimental units) within the population of managed forestlands within the Garcia River Basin. All parameters were to be applied uniformly to multiple plot samples. The goal of this sampling plan was to produce a quantitative "snapshot" of current conditions in representative tributaries to provide a baseline for long-term monitoring (Euphrat et al., 1998). Plots can be located for remeasurement from permanent benchmarks placed at the lower end of plots or at cross-sections that are out of flood-prone areas, increasing the probability of relocation following a flood event with 30 to 100 years recurrence interval. Plot lengths ranged from 39-173 meters (128-568 feet), with plot and interplot distances increasing with drainage area.

CHANNEL MORPHOLOGY AND POOL DEPTHS

Longitudinal thalweg profiles and cross-sections were used to characterize channel morphology for 1998-1999. It was assumed that comparison of thalweg profiles from the same sites over several years would identify trends toward overall channel degradation or aggradation, or degradation in some locations and aggradation in others.

Tributary pools were identified from longitudinal thalweg profiles and depths were calculated from changes in measured elevations. In Table 4, a pool was considered present where there was a drop in elevation of at least one foot relative to the highest elevation measurement occurring downstream. Elevational change was determined to be the residual pool depth. Pool length is proportional to the length of stream in each thalweg profile plot, and is then summarized as the mean of the 4 plots. This method compares the Numeric Target of pools occupying 40% of stream length, which was established during the Garcia River TMDL for 3rd order streams, to the Garcia tributary data. Three streams in the data set met this target. Pool data from the 12 tributaries is summarized by depth in Tables 4 and 5.

Table 4. Proportion of stream length occupied by pools deeper than 1 foot.

Stream #	Strahler Stream Order	Plot 1	Plot 2	Plot 3	Plot 4	Average
1	3rd	0.25	0.16	0.4	0.57	0.29
2	2nd	0.05	0.14	0.09	0.34	0.16
3	4th	0.36	0.3	0.28	0.3	0.31
4	3rd	0.55	0.3	0.23	0.73	0.45
5	3rd	0.36	0.36	0.3	0.47	0.37
6	2nd	0	0.09	0.2	0.09	0.1
7	2nd	0.09	0.06	0.23	0	0.1
8	3rd	0.36	0.27	0.56	NA	0.4
9	3rd	0.28	0.19	0.22	0.19	0.22
10	3rd	0.33	0.35	0.38	0.56	0.41
11	2nd	0.27	0.28	0.52	0.2	0.32
12	3rd	0.31	0.08	0.13	0.3	0.21

Table 5. Number of pools, pools/mile and cumulative number of pools per mile, by pool depth, for the 12 Garcia River study reaches.

Pool Depth Range (ft)	*Total # of Pools*	*Total # Pools/Mile*	*Cumulative Pools/Mile*
0.6-1.0	60	20.3	51.2
1.1-1.5	31	10.5	30.8
1.6-2.0	33	11.2	20.3
2.1-2.5	13	4.4	9.2
2.6-3.0	6	2.0	4.7
3.1-3.5	4	1.4	2.7
3.6-4.0	1	0.3	1.4
4.1-4.5	2	0.7	1.0
4.6-5.0	0	0.0	0.3
5.1-5.5	0	0.0	0.3
5.6-6.0	1	0.3	0.3
Total	151		

WATER TEMPERATURE

The baseline condition was sampled to obtain a general condition of flowing water and care was taken to assure no stagnant pools were measured. Deep holes were ignored so as to reflect average conditions, not cool refugia. Daily minimum, maximum, and average temperatures for the upstream and downstream ends of each study reach from May through October 1999 were determined. Weekly average mean and weekly average maximums were produced from the data set. Seven-day moving averages of daily average temperatures and seven-day moving averages of daily maximum temperatures were also determined.[1]

Salmonid growth and feeding are related to water temperature in a feedback loop. Therefore, determining salmonid impacts from temperature are best estimated in the context of site-specific

[1] The Forest Science Project, associated with the Humboldt State University Foundation in Arcata, CA, utilized a macro-program to analyze the raw data set.

temperature conditions (SRP, 1999). The most obvious effect of elevated light and temperature conditions is increased primary production (algal growth) and increased secondary production (invertebrates) which provide more feeding opportunities (Hicks et al., 1991). A change from diatom-based food webs of well-shaded allochthenous streams to filamentous green algae prominent in warmer autochthenous waters promotes a change in first level consumers toward grazers, which drift more often and thus increase opportunities for foraging for drift-feeding salmonids. However, water temperatures may increase to the point that they become problematic by way of increasing susceptibility to disease, reduced metabolic efficiency in converting food to growth, altering the competitive balance between warm and cold water fishes such that warm water fishes are better able to compete for food and cover, or in tributaries, by increasing temperatures in mainstem habitats.

Preferred temperatures have been reported for chinook, coho, and steelhead as 12-14, 12-14, and 10-13 degrees Celsius, respectively. Upper incipient lethal temperatures were reported for these species as 26.2, 26-28, and 23.9 degrees Celsius (Bjornn and Reiser, 1991).

Analytical Methods

The term Maximum Weekly Average Temperature (MWAT) has been commonly used recently to express water temperature that can reduce salmonid health or cause an avoidance behavior for areas with excessive temperatures. Care is required in comparing reported MWAT temperatures because MWAT has been calculated by several methods, including: daily temperatures averaged over the week and the maximum of these is recorded, which produces a relatively low temperature estimate; daily maxima are averaged and recorded, which yields a relatively high temperature; and seven-day moving averages of daily maximum or average temperatures are determined. Examples of the differing formulas include:

MWAT (Mangelsdorf, 1997)

Average daily temperatures for seven days, extract maximum values, reported weekly.

MWAT here is calculated by averaging daily temperatures and reporting the maximum of the daily averages over the week. No reference is made as to whether dominant or refugia conditions are measured.

MWAT (Hines and Ambrose, 2000)

Peak daily temperatures extracted and recorded daily as 7-day moving average daily maximum (7DMADM). MWAT here is calculated by taking the maximum daily temperatures and using a moving average of these peaks over 7-days. Refugia conditions are measured (i.e., at the bottom of deep pools).

MWAT (Friedrichsen, 1998)

The highest temperature reading of the week extracted and reported weekly. No reference is made as to whether dominant or refugia conditions were measured.

The results of several pre-existing water temperature data sets from Garcia River tributaries were expressed as MWAT values by Mangelsdorf (1998). The 1999 temperature data for the Garcia River from the GRIMP provides both averaged weekly temperatures that are comparable to this data, as well as a 7DMADM (see Table 6). These data refer to an MWAT threshold of 17.4^{o} C for coho salmon (Mangelsdorf, 1997). Other reported thresholds include 16.8 and 18 degrees Celsius, reported by NMFS and USFWS (1997), and Brungs and Jones (1977), respectively.

In examining a recent application of MWAT (here 7DMADM, after Hines and Ambrose, 2000) for coho refugia, it appears that an MWAT value of 17.6^{o} Celsius may be the upper limit of coho tolerance in thermal refugia. In other words, if peak temperatures exceed 17.6^{o} for more than one day in cool water pool refugia, coho are predicted to be absent due to the combination of intensity and frequency of exposure. In coastal basins within Mendocino County, Hines and Ambrose used the 7DMADM (MWAT) interpretation defined above to explain coho absence from tributary streams having coho elsewhere in the basin with no barriers preventing access. Hines and Ambrose hired a statistician to analyze their data, who used a recently revived statistical method, Akaike Information Criterion (otherwise known as AIC), to predict coho presence/absence in streams from their dataset.

AIC compares multiple, competing, mathematical models to predict presence or absence of animal populations based on physical attributes that quantify habitat values. The AIC technique computes an arithmetic number value for each model and the lowest of these scores identifies that model best able to predict presence or absence (Hilborn and Mangel, 1997). AIC has been successfully used to predict presence or absence in wild owl and fish populations over the last few years (Dr. Howard Stauffer, USFS Pacific Southwest Research Station, Arcata, CA, personal communication).

Table 6. Weekly average mean and weekly average maximum temperatures versus threshold water temperatures for the Garcia River tributaries, summer, 1999.

Tributary Code #	Weekly Maximum	Date	Weekly Averages	7DMADM Daily Max Temps	Date	7DMA Daily Ave Temps	Threshold MWATs		
	Maximum Weekly Average Temperatures (MWATs)								
	(deg C)		(deg C)	(deg C)			(deg C)		
1 ds	24.7	7/16/1999	20.11	24.87	7/15/99	20.11	16.8	17.4	18
2 ds	14.79	8/29/1999	14.14	14.84	8/30/99	14.28	16.8	17.4	18
3 us	14.6	9/10/99	13.5	14.67	9/13/99	13.68	16.8	17.4	18
4 ds	20.09	7/16/1999	17.92	20.09	8/29/99	18.3	16.8	17.4	18
5 ds	26.57	7/16/1999	21.81	26.59	7/16/99	21.85	16.8	17.4	18
6 us	18.4	7/16/99	16.8	18.45	8/30/99	17.2	16.8	17.4	18
7 us	14.7	8/30/99	14.0	14.68	8/30/99	14.01	16.8	17.4	18
8 us	25.13	7/16/1999	20.98	25.18	7/15/99	20.98	16.8	17.4	18
9 ds	15.54	8/27/1999	14.3	15.56	8/30/99	14.52	16.8	17.4	18
10 us	24.6	7/16/1999	20.75	24.67	8/28/99	20.91	16.8	17.4	18
11 ds	14.19	8/27/1999	13.49	14.24	8/30/99	13.65	16.8	17.4	18
12 ds	15.43	8/27/1999	14.0	15.45	8/30/99	14.28	16.8	17.4	18

ds = downstream reach; us = upstream reach

Downstream reaches were used unless there was missing data or anomalous factors.

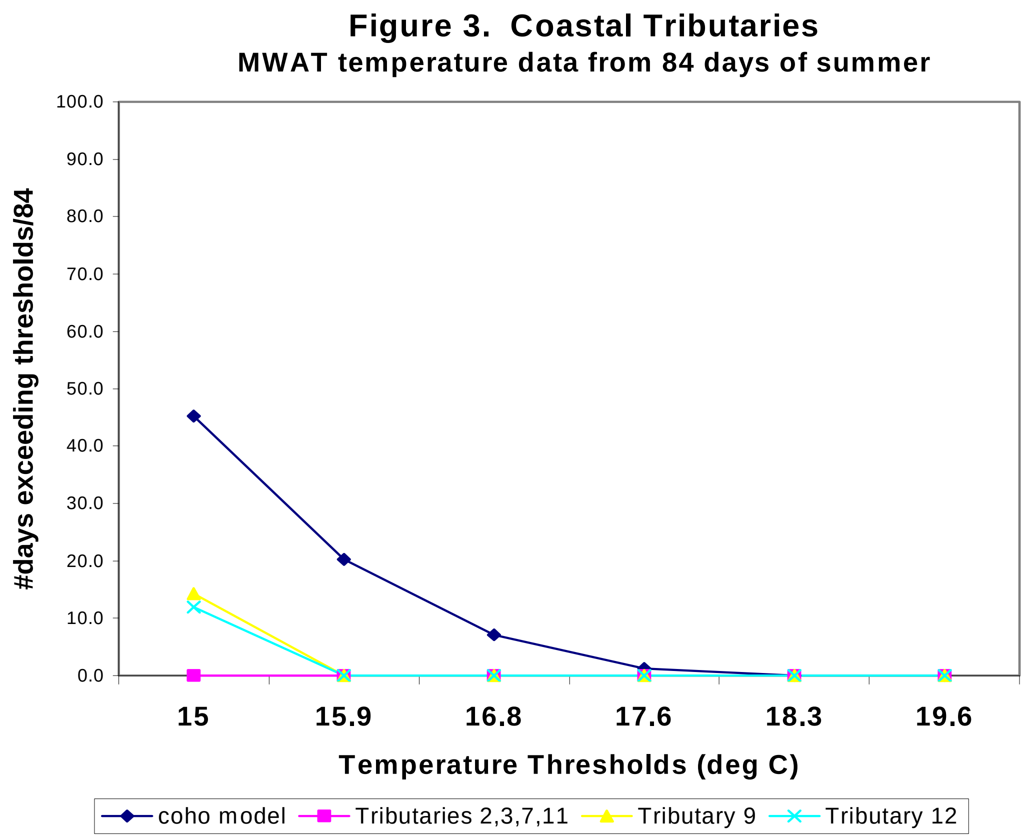
In the MWAT application, the AIC method was used to evaluate several habitat models to identify which combination of temperature metrics best predicted coho presence or absence. The 7DMADM water temperature model yielded the highest probability in explaining coho absence (Hines and Ambrose, 2000). Several threshold MWAT temperatures were examined for utility in the model. The resulting 7DMADM temperature model predicts coho absence when the number of days that water temperature exceeds each of six MWAT temperature thresholds (19.6^o, 18.3^o, 17.6^o, 16.8^o, 15.9^o, and 15^o Celsius) is greater than the number of days predicted by the model for presence.

Summer temperatures in Garcia River tributaries were compared with the coho presence/absence temperature model provided by Hines and Ambrose (2000). The number of exceedence-days in the model, for each threshold, is given in Table 7 and Figures 3 and 4 for the Garcia River tributaries evaluated. It is important to note that the temperature probes were not installed at maximum pool depths to capture refugia, as did Hines and Ambrose. Data for the Garcia reflect average water conditions and the maximum temperatures recorded over the summer weeks are reported, not thermal refugia found in deep pools.

Table 7. Water temperature duration thresholds for Garcia River tributaries based on seven day moving averages of maximum daily temperatures.

	Threshold temperature values (after Hines and Ambrose, 2000)					
Celsius scale	15	15.9	16.8	**17.6**	18.3	19.6
Fahrenheit	59	60.62	62.24	**63.68**	64.94	67.28
Total days = 84[2]	Number of days 7DMADM temperatures exceed thresholds					
(June 11th through Sept 2nd						
coho model	38	17	6	**1**	0	0
Garcia #1us	84	84	84	**83**	80	57
Garcia #2 ds	0	0	0	**0**	0	0
Garcia #3 us	0	0	0	**0**	0	0
Garcia #4 ds	80	78	73	**61**	24	5
Garcia #5 ds	84	84	84	**84**	84	84
Garcia #6 us	81	79	39	**16**	3	0
Garcia #7 us	0	0	0	**0**	0	0
Garcia #8 us	84	84	84	**84**	84	81
Garcia #9 ds	12	0	0	**0**	0	0
Garcia #10 us	84	84	84	**84**	84	82
Garcia #11 ds	0	0	0	**0**	0	0
Garcia #12 ds	10	0	0	**0**	0	0
ds = downstream reach; us = upstream reach						
downstream reaches were used unless there was missing data or anomalous factors						

[2] In the Hines and Ambrose (2000) model, data was included from the start of the 24th week of the year through the end of the 35th week (David Hines, NMFS, Santa Rosa, CA, personal communication.



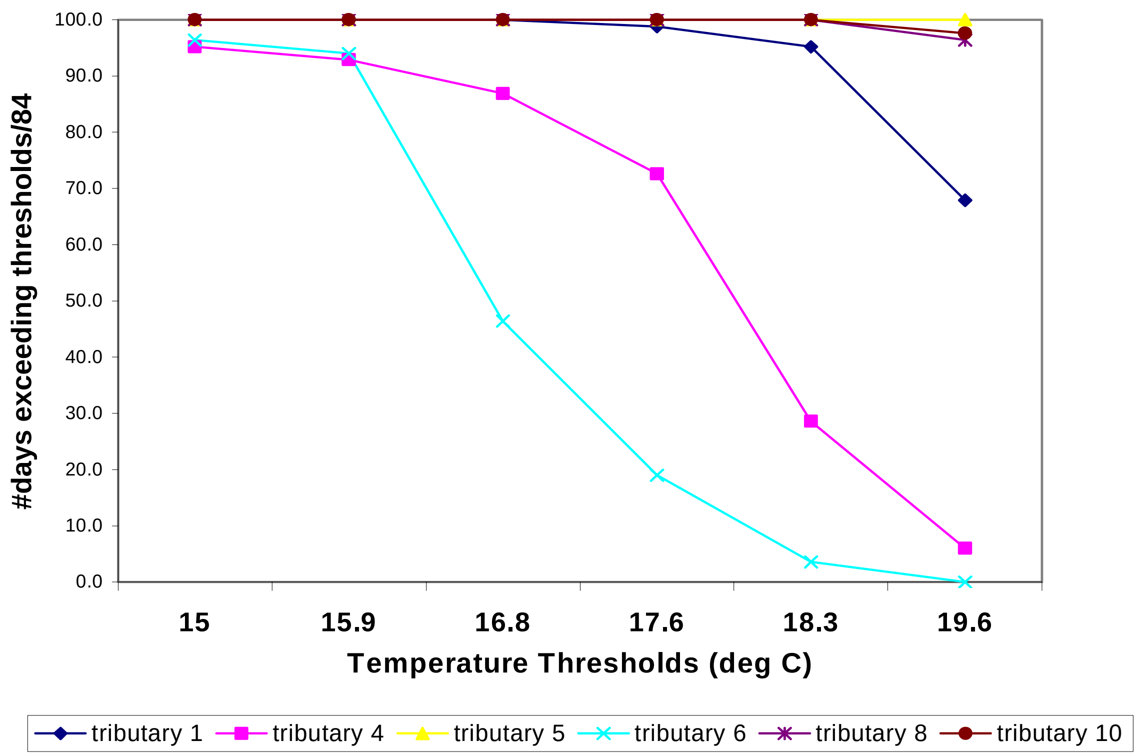
Results

Seven-day moving averages of the daily maximum temperatures for each tributary were determined from the data set. The data were compared to the 7DMADM MWAT threshold of 17.6 degrees Celsius (63.68 degrees Fahrenheit). The 7DMADM MWAT model suggests that a stream which warms to greater than 17.6 degrees Celcius (63.68 degrees Fahrenheit) more than one day during the summer will be coho-absent.

Figure 3 graphically displays the results for the coastal 7DMADM model from Mendocino County coastal creeks (Hines and Ambrose, 2000) as a backdrop on the coastal half of the Garcia River basins. The temperature data for the inland tributaries were also graphed (Figure 4), but without the model shown.

Figure 4. Inland Tributaries

MWAT temperature data from 84 days of summer



Figures 3 and 4 refer to the number of days water temperature exceeded MWAT thresholds. Several thresholds were provided because there are several threshold values in the literature that describe preferred water temperatures. Coastal streams are all within five miles of the coast, and are all tributaries that enter the river's north-northwest trending fault-line exhibited on basin maps of the Garcia River resembling a southern "dog-leg" which culminates in the South Fork Garcia (see map Figures 1 and 2). In contrast, inland tributaries enter the Garcia River at least 10 miles from the coast and are generally out of the fog-belt generating the cooler coastal climate.

Coho absence based upon temperature was not predicted for any of the six coastal tributaries, but none of these streams presently have any coho (Maahs, 1998). All inland streams exceeded the coho temperature tolerance limits predicted by the 7DMADM. No MWAT temperature tolerances for steelhead were examined, but stream temperature does not appear limiting for these fish in that the highest adult steelhead densities were observed in inland Garcia River tributaries.

Conditions that Explain Water Temperature

Water temperature is known to fluctuate over a 24-hour period with changes in air temperature and solar insolation. For example, recent work by Lewis et al. (2000) has shown that stream temperatures vary to a large extent depending on distance from the coast. Geographic position factors are largely surrogates for air temperature. Water temperatures were also found to increase with increasing distance from the watershed divide and with increasing drainage area. Factors that affect water temperature also include shading, channel width to depth ratios and, perhaps, upslope soil temperature effects on runoff and groundwater inputs (Brosofske et al., 1997). The IMP did not include soil and air temperature measurement. Air temperature data for the general region, however, is available from NOAA for weather stations located at Navarro, Booneville, Yorkville, and Point Arena, and can be found at the following website:

http://www.ncdc.noaa.gov

Canopy closure was tested in relation to water temperature and a correlation was found that explains most of the variation in water temperature. This analysis is described more thoroughly in the Riparian Canopy and Shading section that follows.

RIPARIAN CANOPY AND SHADING

Stream canopy and shade were measured with both a spherical densiometer and the Solar Pathfinder in each of the twelve monitored tributaries. Both methods provided long-term monitoring information that was useful in assessing changes in the amount of sunlight reaching the stream channel. As a means to establish an overall estimate of canopy in the basin, the density and closure (from spherical densiometer readings) estimates for each of the 12 study reaches was averaged, resulting in mean basin density and closure estimates of 64, and 52 percent, respectively. Similarly, the averaged Solar Pathfinder readings indicated that the proportion of solar radiation blocked from reaching the stream channel in 1998-99 was 72, 72, 71, 75, and 82 percent, for months May, June, July, August, and September, respectively. Basin averages may be more appropriate than data for individual tributaries, since the goal of the GRIMP is to develop habitat baseline conditions to document instream habitat changes with respect to time and land use practices. However local shade is certainly one important condition driving water temperatures recorded in individual tributaries. Where study reaches are not subject to canopy alteration by land management actions, changes observed through time will provide needed information regarding canopy recovery rates in the Garcia River watershed.

The results of restoration activities should not be confused with results of forest practices. For example, CCC and citizen volunteers have planted trees in many Garcia River watershed riparian locations (Craig Bell, habitat restorationist, Gualala, CA, personal communication). Additionally, the EPA's 319H restoration program grants have facilitated restoration of legacy condition problems in many locations within the basin, including some within the 12 surveyed tributaries.

We examined whether changes in stream temperature were related to densiometer or Solar Pathfinder readings. For this analysis, simple linear regression was used to determine the correlation between canopy and stream temperature. This included a comparison of the following two stream temperature indicators: (1) the maximum temperature reading observed over the summer, and (2) the maximum weekly average of daily maximums, with three canopy indicators: (A) percent closure, (B) percent density (both of these from densiometer readings), and (C) portion of solar radiation blocked from reaching the stream (from Solar Pathfinder readings). Of these comparisons, the regression between maximum stream temperature and percent canopy closure measured with the spherical densiometer gave the highest R-squared value ($r^2 = 0.60$, Figure 5).

The temperature report written by the subcontractor notes that stream # 6 had unusually warm temperatures, even in winter months, and postulated that there is a warm ground-water source near the mouth of the stream. Stream #3 was probably influenced oppositely by surfacing of cold ground water in the area of the temperature monitoring device. With streams 3 and 6 removed from the regression analysis as outliers, the correlation between maximum stream temperature and percent canopy closure was improved to an R-squared of 91% (Figure 6). One of the outlier basins removed was coastal and the other was inland, thereby balancing the effect of removing both outliers.

Certainly coastal fog has a cooling influence on water temperature for streams within that zone. We placed a limitation on the "coastal climate influence" roughly equal to eight miles measured perpendicularly from the coastline. There are several miles between the six western-most tributaries monitored, which we considered coastally influenced, and the other six more inland tributaries.

In comparing the difference between predicted and measured values for inland versus coastal streams, inland tributary measurements averaged 0.7 degrees Fahrenheit higher than predicted values while coastal stream measurements averaged 0.7 degrees cooler than predicted values. In other words, inland streams, for the same canopy coverage, averaged 1.4 degrees (F) warmer than coastal streams. The slope and intercept reported in the regression equations of Figures 5 and 6 define a predictive relationship between maximum summer stream temperatures and canopy closure measured by spherical densiometer in 1999. Solar radiation data collected with the Solar Pathfinder were not sufficiently analyzed by the surveyor nor MCRCD, but the data remain available for further analysis.

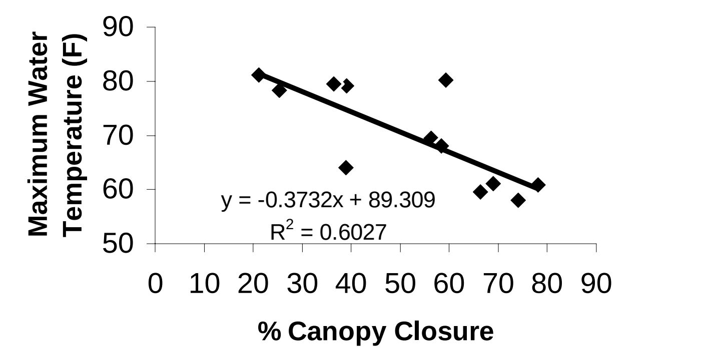


Figure 5. Maximum Water Temperature on Canopy Closure on Garcia River Streams 1999

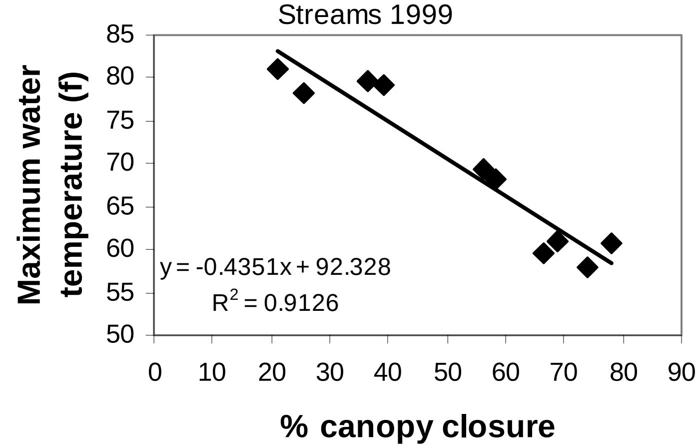


Figure 6. Maximum Water Temperature on Canopy Closure on 10/12 Garcia River Streams 1999

LARGE WOODY DEBRIS

There are a variety of ways to summarize the quantity of wood in the Garcia River tributaries for future comparison. One way is to simply determine the density of LWD pieces. For example, the total length of stream surveyed for LWD was about 4,340 meters, in which there were 1,620 pieces of LWD, for an average of one piece of wood every 2.7 meters. The mean diameter of the LWD can also be calculated. In this study the average diameter was 0.40 meters. A decrease in either the number of pieces or in the average diameter of the pieces of wood could be a reason for concern. Alternatively, an increase in the average diameter of LWD or an increase in the density of LWD pieces could provide evidence of improving watershed conditions. Trends would be less certain where one factor had increased while the other decreased, which can be overcome by using the volume of wood per length of stream, or volume of LWD per unit of area. In this survey, the mean volume of LWD in Garcia River tributaries was estimated at 385 cubic meters per kilometer or, alternatively, 279 cubic meters per hectare.

Variation in the amount of LWD between the studied tributaries was high. Two streams, in particular, had relatively low LWD volumes of 69 and 43 m^3/ha, while three streams had more than 500 m^3/ha. This extreme variation between streams indicates that all of the study streams must be surveyed in future years if any overall watershed comparison is made. There are a host of other comparisons that would be interesting and informative, such as the proportion of pieces meeting a specific diameter classification (e.g., greater than 0.5 meters), or the proportion of pieces, which were classified as fresh, sound or decaying.

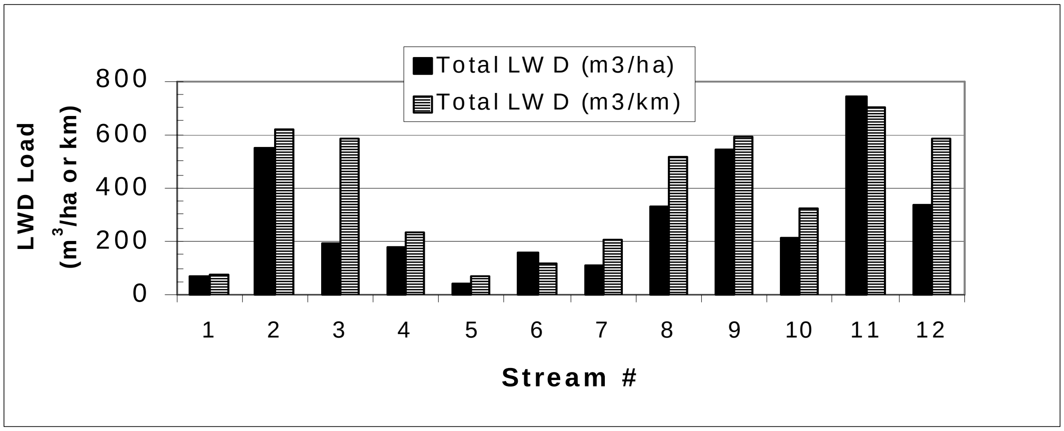
Table 8 shows that most LWD pieces were logs and over half of these were in accumulations or larger jams. Approximately 60% of the LWD was redwood and 25% was hardwood. Just 7% of the LWD was reported to be “fresh”, in the channel one year or less. Most LWD was sound and mildly weathered. The input mechanism could not be determined for 80% of the LWD. Nine percent was reported as input through bank erosion, and 4% each had input by windthrow, mass-wasting, and restoration mechanisms. Nearly one-third of the LWD was partially buried, either in the channel or on terraces, over 40% were pinned by boulders or other LWD, and just 10% appeared to be unconstrained by the channel. Another 10% was rooted into the bed or banks. Only 7% of the LWD had diameters of one meter or larger, which indicates they were legacy pieces. Approximately 25% were pool-related and half of these pools were thought to be formed by the LWD (O’Connor, 2000).

The units of measure most commonly used to compare LWD abundance among streams in the coastal redwood region are volume of LWD per unit area and volume of LWD per length of stream. Figure 7 reports this information by tributary (O'Connor, 2000).

Table 8. Summary of LWD attributes expressed as a proportion of the total number of LWD pieces surveyed in all four plots comprising each survey reach (O'Connor, 2000).

Stream #	1	2	3	4	5	6	7	8	9	10	11	12	Mean
LWD Type													
Log (no rootwad)	0.71	0.90	0.83	0.74	0.89	0.68	0.71	0.51	0.87	0.68	0.83	0.59	0.75
Rootwad (no log)	0.02	0.02	0.01	0.20	0.04	0.00	0.02	0.33	0.02	0.04	0.04	0.00	0.06
Log with rootwad	0.28	0.08	0.16	0.07	0.06	0.32	0.27	0.16	0.11	0.28	0.13	0.41	0.19
Enhancement	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.02
Jam Status													
Single Piece	0.57	0.85	0.10	0.57	0.60	0.51	0.48	0.62	0.36	0.22	0.24	0.37	0.46
Accumulation	0.43	0.06	0.33	0.13	0.40	0.49	0.52	0.38	0.37	0.45	0.47	0.39	0.37
Jam (> 10 pieces)	0.00	0.09	0.57	0.30	0.00	0.00	0.00	0.00	0.27	0.33	0.29	0.25	0.18
Species Class													
Redwood	0.24	0.93	0.71	0.63	0.38	0.18	0.53	0.89	0.69	0.82	0.74	0.56	0.61
Other conifer	0.22	0.01	0.04	0.35	0.36	0.46	0.05	0.04	0.13	0.09	0.09	0.01	0.15
Hardwood	0.48	0.05	0.24	0.02	0.23	0.37	0.42	0.07	0.17	0.09	0.13	0.43	0.23
Unknown	0.05	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.04	0.00	0.01
Relative Age Class													
Fresh	0.07	0.01	0.03	0.39	0.00	0.12	0.08	0.07	0.04	0.01	0.04	0.01	0.07
Sound, weathered	0.69	0.63	0.89	0.54	0.64	0.46	0.44	0.87	0.75	0.90	0.68	0.84	0.69
Significant decay	0.24	0.36	0.07	0.09	0.36	0.42	0.48	0.05	0.21	0.09	0.29	0.15	0.23
Input Mechanism													
Undercutting	0.26	0.02	0.04	0.17	0.00	0.00	0.08	0.16	0.03	0.05	0.03	0.23	0.09
Windthrow	0.00	0.01	0.00	0.35	0.04	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.04
Mass Wasting	0.00	0.00	0.00	0.00	0.11	0.18	0.00	0.05	0.00	0.15	0.00	0.01	0.04
Management	0.00	0.00	0.02	0.02	0.02	0.00	0.00	0.22	0.05	0.01	0.09	0.00	0.04
Unknown	0.74	0.97	0.94	0.46	0.83	0.81	0.92	0.56	0.90	0.80	0.87	0.75	0.80
Stability													
Root system in bank	0.21	0.04	0.06	0.07	0.04	0.23	0.17	0.29	0.05	0.06	0.03	0.14	0.12
Pinned by other LWD/boulders	0.36	0.31	0.80	0.30	0.38	0.37	0.27	0.35	0.56	0.54	0.24	0.54	0.42
Buried in channel or terrace	0.33	0.55	0.08	0.46	0.43	0.25	0.39	0.29	0.29	0.30	0.21	0.26	0.32
No evidence of stability	0.10	0.09	0.06	0.17	0.15	0.16	0.17	0.07	0.10	0.09	0.07	0.03	0.11
Legacy LWD													
Diameter >= 0.5 m	0.10	0.19	0.11	0.30	0.30	0.19	0.15	0.36	0.22	0.25	0.29	0.22	0.22
Diameter >= 1.0 m	0.02	0.05	0.03	0.15	0.04	0.02	0.03	0.25	0.02	0.06	0.08	0.05	0.07
Pool Association													
Assoc. with Pool < 3 ft deep	0.05	0.00	0.41	0.17	0.04	0.04	0.11	0.00	0.11	0.15	0.19	0.01	0.11
Assoc. with Pool > 3 ft deep	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.15	0.01	0.02	0.04	0.00	0.02
Forming Pool < 3 ft deep	0.03	0.04	0.06	0.11	0.02	0.09	0.18	0.00	0.26	0.14	0.21	0.00	0.09
Forming Pool > 3 ft deep	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.24	0.04	0.01	0.07	0.00	0.03
No Pool Association	0.91	0.96	0.52	0.63	0.94	0.88	0.71	0.62	0.58	0.46	0.48	0.99	0.72

Figure 7. Large Woody Debris Abundance as Volume per Units Area and Length (O'Connor Environmental, 2000)



Data collected from North Coast streams classified as "old growth" and "second growth" report LWD per kilometer of stream. The median value for second growth streams is approximately 220 cubic meters per kilometer, while from old growth streams the value is about 1200 cubic meters per kilometer. Figure 7 indicates that LWD in Garcia tributaries is far less abundant than that found in old growth watersheds. For the Garcia as a whole, LWD loading was estimated to be 385 cubic meters per kilometer compared to an average of 220 cubic meters per kilometer in other second growth watersheds. In comparison to average abundance of LWD in second growth watersheds, the majority of the Garcia River tributaries have more LWD.

Recruitment rate is the natural process by which LWD is incorporated into streams. Recruitment rate of LWD into the channels from the watersheds was estimated to be 3.7 cubic meters per hectare per year, compared to 5.3 cubic meters per hectare per year documented at North Fork Caspar Creek (O'Connor, 2000). The larger the diameter of wood recruited, the more likely it will remain against the forces of downstream transport and decay. Diameters of freshly recruited LWD were less than 0.5 meters in mixed hardwood and softwood tree types (Table 9). The small diameter of the reported freshly recruited wood will not replace the longlasting, geomorphically significant pieces seen in streams forming deep pools and routing spawning gravels. Large woody debris is entering these systems at a relatively rapid rate, although it is comprised of multi-species and is of smaller dimension than the longer lasting old-growth redwood seen in persistent pools in the South Fork of the Garcia, Mill Creek, and other tributaries (O'Connor, 2000). An increase in recruitment rate and an increase in diameter of LWD in the channel would generally be indicative of channel recovery. But input mechanisms yielding intensive recruitment of LWD are often viewed as negatives, as in the case of input by landslide or streambank erosion due to the volume of fine sediments associated.

Table 9. Size, volume, species class and input mechanism for "fresh" LWD (O'Connor, 2000).

Stream#	1	2	3	4	5	6	7	8	9	10	11	12	Mean
Average Diameter (m)	0.13	0.16	0.24	0.16	0	0.28	0.26	0.22	0.41	0.20	0.24	0.26	0.23
Total Volume (m^3)	0.26	0.13	5.55	1.12	0	4.57	2.26	1.44	18.6	0.45	2.04	0.61	3.08
Fresh LWD Species (proportion of total LWD)													
Redwood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.01	0.01	0.01	0.01
Other conifer	0.00	0.00	0.01	0.35	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.03
Hardwood	0.07	0.01	0.01	0.02	0.00	0.12	0.08	0.04	0.01	0.01	0.03	0.00	0.03
Unknown	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fresh LWD Input Mechanism (proportion of total LWD)													
Undercutting	0.05	0.01	0.01	0.00	0.00	0.02	0.02	0.04	0.01	0.00	0.02	0.01	0.01
Windthrow	0.00	0.00	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Mass Wasting	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.04	0.00	0.01	0.00	0.00	0.01
Management	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00
Unknown	0.02	0.00	0.01	0.02	0.00	0.04	0.06	0.00	0.01	0.01	0.01	0.00	0.01

SPAWNING GRAVEL COMPOSITION

Particle Size Distribution of Subsurface Bulk Sampling

Trends in the proportion of fines in spawning gravels can be used as an indicator of overall FPR effectiveness. TMDLs have targeted reducing the proportion of the bed occupied by fines smaller than 0.85 and 6.5 mm (U.S. EPA, 1998). In the Garcia, the subcontractor sieved streambed gravels into particle sizes smaller than 128, 64, 32, 16, 8, 5.6, 4.0, 2.8, 2.0, 1.4, 1.0, 0.85, 0.5, 0.25, and 0.125 mm. They focused on the cumulative percent finer than 0.85 and 8.0 mm to characterize the baseline condition, to predict survival to emergence of fry from redds built in these gravels, and suggest their use in detecting changes in gravel composition over time. Unfortunately, only the 0.85 mm and smaller size fraction is directly comparable to the TMDL targets. This size class is also quite useful in that it allows survival to emergence of salmonid eggs to be predicted.

Table 10. Summary of Gravel Particle Size Distribution for 10 Garcia River Tributaries, 1999 (McBain and Trush, 2000).

Cumulative percent finer than 0.85 mm for each tributary bulk sample

	BULK SAMPLE												95% Conf Int		
Tributary Code	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***ý***	***s***	***S.E.***	***Lower***	***Upper***	***CV (s/ý)***
Tributary-1	8.8%		8.5%	9.6%	9.8%	11.9%	12.2%	7.4%		9.7%	1.8%	0.7%	8.1%	11.4%	18.1%
Tributary-3	9.4%	11.1%	6.9%	13.7%	8.2%	9.7%				9.8%	2.4%	1.0%	7.4%	12.3%	24.1%
Tributary-4	12.4%	8.6%	9.7%	6.3%			7.7%	8.0%		8.8%	2.1%	0.9%	6.5%	11.0%	24.2%
Tributary-5	5.3%	8.3%	10.6%	10.2%	11.8%	7.7%	4.8%	8.7%		8.4%	2.5%	0.9%	6.4%	10.5%	29.4%
Tributary-6						3.7%	5.9%	5.0%		4.9%	1.1%	0.7%	2.1%	7.7%	23.2%
Tributary-7	12.1%	8.3%	19.0%	9.2%	12.0%	8.4%	12.0%	7.5%	8.7%	10.8%	3.6%	1.2%	8.0%	13.5%	33.2%
Tributary-8	5.5%	6.6%	7.6%	5.8%		5.2%	5.3%	5.7%		6.0%	0.9%	0.3%	5.1%	6.8%	14.7%
Tributary-9	9.4%	9.9%	9.6%	9.1%	8.0%	14.0%	11.8%	9.0%		10.1%	1.9%	0.7%	8.5%	11.7%	19.0%
Tributary-10			4.6%	5.3%		6.0%	11.1%	8.5%		7.1%	2.7%	1.2%	3.8%	10.5%	38.0%
Tributary-11	11.3%		5.3%	6.7%	5.5%	5.5%	3.5%	2.0%		5.7%	2.9%	1.1%	3.0%	8.4%	51.7%

Cumulative percent finer than 8.0 mm for each tributary bulk sample

	BULK SAMPLE												95% Conf Int		
Tributary Code	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***ý***	***s***	***S.E.***	***Lower***	***Upper***	***CV (s/ý)***
Tributary-1	40.4%		30.4%	25.0%	41.1%	24.5%	23.4%	32.2%		31.0%	7.4%	2.8%	24.2%	37.8%	23.9%
Tributary-3	34.9%	44.9%	29.4%	25.0%	35.0%	25.9%				32.5%	7.4%	3.0%	24.7%	40.3%	22.8%
Tributary-4	42.7%	29.3%	41.3%	43.9%	20.9%	26.3%	38.2%	38.9%		35.2%	8.5%	3.0%	27.4%	42.9%	24.3%
Tributary-5	42.7%	36.4%	41.2%	49.3%	35.3%	39.2%	28.5%	30.2%		37.9%	6.8%	2.4%	32.2%	43.5%	17.9%
Tributary-6						39.9%	44.3%	31.2%		38.5%	6.7%	3.8%	21.9%	55.0%	17.3%
Tributary-7	41.0%	36.5%	50.9%	41.9%	31.3%	34.2%	44.9%	39.6%	36.5%	39.6%	5.9%	2.0%	35.1%	44.2%	14.9%
Tributary-8	36.0%	55.8%	53.8%	38.6%	86.2%	33.8%	67.3%	29.6%		50.1%	19.5%	6.9%	33.3%	67.0%	38.9%
Tributary-9	45.3%	42.3%	18.4%	32.3%	35.6%	24.6%	21.4%	18.8%		29.8%	10.6%	3.7%	21.0%	38.7%	35.5%
Tributary-10			31.9%	25.6%		34.3%	45.7%	41.6%		35.8%	8.0%	3.6%	25.9%	45.7%	22.2%
Tributary-11	38.3%		33.5%	39.3%	31.1%	19.1%	42.0%	43.6%		35.3%	8.4%	3.2%	27.5%	43.0%	23.8%

Gravel particle size composition for fractions finer than 0.85 mm and 8.0 mm are shown for the 10 tributaries evaluated in Table 10. Results indicate that 4.9-10.8% of spawning gravels were composed of fines smaller than 0.85 mm in diameter (the mean for all tributaries was 8.2%, with 95% confidence interval ranging from 5.9% to 10.4%); and 29.8-50.1% of spawning gravels were composed of gravel sizes smaller than 8.0 mm (dry sieve data).

Variability in the samples as characterized by the 95% confidence intervals shows that some tributaries had consistent gravel size distributions while others were wider ranging. The composition of spawning gravels at individual sites showed considerable variability indicating that gravel sizes are different even across the same riffle.

Recovery of channel conditions could be demonstrated if mean proportions of fines in gravels attenuate with time. Increasing variability around the mean increases the range in confidence interval such that in highly variable tributaries, a very strong recovery must be in place before the reduction in gravel sizes is significant enough to cause the mean to fall outside the confidence interval. That is, the significance of any trend in cumulative percent finer from this size class should be interpreted in relation to the variability among samples from the same tributary. The degree of variability among gravels from the same tributary may be so high as to preclude the ability to determine any trend in the improvement of gravel composition for beneficial uses. Detectability could be improved by increasing sample size.

The difference in results obtained from sieving a gravel sample into its size-classes while wet or after drying is on the order of 10%. For this study, gravel was air-dried on tarps after removal from the streambed. No moisture was obviously present on any particles as sieving began. Gravel composition results previously reported in other studies are frequently based on gravel that is sieved immediately after removal from the bed and which has an appreciable mass of water adhering to particles. The mass of the water is incorporated into the mass reported by weight in each size class and, as a result, direct comparison from one data set to another is reasonable only if both data sets were sieved under equivalent moisture conditions. Alternatively, Shirazi and Seim (1979) quantified the water gained by wet-sieved gravel so that wet sieved gravel volumes can be multiplied by a correction factor (different for low, medium, and high density rock) to estimate the volume of the same gravel dry. Garcia gravel was quantified by weight, not volume, but for gross comparisons Table 11 below, reproduced from Shirazi and Seim (1979), may suffice. These correction factors are offered for a moderately dense rock type. For a more precise comparison, correction factors can be established directly by measuring the mass of wet and then dry particles for each size class in the field. It should be noted that dry sieving avoids the errors and bias that is added by the presence of water, so the less certain wet values should be converted to dry values, rather than converting from dry to wet values.

Table 11. Water Gained in a Wet Gravel Sieving Process (Shirazi and Seim, 1979)

Sieve Sizes (mm)	Gram Water Gained Per Gram Dry Gravel	Correction Factor Applied To Wet-Sieved Gravel
256	NA	NA
128	NA	NA
64	.02	.96
32	.02	.96
16	.03	.93
8	.04	.9
4	.06	.86
2.8	.08	.82
1.4	.11	.78
1	.12	.76
.85	.13	.74
.5	.18	.69
.25	.25	.61
.125	.35	.52

Biological Link

Elevated proportions of fines in spawning gravel have been shown to impair permeability of gravel, which in turn, decreases dissolved oxygen levels, increases carbon dioxide levels, and traps fry in their nest. An alternative approach to characterizing the biological integrity of spawning gravel is to measure directly the permeability they provide. The permeability measurement is faster, less energy intensive, and has potential for replacing the bulk sample measurements used widely in the

Pacific Northwest and Northern California. Therefore we measured both gravel composition and permeability in the same places in an attempt to correlate the two and begin testing whether or not permeability can substitute for bulk samples and also correlate to survival-to-emergence from the redd. Table 12 interprets gravel composition and quality in terms of the proportion of fry able to incubate and successfully emerge from a gravel redd composed of measured gravel composition and measured permeability (data for coho salmon were not available).

The EPA-SWRCB numeric target for fines <0.85 mm is 14%, assumed to be determined with the wet sieve technique. Assuming that the difference in results obtained from sieving a gravel sample into its size-classes while wet or after drying is on the order of 10% and the mean reported for the Garcia tributaries examined in the GRIMP is 8.2%, then as a whole, the basin is over the target value. Additionally, based on the reduction in survival caused by inhibiting emergence of chinook salmon reported by Tappel and Bjornn (1983), all tributaries surveyed in the Garcia would presently impair chinook survival (Table 12). Although the Garcia does not support chinook, this concept could be reasonably extended to coho or steelhead (McBain and Trush, 2000).

GRAVEL PERMEABILITY

The challenge of extrapolating the biological significance of fine sediment is even greater than detecting trends in gravel composition. For this reason, the alternative approach of gravel permeability was conceived as a more direct reflection of pore space clogging. A limited test of permeability's utility was conducted as part of the GRIMP. Permeability measurements in themselves reduced variability and improved the detection of differences compared to gravel composition as percent fines. This was partially due to the ease of making permeability measurements, which led to substantially increasing sample size at a minimal cost. While a predictive correlation between percent fines and permeability was obtained in the Klamath basin, permeability was not as good of a predictor of fines in Garcia River tributaries. The relationship between permeability and the bulk samples (using both 32 mm and 0.5 mm size fractions combined) explained 45% of the variability ($r^2 = 0.45$), with the remainder of the variability hypothesized to be due to the packing of substrate particles.

Mean permeability (cm/hour) was obtained for each tributary by averaging 5-10 replicates per site and then averaging each site for one representative permeability value per tributary (Table 13). Each site's measurement of inflow rate (ml/s) was corrected for water temperature using a viscosity correction factor and then converted to cm/hour. Detection of a change in mean permeability would require the future mean to fall outside confidence bands. Representative basin permeabilities from 1999 ranged from 1708-5002 cm/hour and 95% confidence bands generally ranged from 1000 to 2500 cm/hour around each tributary's mean (Table 13). Both gravel composition and permeability are highly variable between and among tributaries. This makes discerning change problematic because management related differences are obscured by the large range of natural variability.

Permeability can also predict survival to emergence from the redd for coho or chinook (after Tagart (1976) and McCuddin (1977), respectively). With the exception of tributary #6, all predictions of survival to emergence from permeability indicated more fry would emerge than predictions based on gravel composition (Table 12).

Table 12. Percent survival of Salmonid Eggs to Emergence from the Redd based on Tappel and Bjornn (1983) and Tagart (1976) and McCuddin (1977) – from McBain and Trush (2000).

	PERCENT FINE SEDIMENT			***PERMEABILITY***		
	estimated chinook survival (%)			***estimated chinook survival (%)***		
	mean	***lower 95% CI***	***Upper 95% CI***	***mean***	***lower 95% CI***	***Upper 95% CI***
Tributary-1	0	0	35	29	18	35
Tributary-3	0	0	41	33	27	37
Tributary-4	13	0	72	43	31	49
Tributary-5	0	0	39	28	18	33
Tributary-6	34	0	64	29	23	33
Tributary-7	0	0	21	29	20	34
Tributary-8	4	0	53	40	25	47
Tributary-9	20	0	63	37	27	43
Tributary-10	15	0	58	43	36	47
Tributary-11	0	0	41	31	20	37

Table 13. Mean Permeability Measured in Spawning Riffle/Pool Tails in Garcia River Tributaries (McBain and Trush, 2000)

Mean Permeability for each pool-tail site (cm/hr)

	POOL-TAIL SITE												95% Conf Int		
Tributary Code	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***ý (trib)***	***s***	***S.E.***	***Lower***	***Upper***	***CV (s/ý)***
Tributary-1	2,185	2,941	1,669	2,214	513	455	1,090	4,001		1,883	1,219	431	864	2,902	0.65
Tributary-3	2,855	3,113	2,414	1,021	2,632	3,057				2,515	778	317	1,699	3,332	0.31
Tributary-4	3,835	3,883	3,785	8,952	8,748		4,050	879		4,876	2,930	1,108	2,166	7,586	0.60
Tributary-5	3,876	1,304	1,231	2,349	1,922	767	1,183	1,031		1,708	1,012	358	862	2,554	0.59
Tributary-6			2,381	761	1,782	2,011	1,974	2,575		1,914	635	259	1,248	2,580	0.33
Tributary-7	1,872	3,743	1,240	598	1,638		1,800	3,014	983	1,861	1,047	370	986	2,737	0.56
Tributary-8	2,826	4,884	2,859	2,006		2,710		8,496		3,964	2,421	988	1,422	6,505	0.61
Tributary-9	734	2,660	2,676	1,034	4,325		2,239	1,438		2,158	1,227	464	1,023	3,293	0.57
Tributary-10	7,268	4,756	7,955	6,157	982	4,300	4,784	3,817		5,002	2,183	772	3,177	6,828	0.44
Tributary-11	1,608		1,313	1,651	4,754	3,238	5,006	5,614		3,312	1,822	688	1,627	4,997	0.55

Mean Permeability for each bulk sample site (cm/hr)

	POOL-TAIL SITE												95% Conf Int		
Tributary Code	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***ý (trib)***	***s***	***S.E.***	***Lower***	***Upper***	***CV (s/ý)***
Tributary-1	1,830	359	3,642	2,849	734	303	732	5,152		1,950	1,778	629	463	3,437	0.91
Tributary-3	4,500		1,699	265	1,832	2,954				2,250	1,579	706	434	4,066	0.70
Tributary-4	4,253	1,622	2,208	12,575	9,023		1,383	812		4,554	4,520	1,708	374	8,734	0.99
Tributary-5	4,967	1,396	559	1,246	571	866	1,714	761		1,510	1,456	515	293	2,727	0.96
Tributary-6			3,027	671	873	2,500	2,246	2,501		1,970	964	394	958	2,981	0.49
Tributary-7	552	4,179	337	792	1,092		2,018	3,637	963	1,696	1,460	516	476	2,917	0.86
Tributary-8	2,043	2,376	1,672	1,161		5,611		2,229		2,515	1,578	644	859	4,171	0.63
Tributary-9	1,503	2,551	1,830	1,797	2,448		1,468	2,048		1,949	426	161	1,555	2,343	0.22
Tributary-10	5,616	7,917	11,075	2,050	779	2,497	2,161	1,922		4,252	3,618	1,279	1,227	7,277	0.85
Tributary-11	1,224		2,781	3,652	4,213	8,122	5,388	8,722		4,872	2,747	1,038	2,331	7,412	0.56

TURBIDITY

Attributes

Turbidity is a promising monitoring parameter that is capable of documenting upslope sediment delivery in the short term (Beschta, 1981; Furniss, 1999). Turbidity measurements must be reported together with discharge at the time of sampling because turbidity naturally rises during storms when stream discharge rises. Reductions in optical clarity (turbidity) caused by suspended sediments result from both eroded particles transported from upslope and re-suspension of bedload sediments. Turbidity levels caused by upslope disturbances that exceed background levels by 20% are in violation of the North Coast Basin Plan developed by NCRWQCB. Additionally, turbidity and suspended sediment concentration values for lethal and sublethal doses have been established quantitatively for several species of salmonids (Noggle, 1978; Newcombe and MacDonald, 1991). The downside of turbidity monitoring has been the expense of setting up monitoring stations that can be sampled during high peak flows. Adequate sampling intensities have usually meant remote, automatic sampling equipment utilizing a randomized sampling design programmed to trigger the sampler (Lewis and Eads, 1998). Alternatively, grab samples can be taken by humans if transportation to the sites is achievable on short notice in extreme weather conditions.

Limitations

Due to prohibitively high estimated costs and remote study reaches, turbidity was not selected as an official measurement parameter for the Garcia River IMP. Gravel monitoring, LWD, cross-sections, thalweg profiles, and water temperature appeared more cost-effective than turbidity when compared to the large funding requirements of programs like the Caspar Creek Watershed Study's turbidity/suspended sediment concentration monitoring system (Henry, 1998; Lewis, 1998). Technical opinion by USFS Pacific Southwest Research Station (PSW) Redwood Sciences Laboratory research staff indicated that this level of investment would be required to obtain unbiased turbidity results. Lower-technology grab sample approaches failed to satisfy statistical and hydrological constraints necessary in formulating quantitative relationships needed to predict turbidity from stream discharge. The USFS PSW's list of required turbidity sampling components includes automatic pumping samplers run by battery power and statistical sampling programs, floating boom intakes, continuously recording turbidimeters, and other costly components (for further details, see the PSW's website at www.rsl.psw.fs.fed.us).

Recently, however, a successful low-technology grab-sample program in Freshwater Creek (Humboldt County) mentored by Dr. Leslie Reid of the USFS-PSW enabled a low-cost application to succeed in meeting statistical and hydrological requirements, indicating turbidity can be affordable, and user friendly. This program is in place and working, and is contracted to Salmon Forever, a local grass-roots salmon recovery organization.

Results

An attempt at measuring turbidity was undertaken in a combined effort by MCRCD staff, the spawning surveyors, and the cross-section surveyor in Garcia River study reaches. As a result of a partial financial committment, efforts were not led by a single entity, but rather tasks were shared among contractors whose primary tasks were not turbidity monitoring. The data reported are sparse and were not nearly as frequently measured as would have occurred under a committed turbidity program. Turbidity rating curves were developed for survey streams 1,4,5,6,8,9,11 and the mainstem (see Figures 8, 9, and 10). The number of samples utilized in these relationships was very low, ranging from 3 to 7 on each tributary, which is generally considered an insufficient number of samples from which to make a regression analysis. While the number of data points is low, these data can be built upon in further studies, so long as discharge (or stage height) and turbidity values are collected at the same time and reported together such that discharge levels can be related to the turbidity sample. Correlation coefficients ranged from 2-93%, suggesting a poor predictive relationship due to the extremely low number of samples measured in each creek (see Figures 8, 9, and 10).

Turbidity monitoring provides a signal of upslope and instream sediment transport. It has utility in evaluating water quality with the NCRWQCB's 20% over background standard. The link between turbidity and biology to lethal and sublethal doses is quantified in the literature for juvenile coho, steelhead, and chinook in laboratory studies. Elevated turbidity at sublethal levels for long periods of exposure abrades gills and lessens the ability to feed over winter, thus reducing a fish's chance to grow to critical smolt length enabling successful ocean competition and for returning as an adult to spawn (Dr. William Trush, Humboldt State University, Arcata, CA, personal communication). Therefore, turbidity and supporting variables are recommended as parameters for measuring whether FPRs are conserving anadromous fisheries habitat. Future monitoring activities should place a high priority on the use of turbidity and discharge measurements.

Ideally, baseline conditions with highly significant predictive correlation coefficients would have been produced as part of the GRIMP. The baseline relationship could then be compared to subsequent monitoring results to determine whether the quantity of suspended sediments are increasing or decreasing with additional management activities. Recovery would be indicated by a consistent trend of decreasing suspended sediments/turbidity with discharge. The baseline turbidity measurements made in 1998-99 were limited by low sampling frequency and by simplified measurements of cross-sectional area and velocity. Improving accuracy in these measurements would help to refine predictive relationships between turbidity and discharge.

Figure 8. Garcia River Turbidity Rating Curves, For Study Reaches 1,4,5,and 6

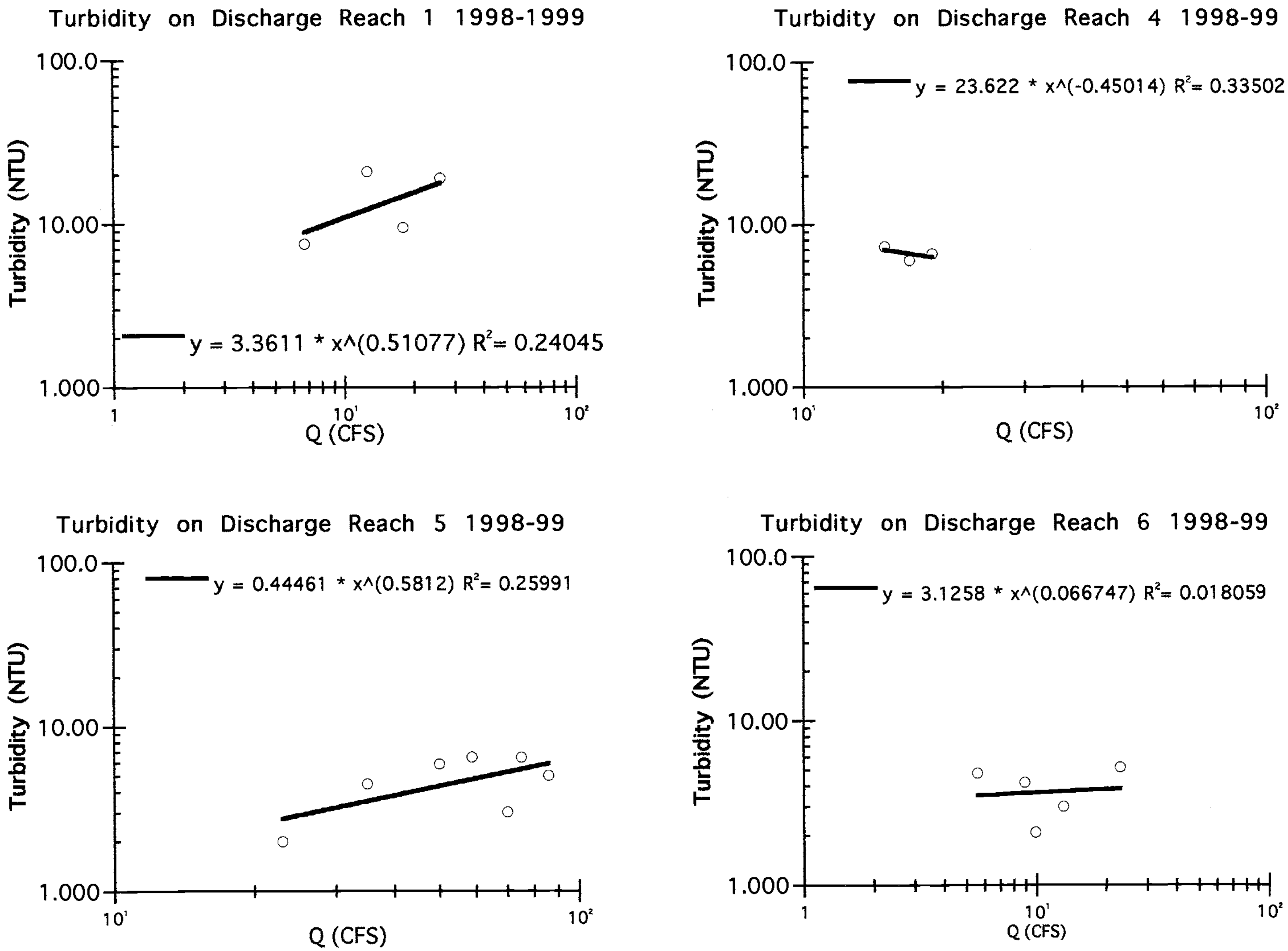


Figure 9. Garcia River Turbidity Rating Curves, For Study Reaches 7,8,9, and 11

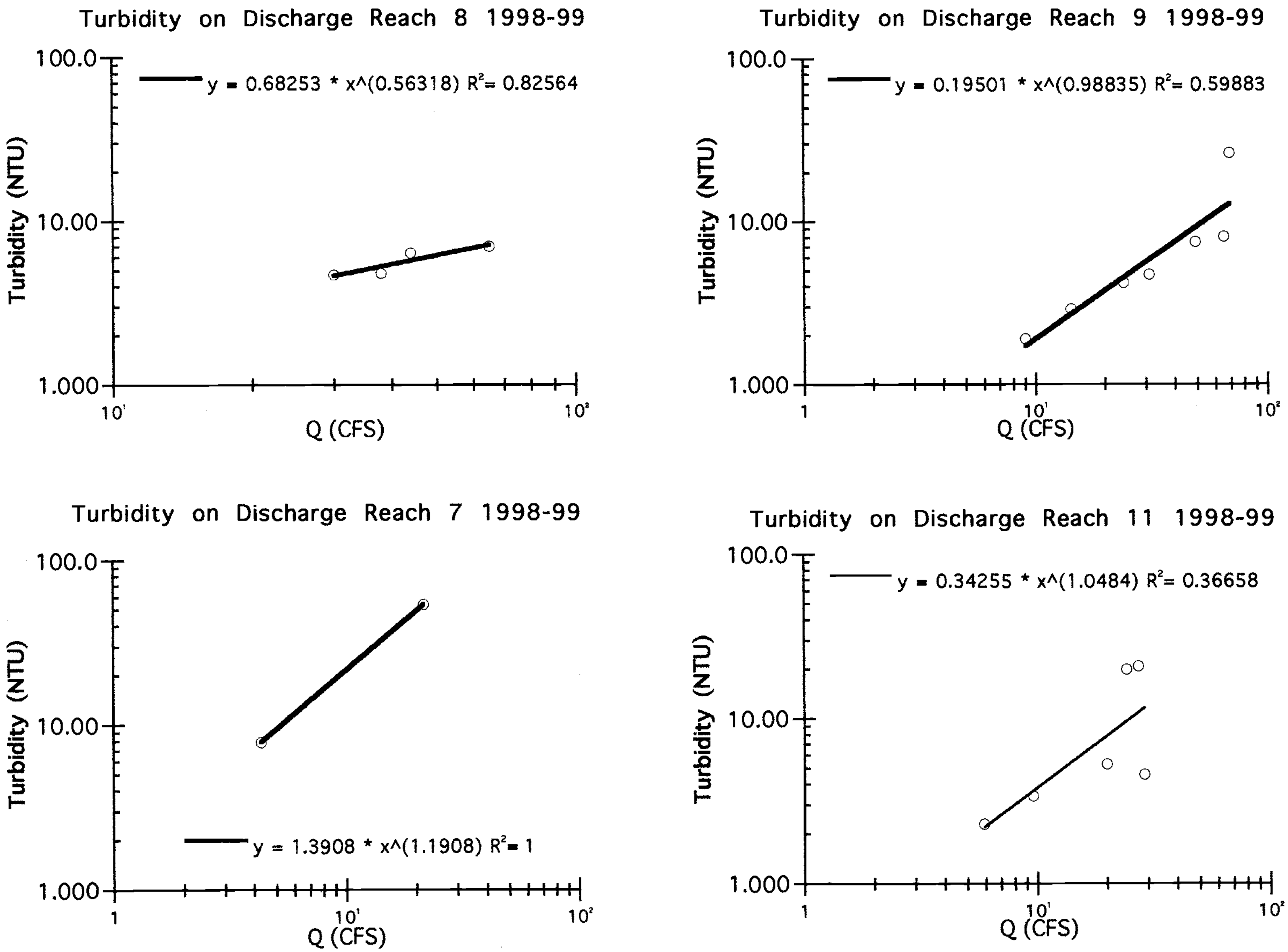
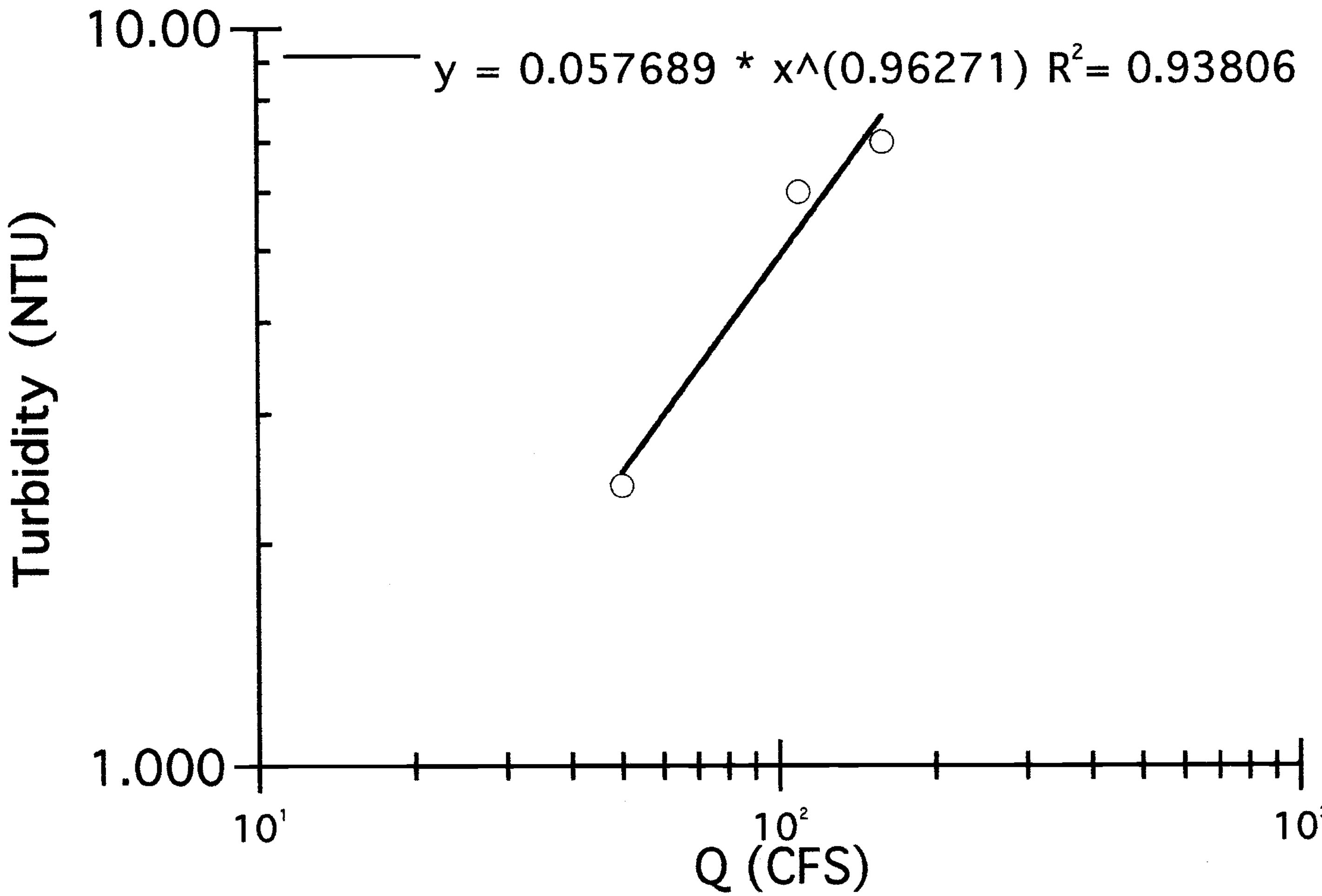


Figure 10. Mainstem Garcia River Turbidity on Discharge 1998-99



SEDIMENT TRANSPORT CORRIDORS

Of 138 sediment transport corridors (STCs) identified in Garcia River surveyed streams during the winter 1998-99, there were 38 gullies, 26 landslides, 26 bank failures, one in-channel headcut, and 47 natural tributaries (Barber, 1999). Natural tributaries can be considered STCs since they process water, sediment, and sometimes fish. Management related STCs include landslides and gullies if a trigger-source can be identified. Background rates of landsliding are beneficial for watershed condition because they provide an input of LWD and coarse sediment needed for spawning habitats. Of more concern, are human-induced, controllable STCs, such as road related landslides and road diversion gullies, which were found to be abundant on the landscape.

Management Related STCs

For evaluating FPR effectiveness it is appropriate to focus on STCs caused by timber management-related activities. Identifying the source of these STCs is crucial. When STCs were traced to a location where a source could be identified, watercourse crossings, ditch relief culverts, and inadequate water bars were found to be the most common cause. Therefore, it is logical to further focus on these road and landing-related STCs (Table 14). The timberlands where these features were documented are owned and managed by a variety of landowners, and are used to access industrial timberlands, small private timberlands, hunting lands, and ranchlands. Many of the roads were constructed prior to the implementation of the Z'Berg-Nejedly Forest Practice Act in 1974. Some fraction of road-related STCs identified in 1998-99 resulted from improper implementation of more recent road-related FPRs. Timber harvesting activities were not the only cause of management related STCs. For example, some streambank failures appeared to be caused by grazing impacts.

Table 14. Road and Landing Related Sediment Transport Corridors in Garcia Tributaries (Barber, 1999).

Stream #	Gullies	Landslides	Streambank Failure
1	1	2	2
2	0	1	1
3	0	0	0
4	1	0	0
5	9	2	1
6	3	2	0
7	0	0	0
8	7	1	1
9	3	1	1
10	11	2	0
11	1	1	0
12	2	0	0
	38	12	6

STCs identified as definitively having management related sources were all caused by changes in redistributing water by roads. All road-related STCs were unnatural landscape voids eroded by moderate and chronic gullying or severe, episodic landsliding. STCs related to other management activities were not discernable to the surveyor. Expected downstream effects include an increase in the volume of fine soil particles and colluvium (non-rounded hillslope rock particles) contributed to streams over and above background levels. These are sediments with no appreciable benefits for downstream habitat (e.g., spawnable gravel). Road related STCs totaled 34 of 38 gullies, 11 of 26 landslides, 5 of 26 bank failures, and 0 of 1 in-channel headcut, for the basin as a whole. Of the 91 non-tributary STCs encountered, 55% were road-related. Seventy percent of the landslides and gullies documented were road-related.

No “Humboldt Crossings” (i.e., stream crossings built by filling channels with logs and soil, thereby risking failure that can move large volumes of sediment downstream) were noted.