DISCHARGE SUMMARY SHEET

LOCATION: Grey Creek Above South Fork Wages Creek

WATER YEAR: 2004 - 2005

Measurement Number	Water Year Msmt #	Date	Made By	Width (feet)	Mean Depth (feet)	Area (ft^2)	Mean Velocity (ft/sec)	Gage Height (feet)	Discharge (cfs)	Rating 1.2		Method	No. of Msmt Sections	Begin Time (hours)	End Time (hours)	Msmt Rating	GZF (feet)	Notes
										Shift Adj.	Percent Diff.							
1	2004-01	2/3/2004	T. Grey	3.9	0.41	1.60	1.93	2.67	3.09		-5	wading	21	11:49	12:12	Poor		
2	2004-02	2/4/2004	T. Grey	4.0	0.38	1.51	1.75	2.63	2.64		-1	wading	21	16:07	16:30	Poor		
3	2004-03	2/17/2004	T. Grey	4.2	0.51	2.15	3.68	2.90	7.90		0	wading	21	16:04	16:31	Poor		
4	2004-04	2/18/2004	T. Grey	4.8	0.57	2.73	2.05	2.79	5.58		3	wading	24	14:35	15:03	Fair		
5	2005-01	2/22/2005	T. Bolton	2.3	0.23	0.52	1.43	2.45	0.76		-4	wading	9	16:45	16:54	Poor		
6	2005-02	3/28/2005	K. Faucher	3.0	0.32	0.97	2.02	2.56	1.95		8	wading	10	14:15	14:23	Poor		
7	2005-03	5/18/2005	K. Faucher	6.5	0.59	3.83	1.33	2.78	5.11		-2	wading	18	19:57	20:33	Fair	2.28	

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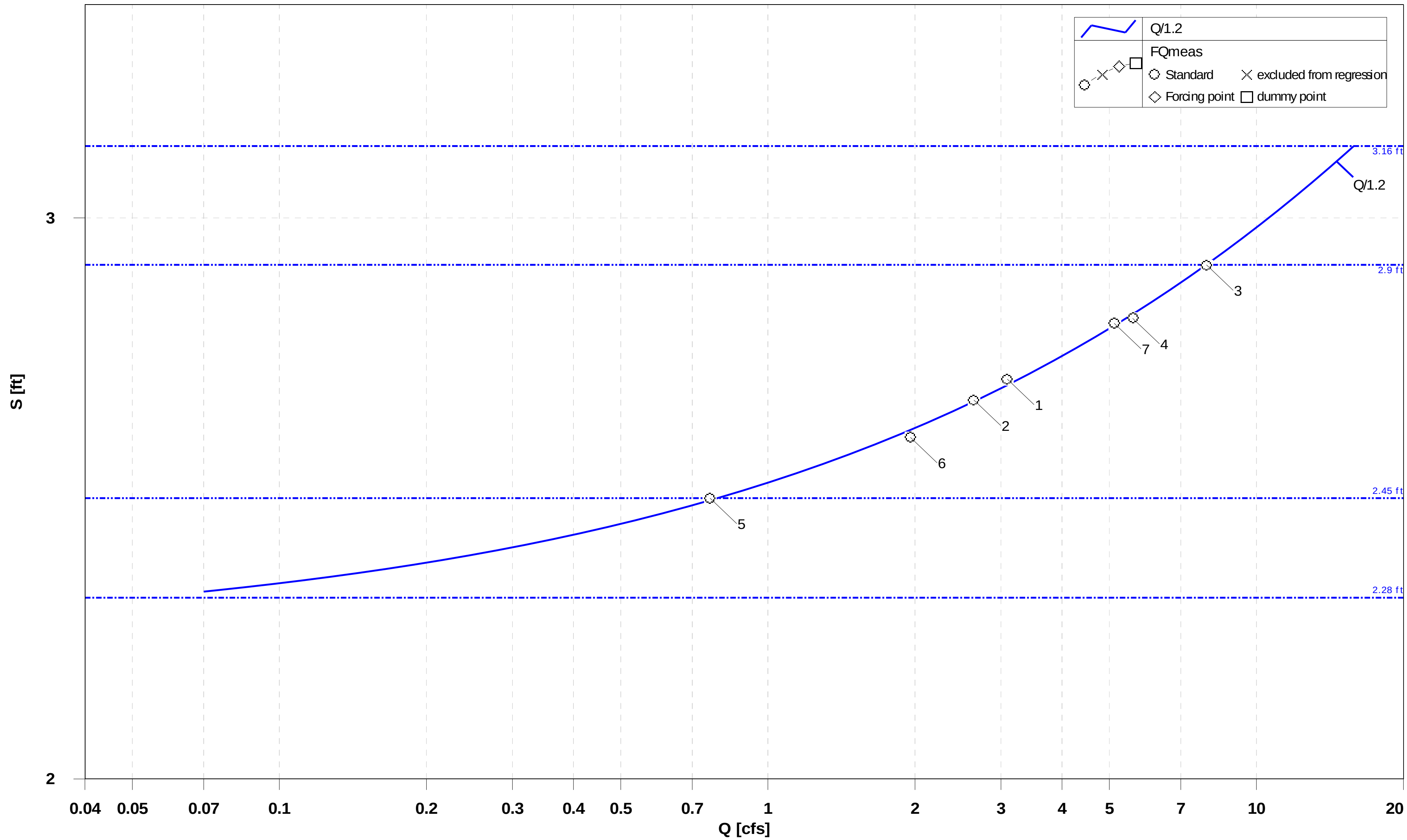
WY 04-05
APPENDIX

C-2

GREY CREEK ABOVE SOUTH FORK WAGES CREEK
Discharge Rating Curve 1.2



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APPENDIX

C-3

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GREY CREEK ABOVE SOUTH FORK WAGES CREEK

RATING TABLE NO.1.2 -- Begin Date 02/03/04

GH	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	1st Diff	2nd Diff
1.6	---	---	---	---	---	---	---	---	---	---	---	---
1.7	---	---	---	---	---	---	---	---	---	---	---	---
1.8	---	---	---	---	---	---	---	---	---	---	---	---
1.9	---	---	---	---	---	---	---	---	---	---	---	---
2.0	---	---	---	---	---	---	---	---	---	---	---	---
2.1	---	---	---	---	---	---	---	---	---	---	---	---
2.2	---	---	---	---	---	---	---	---	---	*0.07*	---	---
2.3	*0.09*	*0.12*	*0.14*	*0.17*	*0.21*	*0.24*	*0.28*	*0.32*	*0.37*	*0.42*	0.35	---
2.4	*0.47*	*0.53*	*0.59*	*0.65*	*0.72*	0.79	0.86	0.94	1.02	1.11	0.69	0.34
2.5	1.19	1.28	1.38	1.48	1.58	1.69	1.80	1.91	2.03	2.15	1.04	0.35
2.6	2.28	2.41	2.54	2.68	2.82	2.97	3.11	3.26	3.42	3.58	1.43	0.39
2.7	3.74	3.91	4.09	4.26	4.44	4.63	4.82	5.01	5.21	5.41	1.83	0.40
2.8	5.61	5.82	6.04	6.25	6.47	6.70	6.93	7.16	7.40	7.65	2.24	0.41
2.9	7.89	*8.14*	*8.40*	*8.66*	*8.92*	*9.18*	*9.46*	*9.74*	*10.0*	*10.3*	2.65	0.41
3.0	*10.6*	*10.9*	*11.2*	*11.5*	*11.8*	*12.1*	*12.4*	*12.7*	*13.1*	*13.4*	3.10	0.45
3.1	*13.7*	*14.1*	*14.4*	*14.8*	*15.1*	*15.5*	*15.8*	---	---	---	---	---
3.2	---	---	---	---	---	---	---	---	---	---	---	---
3.3	---	---	---	---	---	---	---	---	---	---	---	---
3.4	---	---	---	---	---	---	---	---	---	---	---	---
3.5	---	---	---	---	---	---	---	---	---	---	---	---
3.6	---	---	---	---	---	---	---	---	---	---	---	---
3.7	---	---	---	---	---	---	---	---	---	---	---	---
3.8	---	---	---	---	---	---	---	---	---	---	---	---
3.9	---	---	---	---	---	---	---	---	---	---	---	---
4.0	---	---	---	---	---	---	---	---	---	---	---	---

Values in italics are beyond the validated range of the rating

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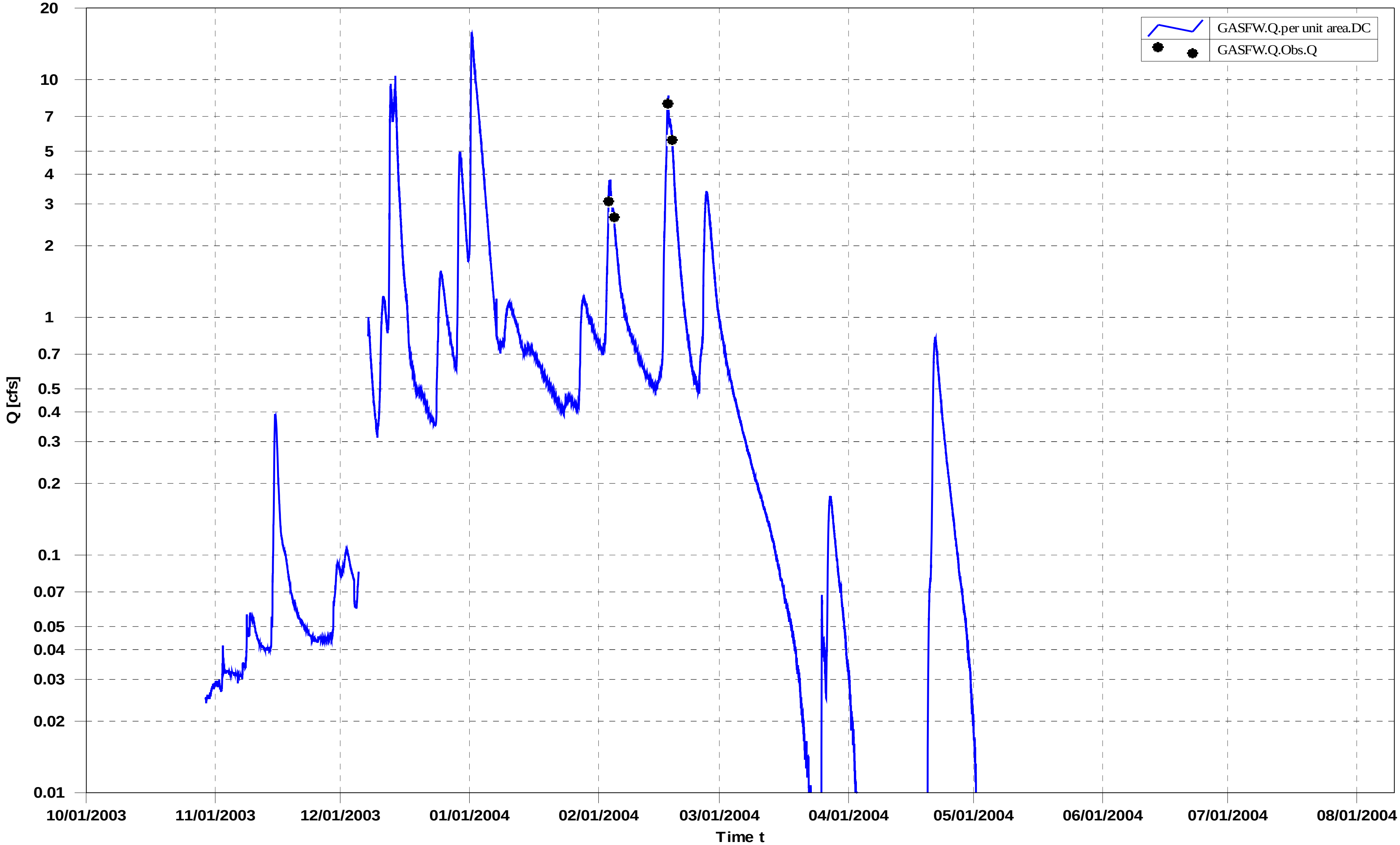
WY 04-05
APPENDIX

C-4

GREY CREEK ABOVE SOUTH FORK WAGES CREEK
Synthetic Discharge Hydrograph Derived from SFWAC Record and Discharge Measurements



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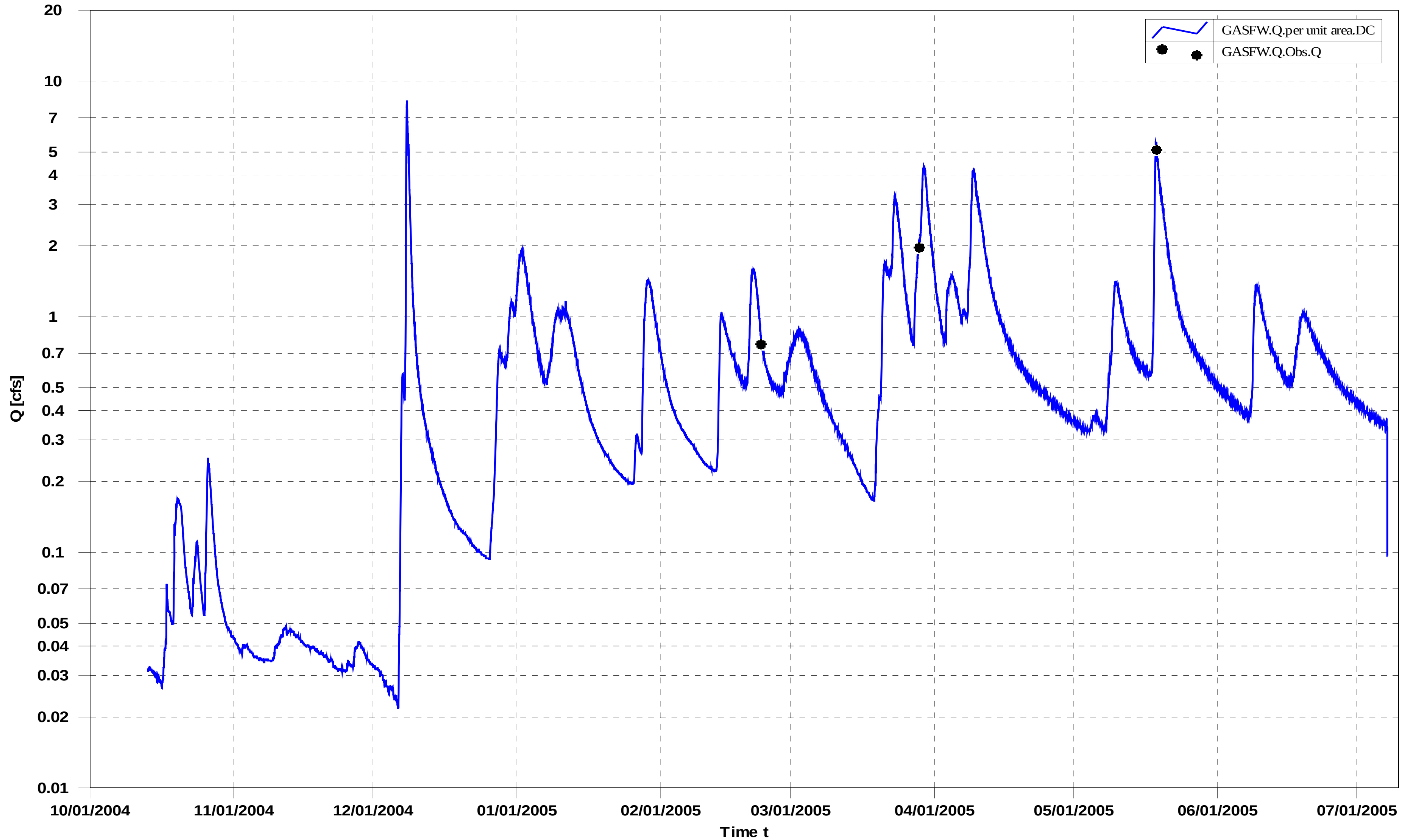
WY 2004
APPENDIX

C-6a

GREY CREEK ABOVE SOUTH FORK WAGES CREEK
Synthetic Discharge Hydrograph Derived from SFWAC Record and Discharge Measurements



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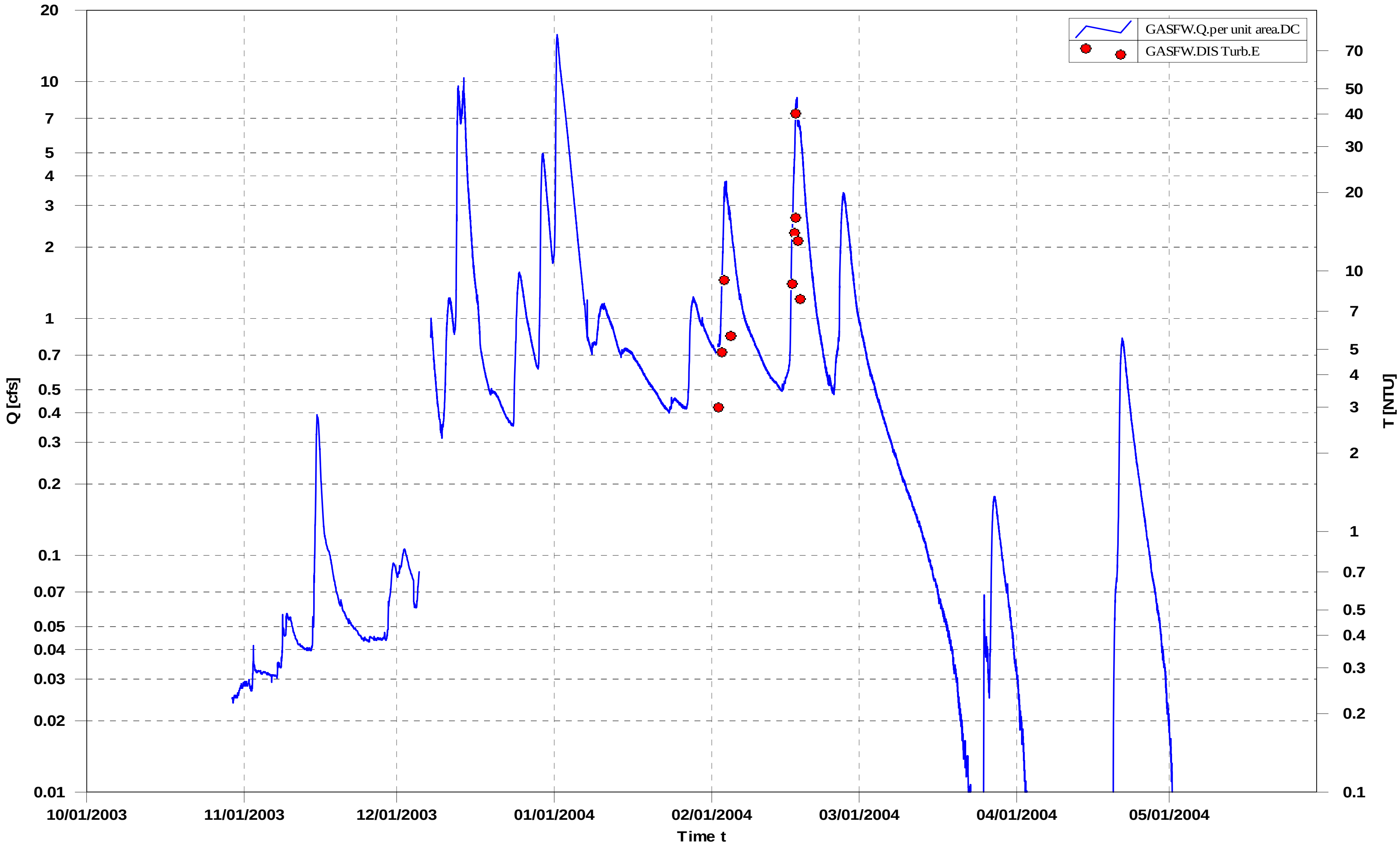
GREY CREEK ABOVE SOUTH FORK WAGES CREEK
Synthetic Discharge Hydrograph with Depth-Integrated Turbidity Samples



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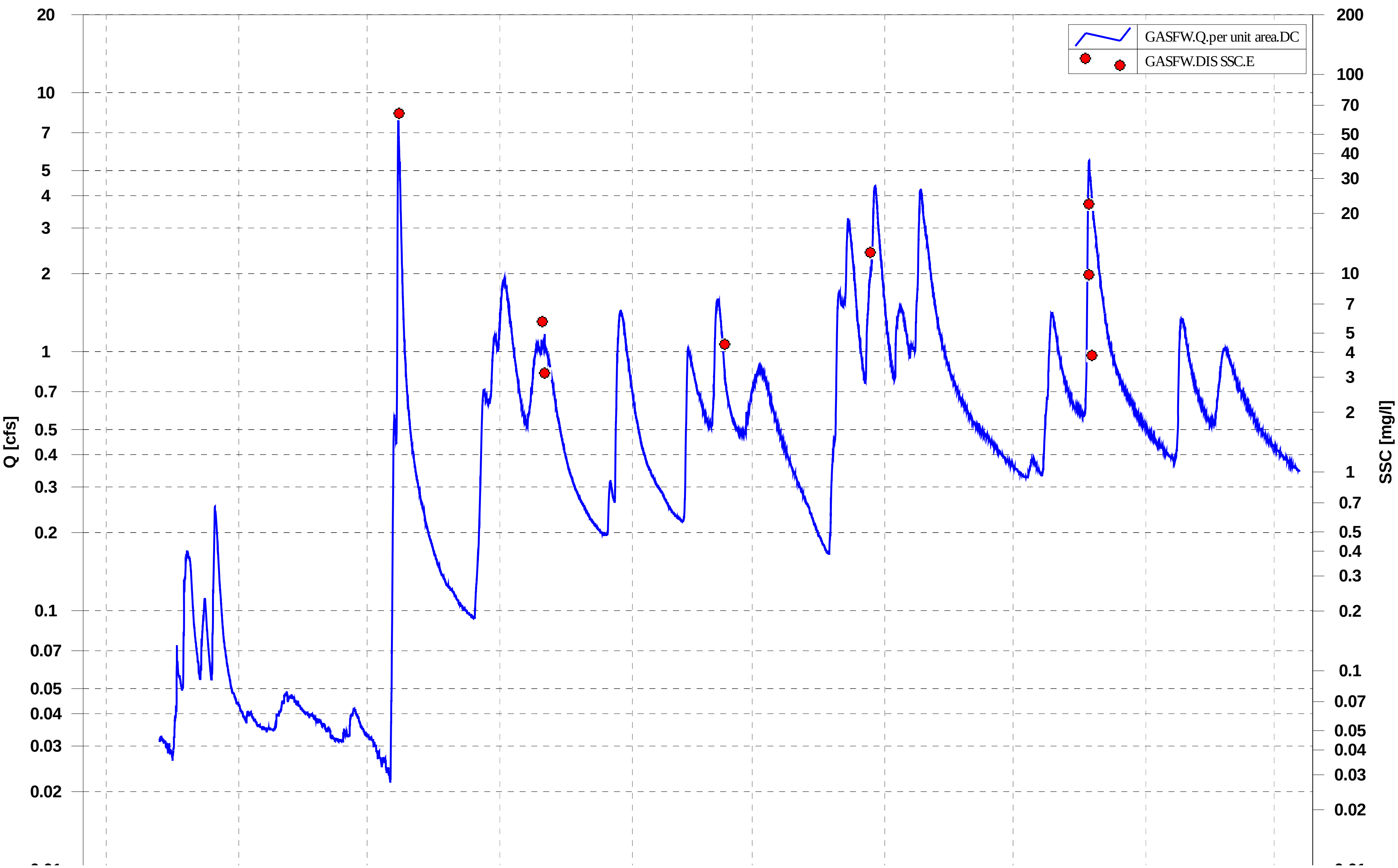
WY 2004
APPENDIX

C-7a

GREY CREEK ABOVE SOUTH FORK WAGES CREEK
Synthetic Discharge Hydrograph with Depth-Integrated Turbidity Samples



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WY 2005
APPENDIX

C-7b

SEDIMENT SAMPLE SUMMARY SHEET

LOCATION: GREY CREEK ABOVE SOUTH FORK WAGES WATER YEAR: 2004

Date Time	Sample Number	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	Q/WSA (cfs/mi^2)	SSL (ton/day)	SSLPA (ton/day/mi2)	Type (DIS, PUMP)	Note
2/2/2004 05:04	GASFW-SSCT2004-01	3.0	5	2.40	0.47	2.76	0.01	0.04	DIS	
2/2/2004 21:08	GASFW-SSCT2004-02	4.9	3	2.47	0.94	5.53	0.01	0.04	DIS	
2/3/2004 06:03	GASFW-SSCT2004-03	7.3	43	2.58	2.03	11.9	0.24	1.4	DIS	Censored
2/3/2004 12:20	GASFW-SSCT2004-04	9.2	11	2.68	3.42	20.1	0.10	0.57	DIS	
2/4/2004 16:32	GASFW-SSCT2004-05	5.6	1	2.63	2.68	15.8	0.01	0.05	DIS	
2/16/2004 18:26	GASFW-SSCT2004-06	8.9	7	2.61	2.41	14.2	0.05	0.27	DIS	
2/17/2004 08:59	GASFW-SSCT2004-07	14	29	2.77	5.01	29.5	0.39	2.3	DIS	
2/17/2004 11:12	GASFW-SSCT2004-08	16	37	2.83	6.25	36.8	0.62	3.6	DIS	
2/17/2004 11:26	GASFW-SSCT2004-09	16	27	2.83	6.25	36.8	0.46	2.7	DIS	
2/17/2004 14:19	GASFW-SSCT2004-10	40	69	2.91	8.14	47.9	1.5	8.9	DIS	
2/17/2004 20:52	GASFW-SSCT2004-11	13	12	2.89	7.65	45.0	0.24	1.4	DIS	
2/18/2004 12:06	GASFW-SSCT2004-12	7.8	5	2.81	5.82	34.2	0.08	0.50	DIS	

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WY 2004
APPENDIX

C-8a

SEDIMENT SAMPLE SUMMARY SHEET

LOCATION: GREY CREEK ABOVE SOUTH FORK WAGES WATER YEAR: 2005

Date Time	Sample Number	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	Q/WSA (cfs/mi^2)	SSL (ton/day)	SSLPA (ton/day/mi2)	Type (DIS, PUMP)	Note
12/8/2004 08:37	GASFW-SSCT2005-01	29	64	2.99	10.3	60.6	1.8	10.4	DIS	
12/8/2004 17:17	GASFW-SSCT2005-02	17	112	2.77	5.01	29.5	1.5	8.9	DIS	Censored
12/9/2004 13:04	GASFW-SSCT2005-03	9.5	45	2.55	1.69	9.94	0.21	1.2	DIS	Censored
1/10/2005 20:53	GASFW-SSCT2005-04	3.1	6	2.45	0.79	4.65	0.01	0.07	DIS	
1/11/2005 11:01	GASFW-SSCT2005-05	2.6	3	2.46	0.86	5.06	0.01	0.04	DIS	
2/22/2005 16:49	GASFW-SSCT2005-06	2.5	4	2.55	1.69	9.94	0.02	0.12	DIS	
3/28/2005 14:08	GASFW-SSCT2005-07	6.1	44	2.58	2.03	11.9	0.24	1.4	DIS	Censored
3/28/2005 14:10	GASFW-SSCT2005-08	6.0	13	2.58	2.03	11.9	0.07	0.41	DIS	
5/18/2005 13:11	GASFW-SSCT2005-09	15	22	2.78	5.21	30.6	0.31	1.8	DIS	
5/18/2005 18:29	GASFW-SSCT2005-10	10	10	2.82	6.04	35.5	0.16	0.94	DIS	
5/19/2005 09:17	GASFW-SSCT2005-11	5.7	4	2.72	4.09	24.1	0.04	0.25	DIS	

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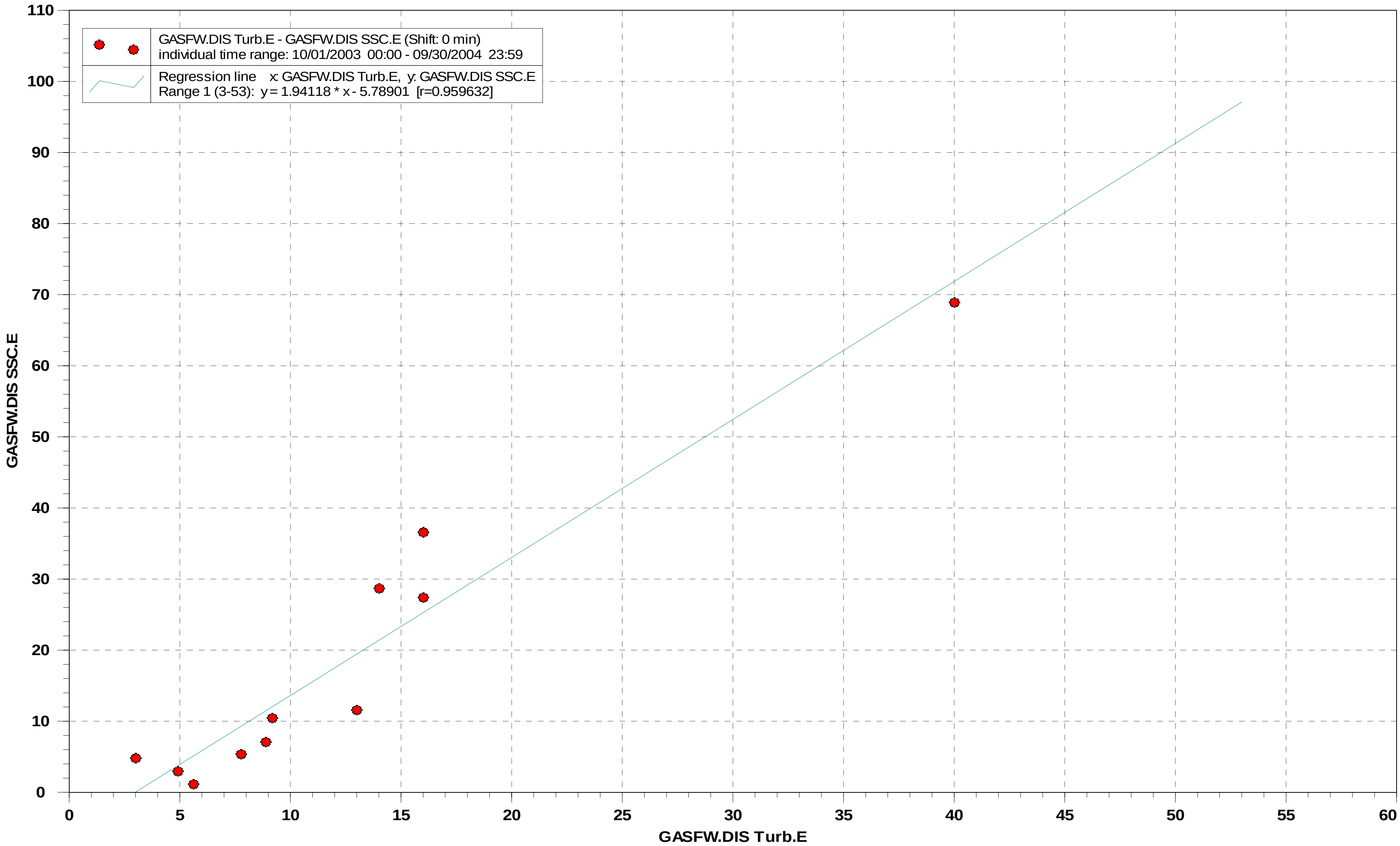
WY 2005
APPENDIX

C-8b

GREY CREEK ABOVE SOUTH FORK WAGES CREEK
Depth-Integrated Turbidity vs Depth-Integrated SSC



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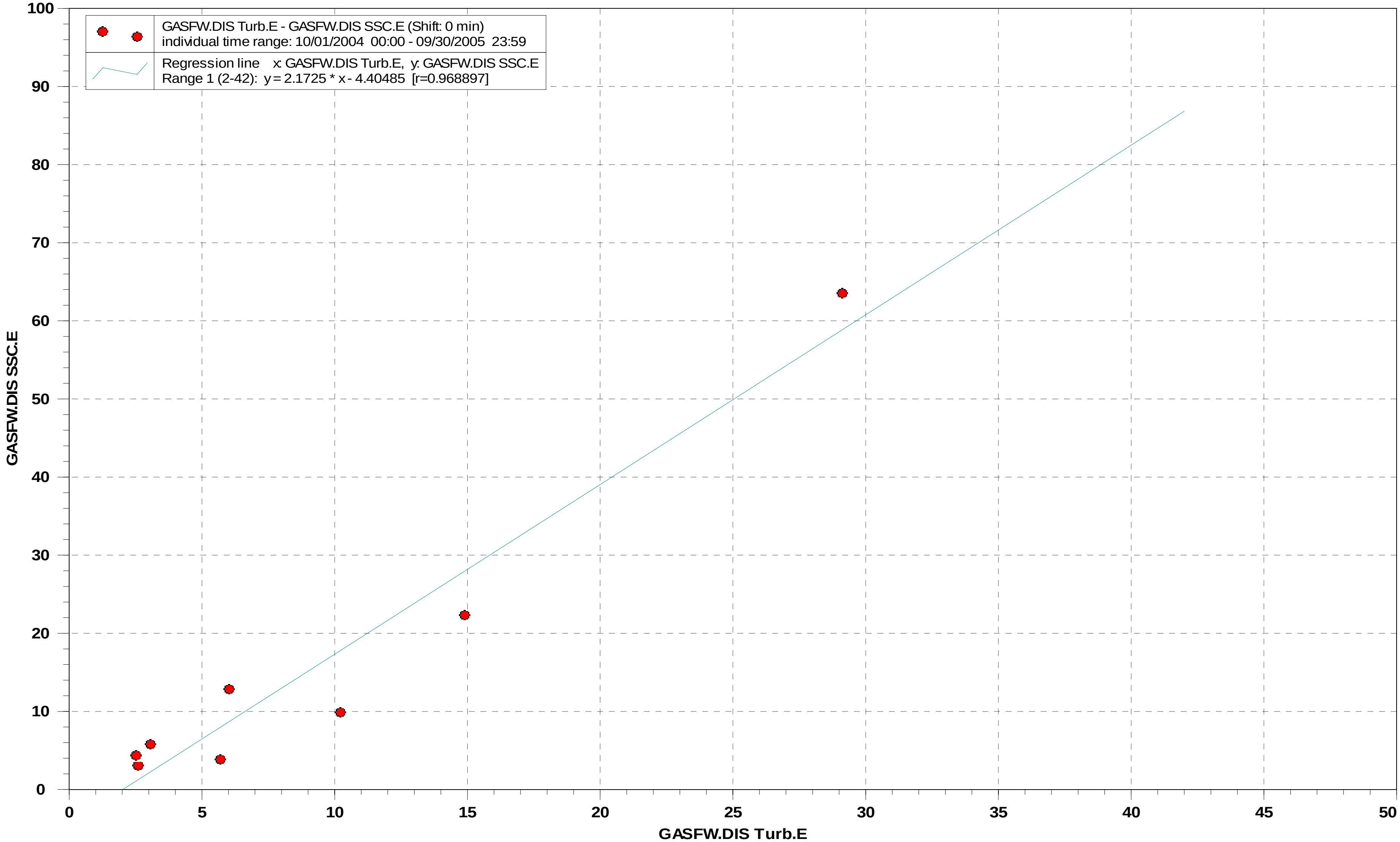
WY 2004
APPENDIX

C-9a

GREY CREEK ABOVE SOUTH FORK WAGES CREEK
Depth-Integrated Turbidity vs Depth-Integrated SSC



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WY 2005
APPENDIX

C-9b

WOOD CREEK ABOVE SOUTH FORK WAGES CREEK
(STATION # CTM 0283015)
STATION ANALYSIS
WATER YEAR 2004 -2005

RECORDS – Surface Water & Water Quality

EQUIPMENT – A Turbidity Threshold Sampling (TTS) station is installed at this site. The TTS station includes an Isco 6712 full size portable sampler, a Campbell Scientific CR510 data collection platform (DCP), a waterlog H-310 pressure transducer and a forest technology systems DTS-12 turbidity sensor. The DCP is housed in a locked steel box that is installed on the left bank. The DTS-12 is housed in an aluminum boom assembly, which is attached to a cable way strung over the creek. The pressure transducer is located on the left bank under the cable way. There is no staff plate installed at this site, a fence post is used as a stage reference point. The fence post is located on the left bank slightly downstream of the cable way.
Inside recording gage: Less than or equal to 0.02% of full scale output (FSO) over temperature range referenced (0 to 40^{o} C) to a straight line stretched from zero psi to maximum pressure (15 psi).
Outside staff gage: A fence post is used as a stage reference. Top of the fence post has an elevation of five feet.

GAGE HEIGHT RECORDS – Record is incomplete for the period.
Water Year 2004 station operation began on December 17, 2003 at 14:00 hours. No problems were encountered for the remainder of Water Year 2004.
The maximum gage height of 1.84 ft occurred on February 17, 2004. The site goes dry between storm events. Minimum gage height of zero flow or GZF at the site is 1.50 ft.
Water Year 2005 station operation began on December 6, 2004 at 17:00 hours. On December 8, 2004 from 13:38 to 13:43 the section behind the wood weir was excavated. A gap in the gage height record exists from April 22, 2004 12:30 to May 18, 17:00. Field notes indicate the missing data is due to a dead battery. The record ends on July 7, 2005 at 15:30 hours.
The maximum gage height of 1.98 feet occurred December 8, 2004 at 08:00. Minimum gage height of zero flow or GZF at the site is 1.50 ft

DATUM CORRECTIONS – The fence post has not been surveyed, no datum correction known.

CONTROL – The control is a V-notched redwood weir. The weir acts as a bedload trap and occasionally it is necessary to excavate the section immediately upstream of the weir. The GZF is 1.50 ft.

RATING – In Water Year 2004, 5 discharge measurements (1-5) were made. Measured discharge ranged from 0.17 cfs to 4.71 cfs. Computed instantaneous discharge ranged from 0.00 cfs to 5.28 cfs.
Measurements 1-5 were used to develop the middle and upper portions of Rating 1.2. Measurements 1 and 2 plotted 2% and -3% respectively from Rating 1.2 and were both rated poor.
Measurement 3 plotted -6% from Rating 1.2 and was rated poor. No shift was computed because the measurements plotted within acceptable limits considering the measurement rating.
Measurement 4 and 5 plotted 0% and 3% from Rating 1.2 and were both rated fair.
In Water Year 2005, two discharge measurements (6 and 7) were made. Measured discharge ranged from 0.09 cfs to 2.52 cfs. Computed instantaneous discharge ranged from 0.00 cfs to 17.0 cfs.

Rating 1.2 in use at the end of Water Year 2004 was continued in use.
Measurement 6 was used to develop the low end of Rating 1.2. Measurement 6 was taken in the V-notch of the weir and was rated poor.
Measurement 7, made on May 19, 2005, plotted -15% from the Rating 1.2 and was rated fair. No check measurement was made. No shift was computed because no check measurement was made and there was no supporting documentation indicating that the weir had shifted.
In developing Rating 1.2 the break in slope was set to the gage height elevation (1.62 ft) at which water flows over the top of the entire weir.

DISCHARGE – Rating 1.2 was used during WY 2004-2005 as follows:
Water Year 2004
Dec. 17 to Sept. 30 (24:00) Rating 1.2

Water Year 2005
Oct. 1 to Jul. 7 (15:30) Rating 1.2

SPECIAL COMPUTATIONS – None Made

REMARKS – Due to the measurements ratings, 4 poor and 3 fair, the record should be considered poor for the entire period.

Gage height records worked by T. Grey 10-05
Gage height records checked by C. Pryor 10-05
Discharge computation worked by C. Pryor 11-05
Discharge computation checked by C. Pryor 12-05

DISCHARGE SUMMARY SHEET

LOCATION: Wood Creek Above South Fork Wages Creek **WATER YEAR: 2004 - 2005**

Measurement Number	WY Msmt #	Date	Made By:	Width (feet)	Mean Depth (feet)	Area (ft^2)	Mean Velocity (ft/sec)	Gage Height (feet)	Discharge (cfs)	Rating 1.2		Method	No. of Msmt sections	Begin Time (hours)	End Time (hours)	Msmt Rating	PZF	Notes
										Shift Adj.	Percent Diff.							
1	2004-01	2/3/2004	T. Grey	3.4	0.24	0.80	0.56	1.67	0.45		2	wading	16	10:43	11:14	Poor		
2	2004-02	2/3/2004	K. Faucher	3.3	0.35	1.15	1.08	1.73	1.24		-3	wading	16	18:53	19:10	Poor		
3	2004-03	2/4/2004	T. Grey	1.9	0.20	0.38	0.44	1.63	0.17		-6	wading	11	14:00	14:13	Poor		
4	2004-04	2/17/2004	K. Faucher	5.2	0.39	2.01	2.34	1.83	4.71		0	wading	25	15:41	16:07	Fair		
5	2004-05	2/18/2004	K. Faucher	4.2	0.43	1.79	1.14	1.76	2.04		3	wading	20	15:03	15:29	Fair		
6	2005-01	3/28/2005	K. Faucher	0.5	0.16	0.07	1.33	1.52	0.09		0	wading	3	12:44	12:46	Poor		
7	2005-02	5/19/2005	K. Faucher	4.2	0.30	1.25	2.02	1.79	2.52		-15	wading	14	17:39	17:50	Fair		No Shift Computed

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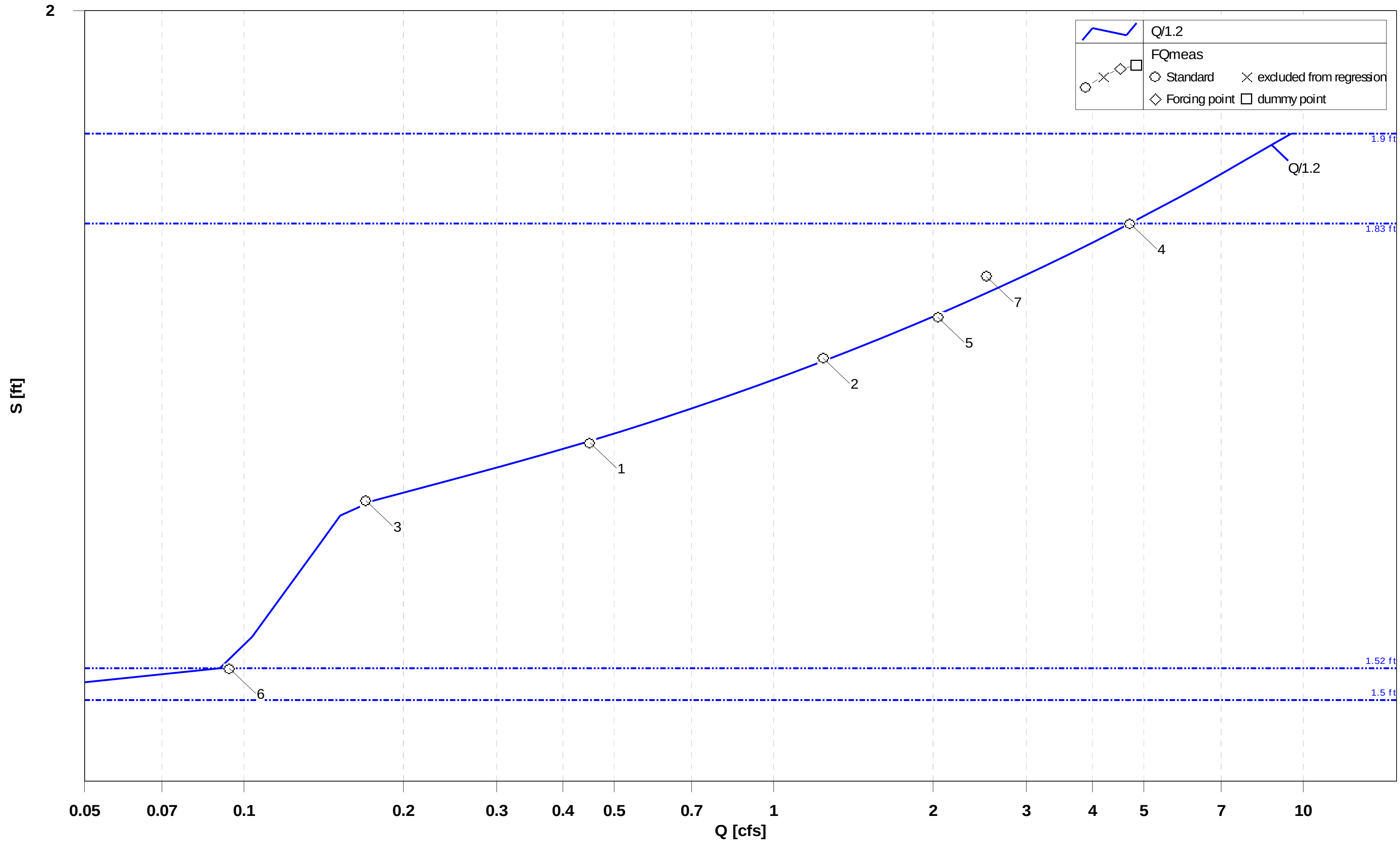
WY 04-05 APPENDIX

D-2

WOOD CREEK ABOVE SOUTH FORK WAGES CREEK
Discharge Rating Curve 1.2



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WY 04-05
APPENDIX

D-3

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WOOD CREEK ABOVE SOUTH FORK WAGES CREEK

RATING TABLE NO.1.2 -- Begin Date 12/08/2004

GH	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	1st Diff	2nd Diff
0.6	---	---	---	---	---	---	---	---	---	---	---	---
0.7	---	---	---	---	---	---	---	---	---	---	---	---
0.8	---	---	---	---	---	---	---	---	---	---	---	---
0.9	---	---	---	---	---	---	---	---	---	---	---	---
1.0	---	---	---	---	---	---	---	---	---	---	---	---
1.1	---	---	---	---	---	---	---	---	---	---	---	---
1.2	---	---	---	---	---	---	---	---	---	---	---	---
1.3	---	---	---	---	---	---	---	---	---	---	---	---
1.4	---	---	---	---	---	---	---	---	---	---	---	---
1.5	*0.00*	*0.04*	0.09	0.10	0.10	0.11	0.11	0.12	0.13	0.13	---	---
1.6	0.14	0.15	0.15	0.18	0.22	0.28	0.35	0.44	0.54	0.65	0.52	---
1.7	0.78	0.93	1.10	1.28	1.49	1.73	1.99	2.28	2.60	2.95	2.30	1.78
1.8	3.33	3.75	4.22	4.70	*5.24*	*5.83*	*6.46*	*7.12*	*7.84*	*8.63*	5.68	3.38
1.9	*9.49*	---	---	---	---	---	---	---	---	---	---	---
2.0	---	---	---	---	---	---	---	---	---	---	---	---
2.1	---	---	---	---	---	---	---	---	---	---	---	---
2.2	---	---	---	---	---	---	---	---	---	---	---	---
2.3	---	---	---	---	---	---	---	---	---	---	---	---
2.4	---	---	---	---	---	---	---	---	---	---	---	---
2.5	---	---	---	---	---	---	---	---	---	---	---	---
2.6	---	---	---	---	---	---	---	---	---	---	---	---
2.7	---	---	---	---	---	---	---	---	---	---	---	---
2.8	---	---	---	---	---	---	---	---	---	---	---	---
2.9	---	---	---	---	---	---	---	---	---	---	---	---
3.0	---	---	---	---	---	---	---	---	---	---	---	---

Values in italics are beyond the validated range of the rating

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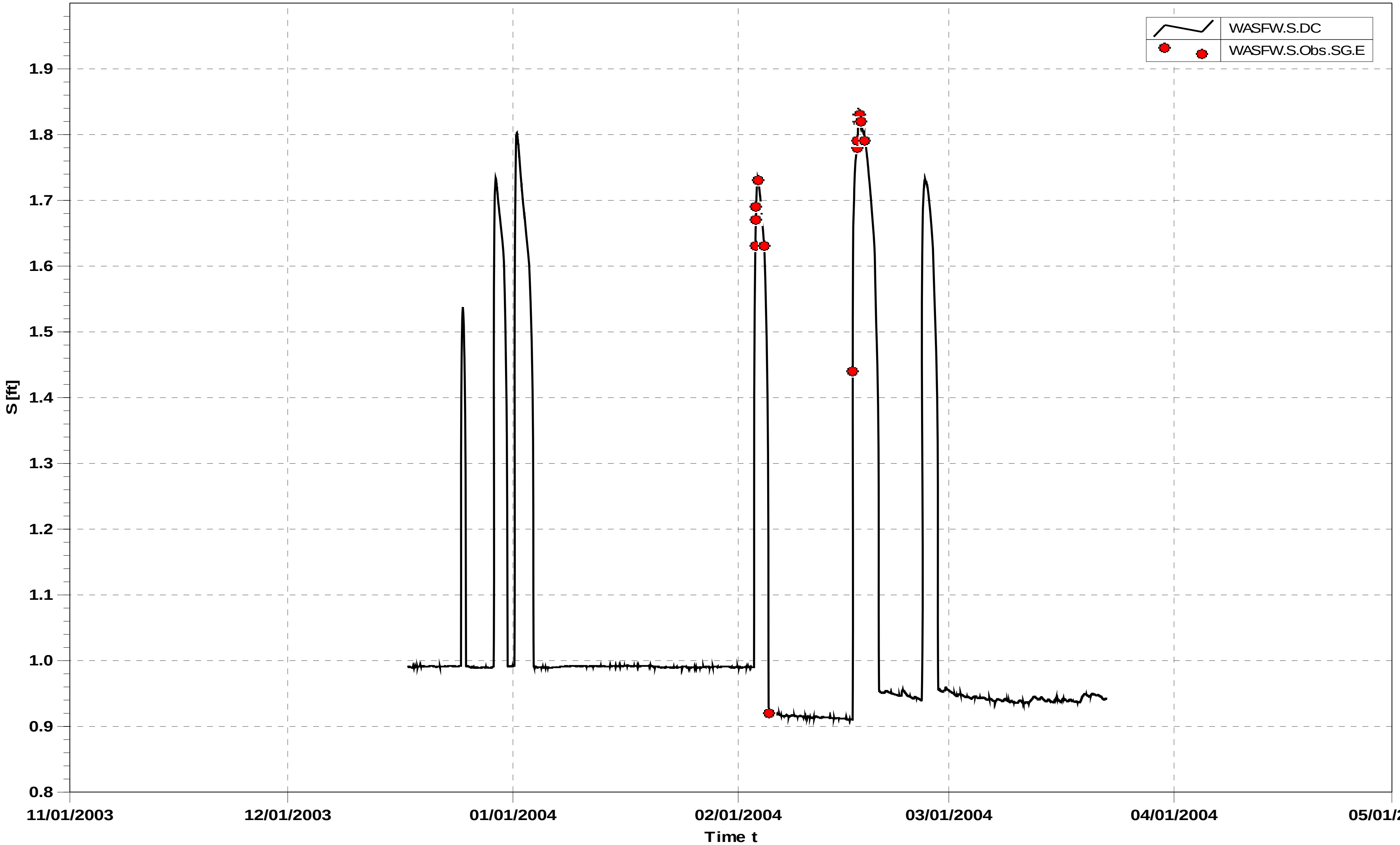
WY 04-05
APPENDIX

WOOD CREEK ABOVE SOUTH FORK WAGES CREEK
15-Minute Adjusted Gage Height Record and Observed Staff Gage Readings



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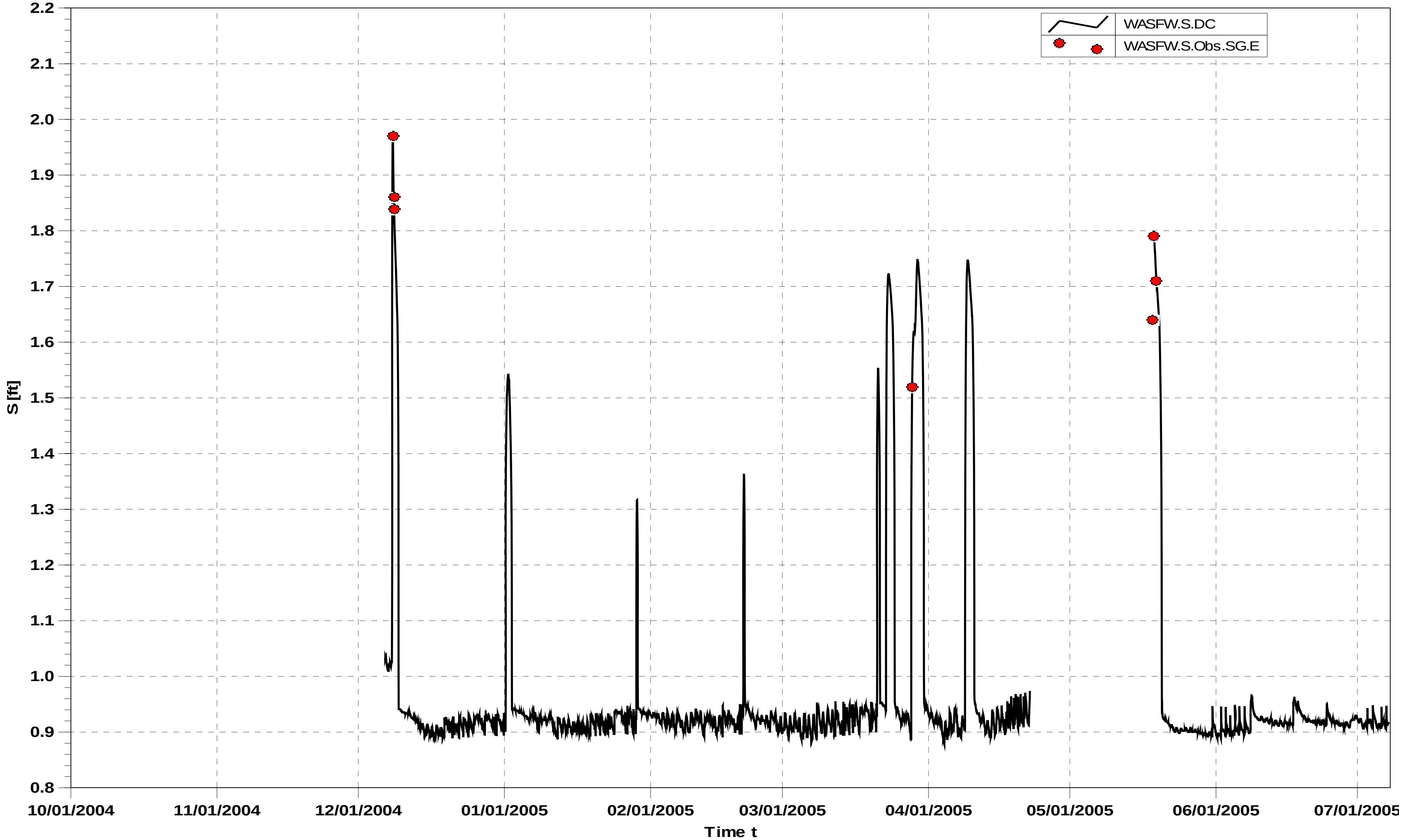
WY 2004
APPENDIX

D-5a

WOOD CREEK ABOVE SOUTH FORK WAGES CREEK
15-Minute Adjusted Gage Height Record and Observed Staff Gage Readings



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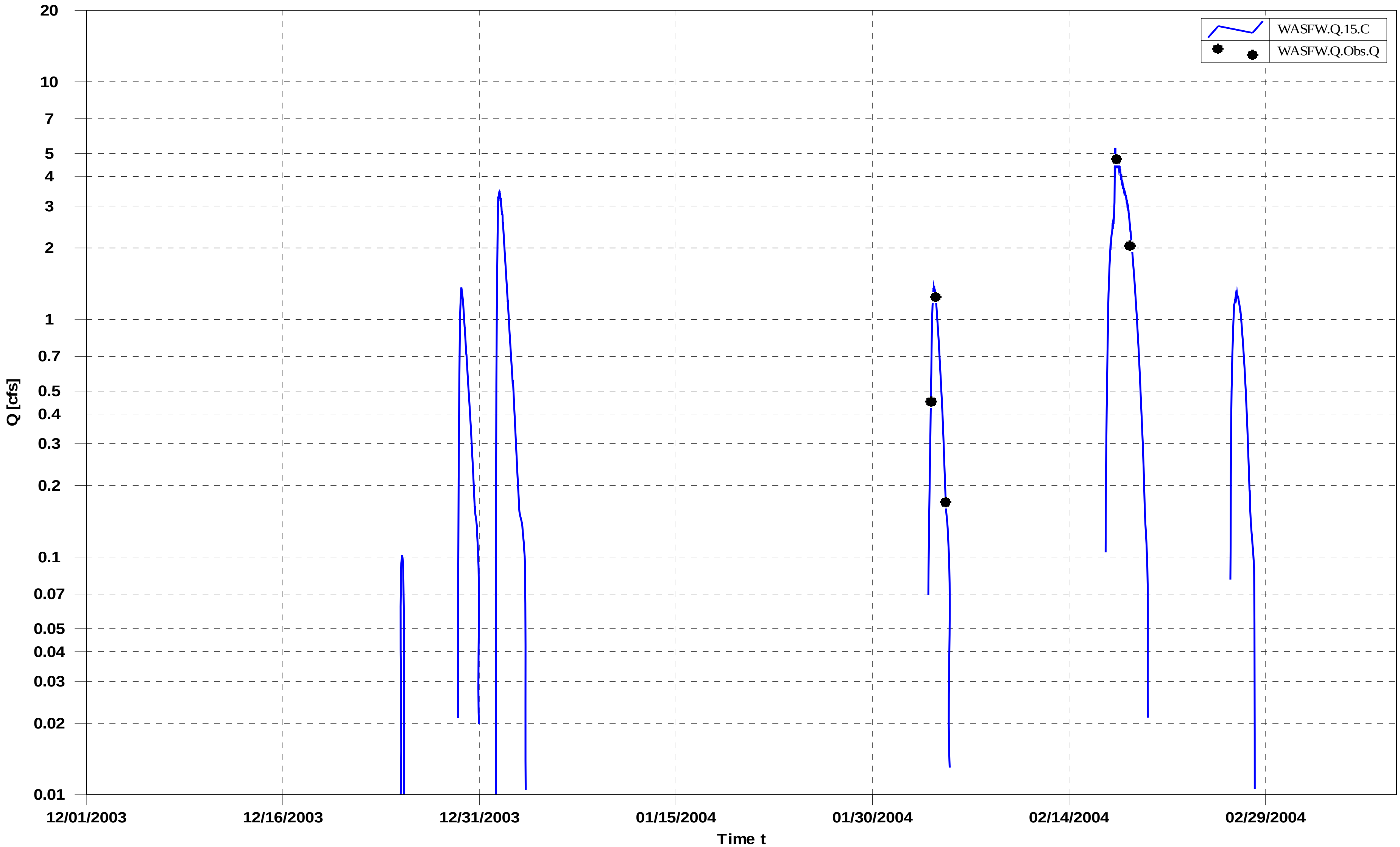
WY 2005
APPENDIX

D-5b

WOOD CREEK ABOVE SOUTH FORK WAGES CREEK
Discharge Hydrograph and Discharge Measurements



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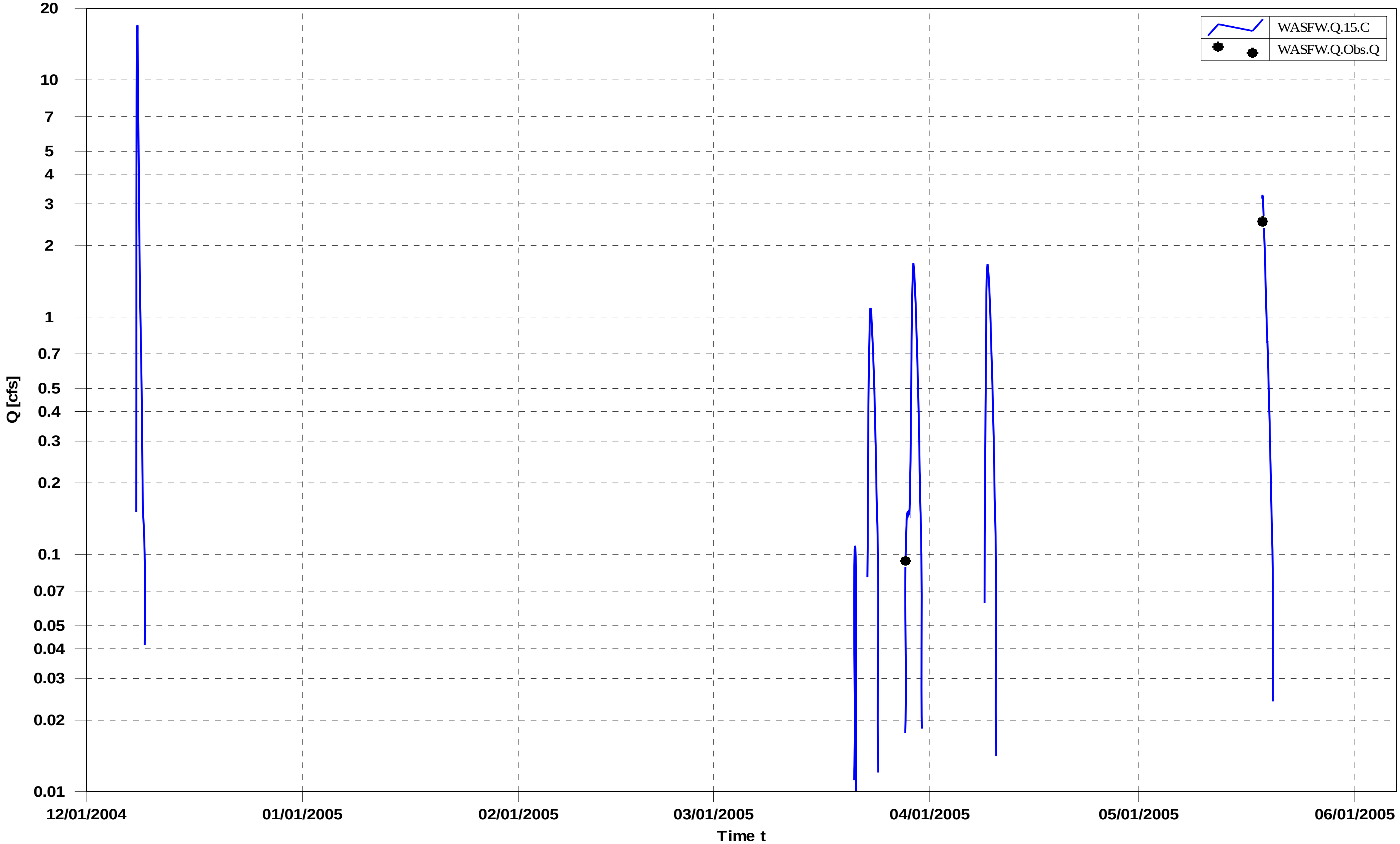
APPENDIX
D-6a

WOOD CREEK ABOVE SOUTH FORK WAGES CREEK
Discharge Hydrograph and Discharge Measurements



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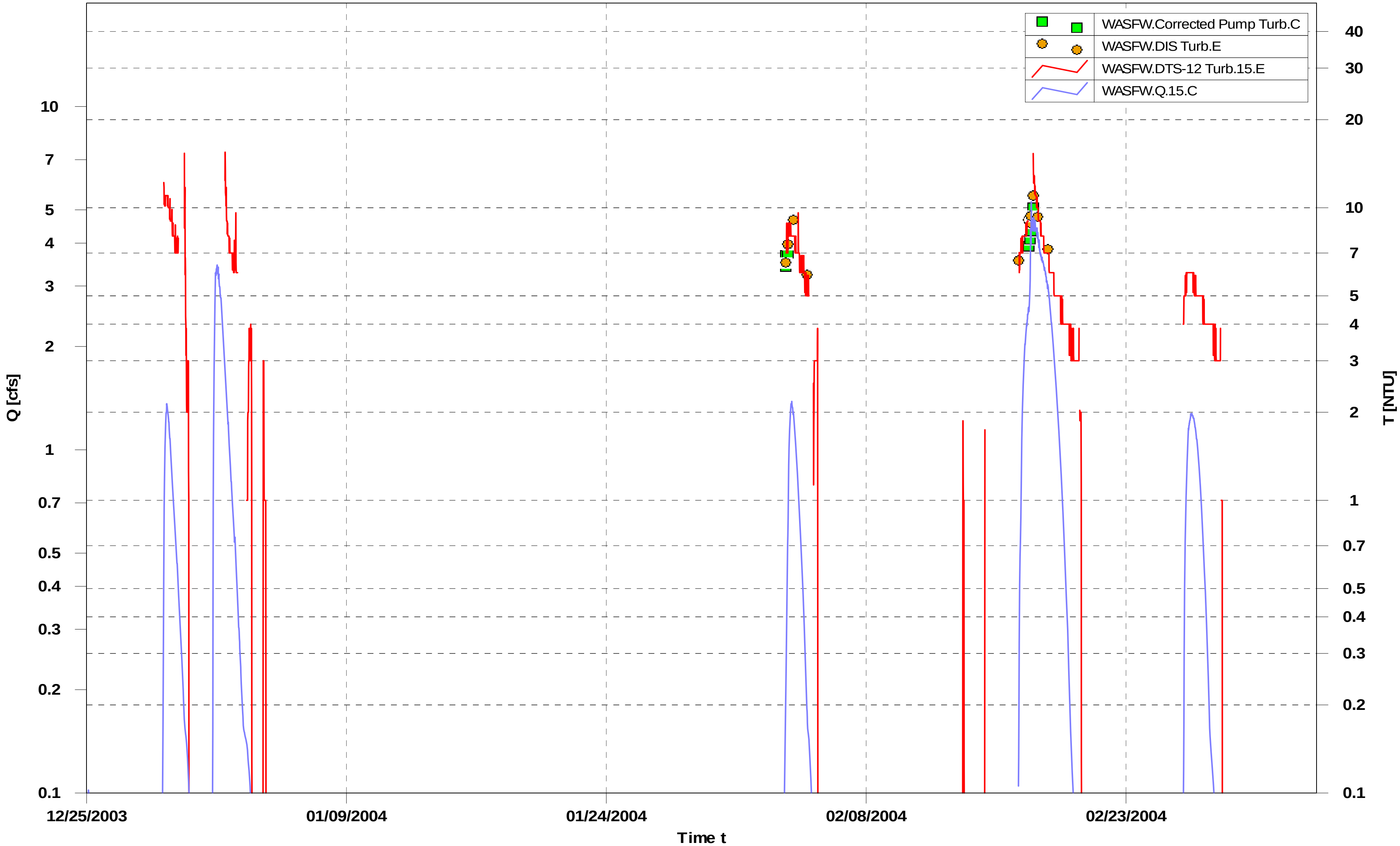
WOOD CREEK ABOVE SOUTH FORK WAGES CREEK

Discharge Hydrograph, Continuous Turbidity with Pump and Depth-Integrated Turbidity Samples



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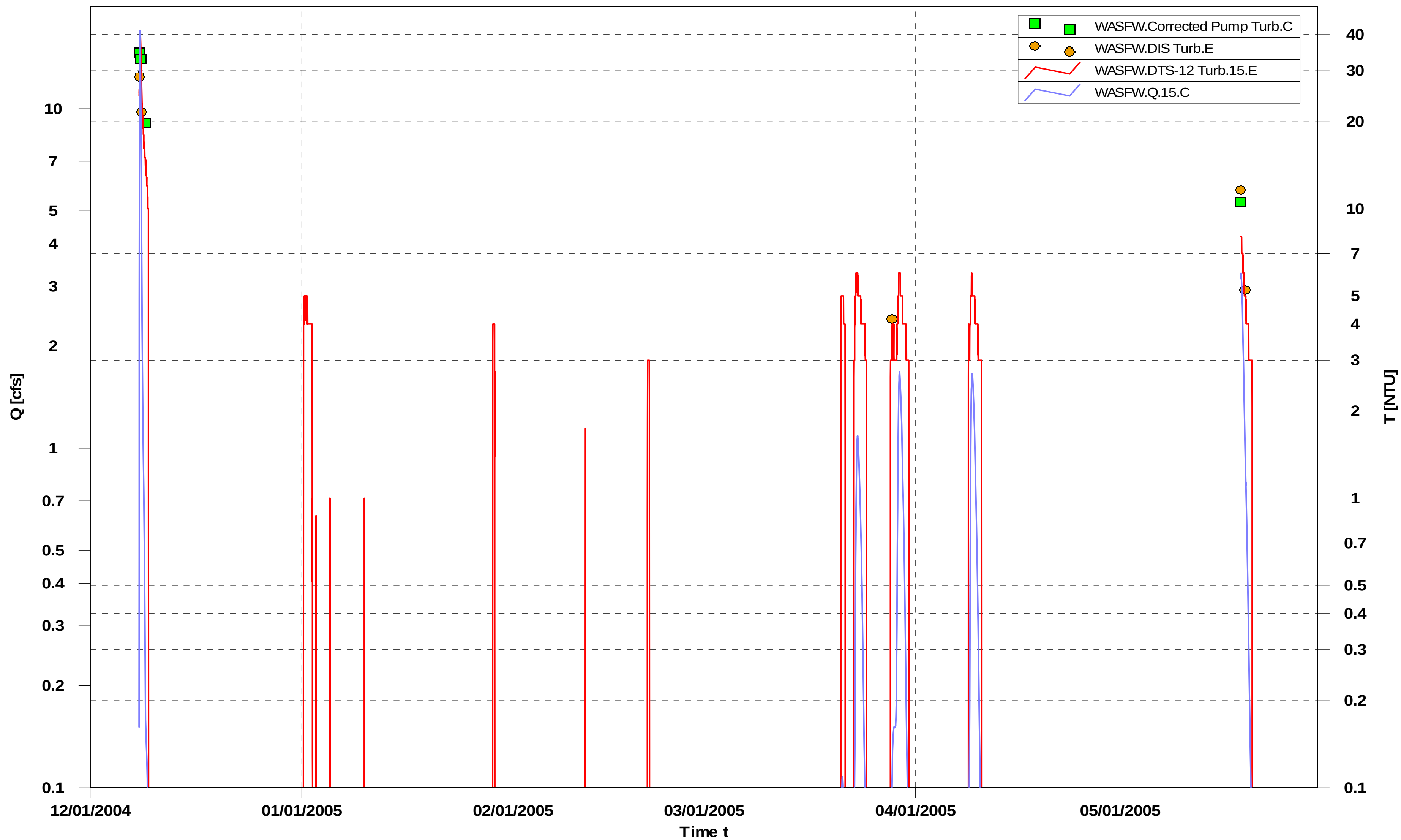
WY 2004

APPENDIX

D-7a

WOOD CREEK ABOVE SOUTH FORK WAGES CREEK
Discharge Hydrograph, Continuous Turbidity with Pump and Depth-Integrated Turbidity Samples



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APPENDIX

D-7b

SEDIMENT SAMPLE SUMMARY SHEET

LOCATION: WOOD CREEK ABOVE SOUTH FORK WAGES **WATER YEAR: 2004**

Date Time	Sample Number	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	Q/WSA (cfs/mi^2)	SSL (ton/day)	SSLPA (ton/day/mi2)	Type (DIS, PUMP)	Note
2/3/2004 08:01	WASFW-SSCT2004-01	6.9	1	1.61	0.15	1.50	0.00	0.00	PUMP	
2/3/2004 08:16	WASFW-SSCT2004-02	6.5	2	1.63	0.18	1.80	0.00	0.01	DIS	
2/3/2004 08:31	WASFW-SSCT2004-03	6.3	1	1.62	0.15	1.50	0.00	0.00	PUMP	
2/3/2004 11:26	WASFW-SSCT2004-04	7.0	1	1.69	0.65	6.50	0.00	0.02	PUMP	Calibrate w/ bottle #1064
2/3/2004 11:46	WASFW-SSCT2004-05	7.5	1	1.69	0.65	6.50	0.00	0.01	DIS	
2/3/2004 19:21	WASFW-SSCT2004-06	9.1	10	1.73	1.28	12.8	0.03	0.34	DIS	
2/4/2004 14:02	WASFW-SSCT2004-07	5.9	3	1.63	0.18	1.80	0.00	0.01	DIS	
2/16/2004 18:37	WASFW-SSCT2004-08	6.6	2	1.44	0.10	1.00	0.00	0.00	DIS	
2/17/2004 09:00	WASFW-SSCT2004-09	9.1	2	1.78	2.60	26.0	0.01	0.12	DIS	
2/17/2004 09:16	WASFW-SSCT2004-10	7.4	2	1.76	1.99	19.9	0.01	0.09	PUMP	T-PROBE = 43 NTU
2/17/2004 10:31	WASFW-SSCT2004-11	7.8	4	1.77	2.28	22.8	0.03	0.25	PUMP	T-PROBE = 182 NTU
2/17/2004 11:06	WASFW-SSCT2004-12	8.9	3	1.79	2.95	29.5	0.02	0.25	DIS	
2/17/2004 12:00	WASFW-SSCT2004-13	9.4	9	1.82	4.22	42.2	0.10	1.0	DIS	
2/17/2004 12:01	WASFW-SSCT2004-14	8.3	3	1.80	3.33	33.3	0.03	0.27	PUMP	T-PROBE = 83 NTU
2/17/2004 15:00	WASFW-SSCT2004-15	11	6	1.83	4.70	47.0	0.08	0.76	DIS	
2/17/2004 15:01	WASFW-SSCT2004-16	9.4	4	1.81	3.75	37.5	0.05	0.45	PUMP	T-PROBE = 917 NTU
2/17/2004 15:31	WASFW-SSCT2004-17	10	6	1.81	3.75	37.5	0.06	0.64	PUMP	T-PROBE = 13 NTU
2/17/2004 21:06	WASFW-SSCT2004-18	9.3	2	1.82	4.22	42.2	0.02	0.17	DIS	
2/18/2004 11:49	WASFW-SSCT2004-19	7.2	2	1.79	2.95	29.5	0.01	0.12	DIS	

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WY 2004 APPENDIX

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SEDIMENT SAMPLE SUMMARY SHEET

LOCATION: WOOD CREEK ABOVE SOUTH FORK WAGES **WATER YEAR: 2005**

Date Time	Sample Number	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	Q/WSA (cfs/mi^2)	SSL (ton/day)	SSLPA (ton/day/mi2)	Type (DIS, PUMP)	Note
12/8/2004 07:01	WASFW-SSCT2005-01	27	29	1.97	17.1	171	1.3	13	Pump	Calibrate with bottle #1944
12/8/2004 07:03	WASFW-SSCT2005-02	29	54	1.97	17.1	171	2.5	25	DIS	
12/8/2004 07:31	WASFW-SSCT2005-03	25	29	1.96	15.9	159	1.2	12	Pump	
12/8/2004 10:16	WASFW-SSCT2005-04	24	209	1.91	10.7	107	6.0	60	Pump	Censored
12/8/2004 10:46	WASFW-SSCT2005-05	23	319	1.90	9.69	96.9	8.3	83	Pump	Censored
12/8/2004 12:31	WASFW-SSCT2005-06	21	278	1.84	5.03	50.3	3.8	38	Pump	Censored
12/8/2004 13:16	WASFW-SSCT2005-07	15	236	1.82	4.14	41.4	2.6	26	Pump	Censored
12/8/2004 14:02	WASFW-SSCT2005-08	22	4	1.84	5.39	53.9	0.05	0.53	DIS	
12/9/2004 00:16	WASFW-SSCT2005-09	15	3	1.72	1.14	11.4	0.01	0.09	Pump	
3/28/2005 13:00	WASFW-SSCT2005-10	4.2	3	1.52	0.09	0.90	0.00	0.01	DIS	
5/18/2005 12:41	WASFW-SSCT2005-11	13	124	1.64	0.22	2.20	0.07	0.74	DIS	Censored, Discharge taken from rating table not from 15 minute record
5/18/2005 17:00	WASFW-SSCT2005-12	8.1	12	1.80	3.16	31.6	0.1	1.0	Pump	Calibrate with bottle #1020
5/18/2005 17:04	WASFW-SSCT2005-13	12	9	1.80	3.16	31.6	0.08	0.77	DIS	
5/19/2005 09:00	WASFW-SSCT2005-14	5.3	1	1.71	0.93	9.30	0.00	0.03	DIS	

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WY 2005 APPENDIX

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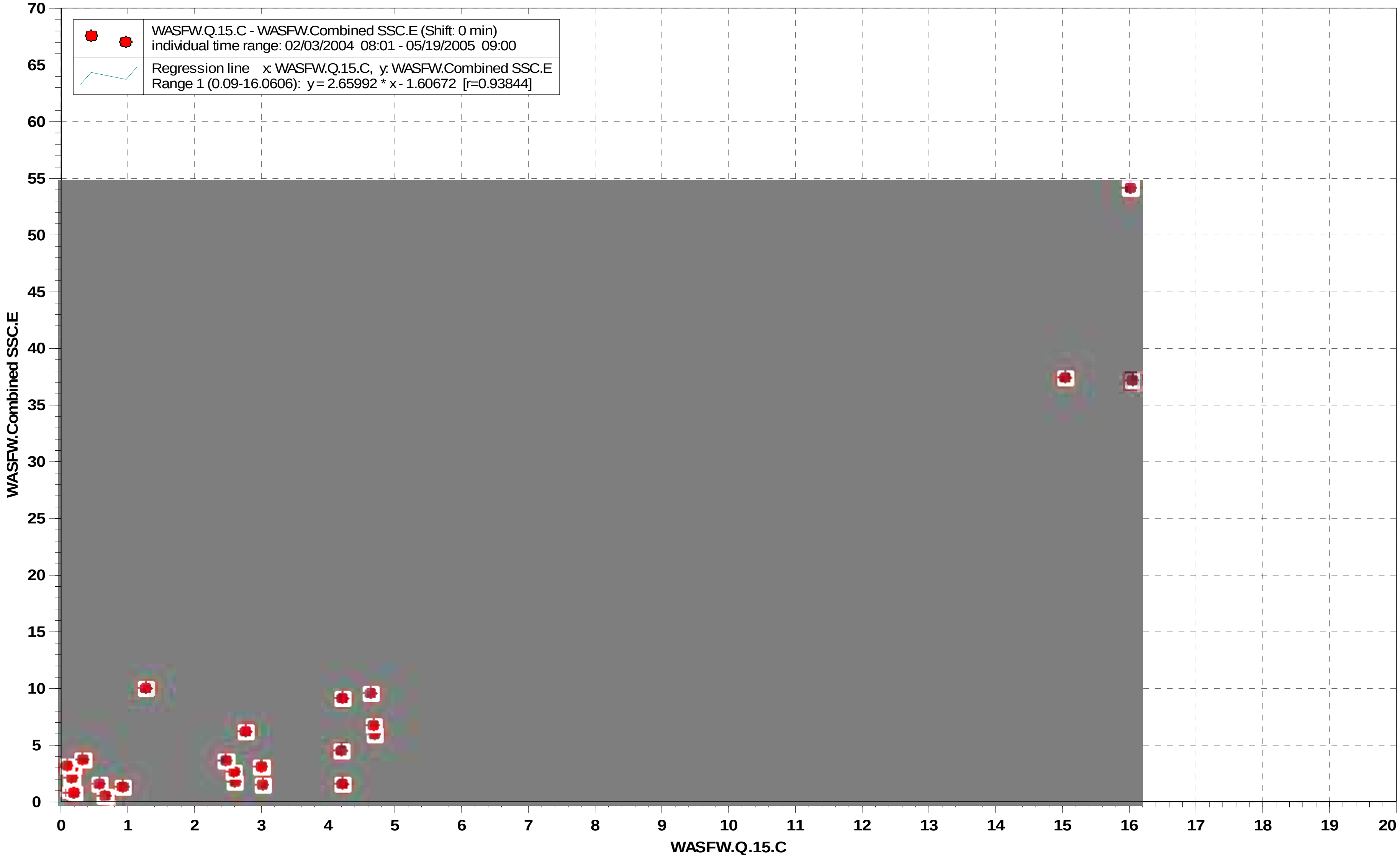
WOOD CREEK ABOVE SOUTH FOR WAGES CREEK
Discharge verses Combined SSC WY 2004 - 2005



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WY 04-05
APPENDIX

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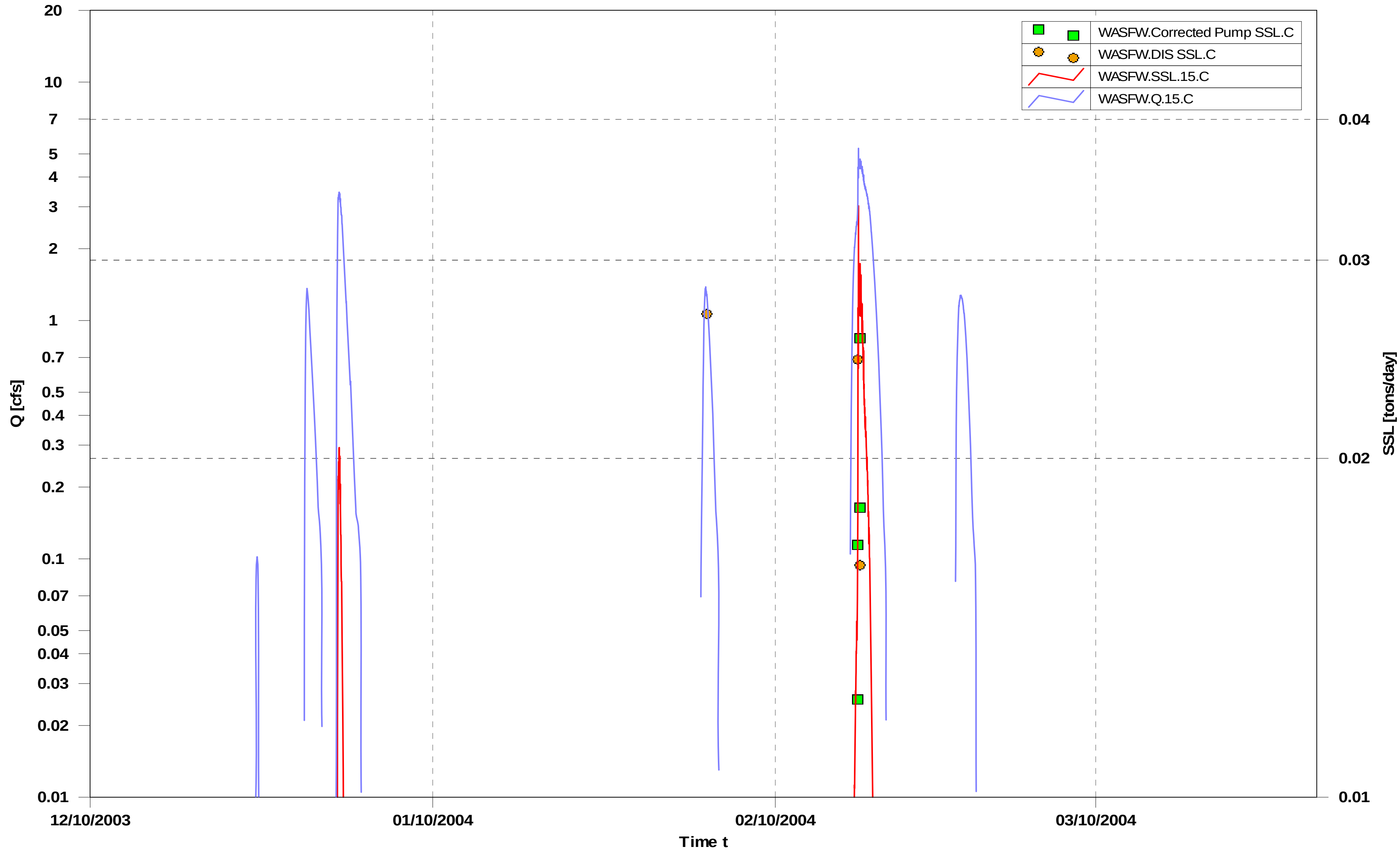
WOOD CREEK ABOVE SOUTH FORK WAGES CREEK
Discharge and Suspended Sediment Load



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WY 2004
APPENDIX

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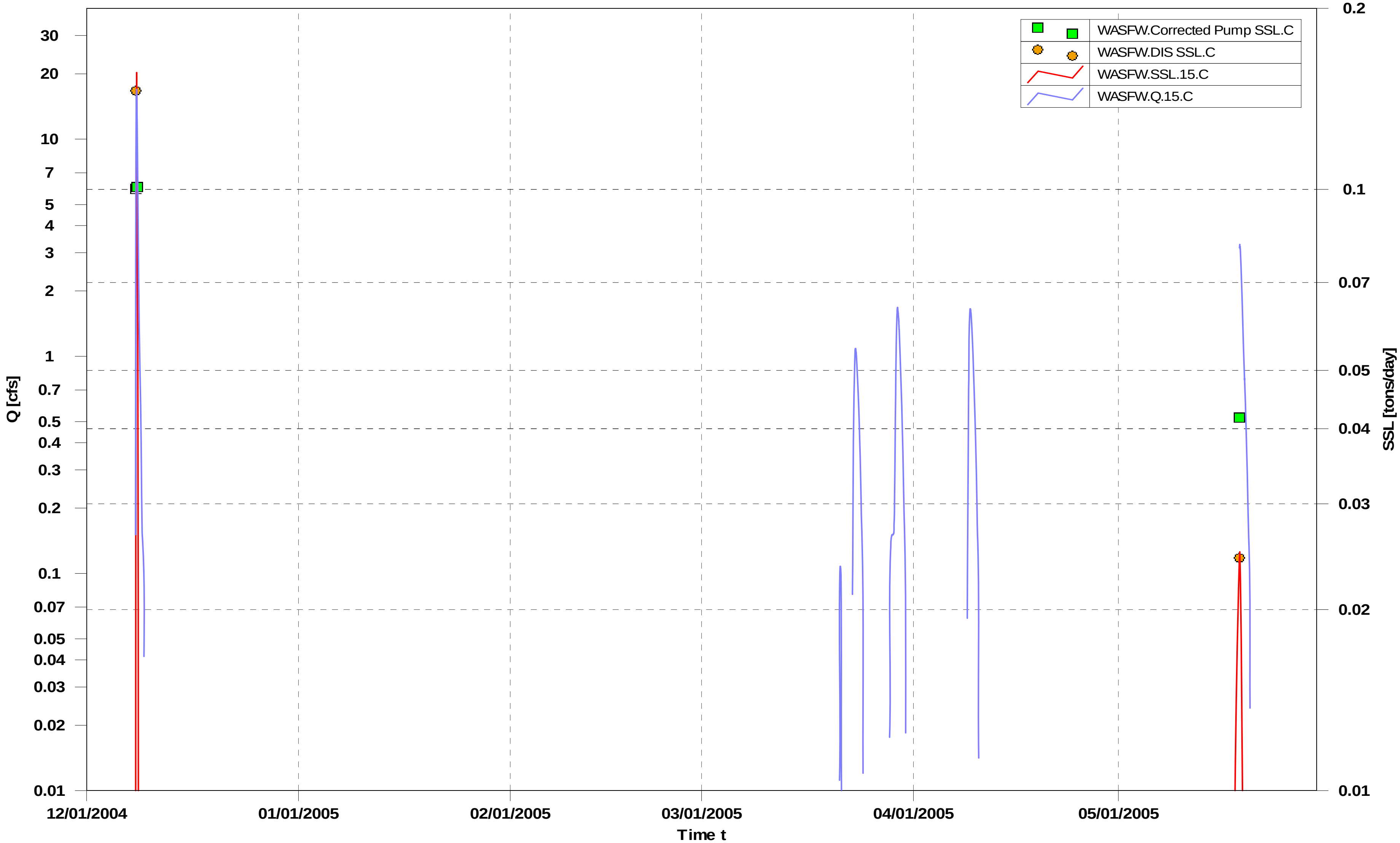
WOOD CREEK ABOVE SOUTH FORK WAGES CREEK
Discharge and Suspended Sediment Load



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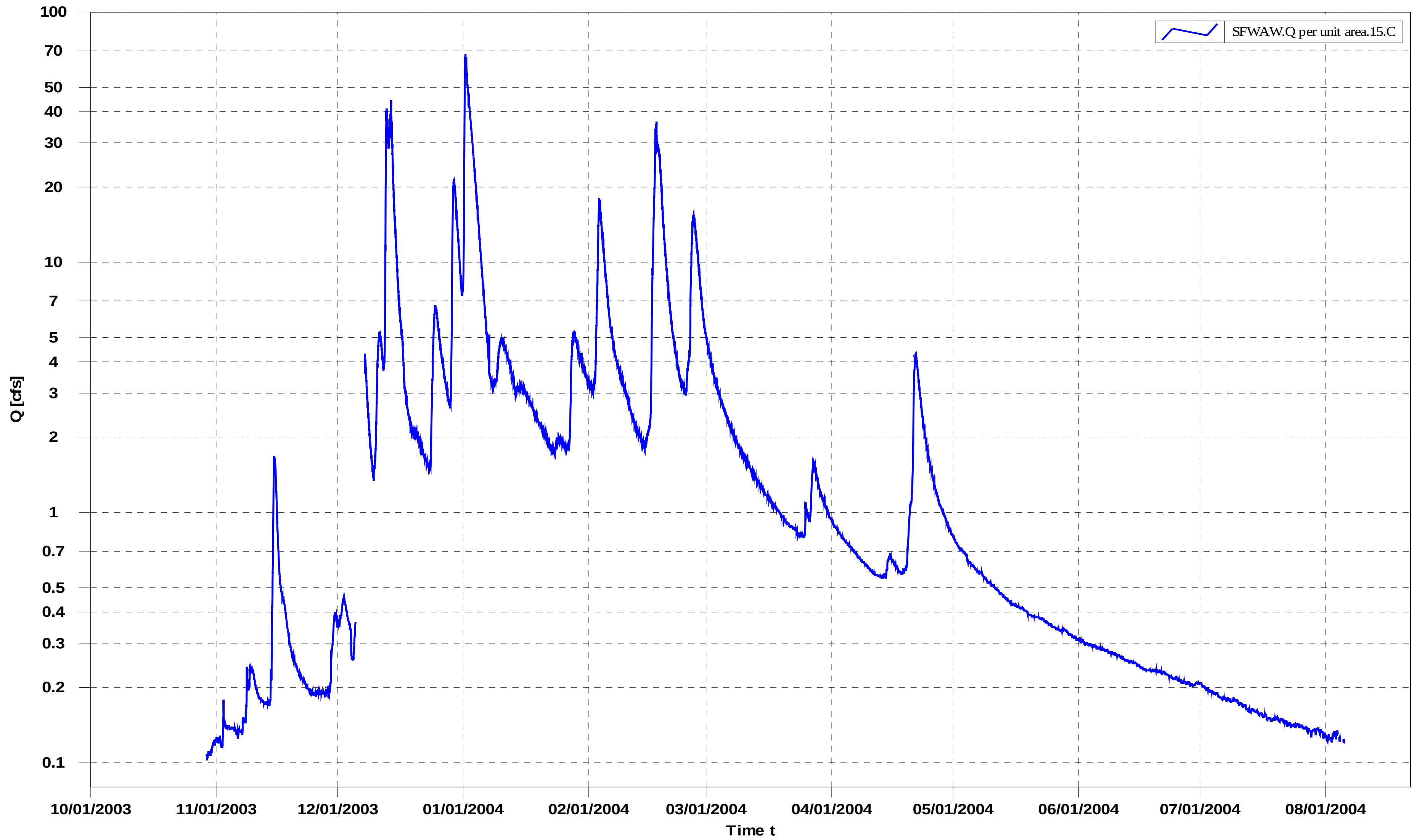
SOUTH FORK WAGES ABOVE WOOD CREEK
Synthetic Discharge Hydrograph Derived from SFWAC Record



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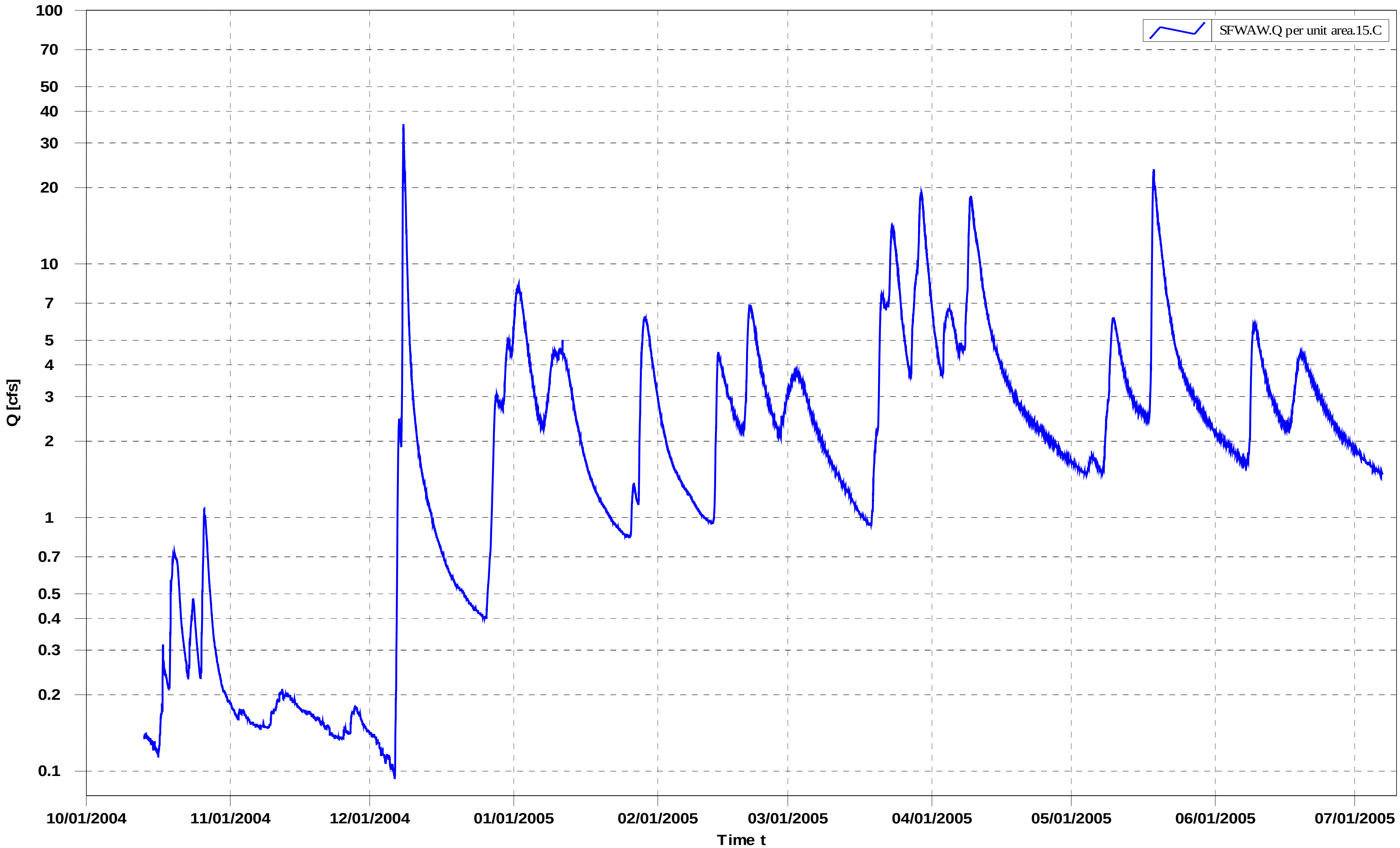
WY 2004
APPENDIX

E-6a

SOUTH FORK WAGES ABOVE WOOD CREEK
Synthetic Discharge Hydrograph Derived from SFWAC Record



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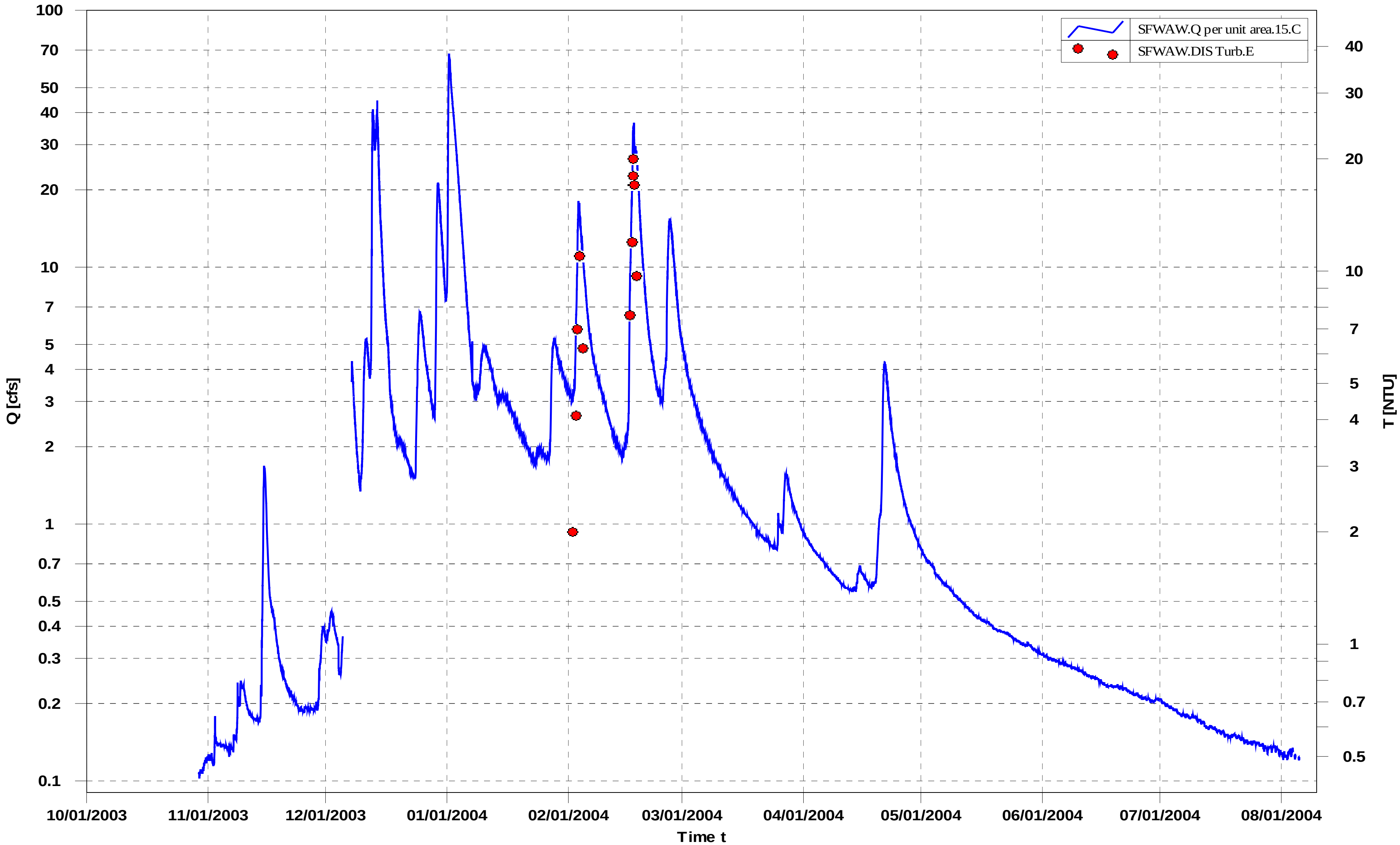
WY 2005
APPENDIX

E-6b

SOUTH FORK WAGES CREEK ABOVE WOOD CREEK
Synthetic Discharge Hydrograph with Depth-Integrated Turbidity Samples



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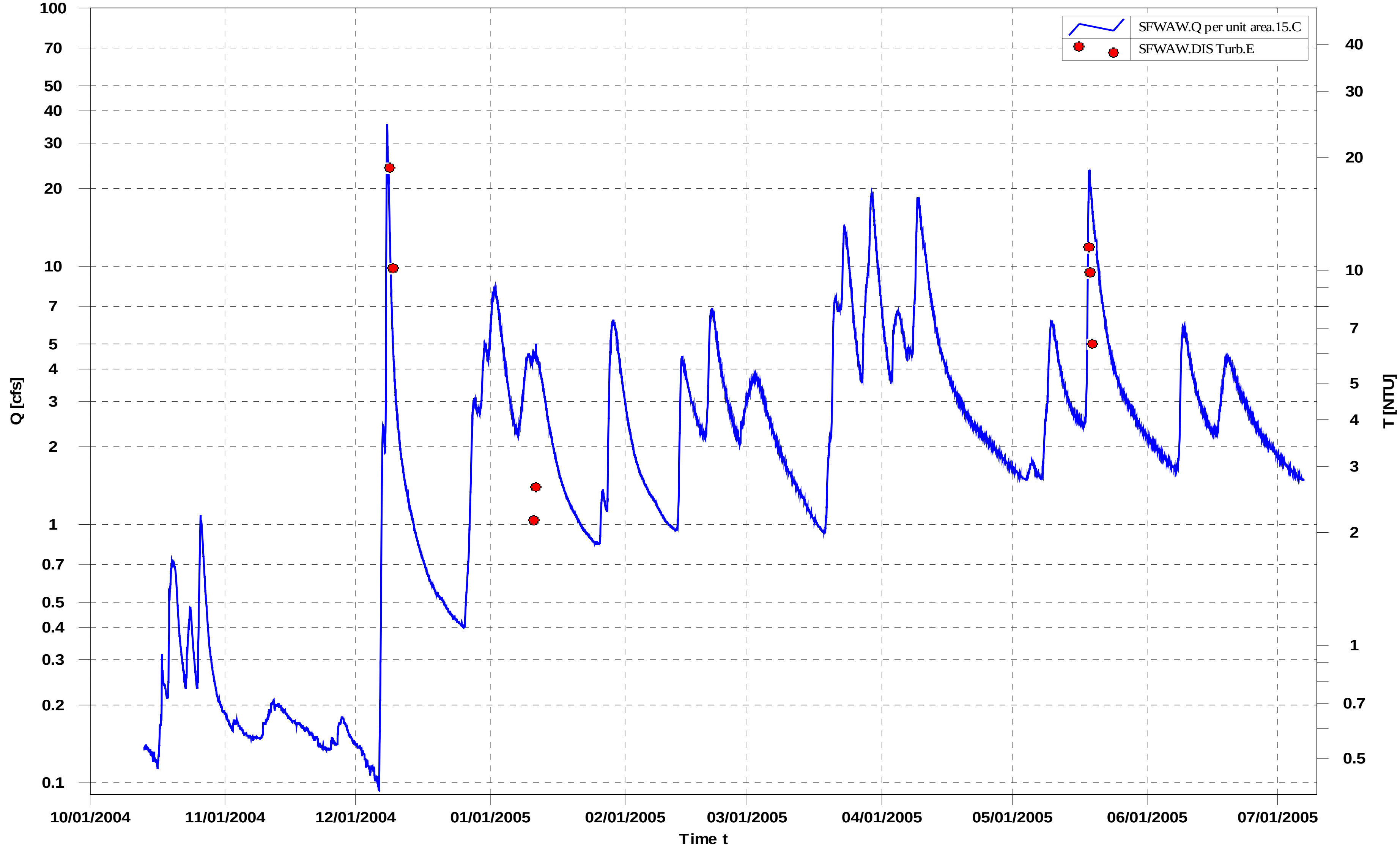
WY 2004
APPENDIX

E-7a

SOUTH FORK WAGES CREEK ABOVE WOOD CREEK
Synthetic Discharge Hydrograph with Depth-Integrated Turbidity Samples



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WY 2005 APPENDIX

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SEDIMENT SAMPLE SUMMARY SHEET

LOCATION: SOUTH FORK WAGES ABOVE WOOD CREEK **WATER YEAR: 2004**

Date Time	Sample Number	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	Q/WSA (cfs/mi^2)	SSL (ton/day)	SSLPA (ton/day/mi2)	Type (DIS, PUMP)	Note
2/2/2004 05:28	SFWAW-SSCT2004-01	2.0	5	1.64	3.22	4.4	0.04	0.06	DIS	
2/2/2004 21:12	SFWAW-SSCT2004-02	4.1	7	1.77	5.39	7.4	0.10	0.13	DIS	
2/3/2004 06:12	SFWAW-SSCT2004-03	7.0	11	1.99	10.3	14	0.30	0.41	DIS	
2/3/2004 19:27	SFWAW-SSCT2004-04	11	24	2.15	16.3	22	1.0	1.4	DIS	
2/4/2004 16:25	SFWAW-SSCT2004-05	6.2	1	2.01	11.2	15	0.04	0.05	DIS	
2/16/2004 19:19	SFWAW-SSCT2004-06	7.6	4	1.92	9.60	13	0.12	0.16	DIS	
2/17/2004 08:44	SFWAW-SSCT2004-07	12	13	2.20	24.8	34	0.84	1.2	DIS	
2/17/2004 11:21	SFWAW-SSCT2004-08	17	31	2.30	30.0	41	2.5	3.4	DIS	
2/17/2004 11:37	SFWAW-SSCT2004-09	18	35	2.36	31.0	42	2.9	4.0	DIS	
2/17/2004 14:26	SFWAW-SSCT2004-10	20	39	2.46	34.0	47	3.6	4.9	DIS	
2/17/2004 20:58	SFWAW-SSCT2004-11	17	15	2.41	33.0	45	1.3	1.8	DIS	
2/18/2004 11:56	SFWAW-SSCT2004-12	9.7	6	2.28	27.0	37	0.45	0.61	DIS	

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WY 2004 APPENDIX

E-8a

SEDIMENT SAMPLE SUMMARY SHEET

LOCATION: SOUTH FORK WAGES ABOVE WOOD CREEK **WATER YEAR: 2005**

Date Time	Sample Number	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	Q/WSA (cfs/mi^2)	SSL (ton/day)	SSLPA (ton/day/mi2)	Type (DIS, PUMP)	Note
12/8/2004 08:24	SFWAW-SSCT2005-01	33	3	2.57	28.5	39	0.19	0.26	DIS	Censored
12/8/2004 17:29	SFWAW-SSCT2005-02	19	9	2.24	17.9	25	0.45	0.61	DIS	
12/9/2004 12:53	SFWAW-SSCT2005-03	10	10	1.88	5.36	7.3	0.14	0.19	DIS	
1/10/2005 21:14	SFWAW-SSCT2005-04	2.2	4	1.75	4.60	6.3	0.05	0.07	DIS	
1/11/2005 11:13	SFWAW-SSCT2005-05	2.7	1	1.76	4.58	6.3	0.02	0.02	DIS	
5/18/2005 13:23	SFWAW-SSCT2005-06	12	19	2.11	19.7	27	1.0	1.4	DIS	
5/18/2005 18:35	SFWAW-SSCT2005-07	9.9	8	2.17	23.3	32	0.50	0.69	DIS	
5/19/2005 09:08	SFWAW-SSCT2005-08	6.4	6	2.06	17.0	23	0.29	0.40	DIS	

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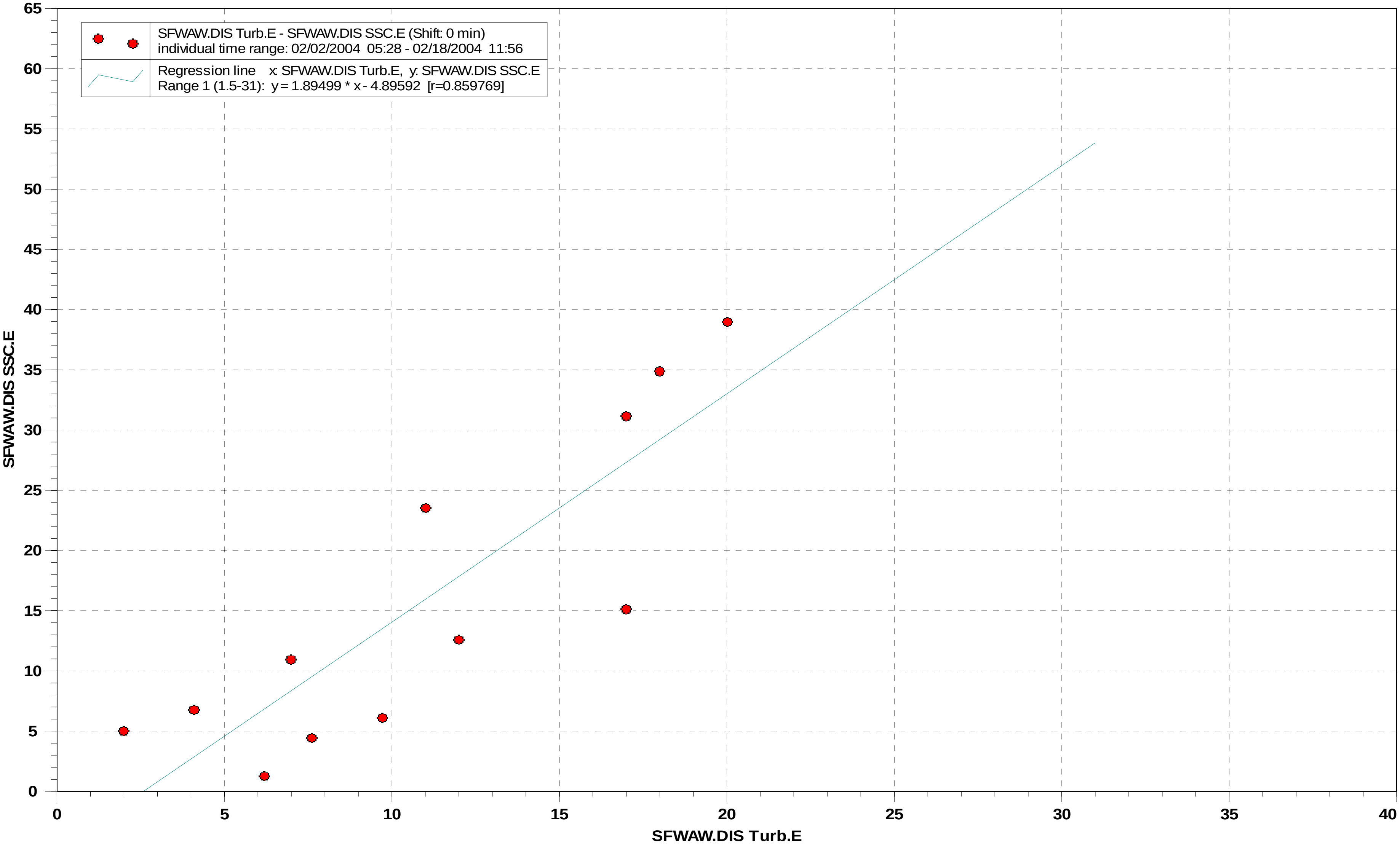
WY 2005 APPENDIX

E-8b

SOUTH FORK WAGES CREEK ABOVE WOOD CREEK
Depth-Integrated Turbidity vs Depth-Integrated SSC



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WY 2004 APPENDIX

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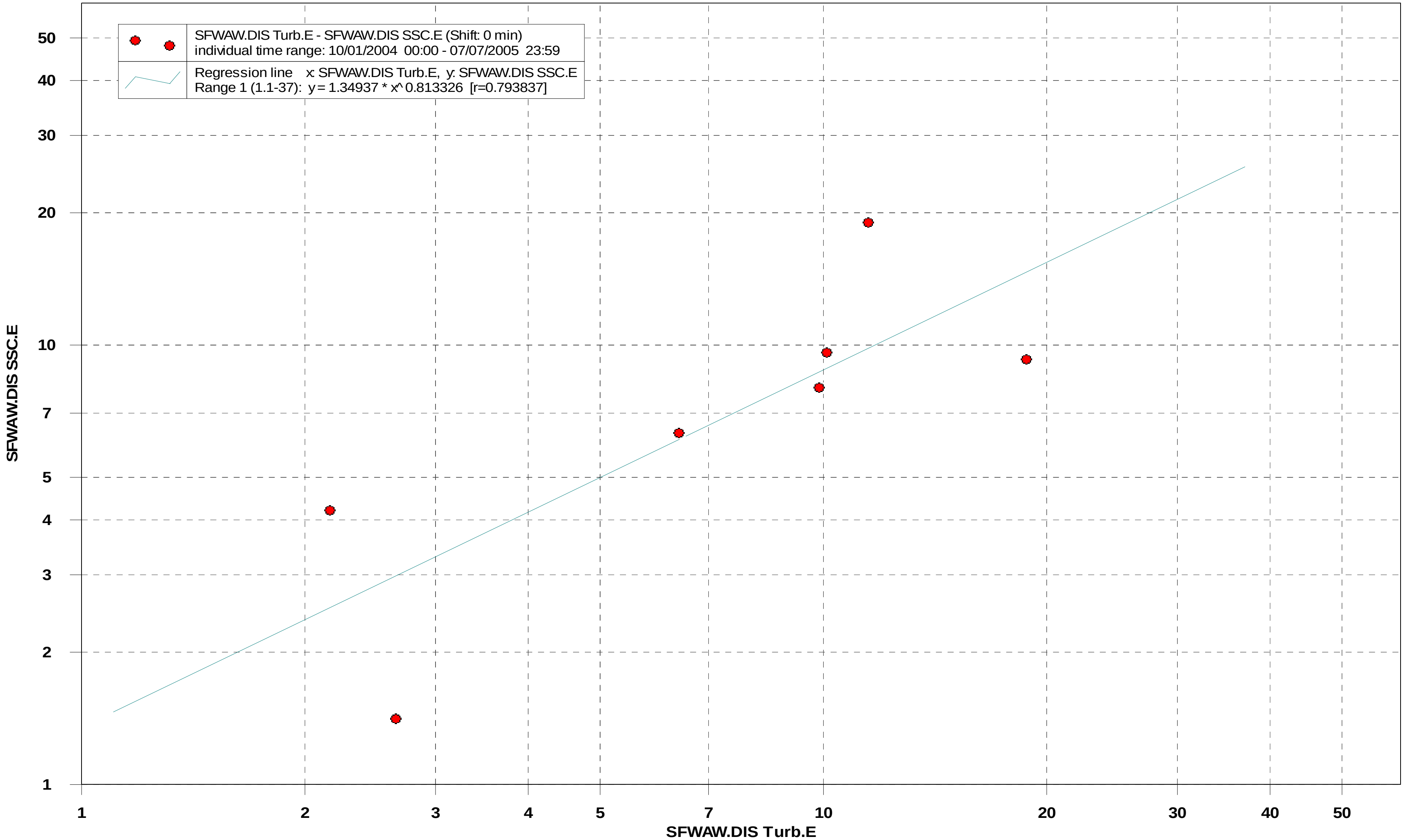
SOUTH FORK WAGES CREEK ABOVE WOOD CREEK
Depth-Integrated Turbidity vs Depth-Integrated SSC



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WY 2005
APPENDIX

E-9b

DISCHARGE SUMMARY SHEET

LOCATION: Rock Creek Above South Fork Wages Creeek **WATER YEAR:** 2004, 2005

Measurement Number	WY Msmt #	Date	Made By	Width (feet)	Mean Depth (feet)	Area (ft^2)	Mean Velocity (ft/sec)	Gage Height (feet)	Discharge (cfs)	Rating 1.2 Shift Adj.	Rating 1.2 Percent Diff.	Method	No. of Msmt sections	Begin Time (hours)	End Time (hours)	Msmt Rating	GZF (feet)	Notes
1	2004-01	2/2/2004	K. Faucher	1.0	0.24	0.24	1.26	2.36	0.30		0	wading	6	15:55	16:00	Poor		
2	2004-02	2/3/2004	T. Grey	6.0	0.62	3.71	1.04	3.04	3.84		-1	wading	25	08:44	09:17	Poor		
3	2004-03	2/3/2004	K. Faucher	6.7	0.61	4.08	1.16	3.20	4.74		-1	wading	23	17:23	18:12	Poor		
4	2004-04	2/4/2004	T. Grey	3.4	0.71	2.43	1.16	2.82	2.81		3	wading	17	14:53	15:14	Poor		
5	2004-05	2/17/2004	T. Grey	7.9	0.67	5.31	2.12	3.48	11.3		1	wading	29	18:19	18:57	Fair		
										Rating 1.3								
6	2005-01	2/22/2005	R. Leisse	2.7	0.37	1.01	0.62	2.67	0.63		7	wading	11	12:57	13:12	poor		
7	2005-02	2/22/2005	R. Leisse	2.7	0.36	0.98	0.57	2.69	0.58		-9	wading	11	13:18	13:28	poor		
8	2005-03	3/28/2005	K. Faucher	2.5	0.40	1.00	2.26	3.02	2.26		-1	wading	9	13:41	13:48	poor		
9	2005-04	5/18/2005	K. Faucher	8.7	0.42	3.69	1.62	3.29	5.97		0	wading	17	19:21	19:38	poor	2.39	high stage pzf, not applied to rating

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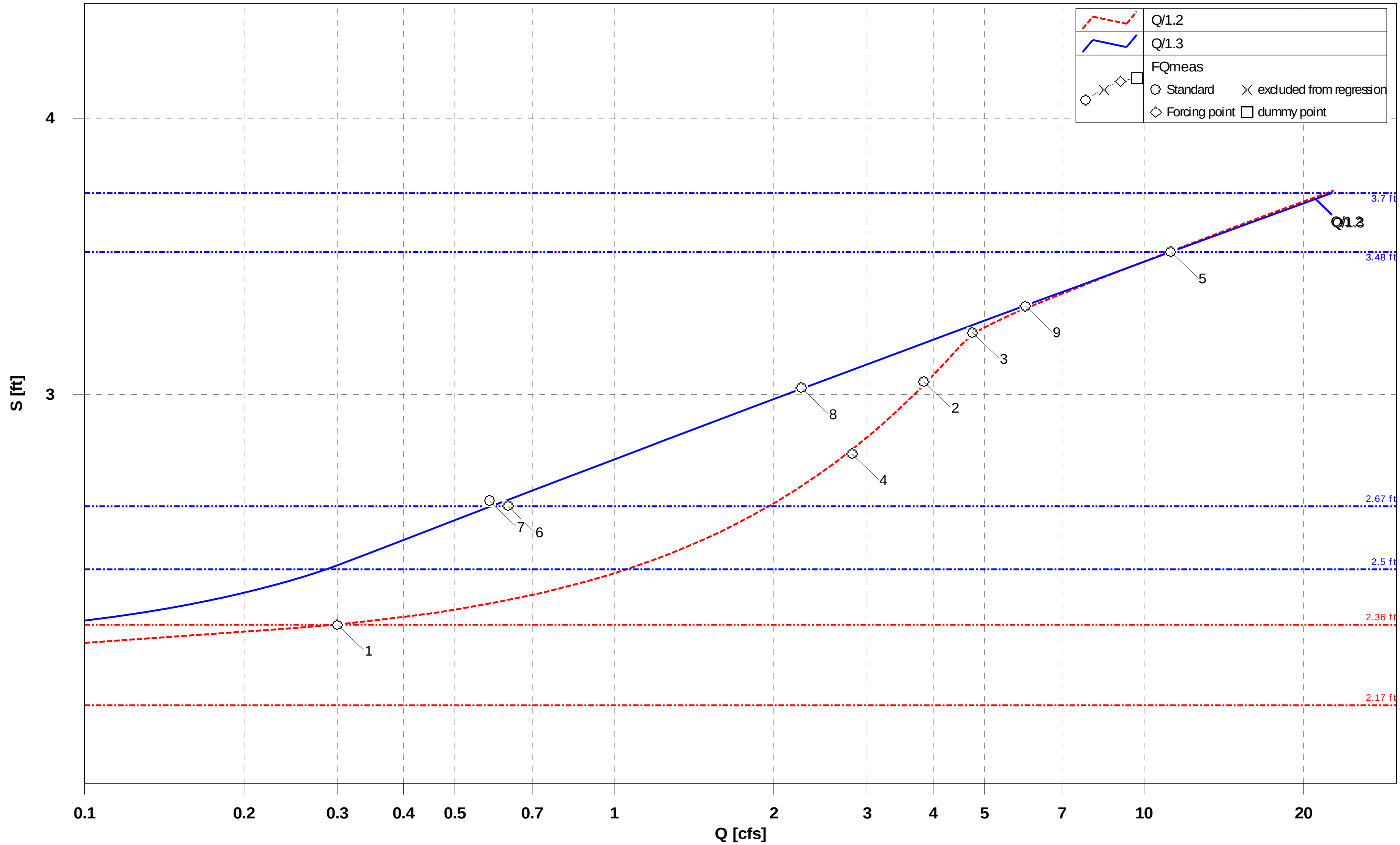
WY 04-05
APPENDIX

F-2

ROCK CREEK ABOVE SOUTH FORK WAGES CREEK
Discharge Rating Curves 1.2 & 1.3



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APPENDIX

F-3

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ROCK CREEK ABOVE SOUTH FORK WAGES CREEK

RATING TABLE NO.1.2 -- Begin Date 10/1/03

GH	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	1st Diff	2nd Diff
1.8	---	---	---	---	---	---	---	---	---	---	---	---
1.9	---	---	---	---	---	---	---	---	---	---	---	---
2.0	---	---	---	---	---	---	---	---	---	---	---	---
2.1	---	---	---	---	---	---	---	---	---	---	---	---
2.2	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.04	0.05		---
2.3	0.07	0.09	0.11	0.14	0.19	0.24	0.3	0.35	0.4	0.46	0.41	---
2.4	0.51	0.57	0.62	0.67	0.73	0.78	0.84	0.89	0.95	1.00	0.54	0.13
2.5	1.06	1.11	1.16	1.22	1.27	1.32	1.37	1.43	1.48	1.53	0.53	-0.01
2.6	1.59	1.64	1.69	1.74	1.8	1.85	1.9	1.96	2.01	2.06	0.53	0.00
2.7	2.12	2.17	2.22	2.27	2.33	2.38	2.43	2.48	2.54	2.59	0.53	0.00
2.8	2.64	2.69	2.74	2.8	2.85	2.9	2.95	3.01	3.06	3.11	0.52	-0.01
2.9	3.16	3.22	3.27	3.32	3.37	3.42	3.47	3.53	3.58	3.63	0.52	0.00
3.0	3.69	3.74	3.79	3.84	3.89	3.94	3.99	4.05	4.1	4.15	4.15	4.15
3.1	4.21	4.26	4.31	4.36	4.42	4.47	4.53	4.59	4.66	4.73	0.58	-3.57
3.2	4.8	4.92	5.04	5.17	5.31	5.46	5.61	5.78	5.95	6.14	1.41	0.83
3.3	6.34	6.54	6.75	6.97	7.19	7.42	7.66	7.9	8.15	8.41	2.27	0.86
3.4	8.67	8.95	9.23	9.53	9.83	10.1	10.5	10.8	11.1	11.5	3.09	0.82
3.5	11.9	12.2	12.6	13	13.4	13.9	14.3	14.8	15.2	15.7	4.20	1.11
3.6	16.2	16.7	17.2	17.8	18.3	18.9	19.5	20.1	20.8	21.4	5.70	1.50
3.7	22.1	22.8	---	---	---	---	---	---	---	---	---	---
3.8	*22.6*	---	---	---	---	---	---	---	---	---	---	---
3.9	---	---	---	---	---	---	---	---	---	---	---	---
4.0	---	---	---	---	---	---	---	---	---	---	---	---
4.1	---	---	---	---	---	---	---	---	---	---	---	---
4.2	---	---	---	---	---	---	---	---	---	---	---	---

Values in italics are beyond the validated range of the rating

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ROCK CREEK ABOVE SOUTH FORK WAGES CREEK

RATING TABLE NO.1.3 -- Begin Date 10/1/04

GH	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	1st Diff	2nd Diff
1.8	---	---	---	---	---	---	---	---	---	---	---	---
1.9	---	---	---	---	---	---	---	---	---	---	---	---
2.0	---	---	---	---	---	---	---	---	---	---	---	---
2.1	---	---	---	---	---	---	---	---	---	---	---	---
2.2	---	---	---	---	---	---	---	---	---	---	---	---
2.3	*0.00*	*0.01*	*0.03*	*0.04*	*0.06*	*0.07*	*0.09*	*0.10*	*0.11*	*0.13*	---	---
2.4	*0.14*	*0.16*	*0.17*	*0.19*	*0.20*	*0.21*	*0.23*	*0.24*	*0.26*	*0.27*	0.14	---
2.5	*0.29*	*0.3*	*0.31*	*0.33*	*0.34*	*0.36*	*0.37*	*0.39*	*0.40*	*0.42*	0.15	0.01
2.6	*0.44*	*0.46*	*0.48*	*0.50*	*0.52*	*0.54*	*0.56*	0.59	0.61	0.64	0.22	0.07
2.7	0.66	0.69	0.72	0.75	0.78	0.81	0.84	0.88	0.91	0.95	0.31	0.09
2.8	0.99	1.03	1.07	1.11	1.15	1.20	1.24	1.29	1.34	1.40	0.45	0.14
2.9	1.45	1.51	1.56	1.62	1.69	1.75	1.82	1.89	1.96	2.03	0.63	0.18
3.0	2.11	2.19	2.28	2.36	2.45	2.55	2.64	2.74	2.84	2.94	0.91	0.28
3.1	3.05	3.16	3.28	3.40	3.52	3.65	3.78	3.92	4.06	4.20	1.26	0.35
3.2	4.35	4.51	4.67	4.83	5.00	5.17	5.35	5.54	5.74	5.94	1.74	0.48
3.3	6.15	6.37	6.6	6.83	7.06	7.31	7.56	7.82	8.08	8.35	2.41	0.67
3.4	8.63	8.92	9.21	9.52	9.85	10.2	10.5	10.9	11.2	11.6	3.25	0.84
3.5	*12.0*	*12.4*	*12.8*	*13.2*	*13.6*	*14.1*	*14.5*	*15.0*	*15.5*	*16.0*	4.40	1.15
3.6	*16.5*	*17.1*	*17.6*	*18.2*	*18.7*	*19.3*	*19.9*	*20.6*	*21.2*	*21.9*	5.90	1.50
3.7	*22.6*	---	---	---	---	---	---	---	---	---	---	---
3.8	---	---	---	---	---	---	---	---	---	---	---	---
3.9	---	---	---	---	---	---	---	---	---	---	---	---
4.0	---	---	---	---	---	---	---	---	---	---	---	---
4.1	---	---	---	---	---	---	---	---	---	---	---	---
4.2	---	---	---	---	---	---	---	---	---	---	---	---

Values in italics are beyond the validated range of the rating

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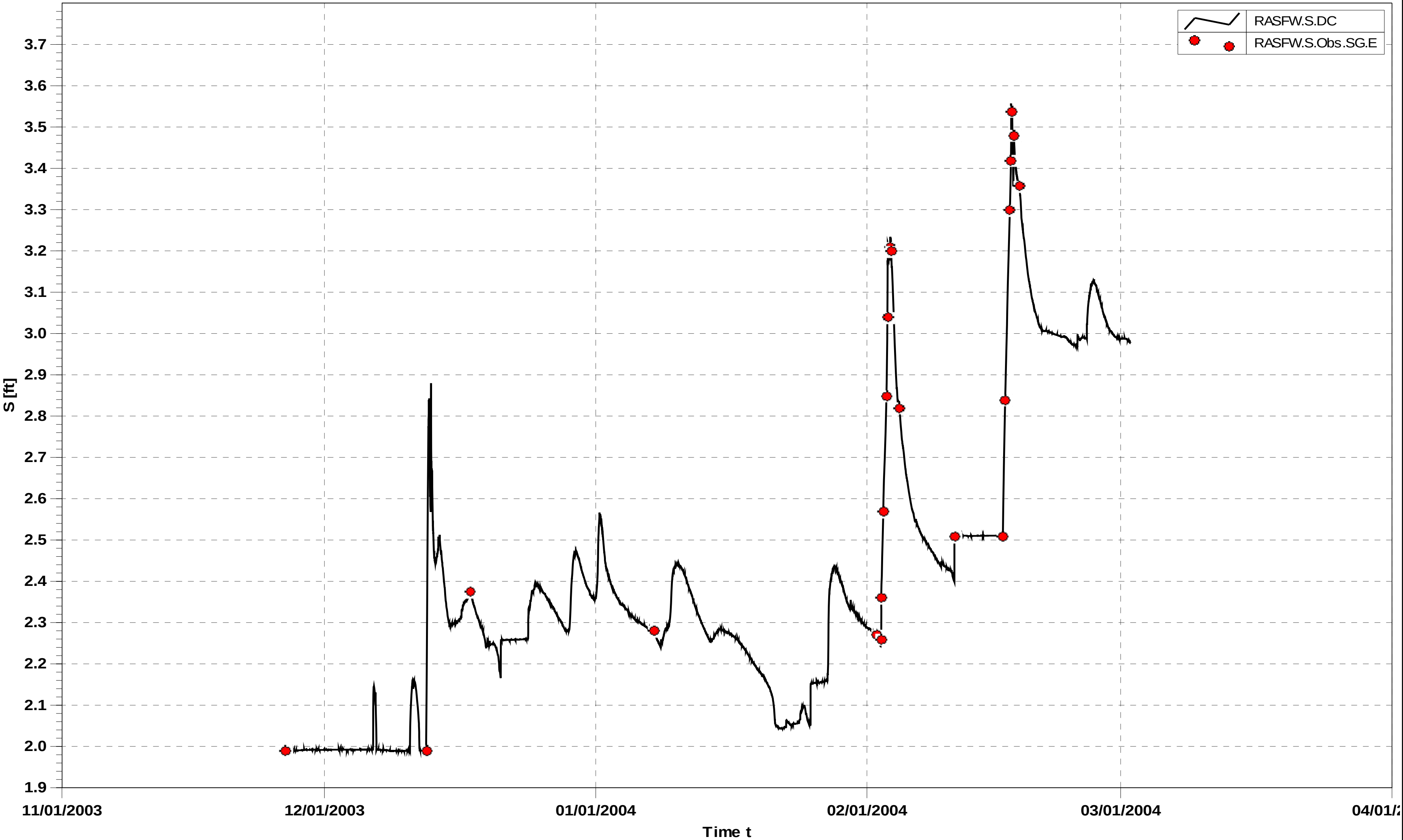
ROCK CREEK ABOVE SOUTH FORK WAGES CREEK
15-Minute Adjusted Gage Height Record and Observed Staff Gage Readings



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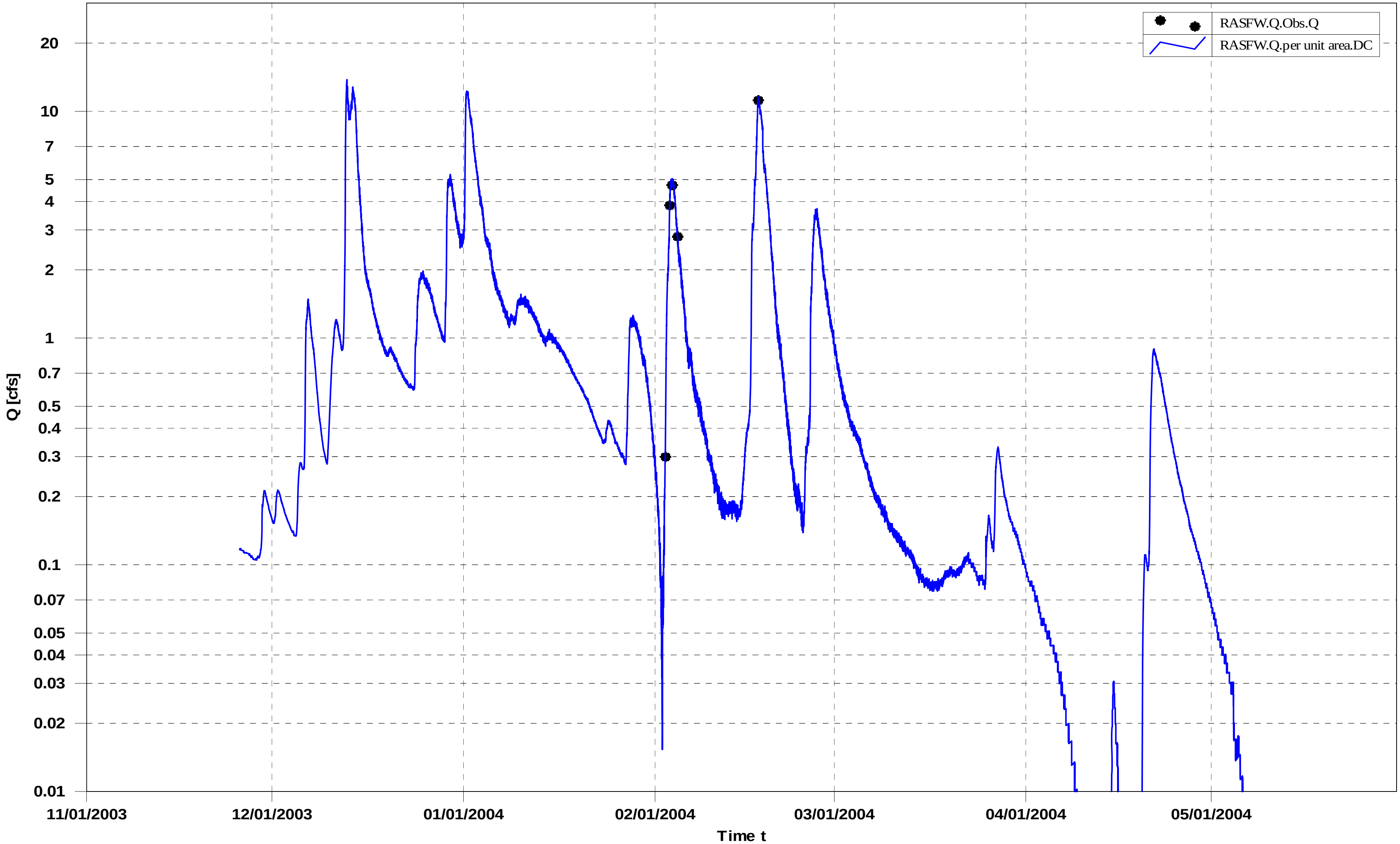
WY 2004 APPENDIX

F-5

ROCK CREEK ABOVE SOUTH FORK WAGES CREEK
Synthetic Hydrograph Derived from SFWAR Record and Discharge Measurements



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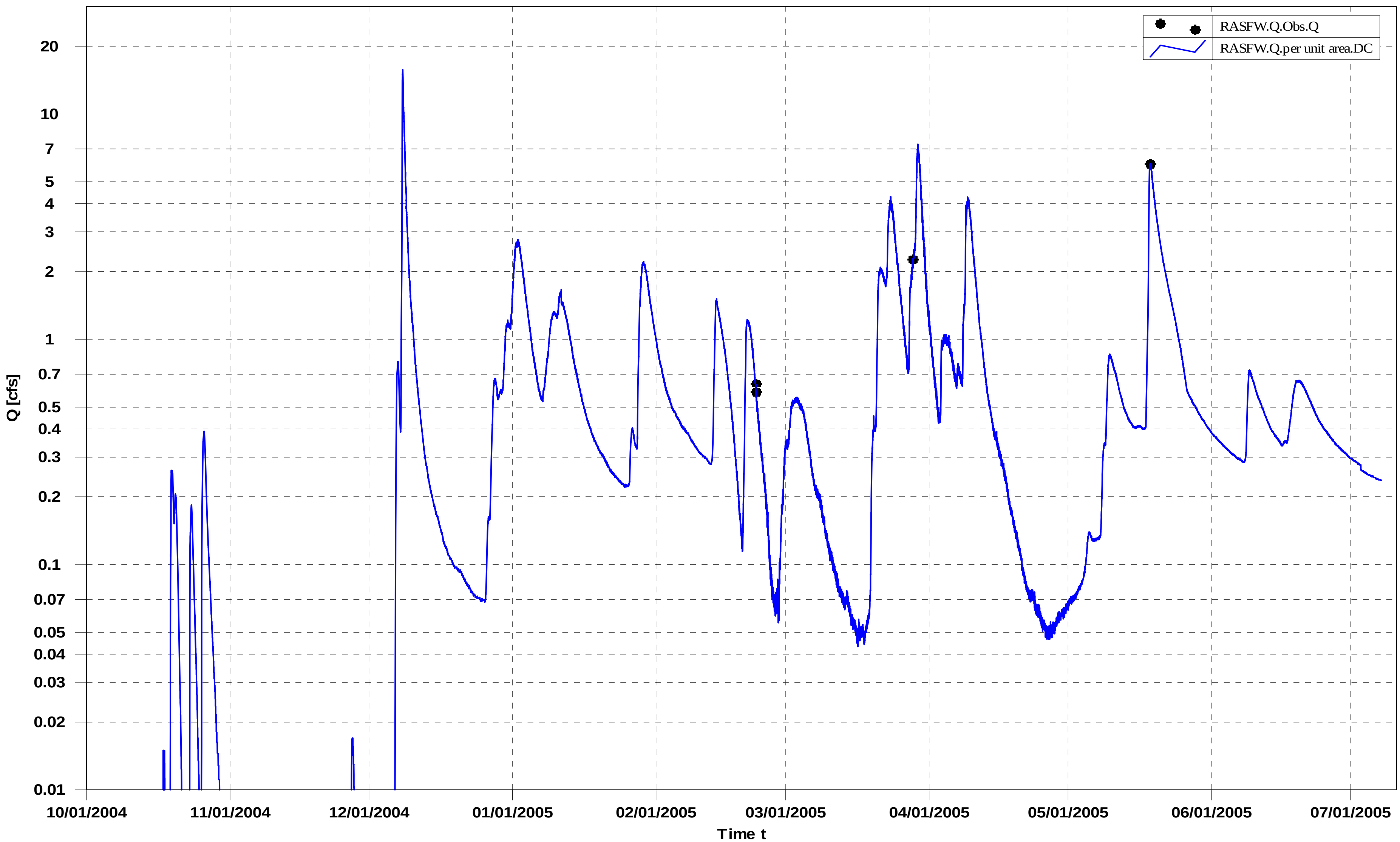
WY 2004
APPENDIX

F-6a

ROCK CREEK ABOVE SOUTH FORK WAGES CREEK
Synthetic Discharge Hydrograph Derived from SFWAR Record and Discharge Measurements



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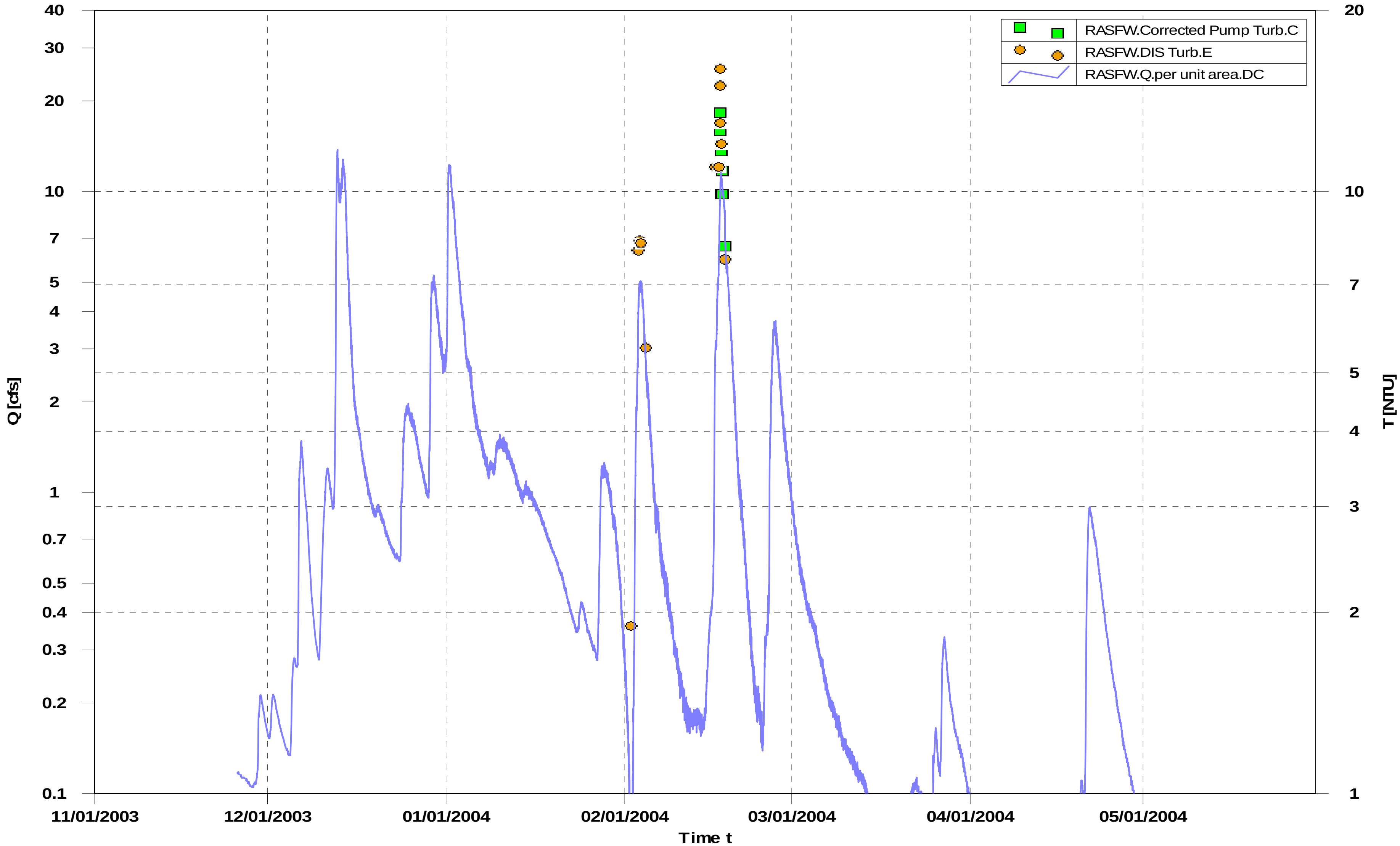
WY 2005
APPENDIX

F-6b

ROCK CREEK ABOVE SOUTH FORK WAGES CREEK
Synthetic Discharge Hydrograph Derived from SFWAR Record with Pump and Depth-Integrated Turbidity Samples



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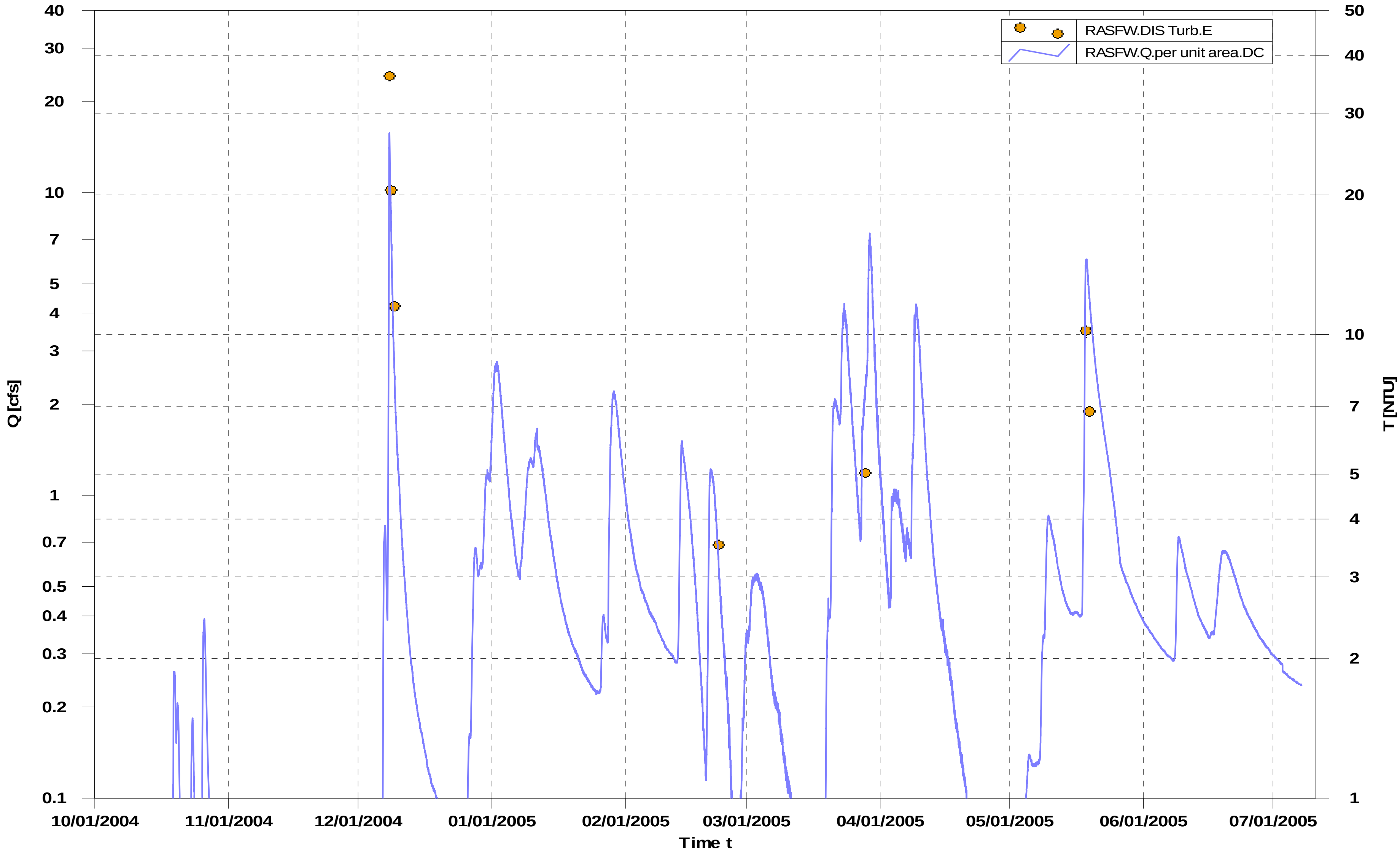
WY 2004
APPENDIX

F-7a

ROCK CREEK ABOVE SOUTH FORK WAGES CREEK
Synthetic Discharge Hydrograph with Depth-Integrated Turbidity Samples



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WY 2005
APPENDIX

F-7b

SEDIMENT SAMPLE SUMMARY SHEET

LOCATION: ROCK CREEK ABOVE SOUTH FORK WAGES **WATER YEAR: 2004**

Date Time	Sample Number	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	Q/WSA (cfs/mi^2)	SSL (ton/day)	SSLPA (ton/day/mi2)	Type (DIS, PUMP)	Note
2/2/2004 04:25	RASFW-SSCT2004-01	1.9	1	2.27	0.03	0.13	0.00	0.00	DIS	
2/2/2004 20:40	RASFW-SSCT2004-02	4.7	17	2.57	1.43	5.96	0.07	0.28	DIS	Censored
2/3/2004 05:34	RASFW-SSCT2004-03	8.0	5	2.85	2.90	12.1	0.04	0.16	DIS	
2/3/2004 08:30	RASFW-SSCT2004-04	8.0	6	3.04	3.89	16.2	0.06	0.25	DIS	
2/3/2004 15:51	RASFW-SSCT2004-05	8.3	5	3.21	4.92	20.5	0.06	0.26	DIS	
2/3/2004 18:27	RASFW-SSCT2004-06	8.2	3	3.20	4.80	20.0	0.04	0.16	DIS	
2/4/2004 16:06	RASFW-SSCT2004-07	5.5	1	2.82	2.74	11.4	0.00	0.02	DIS	
2/16/2004 18:54	RASFW-SSCT2004-08	11	4	2.84	2.85	11.9	0.03	0.13	DIS	
2/17/2004 08:27	RASFW-SSCT2004-09	11	13	3.30	6.34	26.4	0.22	0.93	DIS	
2/17/2004 10:44	RASFW-SSCT2004-10	13	19	3.42	9.23	38.5	0.48	2.0	DIS	
2/17/2004 10:46	RASFW-SSCT2004-11	15	23	2.73	2.27	9.46	0.14	0.58	PUMP	T-PROBE = 20 NTU
2/17/2004 14:15	RASFW-SSCT2004-12	16	23	3.54	13.4	55.8	0.84	3.5	DIS	
2/17/2004 14:46	RASFW-SSCT2004-13	15	17	2.73	2.27	9.46	0.10	0.43	PUMP	T-PROBE = 22 NTU
2/17/2004 15:31	RASFW-SSCT2004-14	14	17	2.72	2.22	9.25	0.10	0.42	PUMP	T-PROBE = 91 NTU
2/17/2004 18:01	RASFW-SSCT2004-15	13	14	2.78	2.54	10.6	0.10	0.40	PUMP	T-PROBE = 166 NTU
2/17/2004 18:46	RASFW-SSCT2004-16	13	17	2.88	3.06	12.8	0.14	0.60	PUMP	T-PROBE = 16 NTU
2/17/2004 19:08	RASFW-SSCT2004-17	12	11	3.48	11.1	46.3	0.32	1.3	DIS	
2/17/2004 19:31	RASFW-SSCT2004-18	11	7	2.88	3.06	12.8	0.06	0.25	PUMP	T-PROBE = 32 NTU
2/17/2004 21:46	RASFW-SSCT2004-19	12	5	2.82	2.74	11.4	0.03	0.15	PUMP	T-PROBE = 24 NTU
2/17/2004 22:46	RASFW-SSCT2004-20	11	5	2.81	2.69	11.2	0.03	0.14	PUMP	T-PROBE = 15 NTU
2/18/2004 09:30	RASFW-SSCT2004-21	7.7	3	3.36	7.66	31.9	0.06	0.27	DIS	
2/18/2004 09:31	RASFW-SSCT2004-22	9.0	12	2.74	2.33	9.71	0.07	0.31	PUMP	T-PROBE = 9 NTU

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WY 2004 APPENDIX

F-8a

SEDIMENT SAMPLE SUMMARY SHEET

LOCATION: ROCK CREEK ABOVE SOUTH FORK WAGES WATER YEAR: 2005

Date Time	Sample Number	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	Q/WSA (cfs/mi^2)	SSL (ton/day)	SSLPA (ton/day/mi2)	Type (DIS, PUMP)	Note
12/8/2004 08:05	RASFW-SSCT2005-01	36	9	3.77	14.2	59.2	0.34	1.4	DIS	
12/8/2004 15:42	RASFW-SSCT2005-02	21	22	3.57	8.07	33.6	0.48	2.0	DIS	
12/9/2004 12:28	RASFW-SSCT2005-03	12	1	2.76	0.84	3.50	0.00	0.01	DIS	
2/22/2005 13:20	RASFW-SSCT2005-04	3.5	4	2.69	0.64	2.67	0.01	0.03	DIS	
3/28/2005 13:50	RASFW-SSCT2005-05	5.0	2	3.02	2.28	9.50	0.01	0.05	DIS	
5/18/2005 13:07	RASFW-SSCT2005-06	10	8	3.25	5.17	21.5	0.12	0.48	DIS	
5/18/2005 18:05	RASFW-SSCT2005-07	10	15	3.33	6.83	28.5	0.28	1.2	DIS	
5/19/2005 08:46	RASFW-SSCT2005-08	6.8	3	3.13	3.40	14.2	0.02	0.10	DIS	

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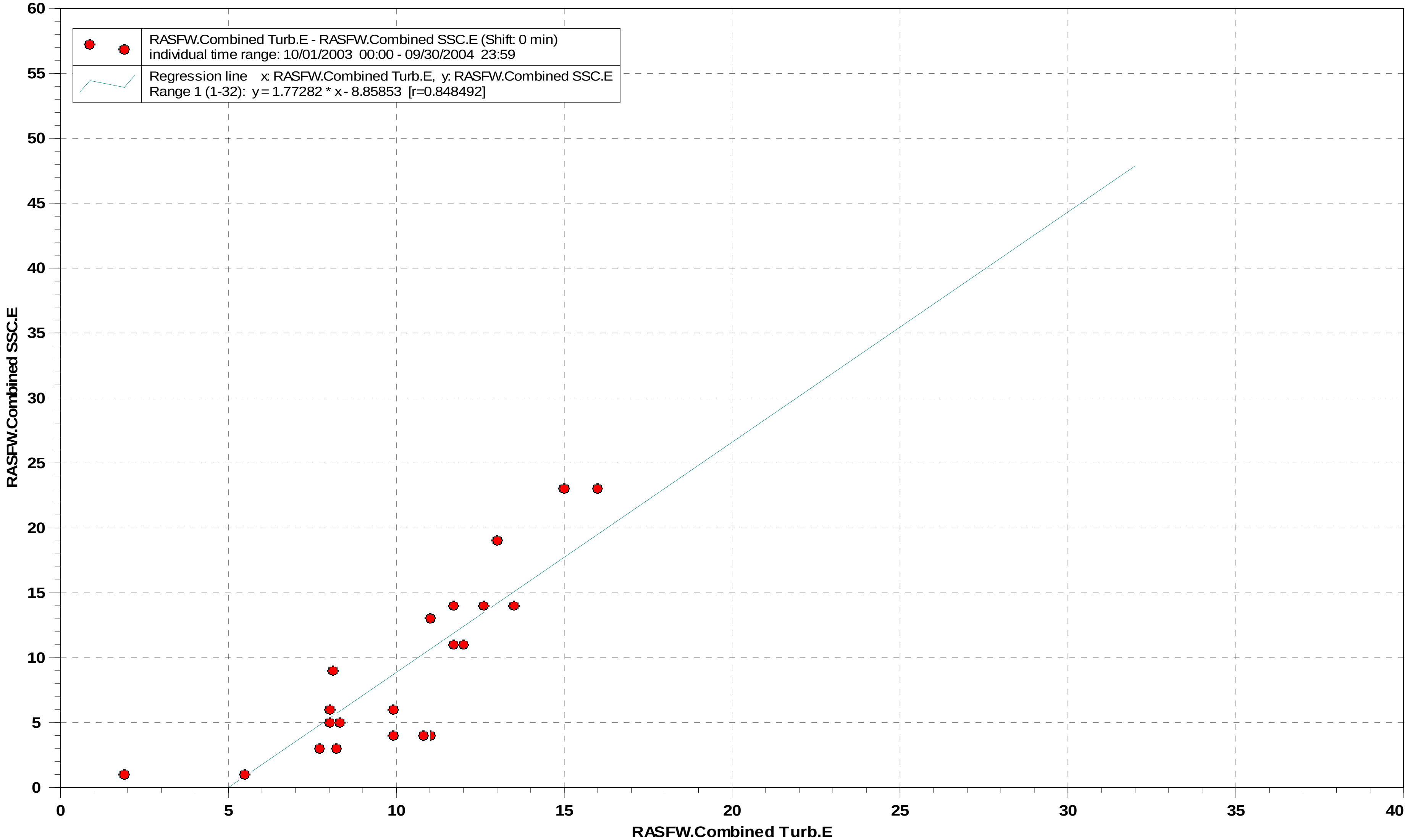
WY 2005 APPENDIX

F-8b

ROCK CREEK ABOVE SOUTH FORK WAGES CREEK
Depth-Integrated and Pump Turbidity vs Depth-Integrated and Pump SSC



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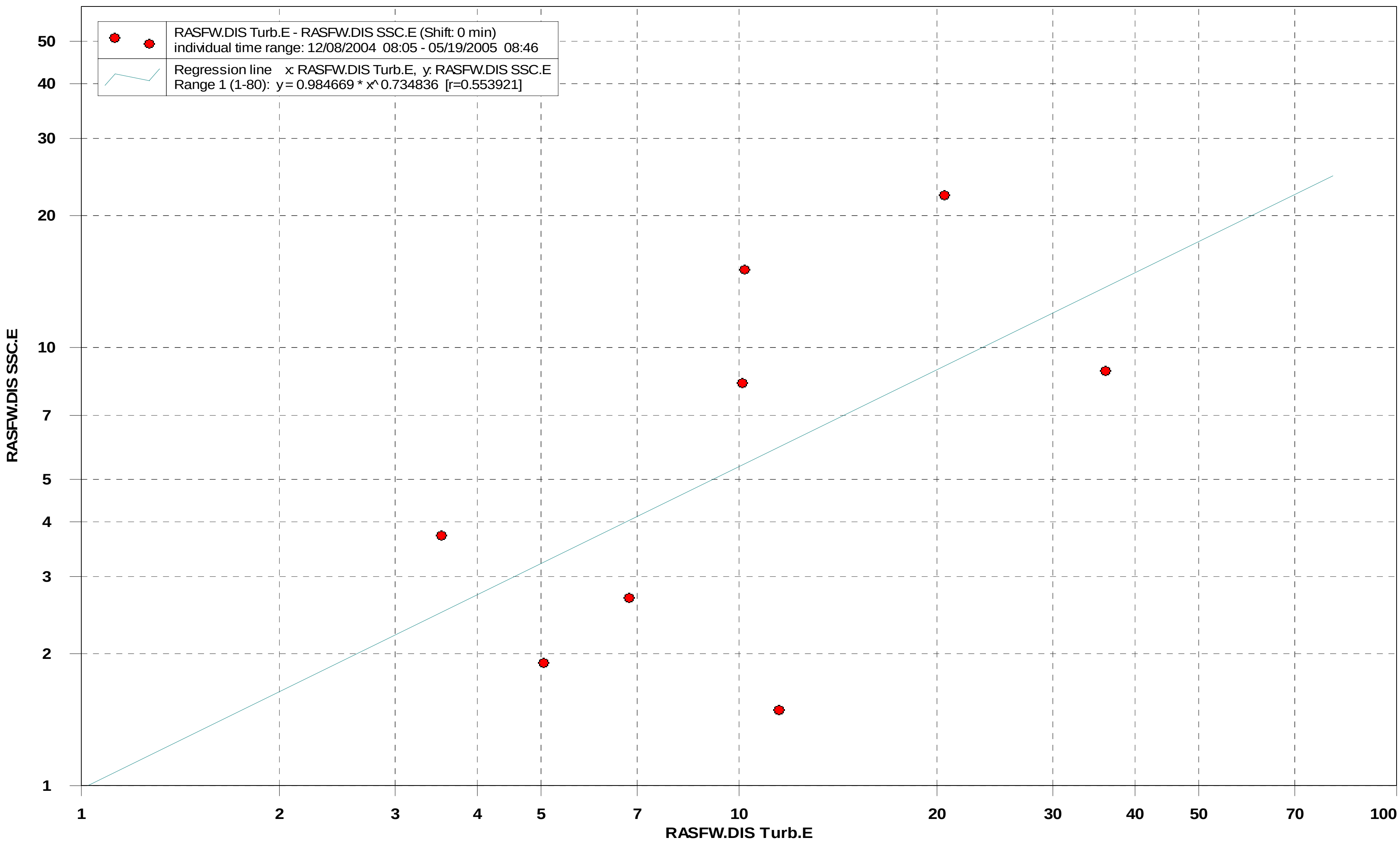
WY 2004
APPENDIX

F-9a

ROCK CREEK ABOVE SOUTH FORK WAGES CREEK
Depth-Integrated Turbidity vs Depth-Integrated SSC



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WY 2005
APPENDIX

F-9b

SOUTH FORK WAGES CREEK ABOVE ROCK CREEK
(STATION # CTM 0283030)
STATION ANALYSIS
WATER YEAR 2004-2005

RECORDS – Surface Water

EQUIPMENT – I Water Year 2004 a continuous streamflow and turbidity station was installed at this site. In Water Year 2005 the site was upgraded with a pump sampler. The TTS station includes an Isco 6712 full size portable sampler, a Campbell Scientific CR510 data collection platform (DCP), a waterlog H-310 pressure transducer and a forest technology systems DTS-12 turbidity sensor. The DCP is housed in a locked steel box that is installed on the right bank. The DTS-12 is housed in an aluminum boom assembly, which is attached to a cable way strung over the creek. The pressure transducer is located on the right bank 20 feet upstream of the turbidity boom. One staff plate is located on the left bank across from the pressure transducer.
Inside recording gage: Less than or equal to 0.02% of full scale output (FSO) over temperature range referenced (0 to 40^{o} C) to a straight line stretched from zero psi to maximum pressure (15 psi).
Outside staff gage: One USGS style A staff gage mounted on redwood and attached to channel iron that has been pounded into the streambed. Limits 0.00 ft. to 3.32 ft.

GAGE HEIGHT RECORDS – The record is incomplete for the period.
Station operation began in Water Year 2004 on November 25, 2003 at 18:45 hours.
A gap in the record exists on December 4, 2003 from 13:30 hours to 14:00 hours. Field notes indicated the station was down for maintenance. A gap exists on December 16, 2003 from 16:15 hours to 17:30 hours. There are no field notes explaining this gap. No other gaps or problems were encountered in Water Year 2004.
The minimum gage height of 0.81 ft occurred on September 26, 2004 at 23:15 hours. The maximum gage height of 1.47 ft occurred on December 13, 2003 at 03:30 hours.
The station was operated across the water year boundary. A gap in the record exists from November 2, 2004 at 13:00 hours through November 3, 2004 at 14:45 hours. Field notes indicate that a new pump sampler was installed on November 3, 2004 and 14:00 hours and that a new program was sent to the DCP. No other gaps or problems were encountered in Water Year 2005
The maximum gage height of 1.50 ft occurred on December 8, 2004 at 06:45 hours. The minimum gage height of 0.79 ft occurred on October 15, 2004 at 00:00 hours.

DATUM CORRECTIONS – Staff plate has not been surveyed, no datum correction known.

CONTROL – The low to mid range control is a gravel riffle subject to periodic shifts. The channel at the gage has small terraces with steep right and left banks.

RATING – In Water Year 2004, four discharge measurements (1-4) were made 1 measurement made subsequent, measurement 5, is used in this analysis. Measured discharge ranged from 1.52 cfs to 17.4 cfs. Computed instantaneous discharge ranged from 0.08 cfs to 22.4 cfs.
Measurements 1-4 were used to develop the middle and upper portions of Rating 1.2. Measurements 1-4 were all rated fair and all plotted within acceptable limits given their measurement rating.

Measurement 5, made on October 13, 2004 was used to develop the low end of Rating 1.2. Measurement 5 plotted directly on the rating and was rated poor.
In Water Year 2005, 7 discharge measurements (5-11) were made. Measured discharge ranged from 0.08 cfs to 7.59 cfs.
Measurement 5 was used to verify that Rating 1.2 was still valid in the beginning of the water year.
Measurement 6, made on December 28, 2004, was not used in this analysis. Measurement 6 had no left edge water information in the AquaCalc Pro file or the field notes.
Measurement 7, made on January 11, 2005, indicated a -0.02 ft shift in Rating 1.2. No check measurement was made. Subsequent measurements, measurements 8, 9, and 10 also indicated a -0.02 ft to -0.03 ft shift in Rating 1.2.
Because the measurement range was fairly narrow in Water Year 2005 it was necessary to shift Rating 1.2 by -0.03 ft in order to be able to calculate flows in Water Year 2005.
Rating 2.1 was developed based on the shifts indicated by measurements 7-10 (-0.02 ft to -0.03 ft). Rating 2.1 has the same shape as Rating 1.2 but is shifted by -0.03 ft. Rating 2.1 is prorated into effect beginning on December 8, 2004 at 06:30 hours and is fully in effect by December 8, 2004 at 18:00 hours. Rating 2.1 is prorated into effect with the idea that the fill of the control had occurred between 06:30 hours, the peak of the December 8th storm, 18:00 hours.
Measurement 7 plotted 7% from Rating 2.1 and was rated poor.
Measurements 8, 9, and 10 all plotted within 5% of Rating 2.1 and were rated poor, poor, and fair respectively. Measurement 9 was a check measurement for measurement 8.
Measurement 11, made on May 18, 2005, plotted -25% from Rating 2.1 and was rated fair. No check measurement was made. The shift indicated by the measurement -0.05 ft and a reading of the GZF also indicated that the elevation of the control had changed. Measurement 11 was used to develop TV05-1. TV05-1 is prorated into effect beginning on March 29, 2005 at 13:30 hours and reaches full weight by March 30, 2005 at 07:00 hours. TV05-1 is prorated into effect with the idea that fill occurred on the control between the peak of the storm on March 29, 2005 and that control most likely stabilized (at a higher elevation) by March 30, 2005 at 07:00 hours. TV05-1 is defined by measurement 11 to within -1 % of Rating 2.1

DISCHARGE – Rating 1.2 and 2.1 were used in Water Year 2005 as follows:

Water Year 2004

Nov. 25 to Sept. 30 (24:00)	Rating 1.2

Water Year 2005

Oct. 1 to Dec. 8 (06:30)	Rating 1.2
Dec. 8 to Dec. 8 (18:00)	Prorate to Rating 2.1
Dec. 8 to Mar. 29 (13:30)	Rating 2.1
Mar. 29 to Mar. 30 (07:00)	Prorate to TV05-1 (0.65,-.05; 1.11,-.05; 1.57,-.05)
Mar. 30 to Jul. 7 (15:00)	TV05-1 (0.65,-.05; 1.11,-.05; 1.57,-.05)

SPECIAL COMPUTATIONS – None Made

REMARKS – Based on the measurement ratings the record for Water Year 2004 is considered fair. Based on the measurement ratings for Water Year 2005 the record should be considered poor. The quality of the record is also downgraded in Water Year 2005 because Rating 1.2 was shifted uniformly and no high flow measurements were available to verify the shift at the higher end of the rating.

Gage height records worked by T. Gray 10-05
Gage height records checked by C. Pryor 10-05
Discharge computation worked by C. Pryor 11-05
Discharge computation checked by C. Pryor 12-05

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DISCHARGE SUMMARY SHEET

LOCATION: South Fork Wages Creek Above Rock Creek **WATER YEAR: 2004 - 2005**

Measurement Number	WY Msmt #	Date	Made By:	Width (feet)	Mean Depth (feet)	Area (ft^2)	Mean Velocity (ft/sec)	Gage Height (feet)	Discharge (cfs)	Rating 1.2 Shift Adj.	Rating 1.2 Percent Diff.	Method	No. of Msmt Sections	Begin Time (hours)	End Time (hours)	Msmt Rating	PZF	Notes
1	2004-01	12/7/2003	T. Grey	6.4	0.24	1.51	1.00	1.02	1.52		3	wading	20	16:04	16:33	fair		
2	2004-02	2/3/2004	T. Grey	7.5	0.45	3.36	2.03	1.24	6.82		-4	wading	26	09:38	10:06	fair		
3	2004-03	2/17/2004	T. Grey	8.1	0.64	5.22	3.33	1.42	17.4		-3	wading	17	19:57	20:18	fair		
4	2004-04	2/18/2004	K. Faucher	9.4	0.98	9.22	1.80	1.39	16.6		6	wading	28	13:13	13:50	fair		
5	2005-01	10/13/2004	S. Franco	1.5	0.14	0.21	0.38	0.79	0.08		0	wading	6	14:42	14:57	poor		
										Rating 2.1								
6	2005-02	12/28/2004	R. Leisse	4.8	0.27	1.31	0.68	1.01	0.89		-14	wading	16	14:57	15:34	poor		Began REW & no PZF; Had to assume LEW CTP
7	2005-03	1/11/2005	T. Bolton	4.6	0.33	1.51	1.91	1.12	2.88		7	wading	16	11:55	12:14	poor	0.65	
8	2005-04	2/22/2005	T. Bolton	4.8	0.27	1.30	1.72	1.09	2.23		5	wading	17	11:54	12:13	poor	0.64	
9	2005-05	2/22/2005	T. Bolton	4.8	0.27	1.29	1.67	1.09	2.14		1	wading	17	12:18	12:31	poor	0.64	Check Msmt
10	2005-06	3/28/2005	K. Faucher	4.6	0.56	2.58	1.78	1.20	4.59		-3	wading	19	13:08	13:29	fair	0.70	
11	2005-06	5/18/2005	K. Faucher	7.2	0.36	2.56	2.56	1.33	7.59	-0.05		wading	14	18:45	19:03	fair	0.88	

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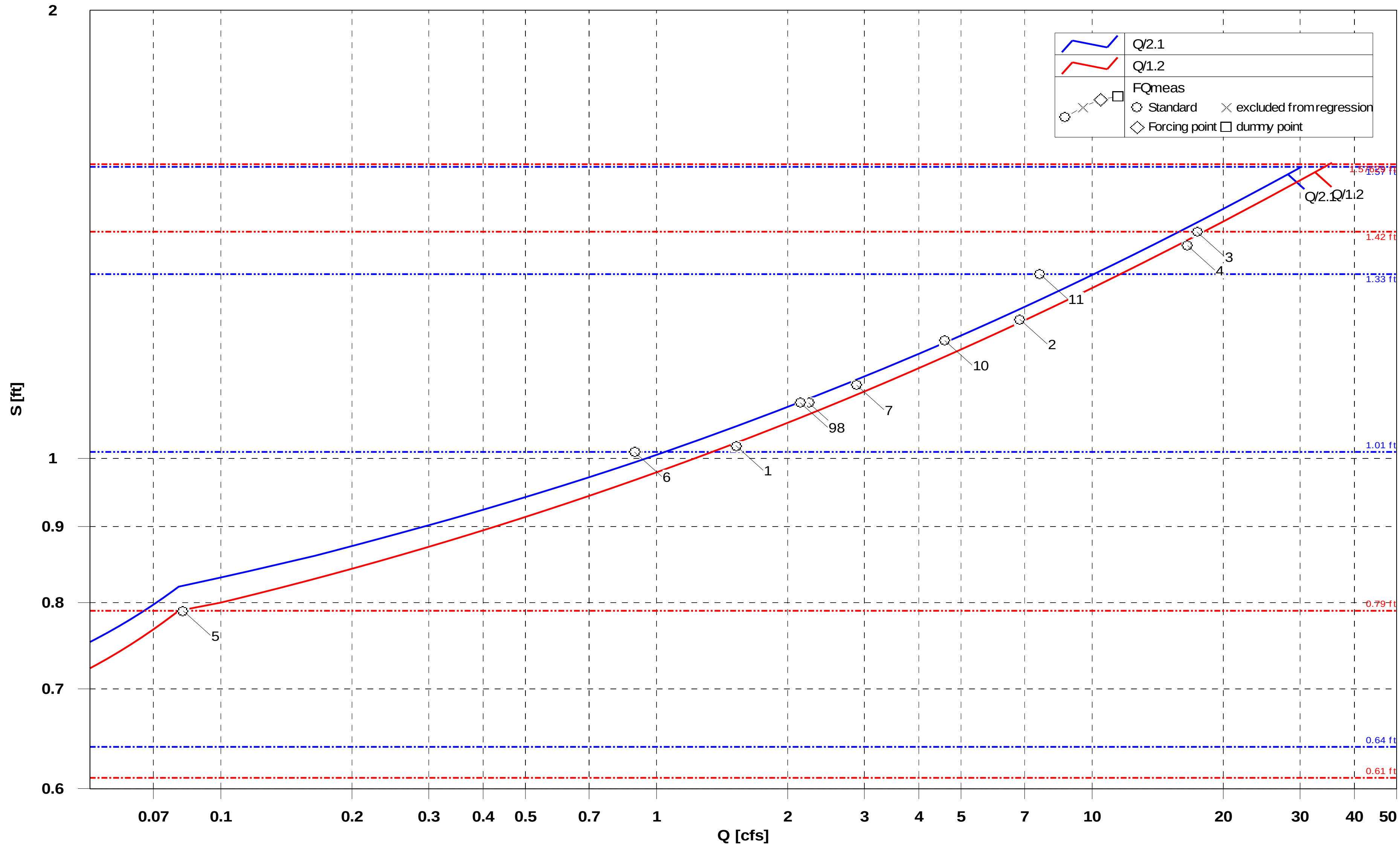
SOUTH FORK WAGES CREEK ABOVE ROCK CREEK
Discharge Rating Curves 1.2 and 2.1



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WY 04-05
APPENDIX

G-3

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SOUTH FORK WAGES CREEK ABOVE ROCK CREEK

RATING TABLE NO.1.2 ------ Begin Date 12/7/2003

GH	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	1st Diff	2nd Diff
0.0	---	---	---	---	---	---	---	---	---	---	---	---
0.1	---	---	---	---	---	---	---	---	---	---	---	---
0.2	---	---	---	---	---	---	---	---	---	---	---	---
0.3	---	---	---	---	---	---	---	---	---	---	---	---
0.4	---	---	---	---	---	---	---	---	---	---	---	---
0.5	---	---	---	---	---	---	---	---	---	---	---	---
0.6	---	---	---	---	---	---	---	---	---	---	---	---
0.7	---	---	---	---	---	---	---	---	---	*0.08*	---	---
0.8	*0.10*	*0.12*	*0.14*	*0.16*	*0.19*	*0.22*	*0.25*	*0.29*	*0.33*	*0.38*	0.30	---
0.9	*0.43*	*0.48*	*0.54*	*0.60*	*0.67*	*0.75*	*0.83*	*0.92*	*1.01*	*1.11*	0.73	0.43
1.0	*1.23*	*1.34*	1.47	1.60	1.74	1.89	2.05	2.23	2.41	2.60	2.60	2.60
1.1	2.81	3.02	3.24	3.48	3.74	4.01	4.28	4.57	4.89	5.21	2.61	0.01
1.2	5.54	5.90	6.28	6.67	7.07	7.49	7.94	8.41	8.89	9.38	4.17	1.56
1.3	9.91	10.5	11.0	11.6	12.2	12.9	13.5	14.2	14.9	15.7	6.32	2.15
1.4	16.4	17.2	18.0	*18.9*	*19.8*	*20.7*	*21.6*	*22.6*	*23.6*	*24.6*	8.90	2.58
1.5	*25.7*	*26.8*	*27.9*	*29.1*	*30.3*	*31.5*	*32.8*	*34.2*	---	---	---	---
1.6	---	---	---	---	---	---	---	---	---	---	---	---
1.7	---	---	---	---	---	---	---	---	---	---	---	---
1.8	---	---	---	---	---	---	---	---	---	---	---	---
1.9	---	---	---	---	---	---	---	---	---	---	---	---
2.0	---	---	---	---	---	---	---	---	---	---	---	---
2.1	---	---	---	---	---	---	---	---	---	---	---	---
2.2	---	---	---	---	---	---	---	---	---	---	---	---
2.3	---	---	---	---	---	---	---	---	---	---	---	---
2.4	---	---	---	---	---	---	---	---	---	---	---	---
2.5	---	---	---	---	---	---	---	---	---	---	---	---

Values in italics are beyond the validated range of the rating

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(530) 623-5327 ph (530) 623-5328 fax

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SOUTH FORK WAGES CREEK ABOVE ROCK CREEK

RATING TABLE NO.2.1 -- Begin Date 12/08/2004

GH	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	1st Diff	2nd Diff
0.0	-	-	-	-	-	-	-	-	-	-	-	-
0.1	-	-	-	-	-	-	-	-	-	-	-	-
0.2	-	-	-	-	-	-	-	-	-	-	-	-
0.3	-	-	-	-	-	-	-	-	-	-	-	-
0.4	-	-	-	-	-	-	-	-	-	-	-	-
0.5	-	-	-	-	-	-	-	-	-	-	-	-
0.6	-	-	-	-	-	-	*0.01*	*0.01*	*0.02*	*0.02*	-	-
0.7	*0.03*	*0.03*	*0.04*	*0.04*	*0.04*	*0.05*	*0.05*	*0.06*	*0.06*	*0.07*	0.05	-
0.8	*0.07*	*0.08*	*0.08*	*0.10*	*0.12*	*0.14*	*0.16*	*0.19*	*0.22*	*0.25*	0.18	0.13
0.9	*0.29*	*0.34*	*0.38*	*0.43*	*0.49*	*0.55*	*0.62*	*0.69*	*0.77*	*0.85*	0.60	0.42
1.0	*0.95*	1.04	1.15	1.26	1.38	1.51	1.65	1.80	1.95	2.12	1.27	0.67
1.1	2.30	2.48	2.68	2.89	3.11	3.34	3.59	3.85	4.12	4.41	2.29	1.02
1.2	4.71	5.03	5.35	5.69	6.05	6.43	6.82	7.23	7.66	8.12	3.71	1.42
1.3	8.59	9.07	9.57	10.1	*10.7*	*11.2*	*11.8*	*12.4*	*13.1*	*13.7*	5.58	1.87
1.4	*14.4*	*15.1*	*15.8*	*16.6*	*17.4*	*18.2*	*19.0*	*19.9*	*20.8*	*21.7*	8.00	2.42
1.5	*22.7*	*23.7*	*24.7*	*25.7*	*26.8*	*27.9*	*29.1*	*30.2*	-	-	-	-
1.6	-	-	-	-	-	-	-	-	-	-	-	-
1.7	-	-	-	-	-	-	-	-	-	-	-	-
1.8	-	-	-	-	-	-	-	-	-	-	-	-
1.9	-	-	-	-	-	-	-	-	-	-	-	-
2.0	-	-	-	-	-	-	-	-	-	-	-	-
2.1	-	-	-	-	-	-	-	-	-	-	-	-
2.2	-	-	-	-	-	-	-	-	-	-	-	-
2.3	-	-	-	-	-	-	-	-	-	-	-	-
2.4	-	-	-	-	-	-	-	-	-	-	-	-
2.5	-	-	-	-	-	-	-	-	-	-	-	-

Values in italics are beyond the validated range of the rating

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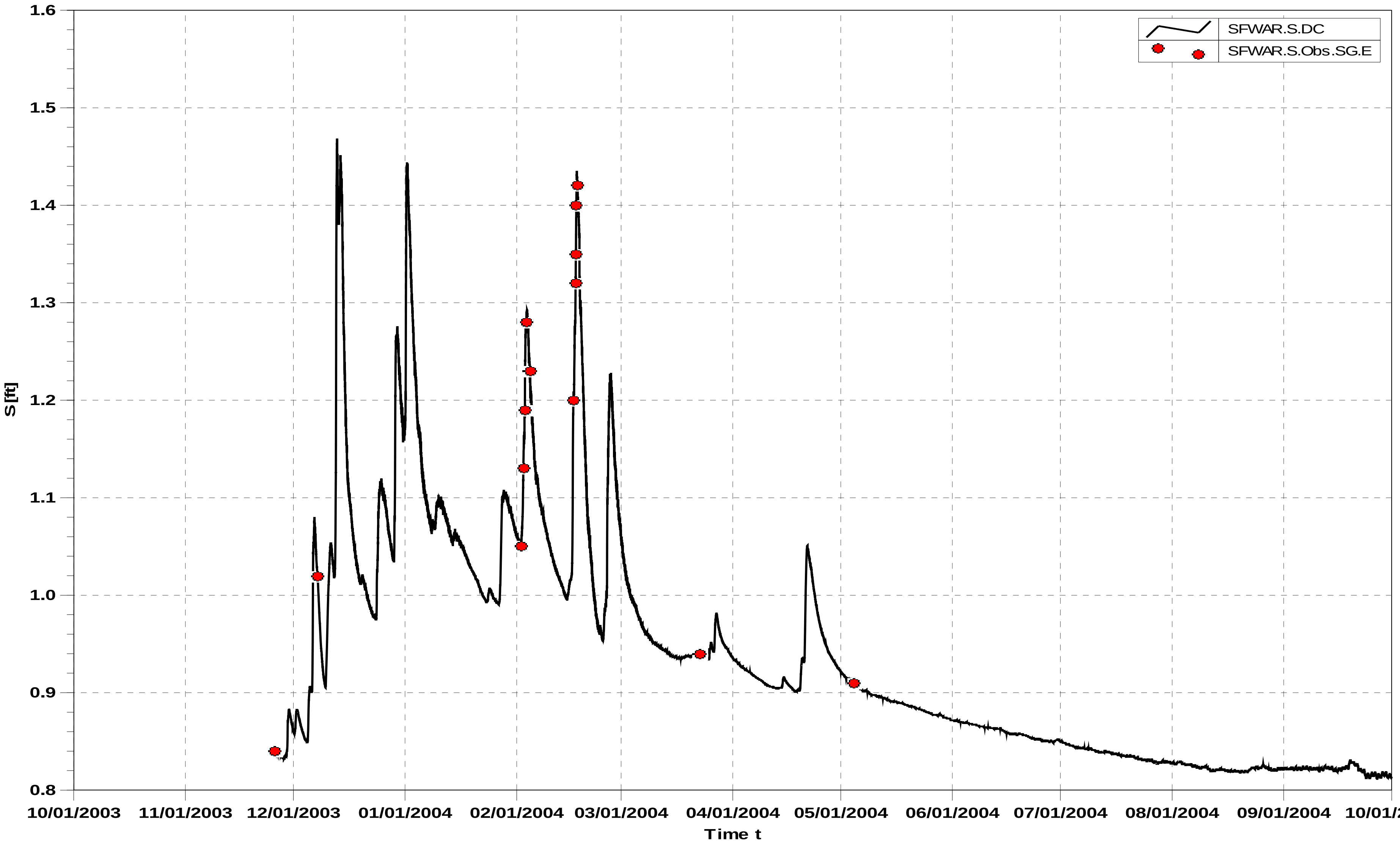
SOUTH FORK WAGES CREEK ABOVE ROCK CREEK
15-Minute Adjusted Gage Height Record and Observed Staff Gage Readings



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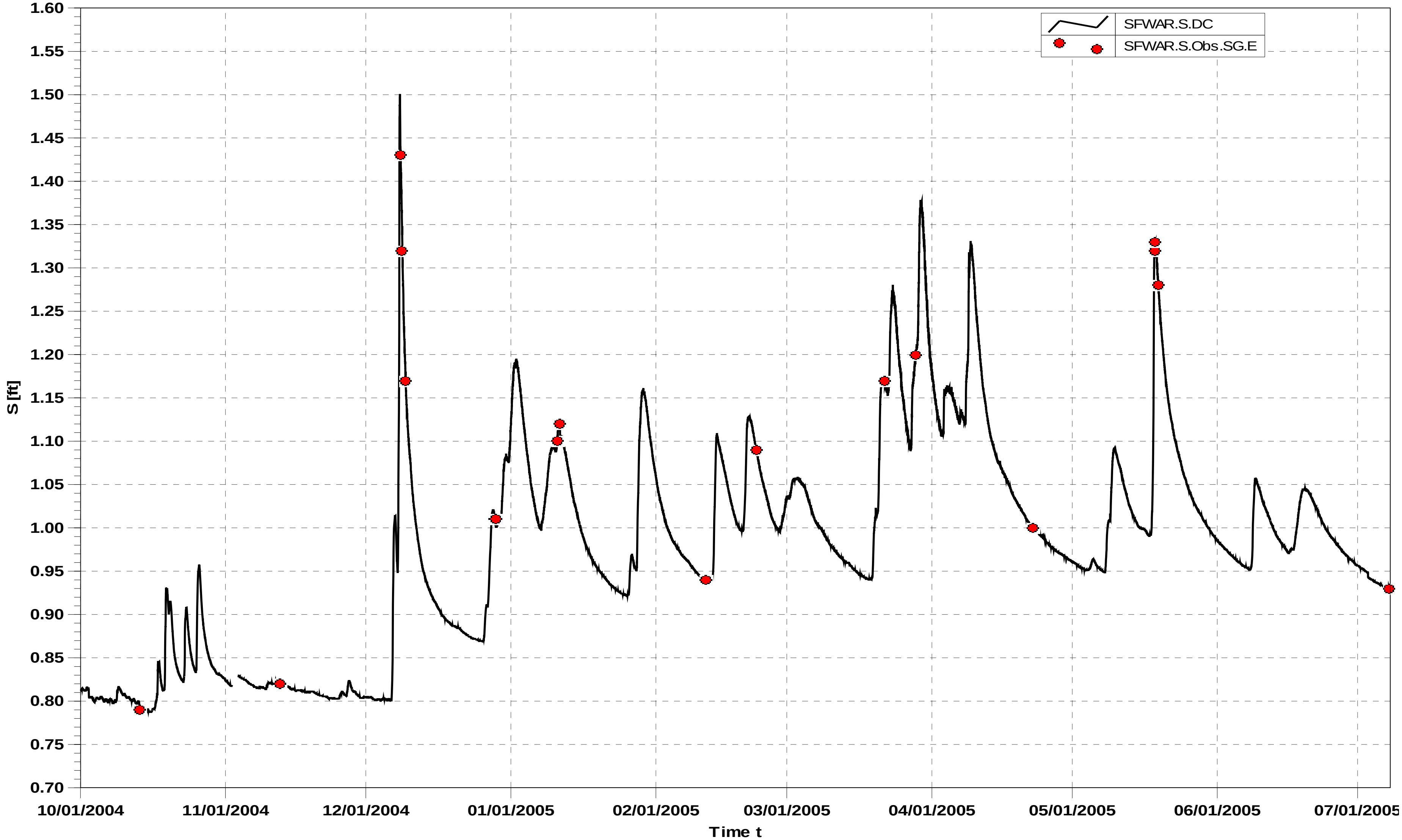
WY 2004
APPENDIX

G-5a

SOUTH FORK WAGES CREEK ABOVE ROCK CREEK
15-Minute Adjusted Gage Height Record and Observed Staff Gage Readings



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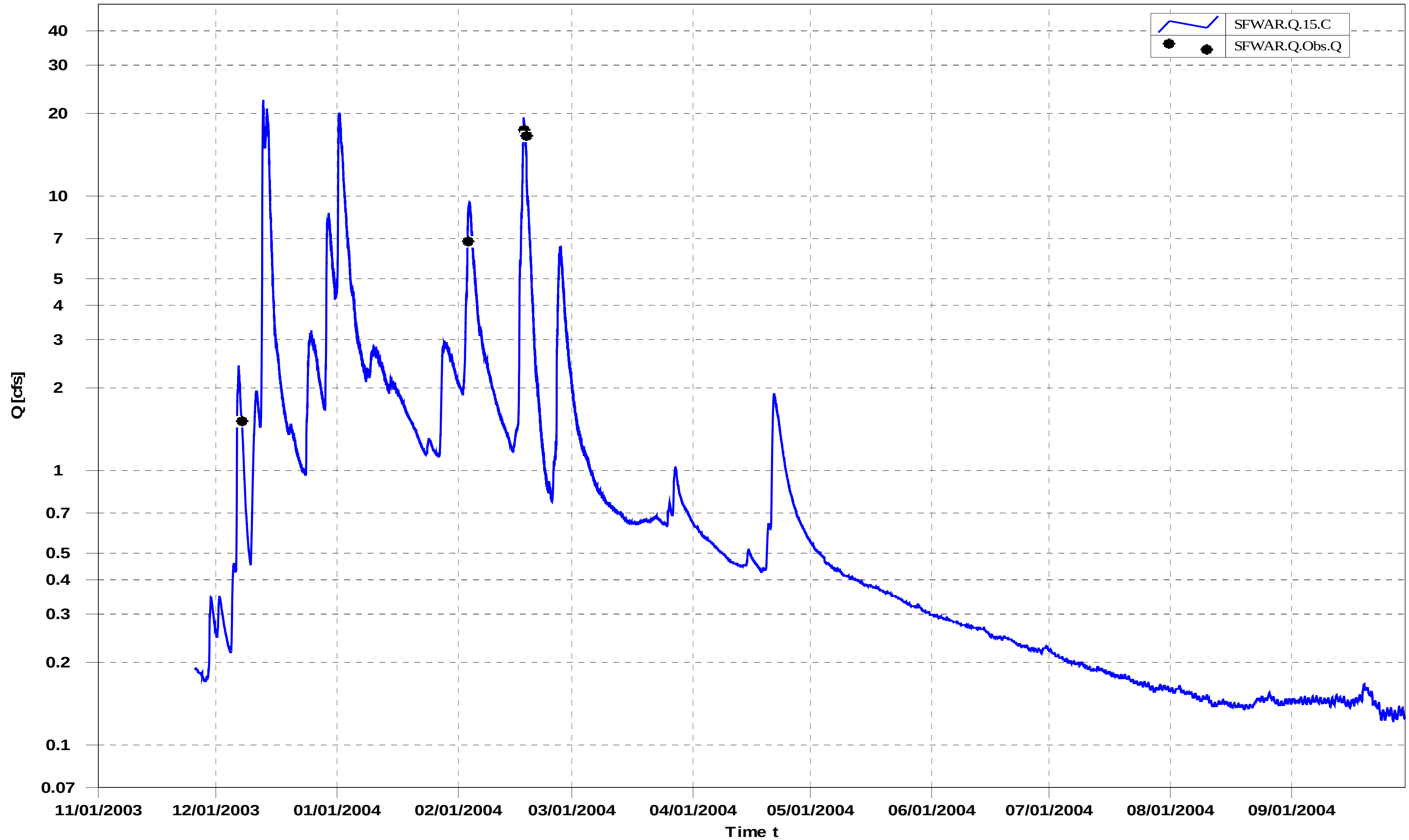
WY 2005 APPENDIX

G-5b

SOUTH FORK WAGES CREEK ABOVE ROCK CREEK
Discharge Hydrograph and Discharge Measurements



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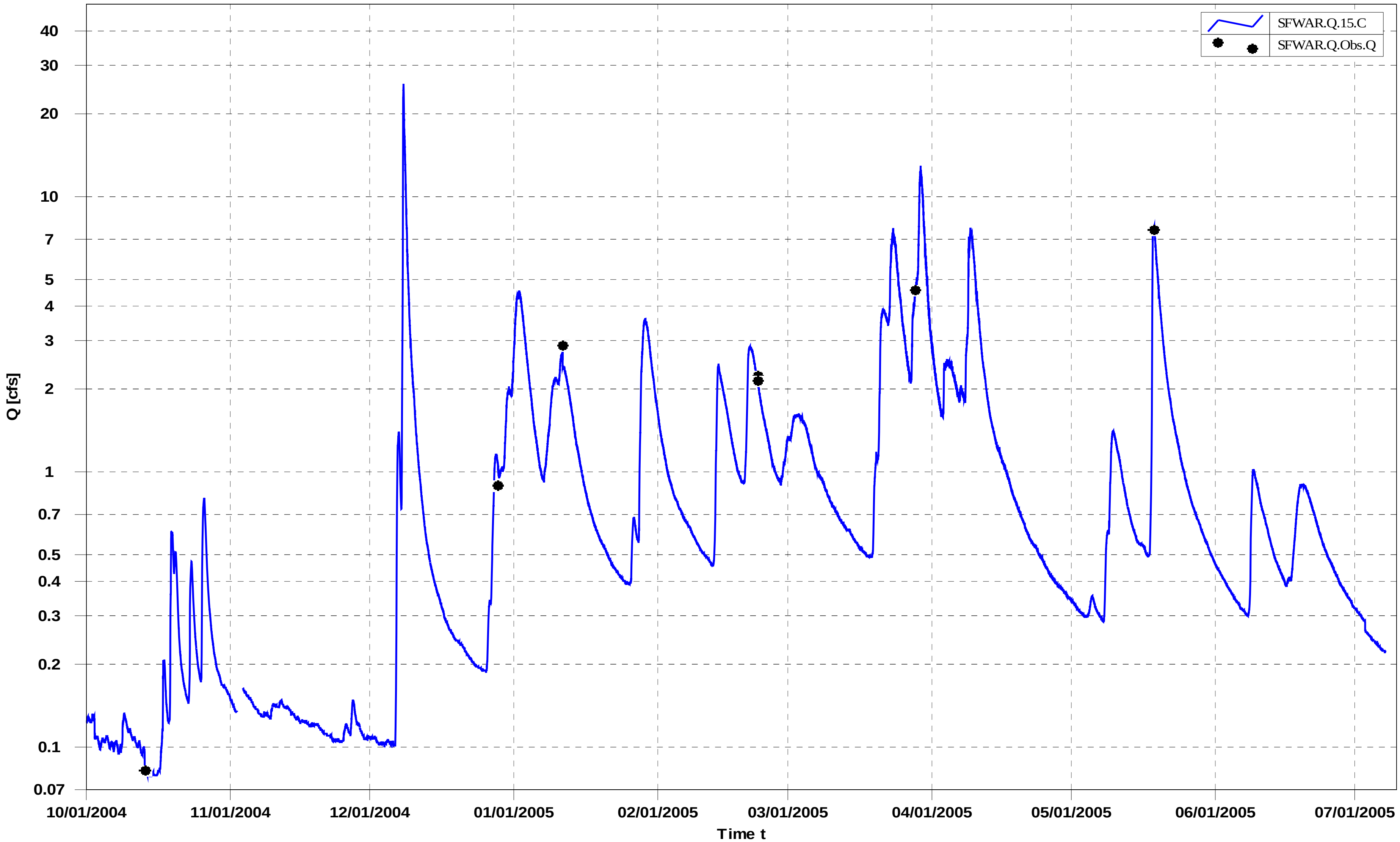
WY 2004
APPENDIX

G-6a

SOUTH FORK WAGES CREEK ABOVE ROCK CREEK
Discharge Hydrograph and Discharge Measurements



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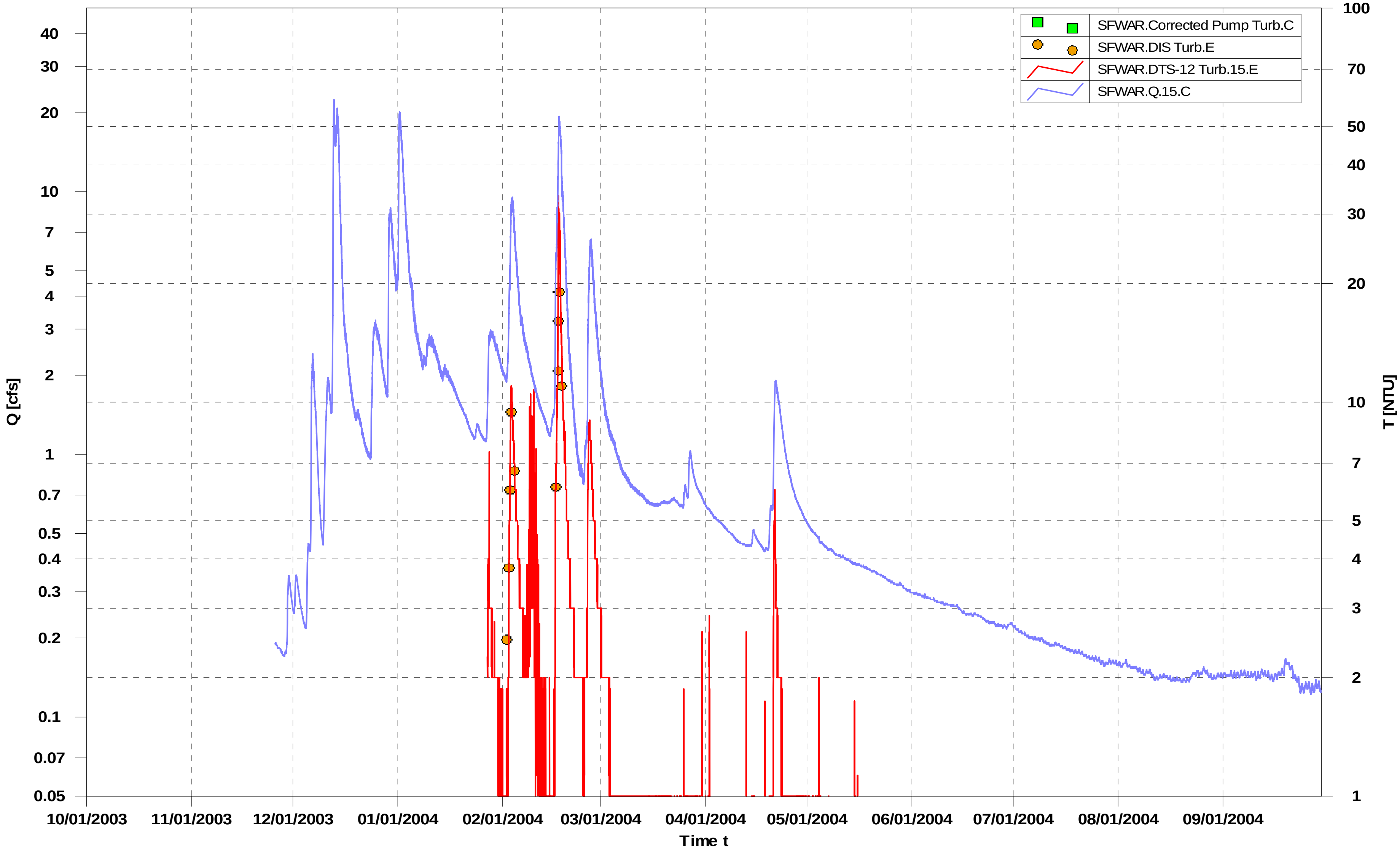
WY 2005
APPENDIX

G-6b

SOUTH FORK WAGES CREEK ABOVE ROCK CREEK
Discharge Hydrograph, Continuous Turbidity with Depth-Integrated Turbidity Samples



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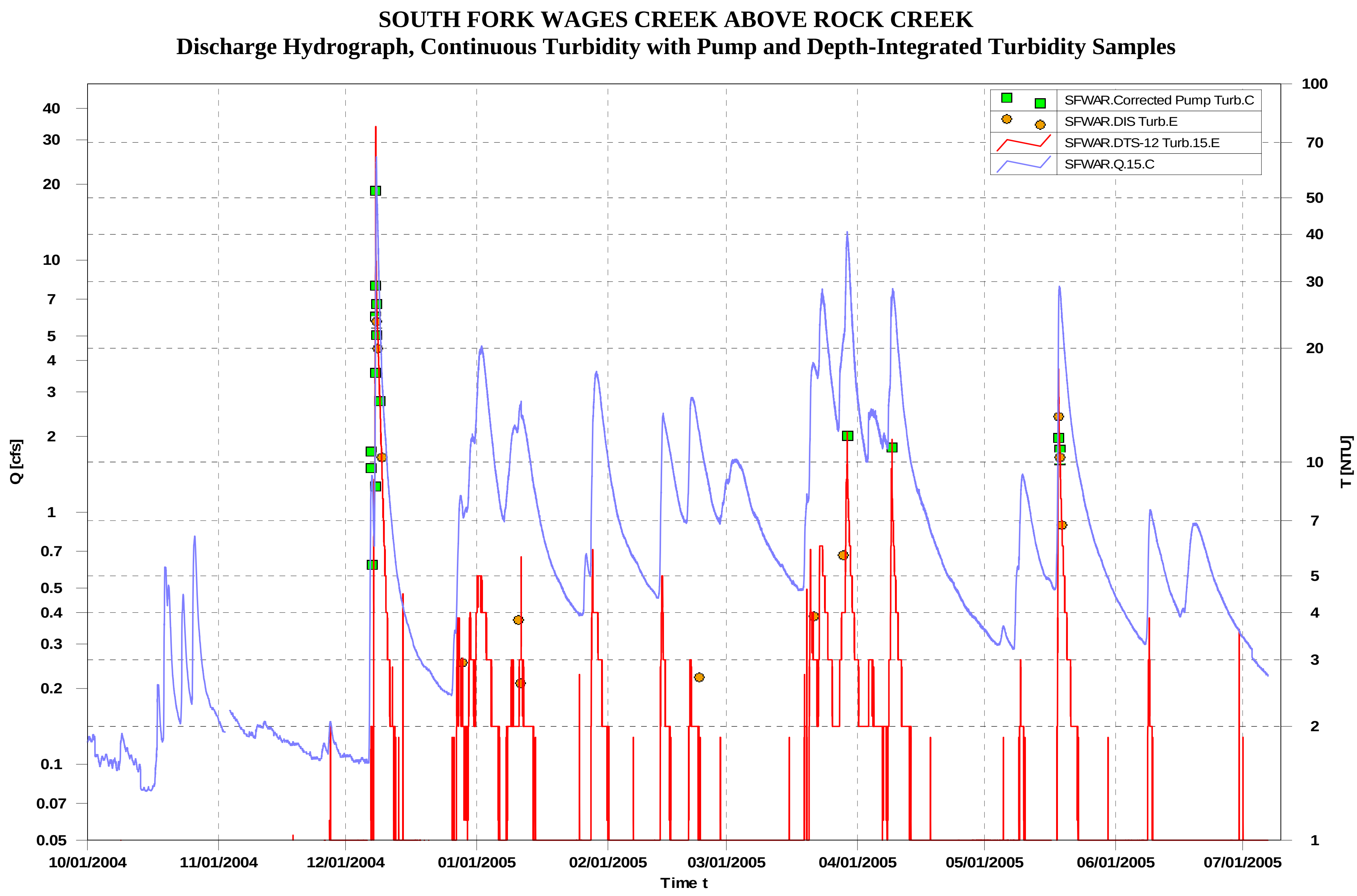
WY 2004 APPENDIX

G-7a



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WY 2005
APPENDIX

G-7b

SEDIMENT SAMPLE SUMMARY SHEET

LOCATION: SOUTH FORK WAGES ABOVE ROCK CREEK **WATER YEAR: 2004**

Date Time	Sample Number	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	Q/WSA (cfs/mi^2)	SSL (ton/day)	SSLPA (ton/day/mi2)	Type (DIS, PUMP)	Note
2/2/2004 04:36	SFWAR-SSCT2004-01	2.5	3	1.05	1.51	3.9	0.01	0.03	DIS	
2/2/2004 20:49	SFWAR-SSCT2004-02	3.8	6	1.13	2.89	7.4	0.05	0.12	DIS	
2/3/2004 05:43	SFWAR-SSCT2004-03	6.0	4	1.19	4.41	11	0.05	0.14	DIS	
2/3/2004 16:02	SFWAR-SSCT2004-04	9.4	5	1.28	7.66	20	0.10	0.25	DIS	
2/4/2004 14:48	SFWAR-SSCT2004-05	6.7	0.7	1.23	5.69	15	0.01	0.03	DIS	
2/16/2004 19:02	SFWAR-SSCT2004-06	6.1	4	1.20	4.71	12	0.05	0.13	DIS	
2/17/2004 08:35	SFWAR-SSCT2004-07	12	10	1.32	9.57	25	0.25	0.63	DIS	
2/17/2004 10:52	SFWAR-SSCT2004-08	16	20	1.35	11.2	29	0.62	1.6	DIS	
2/17/2004 13:48	SFWAR-SSCT2004-09	19	32	1.40	14.4	37	1.2	3.1	DIS	
2/17/2004 19:20	SFWAR-SSCT2004-10	19	18	1.42	15.8	41	0.75	1.9	DIS	
2/18/2004 10:23	SFWAR-SSCT2004-11	11	7	1.43	16.6	43	0.33	0.85	DIS	

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WY 2004 APPENDIX

G-8a

SEDIMENT SAMPLE SUMMARY SHEET

LOCATION: SOUTH FORK WAGES ABOVE ROCK CREEK **WATER YEAR: 2005**

Date Time	Sample Number	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	Q/WSA (cfs/mi^2)	SSL (ton/day)	SSLPA (ton/day/mi2)	Type (DIS, PUMP)	Note
12/7/2004 02:31	SFWAR-SSCT2005-01	11	13	1.01	1.29	3.3	0.05	0.12	Pump	
12/7/2004 03:31	SFWAR-SSCT2005-02	9.6	8	1.01	1.33	3.4	0.03	0.07	Pump	
12/7/2004 09:31	SFWAR-SSCT2005-03	5.4	5	1.00	1.28	3.3	0.02	0.04	Pump	
12/7/2004 23:01	SFWAR-SSCT2005-04	8.6	18	1.04	1.75	4.5	0.08	0.21	Pump	
12/8/2004 00:46	SFWAR-SSCT2005-05	17	27	1.10	2.82	7.2	0.21	0.53	Pump	
12/8/2004 02:01	SFWAR-SSCT2005-06	24	36	1.15	4.01	10	0.39	1.0	Pump	
12/8/2004 03:31	SFWAR-SSCT2005-07	50	113	1.30	9.97	26	3.0	7.8	Pump	
12/8/2004 04:01	SFWAR-SSCT2005-08	29	52	1.38	14.8	38	2.1	5.3	Pump	
12/8/2004 05:01	SFWAR-SSCT2005-09	26	44	1.47	23.1	59	2.7	7.0	Pump	
12/8/2004 07:46	SFWAR-SSCT2005-10	23	13	1.49	23.8	61	0.85	2.2	Pump	Calibrate with bottle #1038
12/8/2004 07:48	SFWAR-SSCT2005-11	24	11	1.43	23.8	61	0.71	1.8	DIS	Calibrate with bottle #313
12/8/2004 10:16	SFWAR-SSCT2005-12	22	13	1.42	17.7	45	0.60	1.5	Pump	
12/8/2004 15:01	SFWAR-SSCT2005-13	20	5	1.38	13.7	35	0.18	0.47	Pump	Calibrate with bottle #1035
12/8/2004 15:02	SFWAR-SSCT2005-14	20	16	1.32	13.7	35	0.60	1.5	DIS	Calibrate with bottle #315
12/9/2004 00:46	SFWAR-SSCT2005-15	15	4	1.26	6.82	17	0.07	0.18	Pump	
12/9/2004 12:11	SFWAR-SSCT2005-16	10	2	1.17	3.85	9.9	0.02	0.06	DIS	
12/28/2004 15:46	SFWAR-SSCT2005-17	3.0	3	1.01	1.05	2.7	0.01	0.02	DIS	
1/10/2005 21:34	SFWAR-SSCT2005-18	3.8	7	1.10	2.29	5.9	0.04	0.11	DIS	
1/11/2005 11:45	SFWAR-SSCT2005-19	2.6	0.5	1.12	2.68	6.9	0.00	0.01	DIS	
2/22/2005 12:30	SFWAR-SSCT2005-20	2.7	3	1.09	2.12	5.4	0.02	0.04	DIS	
3/21/2005 19:32	SFWAR-SSCT2005-21	3.9	6	1.17	3.85	9.9	0.06	0.16	DIS	
3/28/2005 13:35	SFWAR-SSCT2005-22	5.7	6	1.20	4.70	12	0.08	0.21	DIS	
3/29/2005 13:16	SFWAR-SSCT2005-23	12	27	1.37	12.5	32	0.91	2.3	Pump	
4/9/2005 03:46	SFWAR-SSCT2005-24	11	14	1.31	6.91	18	0.25	0.65	Pump	
5/18/2005 13:02	SFWAR-SSCT2005-25	13	31	1.32	7.22	19	0.61	1.6	DIS	
5/18/2005 14:01	SFWAR-SSCT2005-26	12	23	1.32	7.40	19	0.46	1.2	Pump	
5/18/2005 17:31	SFWAR-SSCT2005-27	11	13	1.33	7.70	20	0.27	0.68	Pump	Suspect SSC Value
5/18/2005 17:46	SFWAR-SSCT2005-28	10	8	1.33	7.65	20	0.16	0.40	Pump	Calibrate with bottle #1325
5/18/2005 17:47	SFWAR-SSCT2005-29	10	8	1.33	7.65	20	0.16	0.42	DIS	Calibrate with bottle #321
5/19/2005 08:40	SFWAR-SSCT2005-30	6.8	8	1.28	5.69	15	0.12	0.32	DIS	

PROJECT:

SOUTH FORK WAGES CREEK
STREAMFLOW AND SEDIMENT TRANSPORT MONITORING

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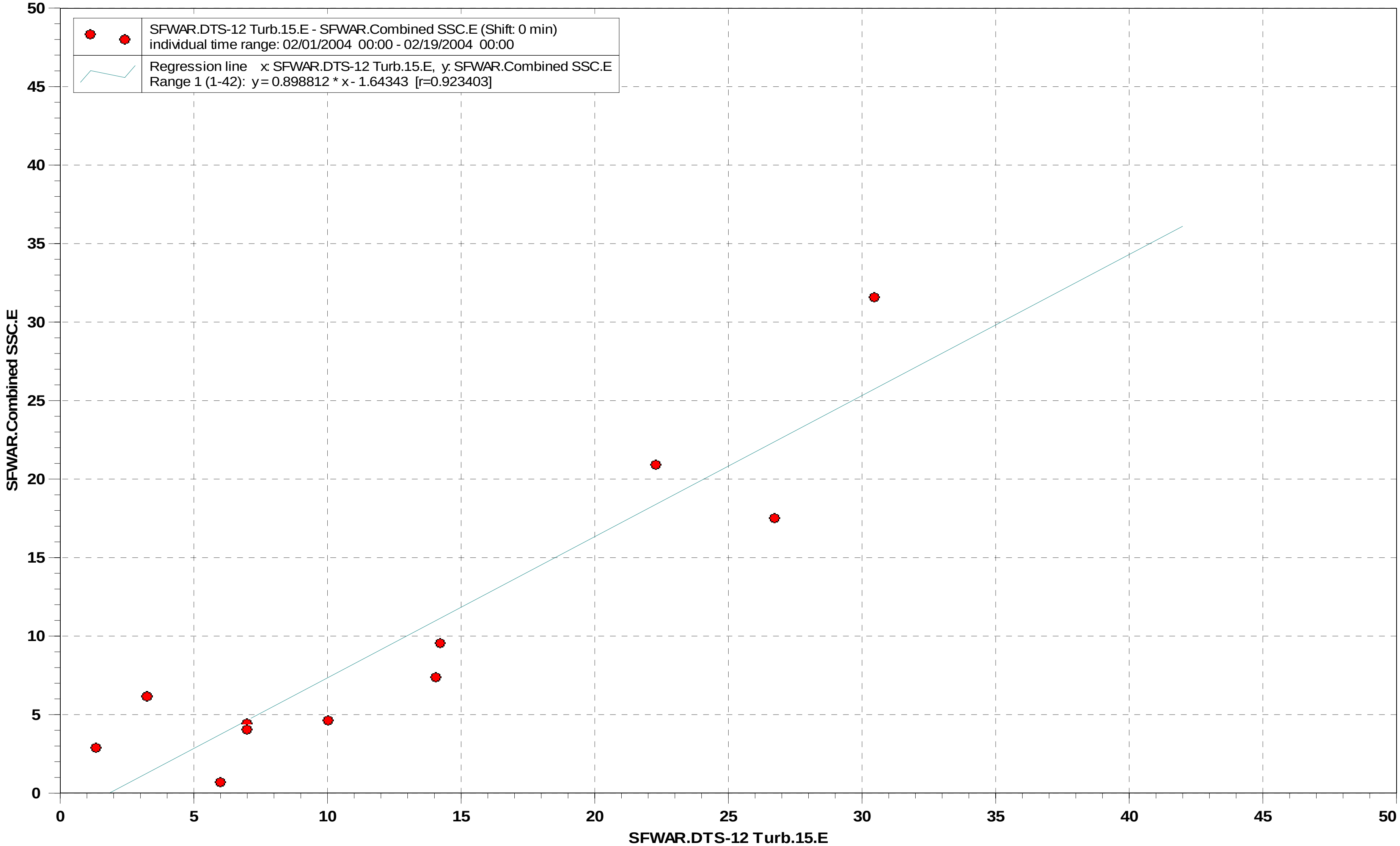
P.O. Box 1516 Weaverville, CA 96093-1516
(530) 623-5327 ph (530) 623-5328 fax

WY 2005 APPENDIX

G-8b

SOUTH FORK WAGES CREEK ABOVE ROCK CREEK
DTS-12 Turbidity verses Depth-Integrated and Pump SSC



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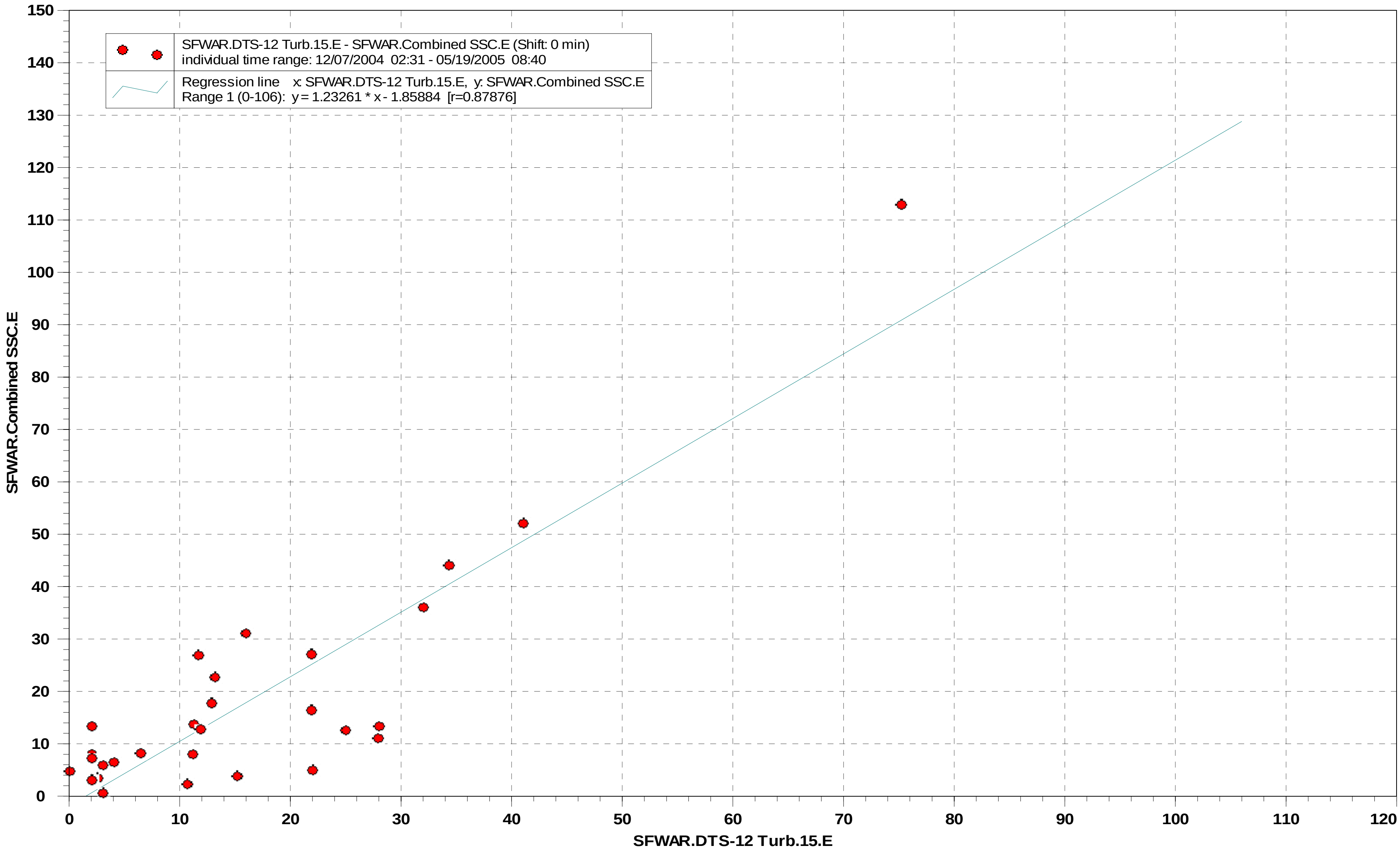
GRAHAM MATTHEWS & ASSOCIATES
Hydrology • Geomorphology • Stream Restoration
P.O. Box 1516 Weaverville, CA 96093-1516
(530) 623-5327 ph (530) 623-5328 fax

WY 2004
APPENDIX

G-9a

SOUTH FORK WAGES CREEK ABOVE ROCK CREEK
DTS-12 Turbidity verses Depth-Integrated and Pump SSC



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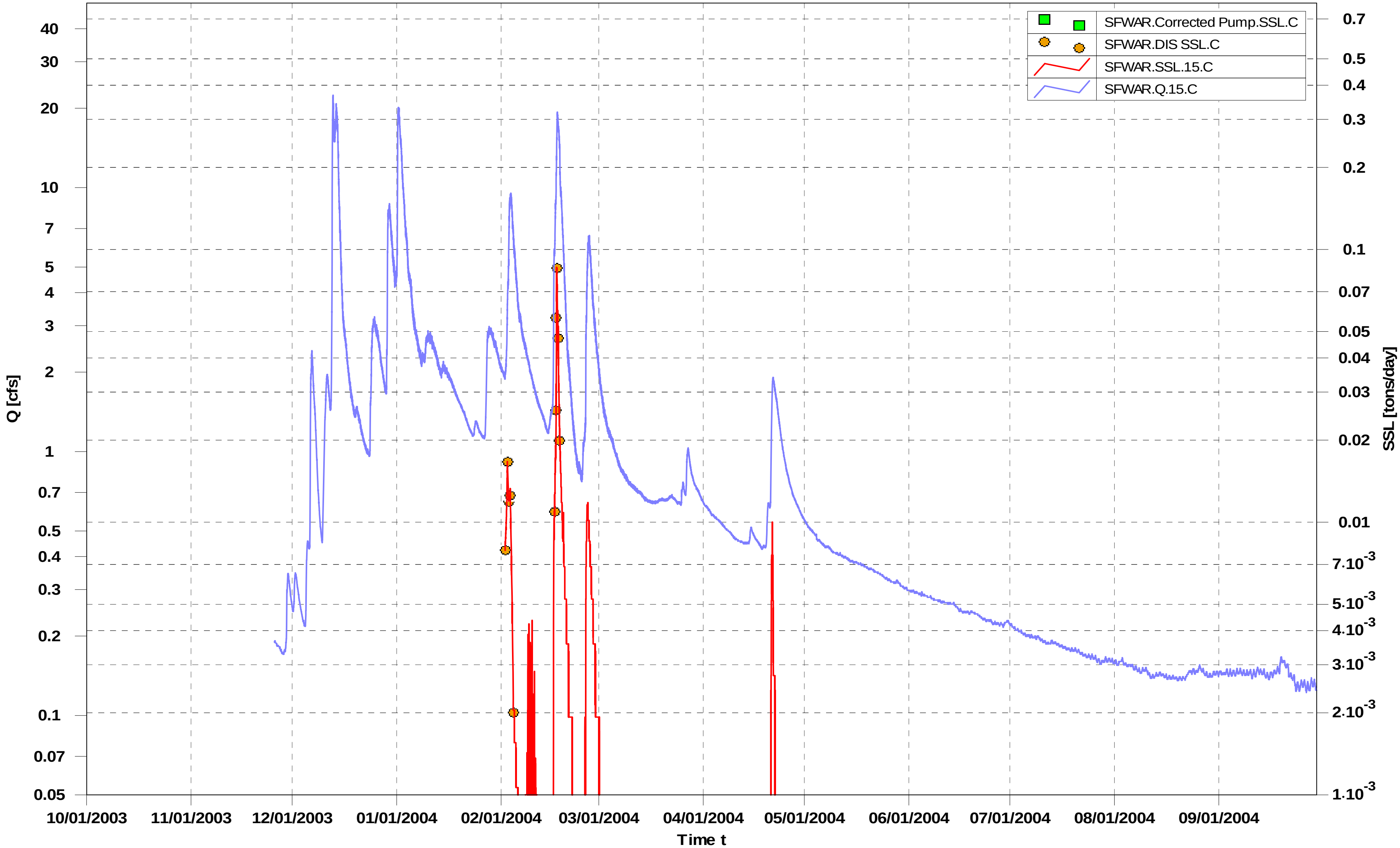
GRAHAM MATTHEWS & ASSOCIATES
Hydrology • Geomorphology • Stream Restoration
P.O. Box 1516 Weaverville, CA 96093-1516
(530) 623-5327 ph (530) 623-5328 fax

WY 2005
APPENDIX

G-9b

SOUTH FORK WAGES CREEK ABOVE ROCK CREEK
Discharge and Suspended Sediment Load



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SOUTH FORK WAGES CREEK
STREAMFLOW AND SEDIMENT TRANSPORT MONITORING

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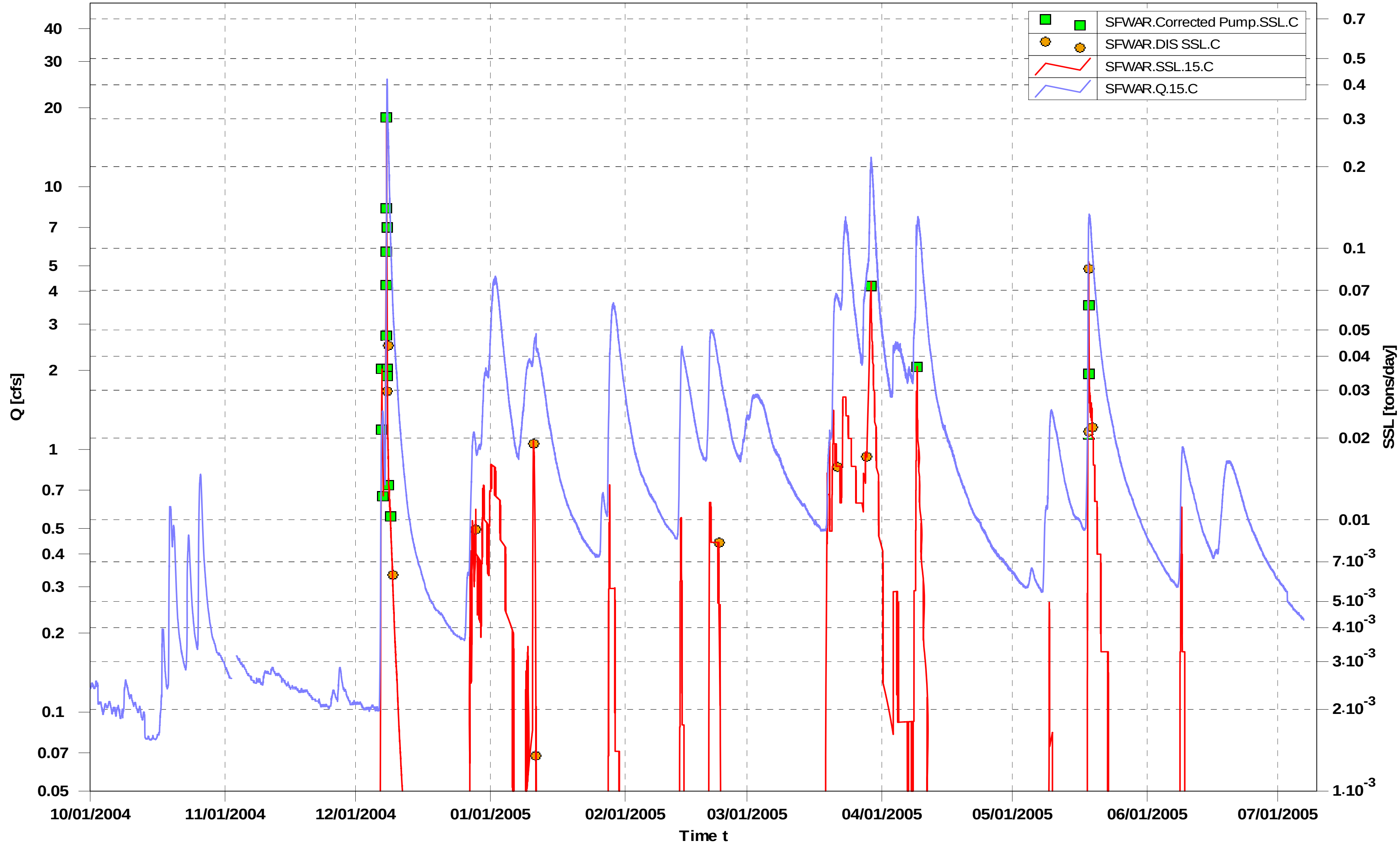
(530) 623-5327 ph (530) 623-5328 fax

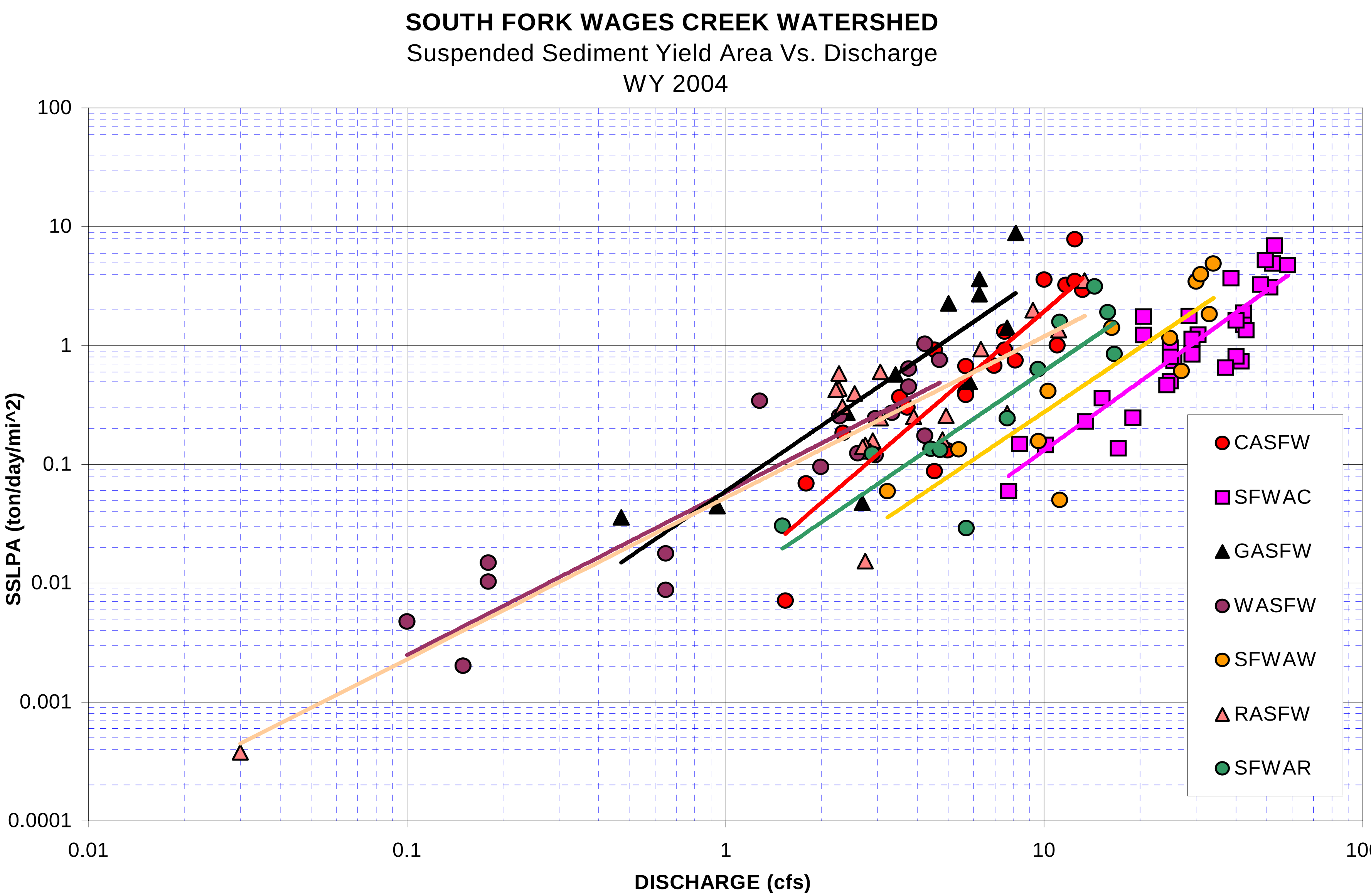
WY 2004
APPENDIX

G-10a

SOUTH FORK WAGES CREEK ABOVE ROCK CREEK
Discharge and Suspended Sediment Load



PROJECT:	GMA	WY 2005 APPENDIX
SOUTH FORK WAGES CREEK STREAMFLOW AND SEDIMENT TRANSPORT MONITORING	GRAHAM MATTHEWS & ASSOCIATES Hydrology • Geomorphology • Stream Restoration P.O. Box 1516 Weaverville, CA 96093-1516 (530) 623-5327 ph (530) 623-5328 fax	G-10b



PROJECT:

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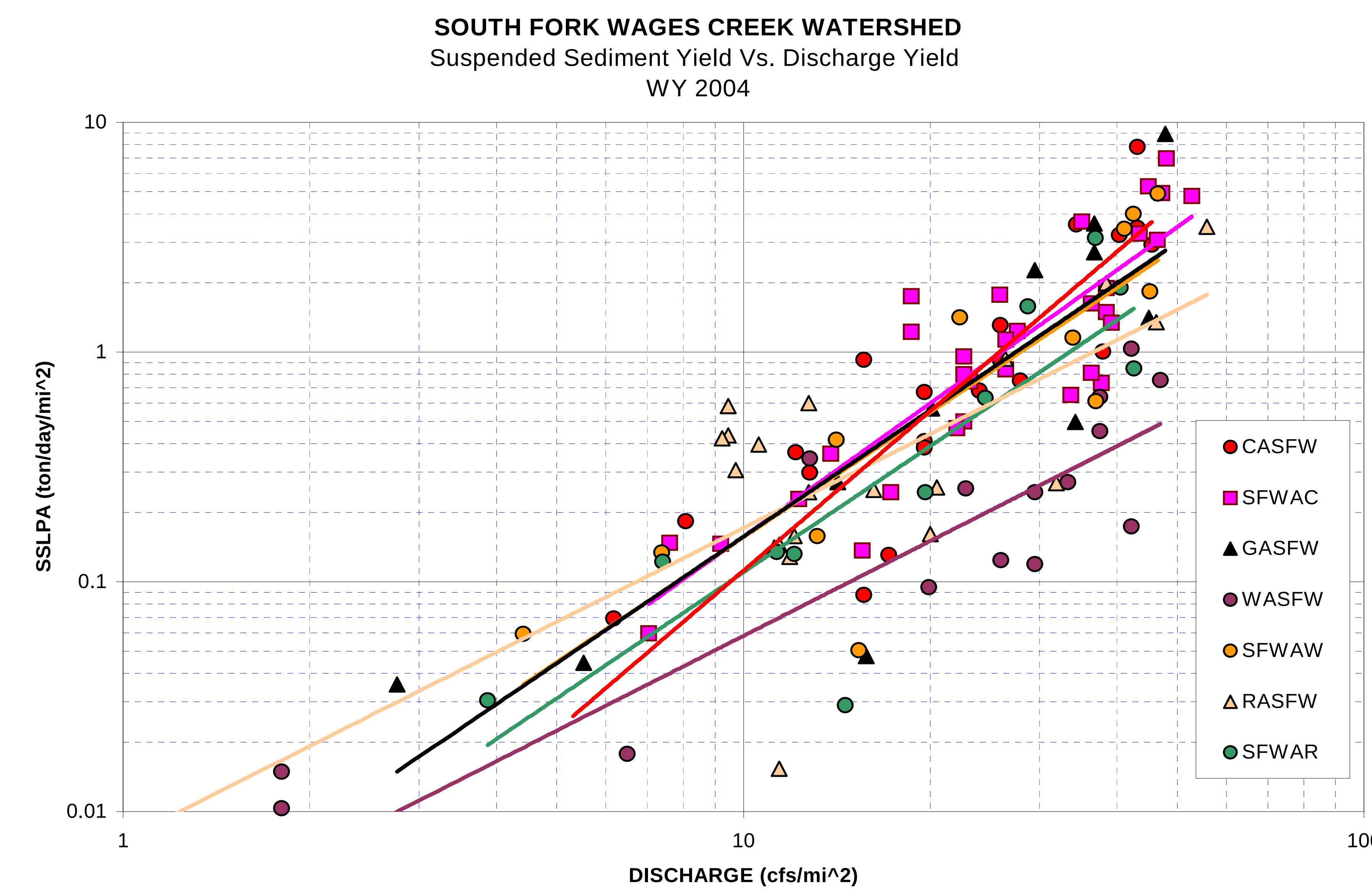
GRAHAM MATTHEWS & ASSOCIATES
Hydrology • Geomorphology • Stream Restoration
P.O. Box 1516 Weaverville, CA 96093-1516
(530) 623-5327 ph (530) 623-5328 fax

WY 2004 APPENDIX

H-1



PROJECT:

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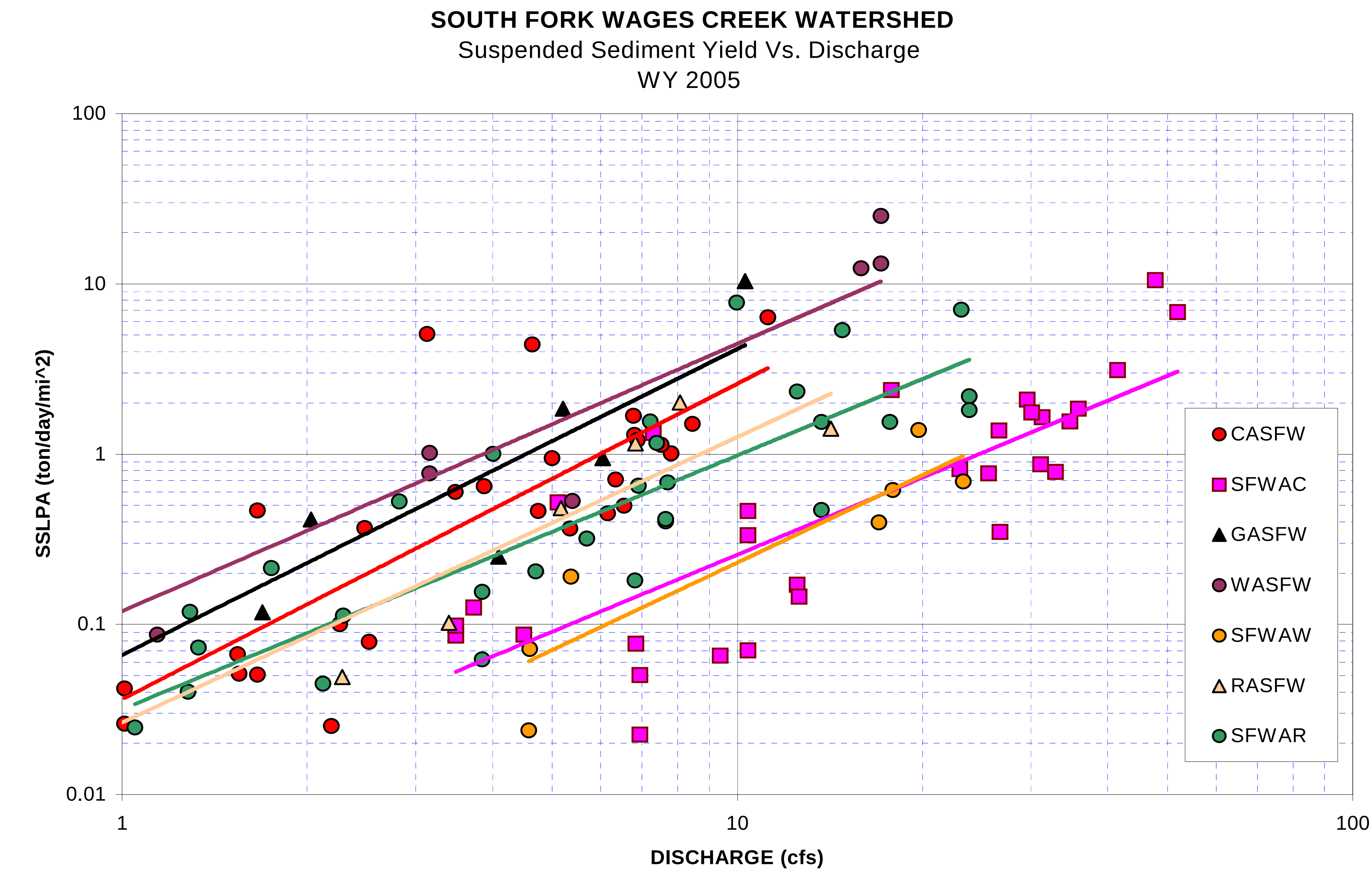
STREAMFLOW AND SEDIMENT TRANSPORT MONITORING

GMA
GRAHAM MATTHEWS & ASSOCIATES
Hydrology • Geomorphology • Stream Restoration
P.O. Box 1516 Weaverville, CA 96093-1516
(530) 623-5327 ph (530) 623-5328 fax

WY 2004
APPENDIX

H-2



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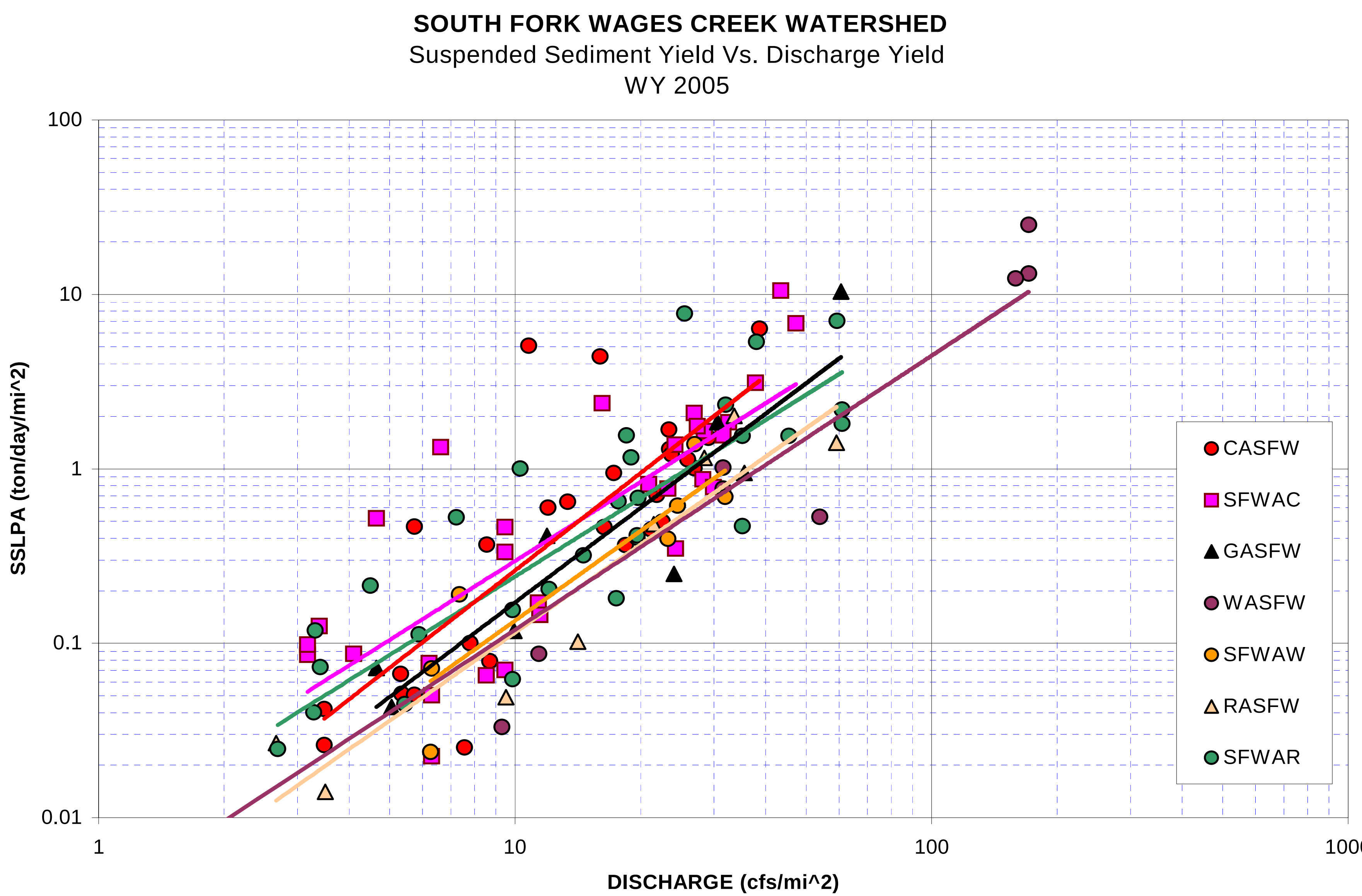
GRAHAM MATTHEWS & ASSOCIATES
Hydrology • Geomorphology • Stream Restoration
P.O. Box 1516 Weaverville, CA 96093-1516
(530) 623-5327 ph (530) 623-5328 fax

WY 2005
APPENDIX

H-3



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GMA
GRAHAM MATTHEWS & ASSOCIATES
Hydrology • Geomorphology • Stream Restoration
P.O. Box 1516 Weaverville, CA 96093-1516
(530) 623-5327 ph (530) 623-5328 fax

WY 2005 APPENDIX

H-4

Changes in Stream Channel Morphology Caused by Replacing Road-Stream Crossings on Timber Harvesting Plans in Northwestern California

Richard Harris, Jared Gerstein, and Peter Cafferata

ABSTRACT

Past studies have shown that roads used for timber management and recreation are major sources of sedimentation in many streams throughout the Pacific Northwestern United States. Stream crossings are portals for the entry of sediment derived from road surface erosion. They are also prone to catastrophic failure during stressing weather events if they are undersized or otherwise deficient in design or construction. In recent years, public and private landowners have replaced or removed numerous deficient crossings in forested watersheds throughout California and elsewhere in the West. The benefits of replacing these crossings include eliminating both chronic and episodic inputs of sediment to streams. When old crossings are replaced with new, properly designed and installed crossings, there is a potential for construction-related erosion. This research examined the postconstruction erosion associated with the replacement of 30 stream crossings in coastal California. Channel surveys were conducted immediately after construction and after the passage of one winter rainy season. The results indicated very little erosion on most sites; 11 experienced no erosion at all. On those sites where erosion did occur, the amounts did not exceed 10 cubic yards. A few sites experienced aggradation or erosion unrelated to upgrading but due to upstream landslides. This research shows upgraded stream crossings on commercial timberland may contribute little sediment to streams after construction under moderate weather conditions if adequate erosion control measures are implemented.

Keywords: forest roads, stream crossings, erosion, California

Roads used for natural resource management and recreation are the principal anthropogenic cause of excessive sedimentation in many forest streams throughout the western United States (Reid and Dunne 1984, Furniss et al. 1991, Luce and Black 1999). Stream crossings and road segments that drain to crossings are particularly high-risk sites for sediment delivery to streams (Wemple et al. 1996). Roadside ditches draining to crossings convey sediment derived from road surface erosion and cut bank failures, crossing fill slopes are susceptible to development of rills and gullies, and peak runoff events may trigger catastrophic stream crossing failures (Furniss et al. 1991, 1998). Excessive sedimentation degrades aquatic habitat, impairs water quality for domestic uses, and reduces the flood conveyance capacity of streams, thereby contributing to downstream flooding (Cederholm et al. 1981, Dissmeyer 2000, Patenaude 2004).

In the forested watersheds of northwestern California, there are innumerable existing stream crossings that were installed over the past 50 to 60 years to accommodate logging and log hauling by trucks. In cases where culverts were installed, they are frequently inadequately sized or positioned to accommodate expected peak streamflow and/or wood and sediment entrained in flood flows (Weaver et al. 1987, Flanagan 2004). They are prone to failure during peak runoff events. When they fail, the sediment and debris accumulated over decades may be released in flood torrents that have significant downstream effects (Furniss et al. 1998). Short of complete failure, when they plug or when flows otherwise overtop the road, the diverted streamflow can produce extensive gullies (Hagans and Weaver 1987, Best et al. 1995).

The "legacy" of inadequate stream crossings in northwestern California has been acknowledged for at least 20 years. State and federal grant and cost sharing programs have shifted priorities over the past decade to support projects that either remove or replace deficient crossings. Most of these projects are justified on the basis of the "sediment savings" associated with eliminating the risk of catastrophic failure (Madej 2001). According to the California Habitat Restoration Project Database jointly maintained by the California Department of Fish and Game, National Oceanic and Atmospheric administration and Pacific States Marine Fisheries Management Commission, approximately 4,000 stream crossings have been removed or replaced with more functional crossing structures over the past 10 years in coastal California using state and federal grant funding (Laurie Williams, California Department of Fish and Game, personal communication, June 2006). Public funds have also been used to remove (decommission) numerous roads and crossings on federal and state lands and restore streams and terrain. For example, the National Park Service has decommissioned approximately 230 miles of old roads and 990 stream crossings in Redwood

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Richard Harris (rrharris@nature.berkeley.edu), Environmental Science, Policy, and Management, University of California, Berkeley, CA 94720-3114. Jared Gerstein, Environmental Science, Policy, and Management, University of California, Berkeley, CA 94720-3114. Peter Cafferata, California Department of Forestry and Fire Protection, Sacramento, CA 94244. *Funding for this study was provided by the Division of Agriculture and Natural Resources, University of California. Cooperators included Matt House, Green Diamond Resource Company; Ted Oldenburg, Hoopa Valley Tribal Forestry; and Dr. Kathleen Sullivan, Pacific Lumber Company. Numerous useful discussions occurred at meetings of the California Board of Forestry and Fire Protection's Monitoring Study Group. Dr. Bill Weaver of Pacific Watershed Associates provided helpful suggestions on study design.*

National Park (Humboldt County) over the past 25 years (Harris and Cafferata 2004).

In northwestern California, many deficient stream crossings are located on land managed for timber production. When a California landowner applies for a permit from the state to conduct timber harvesting, interagency review will identify inadequate stream crossings within the planned timber harvest area or on appurtenant log hauling routes. As part of the permit conditions, the landowner will be required to improve, replace, or otherwise upgrade nonfunctioning crossings to meet current design standards. In some instances, they will be required to remove especially problematic crossings altogether. According to current California forest practice rules, new or upgraded permanent crossings must be adequate to convey anticipated 100-year recurrence interval streamflow plus entrained sediment and debris (California Department of Forestry and Fire Protection 2007). Other design elements are included to prevent catastrophic failure where necessary, such as maintained "trash racks" installed above the crossing inlet. As a consequence of regulatory requirements, thousands of stream crossings have been removed, replaced, or upgraded throughout California's nonfederal commercial timberlands over the past several years with private funding.

When stream crossings are replaced, the process includes excavating the existing crossing and accumulated sediment and debris, restoring the natural channel upstream and downstream from the crossing, and installing the new structure and fill. Most upgraded crossings on non–fish-bearing streams are conventional culverts (steel, aluminum, or plastic). Crossing replacement and removal both pose the risk of producing sediment during and after construction (Switalski et al. 2004). Some erosion is avoided by restricting construction to periods when streams are either dry or at low flows that may be diverted around the construction site. After construction, erosion and sediment delivery can be caused by precipitation or streamflow acting on exposed soil surfaces, such as fill slopes. Crossing replacements can also trigger channel incision and bank erosion because of the change in hydraulic efficiency or change in channel base elevation. Although these "postconstruction adjustments" have received some study in California and elsewhere where crossings have been removed altogether (e.g., Madej 2001), there are no published studies of postconstruction impact at sites where crossings have been replaced.

The benefits of replacing stream crossings that act as chronic or potential catastrophic sources of sediment delivery are obvious (Switalski et al. 2004). There is a pressing need, however, to understand the construction-related impact of these replacements. This need mainly arises from the concerns of State and Regional Water Quality Control Boards about short-term erosion and sedimentation caused by crossing replacements. The objective of this research was to document channel erosion caused by a selection of typical stream crossing replacements in forested watersheds located in northwestern California. Although stream crossing replacements are occurring on lands used for residential and recreational uses, the focus of this study was on privately owned commercial timberland.

Methods

Study Site Selection

Site selection was limited to crossings on intermittent and perennial non–fish-bearing streams in upper watershed areas. These types of streams are denoted as Class II and III watercourses in the California Forest Practice Rules (California Department of Forestry and Fire Protection 2006). It was not possible to select a random or stratified random sample of crossings across different ownerships because: 1) the cooperation of landowners was required; 2) timber harvest activities are not randomly distributed; and 3) there was a need to obtain pre- and posttreatment data within the time frame of the funding for this study. Three land owners agreed to cooperate: Green Diamond Resource Company (GDRC), Pacific Lumber Company (PALCO), and the Hoopa Valley Indian Tribe (Hoopa). All ownerships are located in Humboldt County, California.

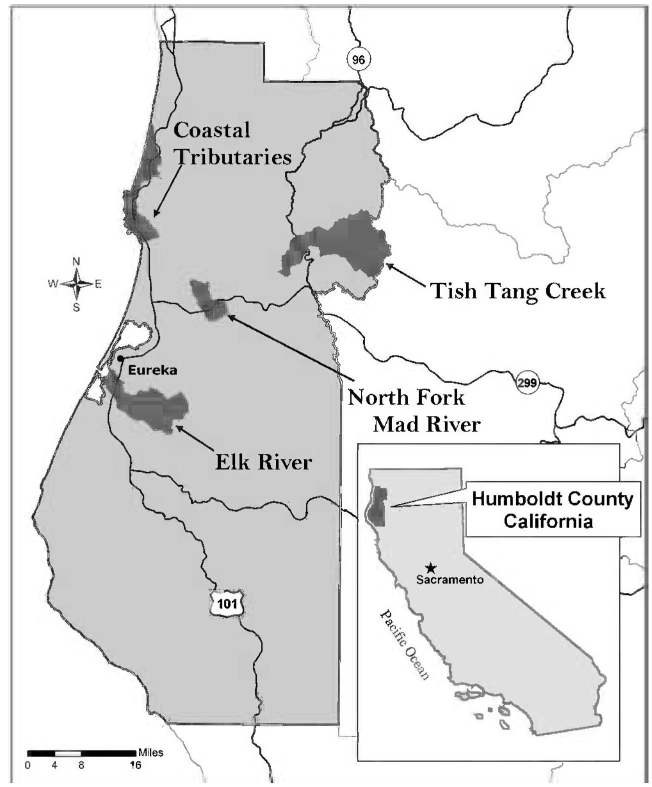

Figure 1. Study site locations.

The research team met with landowner representatives to identify potential study sites. Choices were limited to stream crossings on timber harvest plans that had not yet been upgraded but that would be upgraded prior to the next winter (2005–2006). Of the sites available, 10 were selected on PALCO land located in the Elk River watershed. Six sites were selected at Hoopa in the Tish Tang Creek watershed, a tributary to the Trinity River. An additional 14 sites were located on GDRC land, 9 in the North Fork Mad River watershed, and 5 in unnamed coastal tributaries east of the town of Trinidad (Figure 1 and Table 1).

Data were collected on all 30 sites in the summer and fall of 2005 immediately after construction and prior to any significant rainfall. Data were collected again in the spring of 2006 on all sites after the winter of 2005–2006.

Weather Conditions

Several researchers have noted the importance of extreme (rare) weather events in affecting the amount of erosion experienced at sites where stream crossings were removed and not replaced (Klein 1987, Madej 2001, Pacific Watershed Associates 2005). It is presumed that the responses of the crossing sites evaluated in this study were strongly dependent on the weather conditions during the winter of 2005–2006. Site-specific rainfall and runoff data were not

Table 1. Ownership, location, and characteristics of study sites. Data on pretreatment culvert diameters were not available.

Owner	Location	Site number	Volume of fill prior to treatment (cubic yards)	Installed culvert diameter (in.)
GDRC	Trinidad Coastal	1	445	24
GDRC	Trinidad Coastal	2	1356	48
GDRC	Trinidad Coastal	3	900	36
GDRC	Trinidad Coastal	4	1479	36
GDRC	Trinidad Coastal	5	1111	60
GDRC	N. Fork Mad River	6	117	36
GDRC	N. Fork Mad River	7	92	36
GDRC	N. Fork Mad River	8	121	36
GDRC	N. Fork Mad River	9	299	24
GDRC	N. Fork Mad River	10	115	24
GDRC	N. Fork Mad River	11	341	24
GDRC	N. Fork Mad River	12	469	24
GDRC	N. Fork Mad River	13	196	24
GDRC	N. Fork Mad River	14	164	24
Hoopa	Tish Tang Creek	15	332	60
Hoopa	Tish Tang Creek	16	817	48
Hoopa	Tish Tang Creek	17	198	24
Hoopa	Tish Tang Creek	18	557	48
Hoopa	Tish Tang Creek	19	446	72
Hoopa	Tish Tang Creek	20	530	60
PALCO	S. Fork Elk River	21	363	36
PALCO	S. Fork Elk River	22	Unknown	36
PALCO	S. Fork Elk River	23	Unknown	36
PALCO	S. Fork Elk River	24	1472	36
PALCO	N. Fork Elk River	25	Unknown	24
PALCO	N. Fork Elk River	26	Unknown	24
PALCO	N. Fork Elk River	27	Unknown	24
PALCO	N. Fork Elk River	28	450	36
PALCO	N. Fork Elk River	29	250	36
PALCO	N. Fork Elk River	30	250	24

collected, but weather conditions may be inferred from nearby stream gauging and precipitation stations. Little River near Trinidad is the gauged, unregulated stream with a long period of record closest to the GRDC sites; Bull Creek is nearest to the PALCO sites; and the South Fork Trinity River is closest to the Hoopa sites. In water year 2006, these stations experienced maximum instantaneous peak flows with estimated recurrence intervals between 2 and 6.5 years (Table 2).

Precipitation data for the winter of 2005–2006 are available from several stations in Humboldt County (Table 3). For stations nearest to the GDRC and PALCO sites (Eureka, Arcata, and Scotia), maximum daily precipitation did not exceed amounts greater than a 2-year recurrence interval event. At Hoopa, daily precipitation reached a maximum of a 5-year recurrence interval event.

Rainfall depth–duration frequency data for weather stations located in Eureka and Arcata in the vicinity of the GDRC and PALCO sites also indicate mild to moderate precipitation totals during the winter of 2005–2006. The maximum 5- and 10-day duration precipitation amounts were recorded at the Eureka station and had estimated recurrence intervals of approximately 2–3 years (Table 4). In contrast, the maximum 3-, 5-, and 10-day duration precipitation amounts at Hoopa all had return intervals of 5 to 10 years.

The GDRC and PALCO sites were not subjected to a substantial stressing storm event, since most researchers and practitioners consider these events to have a return interval of at least 5 to 10 years. The sites at Hoopa were subjected to at least one stressing storm event. For all sites the results presented below should be considered preliminary rather than conclusive, because of the weather and because the crossings were only subjected to one overwintering period.

Field Data Collection

Data collected at each site included longitudinal profiles extending above and below each road crossing, cross sections located above and below each crossing and estimates of erosion voids in stream channels and fill slopes. Methods generally followed those described in MacDonald et al. (1991) and Klein (2003). In addition, methods described in Hall (2001) were used to take pre- and posttreatment photographs from established photopoints.

Longitudinal Profiles and Cross Sections

An automatic level and stadia rod were used to survey long profiles and cross sections after construction and after the winter rainy season at all sites. The endpoints for the long profile surveys were established 20 to 50 ft beyond the upstream and downstream limits of excavation. The upper end station (UES) or starting point for each long profile was marked with a metal stake driven into the channel and/or with permanent markers in the stream bank on either side of the UES. Benchmarks were also permanently marked, and a site sketch showing the relative positions of all relevant points was prepared for each site.

A 300-ft fiberglass tape measure was strung down the channel to establish long profile measurement stations. Elevation measurements were made at the thalweg every 5 ft and/or at grade breaks within the channel, particularly at steps in the profile.

Four permanently marked cross sections were installed and surveyed after each site was constructed and then remeasured after the winter. One cross section was located 10 ft upstream of the limit of excavation and one 10 ft downstream of the limit of excavation. Two more cross sections were installed within the excavated area, at distances equal to the diameter of the culvert (in feet) above and below each end of the culvert. Elevation measurements were recorded every 2 ft and/or at grade breaks.

The long profile data were used to detect changes in thalweg elevation from the posttreatment condition to the postwinter condition. These data were used to calculate the maximum elevation change and total length of incision or deposition. The cross sectional area data were used to detect changes in thalweg depth as well as changes in cross sectional area.

Void Estimates

Channel scour (fluvial erosion) through excavated stream crossings was estimated by measuring the height of erosion scarps (Figure 2, $d1$ and $d2$) and top widths (Figure 2, W) at cross sections (Figure 3, X1, S2, etc.) placed within lengths of geomorphically similar channels (Figure 3, L 1, L 2 etc.). This method generally provides estimates that are within 8–17% of void volumes estimated by more precise methods (Casali et al. 2006). By measuring only scarp height and top width, however, the resulting product overestimated actual void area. Only a portion of this gross area represented actual losses since the eroding channel is scouring into a sloping surface.

Klein (2003) developed a mathematical calculation method to reduce gross measurements of channel scour and void development to generate approximate true erosion cross-sectional areas. The uncorrected cross-sectional area at any single cross-section, or "average" cross-section for a segment of channel, was calculated by multiplying the product of average scarp height $(d1 + d2)/2$ and top width: $A = d(\text{avg}) \times W$. This maximum cross-sectional area was

Table 2. Summary of stream discharge data for water year 2006 at selected unregulated stream gaging stations located in Humboldt County*

Station name and US Geological Survey number	Water year maximum discharge (ft^3/sec)	Date	Estimated recurrence interval (years)†
Little River near Trinidad, no. 11481200	4,600	Dec. 28, 2005	2
Bull Creek near Weott, no. 11476600	3,650	Dec. 30, 2005	3.5
South Fork Trinity River below Hyampom, no. 11528700	47,600	Dec. 30, 2005	6.5

* CDWR 2007a; T. Reed, US Geological Survey, Redding, CA, personal communication, August, 2006; and G. Susich, US Geological Survey, Eureka, CA, personal communication, September, 2006.
† Calculated using the US Geological Survey PEAKFQ software program (USGS 2007).

Table 3. Summary of daily maximum precipitation data for water year 2006 at selected stations located in Humboldt County*

Station name	Daily maximum precipitation (inches)	Date	Estimated recurrence interval (yrs)†
Eureka	2.04	2/01/06	$<$2
Arcata Airport	1.89	12/28/2005	$<$2
Scotia	3.16	3/05/2006	$<$2
Hoopa	4.40	12/30/2005	~5

* CDWR 2007a; T. Ashford, National Weather Service, Eureka, CA, personal communication, August 2006; J. Ashby, Western Regional Climate Center, Reno, NV, personal communication, August 2006; and T. Oldenburg, Hoopa Tribal Forestry, Hoopa, CA, personal comunication, September 2006.
† Estimated recurrence interval data is from CDWR 2007b.

then "adjusted" or reduced according to the side slope steepness as follows:

$$A_A = -0.561 * \text{slope\%}_{avg} + 0.9244$$

where A_A = the adjusted cross-sectional area, and slope$\%_{avg}$ is the average gradient of the left and right side slopes. This technique was originally developed for decommissioned crossings, but it appeared to yield reasonable estimates in this study.

Simple quantitative measurements of bank slumps in stream crossing excavations were quantified using the field measurements of width, length, and depth (see Figures 2 and 3) and applying a formula consistent with the parabolic shape typical of these features (Klein 2003). The surface area was calculated by the following formula:

$$A = \tfrac{2}{3}XY$$

where A = surface area in ft^2, X = maximum width along channel (Figure 3, W, feet), and Y = maximum length up from channel (Figure 3, L, feet).

The void or volume of bank slumps was calculated by multiplying area (A, above) by average depth (Figure 2, D, feet). Average depth of the failure void was measured or, if the slump mass was still there, visually estimated in the field as the depth perpendicular to the adjacent slopes ("slope normal"). Volume was reported in cubic yards. The percentage of slump volume actually delivered to the channel was estimated for each feature.

The volume of material scoured from the channel plus the volume of material contributed by bank slumps was summed for each site. For sites where material was deposited or aggraded an estimate of the area and depth was made to calculate a volume, similar to the bank slump method discussed above. The net change in material (scour + deposition) was reported for each site.

Analysis

Study sites were not randomly selected, and in any event, stream crossings would not be considered to be a population that is randomly distributed. Consequently, the opportunities for statistical analysis and inference are limited.

Analysis consisted of summing postwinter estimates of erosion or deposition at each site for comparison. In addition, longitudinal profiles and cross sections for each site where significant erosion or deposition occurred were compared before and after the winter to determine the extent of changes in stream channel morphology experienced. All calculations were made in spreadsheets using Microsoft Excel.

These changes were expressed as maximum and average depths and lengths of incision or deposition for long profiles and changes in cross sectional area for cross sections. Changes in channel morphology are described below for examples of the sites that experienced significant erosion or deposition.

Results

Both erosion and aggradation were measured at the 30 study sites after the winter of 2005–2006 (Table 5). Four sites located at Hoopa (Table 5, sites 15, 16, 19, and 20) showed substantial aggradation or erosion not directly attributable to the upgrading, as discussed below, and one additional GDRC site (site 4) was aggraded. In the case of the GDRC site, it appeared that erosion beneath armoring occurred and that the products were deposited downstream. The presence of the armoring prevented accurate measurements of the thalweg elevation. Excluding these sites, total measured erosion attributable to upgrading was 48.9 cubic yards, or less than 2.0 cubic yards/site. Eleven sites showed no erosion at all. Only five sites had erosion volumes greater than 5 cubic yards, and only two had volumes of 10 cubic yards or more. Even these volumes would be considered relatively minor. A measurement detection threshold of 10 cubic yards for erosion voids has been used in other California watershed erosion and monitoring studies (Cafferata and Spittler 1998, Cafferata and Munn 2002).

The changes at four Hoopa sites (sites 15, 16, 19, and 20) occurred due to large upstream inputs of sediment from inner gorge landslides. In three cases, aggradation occurred (Table 5 and Figure 4).

At site 19, it appeared that the sediment pulse temporarily plugged the culvert and caused erosion both upstream and downstream when it finally released (Figures 5 and 6). None of the changes at the Hoopa sites appeared to be caused or aggravated by upgrading. Madej (2001) made similar observations at decommissioned crossings in Redwood National Park and similarly did not attribute the observed changes to the treatments. The relatively severe rainfall conditions experienced at Hoopa (Table 4, events in

Table 4. Summary of daily maximum precipitation data for water year 2006 at selected stations located in Humboldt County*

Recurrence Interval (RI)	1 Day (in.)	3 Day (in.)	5 Day (in.)	10 Day (in.)
Eureka				
RP 2	2.35	3.87	4.69	6.51
RP 5	3.16	5.25	6.32	8.6
RP 10	3.67	6.13	7.36	9.86
WY 2006 maximum	2.04	3.39	4.9	7.16
Date	Feb. 1, 2006	Mar. 1, 2006	Dec. 22, 2005	Dec. 28, 2005
Approximate RI	<2	<2	3	3
Arcata				
RP 2	3.26	5.35	6.88	9.57
RP 5	4.37	7.27	9.28	12.65
RP 10	5.08	8.48	10.81	14.50
WY 2006 maximum	1.89	3.44	5.21	7.61
Date	Dec. 28, 2005	Dec. 30, 2005	Dec. 22, 2006	Dec. 28, 2005
Approximate RI	<2	<2	<2	<2
Hoopa				
RP 2	3.38	5.34	6.52	9.09
RP 5	4.53	7.25	8.79	12.01
RP 10	5.27	8.46	10.24	13.76
RP 25	6.16	9.93	11.99	15.82
WY 2006 maximum	4.40	7.78	11.26	13.24
Date	Dec. 30, 2005	Dec. 20, 2005	Dec. 31, 2005	Dec. 31, 2005
Approximate RI	~5	~7.5	>10	~8.5

* CDWR 2007a; T. Ashford, National Weather Service, Eureka, CA, personal communication, August 2006; J. Ashby, Western Regional Climate Center, Reno, NV, personal communication, August 2006; and T. Oldenburg, Hoopa Tribal Forestry, Hoopa, CA, personal communication, September 2006. Estimated recurrence interval data is from CDWR 2007b.

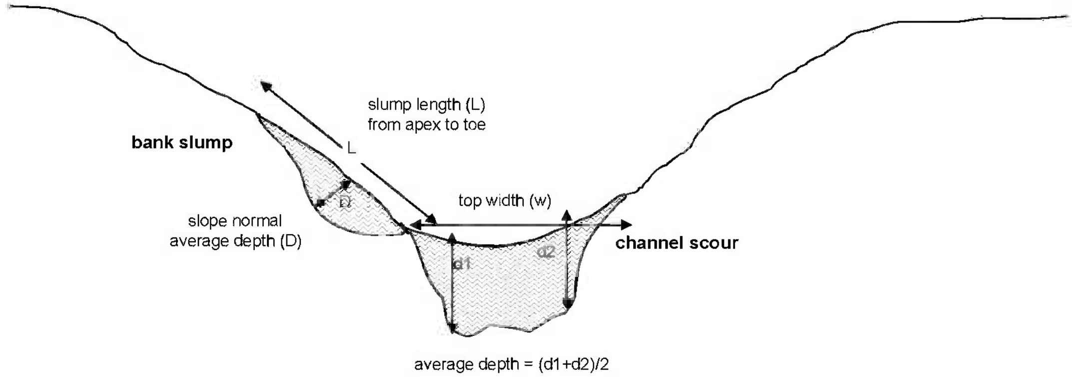

Figure 2. Void measurement technique as viewed in cross section. Source: Klein (2003), used with permission.

excess of 5-year recurrence interval storms) are considered responsible for the major landsliding observed during the winter of 2005–2006. Two sites at Hoopa (Table 5, sites 17 and 18) were not affected by landslides and showed no erosion or deposition.

Relatively mild weather is no doubt partly responsible for the absence or near absence of erosion at the PALCO and GDRC sites, but the efforts taken to mitigate erosion must also be considered. These mitigation measures included extensive rock armoring both upstream and downstream from crossings, as well as on crossing fill faces (Figure 7). Silt fences, straw mulching, and revegetation with erosion control grasses were also used at most sites. Most of these mitigation measures were required as conditions for granting permits for timber harvesting and log hauling.

On the sites experiencing erosion, the main source was incision of the channel bed. Bank slumps were relatively rare and small. Instances of channel widening or changes in horizontal position were not observed except at the Hoopa sites subjected to landslides. Erosion was limited to the excavated area for most sites, with very little evidence of incision propagating upstream or downstream.

For the five sites that exhibited erosion in excess of 5 cubic yards, postwinter longitudinal profiles indicated incision above and/or below the crossing (Figure 8). In some instances, the relatively uni-

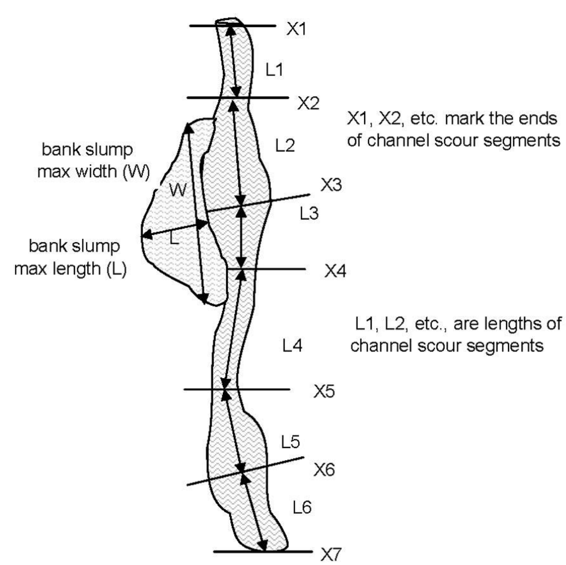

Figure 3. Void measurement technique as viewed from above. Source: Klein (2003), used with permission.

Table 5. Total measured erosion or deposition and changes in long profile, all study sites.

Site number[a]	Total erosion (−) or deposition (+) (cubic yards)[b]	Maximum vertical change (ft)[c]	Maximum length of change (ft)[d]
1	−1.0	<1	<1
2	0	0	0
3	−1.0	<1	<1
4	+11.0	+2.2	50
5	−1.0	−2.0	10
6	−10.1	−1.1	20
7	−8.7	−2.3	27
8	−1.1	−1.3	10
9	−0.1	0	0
10	−0.1	0	0
11	−1.8	−1.5	15
12	−1.0	−1.7	10
13	0	0	0
14	0	0	0
15	+100.0	+4.2	71
16	+534.0	+8.3	138
17	0	0	0
18	0	0	0
19	−424.0	−4.2	92
20	+84.0	+4.5	43
21	0	0	0
22	0	0	0
23	0	0	0
24	−3.0	−2.3	37
25	0	0	0
26	0	0	0
27	0	0	0
28	−5.0	−3.9	16
29	−10.0	−2.3	22
30	−5.0	−4.3	9

[a] See Table 1 for owner and location.
[b] Total erosion measured in voids.
[c] Maximum change in thalweg elevation as measured along the long profile.
[d] Maximum distance along long profile that experienced incision or aggradation.

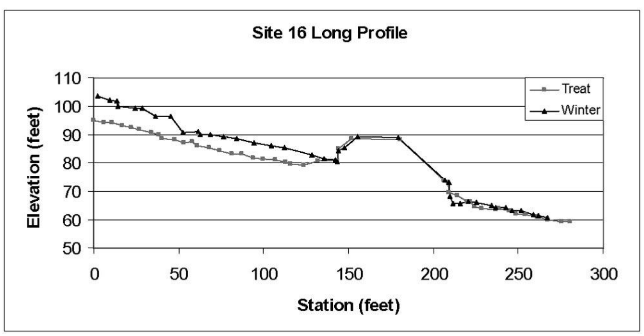

Figure 4. Longitudinal profile of site 16 (see Table 5) at Hoopa showing up to 8 ft of aggradation upstream of inlet due to a large landslide. The crossing structure and fill are located approximately at stations 150–200 ft.

form, flat channel bottoms created upstream and downstream from crossings by construction were simply "roughened" by the actions of various flows over the winter (see Figure 8, downstream section). At many of the study sites, it was not considered feasible to fully excavate fill and debris associated with past logging and transportation systems. As a consequence, some observed incisions represented evacuation of that stored material rather than changes to the native stream bed. Efforts taken to reduce the movement of stored material included armoring of potential head cuts and channel beds.

The maximum depth of incision observed at any site was 4.3 ft, and the maximum length of affected profile was 37 ft. Most profiles showed very minor changes.

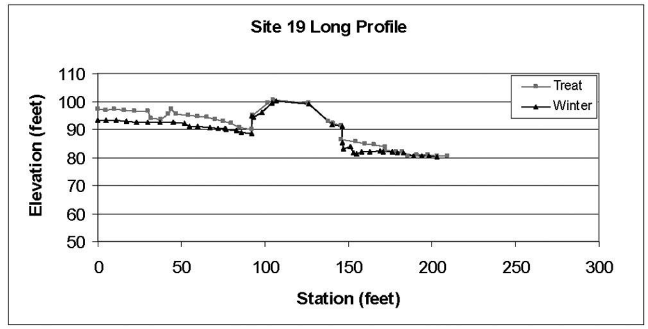

Figure 5. Long profile of site 19 (see Table 5) at Hoopa showing scour above and below the culvert caused by temporary plugging of the culvert and subsequent clearing. The crossing structure and fill are located approximately at stations 100–150 ft. A constructed water drafting pool was located at station 50 ft.

Few cross sections were located in places that coincided with significant incision or deposition. Those that did were found at sites where longitudinal profiles indicated the most erosion (Figure 9). Cross sections alone were not close enough to capture channel changes. The longitudinal profile was a superior method for measuring changes to the channel bed.

Discussion

There is an enormous amount of stream crossing upgrading and decommissioning occurring throughout the Pacific Northwest. Much of this work is happening on commercial timber land and is intended to benefit fisheries and water quality. The findings of this study indicate that under moderate weather conditions, design and construction practices and measures taken to prevent erosion at replaced crossings were effective on areas undergoing timber harvest pursuant to California's state Forest Practice Regulations. There is, however, the possibility that further erosion will occur at these sites in the future, especially during more severe weather.

There are no published studies that document the effects of stream crossing replacements on channel morphology to compare with the present study. The results of this study compare well with published and unpublished studies on responses of decommissioned crossings (totally removed, with restored natural channel) in terms of the percentage of crossings experiencing significant erosion. In this study, 20% of the crossings accounted for 76% of the measured erosion. Madej (2001) evaluated the performance of 207 decommissioned crossings at Redwood National Park several years after treatment and subsequent to a 12-year recurrence interval streamflow event in Redwood Creek. She found that 20% of the crossings accounted for 73% of the measured erosion. Similarly, in the South Fork of Caspar Creek in Mendocino County, South of Humboldt County, 26 watercourse crossings were decommissioned in 1998, removing a total of approximately 23,410 cubic yards of fill material. Surveys of the decommissioned crossings showed that downcutting following three winter seasons resulted in 932 cubic yards of sediment production, or 4% of the total amount of sediment removed. Approximately 50% of this material came from three crossings, or 12% of the crossings surveyed (Keppler et al. 2007). Others have reported that when a relatively large number of decommissioned crossings are evaluated, most sediment production occurs on a small percentage of them, usually during the first storms after excavation (Klein 2003, Pacific Watershed Associates 2005).

Figure 6. Erosion of road fill at site 19 at Hoopa caused by temporary culvert plugging from landslide debris and sediment. Incision occurred downstream as well.

Figure 7. Typical crossing and road installation, PALCO lands, Humboldt County. Design features include alignment and slope of culvert conforming to the natural channel, extensive armoring to prevent fill slope and channel erosion, and provision of a "critical dip" in the road surface to prevent diversion of flow down the road if the culvert plugs. All exposed soils were treated with straw mulch and grass seeding to prevent erosion.

The results do not correspond as well in terms of the amount of erosion observed in comparison to decommissioned crossings. In this study, the maximum amount of erosion caused by upgrading was slightly over 10 cubic yards. Average erosion across all sites was 2 cubic yards. Klein (2003) reported the average erosion at 18 decommissioned stream crossings in the upper Mattole River watershed in southern Humboldt County as 15.5 cubic yards. Pacific Watershed Associates (2005) estimated average erosion at 52 decommissioned crossings in the Elk River watershed as 17 cubic yards. In the South Fork of Caspar Creek, an average of 36 cubic

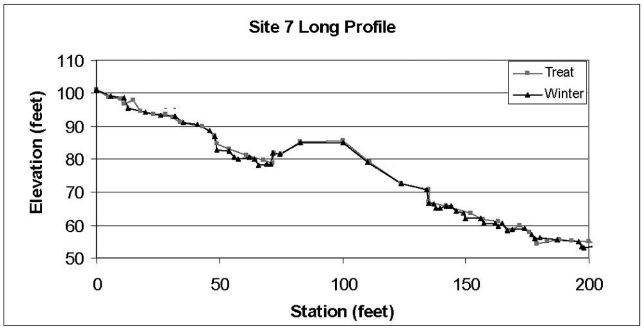

Figure 8. Profile showing incision above and below an upgraded stream crossing at site 7. XS indicates the locations of measured cross sections. Note that cross section locations alone have not captured the changes in the channel. TOP and BOT indicate the limits of excavation upstream and downstream, respectively.

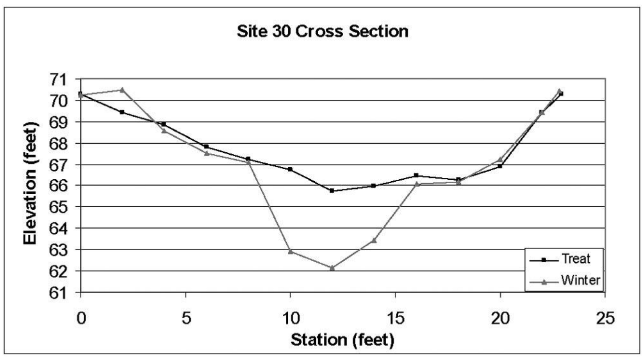

Figure 9. Cross section below upgraded crossing indicating incision of approximately 4 ft at the thalweg.

yards was produced from 26 crossings (Keppler et al. 2007). Madej (2001) reported an average of 65 cubic yards of erosion at her 207 decommissioned crossings.

The limited amount of amount of erosion we observed relative to decommissioned crossings appears to be due to at least four factors. First, decommissioned crossings with natural bottoms are more prone to channel incision (down-cutting) than upgraded crossings with culverts. Second, extensive erosion control measures were implemented at most of the crossings included in this study. Third, the winter of 2005–2006 was only low to moderate in terms of strong stressing storms for most of our sites. Finally, the study only covered one winter's effects. Although most postdecommissioning erosion at excavated crossings occurs during the first few years following removal work (Klein 1987, Bloom 1998), clearly additional erosion can occur after several years. In Madej's (2001) study with an average of 65 cubic yards per crossing, the 207 crossings had been decommissioned over a period of 17 years, from 1980 to 1997.

The results presented here may not be representative for the wide variety of crossing upgrading practices occurring in coastal California and throughout the Pacific Northwest. Many treated stream crossings do not have the extensive erosion control measures that were required on these timber harvest sites. Also, the wide variety of geologic and land use conditions across the region reduces the confidence level in extrapolating these results elsewhere. Nevertheless, it appears that if crossings are replaced and appropriate mitigation measures are implemented to prevent postconstruction erosion, the adverse effects on water quality can be minimized.

Crossing replacements on regulated timber harvests receive exceptional scrutiny, particularly on the California north coast where sedimentation effects on water quality and anadromous fisheries are significant issues. As previously noted, thousands of crossings are being replaced or decommissioned on other lands with funding from federal and state grant programs. It is currently uncertain whether or not these projects are provided with the same level of erosion control during and after construction. A potentially fruitful avenue for future research would be to replicate this study at other sites to determine whether similar measures are being applied and, if not, whether sediment production after construction differs from the results presented here.

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PROGRAMS ASSESSING IMPLEMENTATION AND EFFECTIVENESS OF STATE FOREST PRACTICE RULES AND BMPS IN THE WEST

GEORGE ICE [1]*, LIZ DENT [2], JOSH ROBBEN [2], PETE CAFFERATA [3], JEFF LIGHT [4], BRIAN SUGDEN [4] and TERRY CUNDY [5]

[1] *National Council for Air and Stream Improvement, Inc., P.O. Box 458, Corvallis, Oregon 97339, U.S.A.;* [2] *Oregon Department of Forestry;* [3] *California Department of Forestry and Fire Protection;* [4] *Plum Creek Timber Company;* [5] *Potlatch Corporation*

(author for correspondence, e-mail: GIce@NCASI.org)*

Abstract. The major forest nonpoint source control programs in the West are largely regulatory, either under forest practices acts (California, Idaho, New Mexico, Nevada, Oregon, and Washington) or a streamside management act (Montana). These programs and the specific rules they enforce continue to undergo intensive scrutiny. Still, the questions are the same for these regulatory programs as for states that base nonpoint source control on voluntary BMPs (Arizona, Colorado, Utah, Wyoming). Are the rules or BMPs being applied, and are they effective in reducing nonpoint source pollution to levels that protect beneficial uses of water? The level of debate about forestry in the West has resulted in detailed monitoring and research to answer these questions. In the past, state agencies have assumed levels of BMP compliance based on the percent of operations without enforcement actions. These estimates are being replaced by statistically valid and reproducible monitoring of forest practices rules and BMP compliance levels. BMP effectiveness is being assessed using both qualitative and quantitative methods. This can involve field assessments, process-based research, and control watershed studies. Some trend monitoring is also beginning. With the regional implementation rate for forestry BMPs at about 94% and rising, it is likely that effectiveness testing will continue to be a priority and consume the majority of assessment resources for this region.

Keywords: BMPs, forest practices, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, water quality, Wyoming

1. Introduction

When the 1972 Water Pollution Control Act Amendments (later amended and renamed the Clean Water Act and hereinafter referred to as the CWA) became law only one state, Oregon, had a formal (albeit rudimentary) nonpoint source (NPS) control program for forestry. The CWA identified two types of pollution: point and nonpoint sources. Point sources are discrete discharges, such as sewage treatment plants. Nonpoint sources, such as those from most agricultural and forestry activities, are not traceable to any discrete facility or site, are usually best controlled through prevention rather than treatment, and are often induced by natural processes (e.g., runoff resulting from rain or snowmelt). Under the CWA, states were required to develop NPS control programs. In 1974 the U.S. Environmental

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Protection Agency (EPA) proposed that states adopt NPS control programs for forestry activities that were modeled after the forest practices acts of the Pacific Coast states (Rey 1980). This 'one-size-fits-all' approach was vigorously opposed and in 1977 EPA issued guidelines allowing either regulatory or voluntary NPS control programs if '...such programs were adequate to achieve desired water quality goals' (USEPA, 1977). As a result of this guidance and the unique conditions in each state, a variety of different types of NPS control programs, both regulatory and nonregulatory, would eventually be adopted. Still, the key measure of program success, laid out by the EPA 1977 guidance and the overall goals of the CWA, was whether the NPS control program could achieve desired water quality goals.

While different types of NPS control programs are adopted by states to achieve water quality goals, these programs all achieve reductions in water quality impact by requiring or encouraging the use of specific management practices known as Best Management Practices (BMPs). Best Management Practices are defined as 'a practice or usually a combination of practices that are determined by a state or designated planning agency to be the most efficient and practicable means (including technological, economic, and institutional considerations) of controlling point and nonpoint source pollutants at levels compatible with environmental quality goals' (Helms, 1998). For forestry, these BMPs can include streamside management zones, specific road construction and maintenance practices, appropriate timber yarding methods, careful application and handling of silvicultural chemicals, and a variety of other practices, all designed to protect water quality. In states with forest practices acts, the forest practice rules (and implementing process) are the state BMPs.

Program success can be largely assessed by two measures: when BMPs are applied do they reduce impacts so that desired water quality goals are achieved and are BMPs being used? In the South, where many states developed nonregulatory programs, the first questions that EPA and states raised were about BMP implementation levels. Do operators and landowners routinely apply BMPs and are implementation rates different than those found for regulatory programs? In the West, the questions were more about whether BMPs were effective in controlling NPS impacts. Efforts to measure the effectiveness of BMPs are not straightforward. When we discuss controlling BMPs it is recognized that NPS pollution cannot be completely eliminated yet can be reduced to an acceptable level. But water quality goals have become a moving target. Initially, BMPs were considered effective if they reduced gross water quality impacts to achieve the fishable and swimmable goals of the CWA. Early forest practice rules had language like, 'maintain riparian shade where possible'. These rules have continued to evolve, becoming more prescriptive about performance measures (e.g., percent of shade that must be maintained) and incorporating new findings about NPS impacts (e.g., maintain trees of sufficient size, species, and location for recruitment of large woody debris). While the ability to achieve water quality standards is often considered the ultimate measure of BMP effectiveness, researchers are now finding that sometimes water quality standards cannot be achieved even for the least-impaired forest streams (HDR, 2002; Ice, 2002; Ice and Binkley, 2003). Therefore, the fishable/swimmable goals of the CWA or protection of beneficial uses of water becomes the most relevant water quality goals for assessing BMP effectiveness (ODF and ODEQ, 2002).

Of course over time, both these questions, implementation and effectiveness of BMPs, need to be answered to evaluate whether a state NPS control program is achieving desired water quality goals. Here we describe efforts in the 11 contiguous western states (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming) to assess BMP implementation and effectiveness. This review does not address management on federal lands that occupy much of the forestland in the western region, focusing instead on programs for private forest operations. While we address all 11 states in this region, this review further focuses on the programs of California, Idaho, Montana, Oregon, and Washington, where the majority of commercial forest operations occur.

2. Individual State Reviews

The reviews for individual states cover a brief description of the state forest conditions (acres, growing volume, harvest level), the NPS control program for silviculture, and efforts to assess the implementation or effectiveness of BMPs. Land and timber statistics for the states for 2002 are available on the USDA Forest Service web site (USDAFS, 2002). These reviews are not meant to be comprehensive, but rather an introduction to further information about state programs. Contact information and links to additional descriptions of individual state NPS control programs for forestry are available on the worldwide web at http://www.usabmp.net.

2.1. Arizona

Nearly 60% of the forestland in Arizona is in public ownership (e.g., National Forest) and additional large tracts are in tribal ownership. Even though there are 19 million acres of forest in the state, the timber growing stock volume and harvest levels are very low. The state relies mainly on USDA Forest Service standards and guidelines, and tribal forest management programs to ensure that silvicultural operations protect water quality. Forestry is generally ranked a low-priority water quality issue for the state. Silviculture was not even listed as a probable source of stress to Arizona streams in the draft 2000 305(b) report and silviculture was ranked only the twelfth leading source of impairment to lakes in Arizona. No review of BMP implementation or effectiveness has been conducted.

2.2. California

California had the third highest timber harvest level (628 million ft^3) of the 11 western states in 2002. There are more than 40 million acres of forest in the state and like Arizona, nearly 60% is public land. California's modern Forest Practice Act (FPA) was adopted in 1973, with full field implementation occurring in 1975. Under this Act, Timber Harvesting Plans (THPs) for commercial timber harvesting on all nonfederal timberlands must be submitted to the California Department of Forestry and Fire Protection (CDF). THPs are reviewed for compliance with the FPA and the Forest Practice Rules (FPRs) adopted by the California State Board of Forestry and Fire Protection (CSBOF), as well as other state and federal regulations protecting watersheds and wildlife. CDF, along with other state agencies (Department of Fish and Game, California Geological Survey, and Regional Water Quality Control Boards), conducts Pre-Harvest Inspections (PHIs) of proposed harvest areas to determine if plans are in compliance with the Act and FPRs. During PHIs, additional mitigation beyond the standard rules is usually recommended based upon site-specific evaluations. CDF also conducts field inspections during active timber operations and postharvest inspections when logging is completed.

Many monitoring efforts have been conducted during the past two decades to learn more about the implementation and effectiveness of FPRs in protecting water quality. These efforts complement the CDF Forest Practice compliance inspection program that has been in place for more than 25 years. A qualitative assessment of forest practices was conducted in 1986 by a team of four resource professionals who audited 100 completed THPs distributed throughout the state. The team found that the rules were generally effective when implemented on terrain that was not overly sensitive, and that poor rule implementation was the most common cause of water quality impacts (CSWRCB, 1987). Several changes to the FPRs were recommended based on the observations. Another example is the Critical Sites Erosion Study (Durgin *et al.*, 1989; Lewis and Rice, 1989), which collected extensive data on management and design factors associated with mass wasting events.

In 1988, CSBOF formed an interagency task force to develop a long-term monitoring program (LTMP) that could test the implementation and effectiveness of FPRs in protecting water quality. The resulting LTMP has implementation and effectiveness monitoring components, and a pilot project was used to develop appropriate techniques for both hillslope and instream monitoring (CSBOF, 1993). The Pilot Monitoring Program was completed during 1993 and 1994, with final reports written in 1995 (Tuttle, 1995; Rae, 1995; Spittler, 1995). The Hillslope Monitoring Program (HMP) pilot project developed methods for measuring rule implementation and effectiveness by modifying previously developed USDA Forest Service hillslope monitoring forms (USDAFS, 1992) and preparing new forms for practices that are unique in the FPRs (Tuttle, 1995).

The HMP has been conducting statewide evaluation of the implementation and effectiveness of Forest Practice Rules since 1996 using an annual random sample of 50 completed THPs that have over-wintered from one to four years. Detailed information is collected from sampled plans in the summer months and includes data on: (1) randomly located road, skid trail, and watercourse and lake protection zone (WLPZ) segments, as well as randomly located landings and watercourse crossings; and (2) large erosion events (e.g., mass wasting features) where they are encountered. Winter documentation of fine sediment delivery to streams is not undertaken with this program. The monitoring work is done by highly qualified independent contractors who act as third party auditors by collecting field data and entering them into an extensive database. A report of interim findings was prepared in June 1999, and an updated report based on the first 300 projects was completed in 2002 (Cafferata and Munn, 2002). This is an ongoing program. Data collected as part of the HMP from 1996 through 2001 show that implementation rates of the FPRs related to water quality are high (averaging 94%) and that individual practices required by the rules are effective in preventing hillslope erosion when properly implemented. Implementation of applicable rules at erosion sites was nearly always found to be less that that required by the FPRs. Roads and their associated crossings have been found to have the greatest potential for sediment delivery to watercourses (CSBOF, 1999; Cafferata and Munn, 2002). These conclusions were similar to those reached in the earlier audit of 100 THPs (CSWRCB, 1987).

Beginning in 2000, an additional monitoring component was added by CDF to evaluate Act and rule compliance and effectiveness. The goal of Modified Completion Report (MCR) monitoring is for CDF's own Forest Practice Inspectors to monitor a random selection of 12.5% of all completed THPs for implementation and effectiveness of the FPRs related to water quality protection. For each THP evaluated, a randomly selected road segment, Water Course and Lake Protection Zone (WLPZ) segment, and two watercourse crossings are rated for FPR implementation at the time logging is completed. Effectiveness of erosion control facilities and crossing design and construction are rated a second time for the same road segment and crossings during an Erosion Control Maintenance inspection after one to three over-wintering periods. This monitoring process is providing data that complements the more detailed information supplied by the HMP.

Over 7,000 CDF Forest Practice inspections are completed each year on about 700 THPs, along with numerous other types of projects (timberland conversions, nonindustrial management plans, exemptions, etc.). These inspections are the major tool utilized by CDF to determine if timber operations are in compliance with the Act and rules. Water quality violations are corrected when and where possible as part of the normal Forest Practice Inspection process. A query of CDF's Forest Practice Program Database to determine the frequency of FPR violations issued for rules related to water quality from 1998 to 2000 found 975 violations were identified from the 4,749 THPs open during that period. These violations can be separated into three basic groups: harvesting practices and erosion control (347), watercourse and lake protection (308), and logging roads and landings (320). The FPRs with the highest number of violations generally involved waterbreak rules, timber operations in the winter period, proper removal of temporary crossings, roads and landings located outside of WLPZs, removal of debris from very small watercourses, WLPZ trees felled away from the watercourse, removal of accidental depositions in watercourses, crossings open to unrestricted passage of water, size/number/location of drainage structures adequate to minimize erosion, and crossing removal adequate to prevent erosion. This type of information complements the data from the HMP and MCR monitoring work. Together, these three independent data sources allow cross-checking and corroboration of the results of each type of monitoring.

Determining which rules have the poorest implementation and effectiveness and the highest frequency of violations both provides input to the CSBOF on needed rule changes and identifies training needs for: (1) CDF's Forest Practice Inspectors; (2) Registered Professional Foresters (RPFs) submitting THPs; and (3) Licensed Timber Operators (LTOs). As an example of how the monitoring data have been used, the CSBOF adopted rule language in 2000 requiring RPF supervision of active timber operations based on information provided by the HMP and Ligon *et al.* (1999). In terms of training needs identified by monitoring, workshops on proper watercourse crossing design, construction, and maintenance were held in 2003.

Another important ongoing project that allows the state to assess rule effectiveness is the Caspar Creek Watershed Study conducted by CDF and the USDA Forest Service Pacific Southwest Research Station. This study provides research-level data on how forest practice operations prior to and after the implementation of the FPA have affected water quality (Ziemer, 1998; Cafferata and Spittler, 1998; Lewis, 1998; Lewis *et al.*, 2001; Ziemer, 2001). This study shows that modern FPRs have successfully reduced water quality impacts. Selective tractor logging and roading along the stream in the South Fork prior to implementation of the FPA was found to have increased suspended sediment yields 2.4 to 3.7 times over those measured with clearcutting and cable logging operations in the North Fork conducted under the modern FPRs (Lewis, 1998; Ziemer, 2001). Numerous landslides were documented after road construction and logging in the South Fork, while the size and number of landslides through 1998 were similar in logged and unlogged units in the North Fork (Cafferata and Spittler, 1998). CDF and the USDA Forest Service Pacific Southwest Research Station have signed a 100-year agreement for continuation of research at Caspar Creek. New streamflow and sediment monitoring stations with recording turbidimeters have been installed in nine tributaries of the South Fork to characterize hydrologic conditions prior to further second-growth harvesting. This ongoing research will allow for additional comparison of water quality and aquatic habitat impacts with and without application of the current FPA regulations. More than 100 papers and reports for the Caspar Creek Watershed Study are available at http://www.rsl.psw.fs.fed.us/projects/water/caspubs.html.

2.3. Colorado

There are nearly 22 million acres of forest in Colorado but almost two-thirds of these are public lands. Forest inventory data (USDAFS, 2002) shows substantial growing stock volumes in the state, however growth and harvest rates are very low. Colorado has new BMPs for forest operations known as forest stewardship guidelines. These guidelines were adopted in 1998 and are outlined in a booklet adapted from Montana (CSFS, 1998). The state has been active in education outreach, largely through the Central Rockies Sustainable Forestry Education Program (other participating states are Wyoming and South Dakota) that involves a 30-hour course on forest BMPs and other issues. The state has used anecdotal feedback on BMP implementation through these workshops but has not conducted a formal survey to determine implementation. The Colorado State Forest Service is working with the Colorado Timber Industry Association to secure funding for a statewide audit of BMP implementation The state has also established multiple station water quality monitoring in two managed forest watersheds to track long-term water quality trends. These are actively managed watersheds that were selected to provide some feedback on responses to the new BMPs.

2.4. Idaho

Idaho has 21 million acres of forest and supports the fourth highest harvest levels of the western states. Public ownership represents 84% of the forest land. Under the State of Idaho Forest Practices Water Quality Management Plan (Bauer *et al.*, 1988), the state is required to evaluate the implementation and effectiveness of state forest practice rules. There are two primary mechanisms for formally evaluating implementation and effectiveness. First, the quadrennial (once every four years) Forest Practices Water Quality Audit is led by the Idaho Department of Environmental Quality. Second, an annual (except on quadrennial audit years) Best Management Practices Internal Audit is conducted by the Idaho Department of Lands and the USDA Forest Service.

Initially, these evaluations focused primarily on implementation. Implementation rates have increased over the years from approximately 85% during the first survey to 96% in the 2000 Forest Practices Water Quality Audit (Hoelscher *et al.*, 2001). The implementation rates are not strictly comparable over time because the focus of the audits changes at the recommendation of the Forest Practices Act Advisory Committee. For example, the main focus of the 1996 audit was sediment delivery to streams, while the 2000 audit evaluated stream protection zones more closely.

In recent years, evaluations of effectiveness have become a larger part of evaluation processes. In the 1996 audit (Zaroban *et al.*, 1997), a simple yes/no evaluation was made on the question, ‘Was sediment delivered to the stream from this forest practice?’ No effort was made to quantify the amount of sediment or to evaluate the effects of the sediment on water quality and fish habitat. In a 1999 Forest Practices

Water Quality Audit (Colla and DuPont, 2000), the effort focused on habitat quality for bull trout in unharvested 'reference' and recently harvested sites. The 2000 Forest Practices Water Quality Audit (Hoelscher *et al.*, 2001) evaluated canopy cover, large woody debris, and fish passage at culverts (among other things). These audits generally show that the forest practice rules are effective. Zaroban *et al.* (1997) reported, 'On an individual rule basis, we found that when properly implemented and maintained, the practices described in the forest practice rules were effective 99% of the time'. However, they go on to say:

> We also found that half of the timber sales we audited had sediment being delivered to streams or stream channels as a result of forest practices activity. This apparent inconsistency can be attributed to management practice design, construction, maintenance, rule interpretation and other factors. The impact of this sediment delivery on the beneficial uses of the streams within these sale areas was not assessed.

Colla and DuPont (2000) wrote, 'This audit reaffirms what has been learned in past department and interagency audits. If the BMPs or rules are correctly implemented, they appear to be effective at minimizing or avoiding impacts to affected resources'.

Although these forest practices audits are not designed to directly determine the impact of sediment or other nonpoint source pollutants on beneficial uses, Idaho is responding to impaired waters listed under CWA §303(d) utilizing the Beneficial Use Reconnaissance Program (BURP). Like all states, Idaho is required to develop a list of waters not meeting water quality standards and develop Total Maximum Daily Load (TMDL) assessments to set load (point) and waste load (NPS) allocations that will achieve water quality standards and protect beneficial uses. BURP uses field measurements of water quality, stream habitat condition, and aquatic organisms to determine if beneficial uses are protected or impaired. Many forest stream reaches assessed using BURP were found not to be impaired.

Hoelscher *et al.* (2001) concluded that existing road and skid trail erosion control rules were both well implemented and effective. They did, however, have concerns about leave tree and shade requirements in stream protection zones. The latter issues are currently being addressed within the Forest Practices Act Advisory Committee and some rule changes are expected.

In addition to these state efforts, the effectiveness of the state forest practice rules is being tested by Potlatch Corporation and cooperators at Mica Creek in northern Idaho. The Mica Creek watershed project, initiated in 1990, represents a major paired and nested watershed test of forest practice impacts. The study design was inspired by the Caspar Creek Watershed Study in California and allows researchers to measure cumulative impacts. The 29 km^2 study area includes paired watersheds at three different scales. After a calibration period, road construction effects were monitored, and monitoring is continuing to document the effect of timber harvesting in 2002 (McGreer *et al.*, 1995; Cundy *et al.*, 2001). Results from Mica Creek are just beginning to be reported (Ice *et al.*, 2002).

The adaptive management or continuous improvement model adopted to implement the Idaho Forest Practices Act in 1974 and the audit processes required under the 1988 Water Quality Management Plan work well. Data are collected on a regular basis, results are analyzed, and adjustments are made to rules. With the flexibility to focus evaluations on areas of high concern, all stakeholders can be assured that the program resources are used to understand and address the most relevant current issues.

2.5. MONTANA

Montana has 23 million acres of forest, three-quarters of which are in public ownership. In 2002 it had the fifth largest timber harvest of the 11 western states. Prompted by increasing public concern about timber harvesting impacts on water quality, the 1987 Montana Legislature directed the Montana Environmental Quality Council (EQC) to examine how current forest practices were affecting watersheds, and summarize what options existed to better control the impacts. The EQC is a legislated working group composed of elected state representatives, as well as governor-appointed citizen members (Montana Code Annotated [MCA] 5–16–101). It is periodically tasked by the legislature to work on environmental issues during the 2-year period between state legislative sessions (MCA 75–1-324). The final report (EQC, 1988) found that BMPs were properly applied 82% of the time, and that management of streamside areas and road erosion received the lowest overall ratings. Recommendations from their report (EQC, 1988) precipitated several changes in Montana's nonpoint source management program for forestry, including formation of a Technical Committee to guide development of a set of statewide forestry BMPs. This committee included industrial and nonindustrial landowners, logging contractors, Montana Water Quality Bureau staff, representatives of the USDA Forest Service, and was led by the Montana Department of Natural Resources and Conservation (DNRC).

In July 1989 the BMP Technical Committee finalized a consistent set of voluntary statewide forestry BMPs, which were updated in 1997. These BMPs are contained within the state Nonpoint Source Management Plan (Montana DEQ, 2001). Also in 1989, the Montana Legislature enacted a law requiring landowners to notify DNRC of plans to initiate a forest practice (MCA 76–13–131) in advance of operations (∼1300 notices per year statewide). The DNRC then distributes information to the landowner on state forestry BMPs and information on stream crossing permits that may be needed from the local Conservation District. If a proposed activity is in an area of high priority for watershed conservation, or there are other watershed concerns, the DNRC may require an onsite visit with the landowner by a state service forester (∼140 onsite visits per year). Notifications also allow the state to maintain a database of the amount and location of harvesting, which serves as the basis for BMP audit site selection.

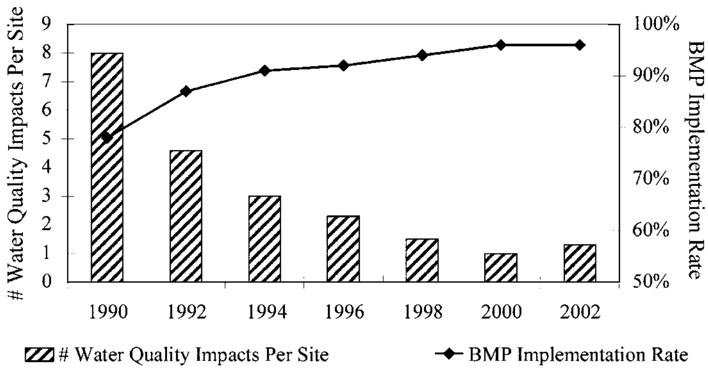

Figure 1. Montana BMP implementation rates for the period 1990–2002, and the number of observable water quality impacts per harvest site (Ethridge, 2003)

Streamside management zones (SMZs) had been found in 1988 to be areas of lower BMP compliance. In 1991, the state legislature passed a law governing commercial harvesting in streamside areas (Streamside Management Zone Act, MCA 77–5–301). This act requires 50- to 100-foot partial retention buffers along all streams, depending on sideslope steepness. Numerous other prohibitions exist within the SMZ, including streamside road construction, broadcast burning, depositing road fill, hazardous chemical application, and equipment operation.

BMP compliance in Montana has been monitored biannually since 1990. Audits are coordinated by the Montana DNRC, but audit team membership consists of resource professionals from state and federal agencies, the forest products and logging industries, environmental community, and other volunteers. Four interdisciplinary teams audit a total of 40 to 45 sites. Teams include a forester, road engineer, hydrologist, soil scientist, fisheries biologist, a small private landowner or logger, and someone from the environmental community. To qualify for the audit, harvest areas must contain an SMZ, have road construction, use tractor logging on steep slopes, or in some other fashion be considered higher risk. Requiring road construction and/or SMZs in the harvest area allows for the full range of BMPs to be rated. From this available pool, audit sites are randomly selected for different ownership categories and regions of the state (in proportion to the amount of harvest).

Results since 1990 show continued improvement in statewide BMP implementation rates (Figure 1). Statewide application of BMPs in 1990 averaged 78%. By 2000, this had improved to 96% (Ethridge and Heffernan, 2001; Ethridge, 2003). Additionally, the 2000 audit found that regulatory SMZ law requirements were met 96% of the time. Improvements in BMP implementation have occurred across all ownership categories and geographic regions of the state.

The steady pace of improvement is attributed to logger education efforts by the Montana Logging Association and Montana DNRC, which typically reach 250 loggers each year. Small private landowner education has also improved through the

Montana Forest Stewardship Program administered by Montana State University Extension. This program has resulted in forest management plans on 750,000 acres to date, or about one-quarter of the nonindustrial private forestland in Montana. Improvements on industrial private lands have resulted from corporate management placing a high priority on environmental compliance.

The audit process itself has proven to be a major educational tool. In addition to foresters, loggers, road builders, and others connected with harvest usually participate as observers. Having the folks that do the work on the ground exchange ideas with the audit teams proves to be a tremendous learning experience. The audit report is widely distributed to everyone in the forest products industry. The most problematic BMPs are distilled into a 'top ten list' which helps focus everyone's educational effort.

Evaluation of BMP effectiveness is addressed qualitatively during the BMP audit process. Each BMP rated for application is also assessed for its effectiveness in preventing visible erosion and/or sediment delivery to streams (as evidenced by gullies or sediment paths). While subjective, these assessments are believed to yield important information that may not be deduced by instream methods (Corner *et al.*, 1996). The frequency of observable water quality impacts (sediment delivery to streams) has decreased dramatically as BMP implementation rates have increased (Figure 1).

Currently, there is no coordinated statewide agency program in place for comprehensive research investigations to examine BMP effectiveness. Plum Creek Timber Company, the state's largest industrial timberland owner, is conducting the most extensive BMP effectiveness research as part of its Native Fish Habitat Conservation Plan (Plum Creek Timber Company, 2000). This research includes investigations of reach- and watershed-scale effects of streamside timber harvesting on water temperature, and effectiveness of road improvements in reducing fine sediment delivery to streams and improving spawning gravel quality. Plum Creek research also includes validation of assumptions used in large woody debris recruitment and sediment models. The state DNRC is initiating some effectiveness monitoring as part of its State Forest Land Management Plan.

2.6. NEVADA

While Nevada is reported to have 10 million acres of forest it supports by far the lowest growing stock volumes and timber harvest volumes of the 11 western states. Despite the low level of forest management, silvicultural activities in Nevada are strictly regulated by the Nevada Forest Practices Act (NFPA) and the State Diffuse Source Law. Under the NFPA a timber harvest permit from the state is required to conduct harvest operations. This involves a timber harvesting plan (utilizing BMPs) and a performance bond to ensure satisfactory compliance. Commercial timber harvesting is minimal in the state, averaging about three or four sales a year. These activities are almost always near Lake Tahoe and are subject to intense scrutiny.

Timber harvests in this area are also subject to regulation by the Tahoe Regional Planning Agency (TRPA) and must adhere to TRPA rules. As a result there have been no defaults on the performance bonds in recent years. An emerging issue is the development of BMPs for harvesting pinyon-juniper forests for biomass recovery and to restore wildlands (wildfire hazard reduction and reduced evapotranspiration stress).

2.7. New Mexico

New Mexico has 16.6 million acres of forest but harvest levels are low. Public lands comprise 62% of the forest. New Mexico has a forest practices act and adopted revised forest practice rules in January 2002 (http://www.nmforestry.com). Timber harvest plans are required for operations of 25 acres or larger. Forest practice rules are still required on smaller operations. Implementation of the rules was estimated to be 75% (Ice and Stuart, 2001), based on the inspection reports required for each timber harvest plan, however this is probably an underestimate of the current level of compliance. A statewide database for these inspections is not currently available but is planned. Once the implementation database is operating the state plans to explore opportunities to test the effectiveness of the rules.

2.8. Oregon

Oregon has historically been the leading timber producing state in the United States but has recently slipped due to reduced harvests on federal forest lands. The state has 29.6 million acres of forest and 63% of these are public. Still, annual harvest levels are near the top, not only for the west but the entire United States. The Oregon Department of Forestry (ODF) regulates forestry operations on nonfederal land. Landowners and operators are subject to the Forest Practices Act (adopted in 1971) and rules when any commercial activity relating to the growing or harvesting of trees is conducted. The Oregon Board of Forestry has exclusive authority to develop and enforce statewide and regional rules. The Board believes continued monitoring and research is necessary to provide information about the adequacy of the Oregon Forest Practice Act (FPA) and rules and how to improve them. The Oregon Department of Forestry's Forest Practices Monitoring Program (FPMP) provides scientific information for adapting regulatory policies, management practices, and volunteer efforts on nonfederal forest land.

The FPMP is responsible for monitoring the implementation and effectiveness of the rules and reporting those findings and recommendations to the Board of Forestry on an annual basis. These rules are subject to revision as necessary based on the best available science and monitoring data. The rules have undergone many revisions since 1972. The most recent changes to the water protection rules were in 1994 and 1995. The FPMP conducts a variety of projects designed to assess how well current rules are achieving the desired goals (effectiveness monitoring) and the rate of rules implemented in the field (compliance monitoring). What follows is a summary of two of ODF Forest Practices monitoring projects; one focusing on effectiveness and the other on compliance.

In 1994 new rules were adopted to maintain and promote *desired future riparian stand conditions* that will provide ample shade, an abundance of large wood to the channel, bank stability, snags, nutrient input, and nutrient uptake. These rules require the establishment of Riparian Management Areas (RMAs) on most streams that are within or adjacent to a harvest unit. The RMA width requirements vary depending on the stream classification. ODF classifies streams by 'Type' (fish-bearing, domestic water source, non-fish-bearing) and by stream size. A landowner has multiple options for managing RMAs. The objectives of this monitoring project were to determine if the forest practice riparian rules promote riparian conditions that are consistent with levels observed in mature riparian forests and if the rules are effective at maintaining structure that will promote the desired future conditions for large wood recruitment and shade.

The study used pre- and postharvest comparisons of riparian function and structure to evaluate harvest effects. It was conducted at volunteered sites distributed throughout the state of Oregon. A detailed field protocol is available from ODF (http://www.odf.state.or.us/internal.htm). Results indicate substantial variability in conifer stocking within and between georegions and stream sizes. Basal area standard targets were commonly met within 20 ft of the stream on small (72% of sites) and medium (81%) streams. Under such circumstances a landowner would have the option to clearcut harvest to within 20 ft of the stream. However, results also indicate that, in most instances, landowners are not exercising this option.

Both shade and large wood recruitment potential were reduced on small and medium streams as compared to preharvest conditions. Results indicate that stand characteristics of these riparian forests vary greatly across the landscape, making a single regulatory goal problematic. However, it appears the current rules underestimated the prevalence of conifer trees within the first 20 ft of small and medium streams, thereby underestimating the amount of coniferous basal area that is available on these streams. Recommendations were made to the Forest Practices Advisory Committee to increase conifer leave tree requirements along small and medium streams. A final report is available (Dent, 2001).

The ODF Forest Practices Monitoring Program implemented the BMP Compliance Monitoring Project (BMPCMP) to evaluate compliance with the rules on nonfederal forestland. The first year of the project (1998) was a pilot study used to revise the site selection and data collection protocols, determine the needed sample size, and provide preliminary compliance results. During the 1999 and 2000 field seasons, the final version of the BMPCMP was implemented. The goal of the BMPCMP was to identify the level of forest operations in compliance with the Forest Practice Rules based on a statistically reliable sample and to determine if adjustments to administration of the program are needed, such as areas where forest practice rule language can be clarified, administration of the rules can be improved, or additional education and training are needed.

A total of 189 harvest operations associated with streams and wetlands were surveyed for this project. Operation units were randomly selected and stratified statewide to account for regional differences in the numbers of notifications and types of practices implemented; differences between industrial, nonindustrial, and other (generally government) landowners; and heightened concern for fish-bearing streams. Site selection was done so that the sample distribution was proportionate to that of the total population of 1998 notifications. The exception to this was an intentional bias towards the selection of units associated with fish-bearing (Type F) streams in order to better assess those rules which would apply only to these sensitive and valued resources. The weakness of this stratification is that it may undersample steep terrain, as steep units are less likely to have Type F streams.

At selected harvest unit sites, practices and features within that unit (harvest practices, roads, skid trails, riparian management areas, wetlands, etc.) were evaluated for compliance with 150 Forest Practice Rules designed to protect water quality and fish habitat. Each unit was surveyed by a former Forest Practices Forester who evaluated all individual BMP applications as either 'compliant' or 'noncompliant'. To view the detailed protocol for this project, visit http://159.121.125.11/FP/fpmp/default.htm. Stream crossing structures (bridge, culvert, or ford) were evaluated for fish passage and 50-year stream flow event capacity using a separate selection process and field protocol. These results are discussed in a report titled *Oregon Department of Forestry: Compliance with Fish Passage and Peak Flow Requirements at Stream Crossings, Final Study Results* (Paul *et al.*, 2002). The stream crossing protocol and final report can be found online at the website listed above. A total of 13,506 BMP applications were reviewed on the 189 harvest operations. The overall compliance rate for these applications was 96.3%. The compliance rates for all rule applications within each rule division are shown in Table I.

There were ten specific practices identified as having the most significant compliance issues (<96% compliance and five or more noncompliant practices). These were slash piling within stream channels and wetlands, removal of petroleum-related waste from the unit, stream crossing fill stability, road surface drainage, felling of trees into small Type N streams, skid trails near streams and wetlands, removal of temporary crossings, protection of other wetlands, prior approval requirements, and written plan requirements. Of the 502 total noncompliant practices surveyed, 185 (37%) were with administrative requirements not directly affecting riparian and channel conditions, 147 (29%) had the potential to impact riparian and channel conditions in the future, and 170 (34%) had an observed impact to riparian and channel conditions. In order to help achieve the highest possible level of BMP compliance, the results of this project are currently being presented to landowner groups, operator workshops, and department conferences. These results are also being used to clarify guidance language, develop additional implementation tools, and guide future monitoring needs.

TABLE I
Compliance rates for Oregon forest practices rule categories

Section description	Compliance rate
Reforestation (riparian management area reforestation only)	100.0%
Treatment of slash	98.2%
Chemicals and petroleum products	94.3%
Road construction and maintenance	97.6%
Harvesting	98.1%
Vegetation retention along streams	96.4%
Protection measures for significant wetlands	88.1%
Protection measures for other wetlands	69.8%
Protection measures for lakes	N/A
Operations near Waters of the State (WOS)	100.0%
Administrative requirements	83.0%

These examples represent just two of the FPMP activities. Additional studies have been implemented to evaluate riparian function, stream temperature, chemical applications, reforestation, and sediment delivery from forest roads. The complete Forest Practices Monitoring Program Strategy (Dent, 2002) can be viewed at http://159.121.125.11/FP/fpmp/default.htm.

Two other forest practice rule assessment efforts in Oregon deserve note. A number of forest industry and agency cooperators are just beginning calibration of paired watersheds in the Hinkle Creek Drainage in southwest Oregon to test the effectiveness of the current forest practice rules in protecting fish and water quality. Stream temperature, riparian habitat, and fish response are some of the response variables that will be measured. Also, since 1990 the Oregon Department of Fish and Wildlife (ODFW) has been working with forest landowners to collect information on stream habitat conditions as part of the Aquatic Inventory Project (AIP). This project has created a database representing 4,000 stream reaches throughout Oregon. With resurveys of the stream reaches, it is possible to assess trends in stream habitat conditions. The information has been organized by Oregon State University scientists into a GIS database with nearly 100 variables describing stream and habitat attributes (Wing and Skaugset, 1998). One additional program of note is the Headwater Research Cooperative that is supporting research on mostly non-fish-bearing forest headwater streams to assess how they function and appropriate management practices. Information on this cooperative is available at http://www.headwatersresearch.org.

2.9. Utah

There are 15.7 million acres of forest in Utah but most forest land (82%) is in public ownership. Annual harvest levels are low. Utah has voluntary BMPs for private forest lands. These are referred to as Forest Water Quality Guidelines (FWQG). One of the earliest assessments of forest nonpoint source impacts in any state was conducted in Utah and published by the Division of State Lands and Forestry (Hosking *et al.*, 1982). The assessment involved field surveys of 55 timber sales (less than 10 years old) that were selected on the basis of the '... potential to impact water quality'. The number of USDA Forest Service, state, and private sales surveyed was roughly proportional to the number of harvests conducted annually in the state. Of the 55 sales investigated, 16 exhibited '... noticeable adverse water quality impacts', but only 5 impacted '... water quality to a degree that remedial action should be considered'. Because state and federal harvests represent 92% of the harvest operations and FWQG are required on state lands and federal lands are carefully managed, it was concluded that silviculture is not a significant NPS in the state.

No assessments of the effectiveness or implementation rates for the FWQG have been conducted since the 1982 field survey; however, substantial changes have occurred and will occur in the near future. In 2001 the state legislature passed a forest practices act that requires registration of operators and notification by operators of plans to harvest timber. FWQG are still voluntary but the notification process will allow for education outreach to operators. A two-tiered FWQG monitoring program is being implemented. The first tier involves field audits of 100% of all sales involving state service foresters (FWQG field audits). The second tier will involve a periodic interdisciplinary team assessment of a subset of the timber sales in the state. This team assessment is being modeled after the Montana BMP survey.

2.10. Washington

Washington has 21.8 million acres of forests and nearly 60% of these lands are public. In 2002 Washington had the highest volume of harvest in the United States. Washington has one of the most heavily regulated forest management systems in the United States (Green *et al.*, 2000). Virtually all forest management activities are governed by the Forest Practices Act. Forest practices rules (FPRs) were established in 1975 and have been revised 13 times (Holter, 2001). The most significant improvements for BMPs relating to fish habitat and water quality protection occurred in 1987, 1992, and 2001. In 1987, the Timber, Fish, and Wildlife (TFW) Agreement was finalized. This agreement set forth goals, a framework, procedures, and requirements for cooperatively managing the state's private and state timberlands. Parties to the agreement included private landowners, Native American tribes, state agencies, and environmental groups. This rule change expanded the protection for riparian areas, cultural resources, and upland habitat for wildlife, increased regulations on use of forest chemicals, and broadened stakeholder involvement in forest management. Interdisciplinary teams comprised of representatives from TFW stakeholder groups were frequently used in field reviews of forest practice applications.

In 1992, a cumulative effects assessment process was developed through the TFW program. This process, termed Watershed Analysis, was codified in the FPRs and became a means of developing basin-specific BMPs for the protection of fish habitat and water quality (Washington Forest Practices Board, 1997). By design, Watershed Analysis required an evaluation of BMP performance in the study basins. Subsequently many other states, provinces, and agencies have developed various watershed assessment and analysis methods and these often have elements that allow for assessment of practice effectiveness (Ice and Reiter, in press; Cook and O'Laughlin, 2000). At the same time Watershed Analysis was adopted, other revisions were made to the FPRs (e.g., wetlands and stream temperature protection, additional restrictions on forest chemicals and fertilizers, clearcut size and timing requirements).

The most recent revisions to Washington's FPRs occurred in 2001. These changes were prompted by common themes encountered in Watershed Analyses and the numerous listings of native salmonid fish species under the federal Endangered Species Act. The original TFW stakeholder group was expanded to include federal agencies (NMFS, USFWS, and EPA). Almost every facet of the FPRs was overhauled in this update. These rules are intended to satisfy federal requirements for protection of freshwater habitat for fish and other aquatic vertebrates under the Endangered Species Act, and for water quality under the Clean Water Act (DNR, 2002).

For the past 15 years, an important feature of Washington's forest management system has been the use of the adaptive management approach to guide BMP development. Adaptive management requires the collection of information for feedback on system performance. This spurred a series of research-level investigations of compliance and effectiveness of different types of practices. In 1991, the TFW Field Implementation Committee conducted a compliance survey (TFW, 1991). In this survey, 191 completed projects were randomly selected and field reviewed for rule compliance. Compliance varied from low for road maintenance and riparian timber harvest to high for road construction, yarding, site preparation, and hydraulic considerations. A follow-up study was conducted to more thoroughly investigate compliance with rules governing activities in and near riparian areas (TFW, 1994). In this study, 94 timber sales were randomly chosen from a sample of 1,708 forest practice applications (FPAs). Results showed generally high (>90%) compliance with operational rules (use of heavy equipment in riparian areas, slash disposal, etc.). Compliance rates were also high (81 to 100%) for riparian management zone width and tree count requirements in western Washington. Postharvest blowdown of trees left in riparian buffers was also qualitatively evaluated at 91 sites. Winds felled less than 10% of the leave trees at 82% of the sites. One site had >50% blowdown. Landowners often left wider buffers than were required by law. The details of these studies provided information about the practices that were most prone to violations, and often led to changes in BMPs.

Aside from these detailed but sporadic studies of rule implementation, Washington has no program to document FPR compliance. However, the Department of Natural Resources (DNR), the state agency that administers the forest management system, does use procedures to foster implementation success. With limited resources and high volumes of FPAs, the DNR is forced to concentrate its efforts on the review and conditioning of FPAs that have the potential to significantly impact public resources (i.e., 30-day Class III and Class IV special FPAs). DNR's Forest Practices Foresters therefore expend considerable effort during the preapproval review phase of the FPA permitting system. In most DNR regions, a high proportion of these sensitive FPAs are scrutinized and reviewed in the field before approval to ensure the operations are properly designed for site conditions (Gary Gideon, DNR Forest Practices Division, personal communication). In addition, DNR's goal is to visit and evaluate compliance for at least half of Class III and all of Class IV special FPAs after the operations are completed.

The need for information on implementation success was recognized during the most recent rule negotiations. To measure and report compliance of the newly revised practices, DNR is charged with providing 'statistically sound, biennial compliance audits and monitoring reports' (WAC 222–08–035). To date, no program has been established or funded to complete this task. However, efforts are underway to measure effectiveness of the new rules and to validate some of the scientific underpinnings of the FPRs.

To study the effectiveness of forest practices and to monitor status and trends of public resources, the TFW Cooperative Monitoring, Evaluation, and Research Committee (CMER) was formed in 1987. Steering committees were organized by discipline to address different research areas. For example, the Water Quality Steering Committee sponsored a series of important studies on the effectiveness of forest practices affecting water quality. One of the first of these was a study of the adequacy of riparian rules for protecting stream temperatures (Rashin and Graber, 1992). This was followed by an evaluation of BMPs for aerial application of forest pesticides (Rashin and Graber, 1993), and finally by a study of the effectiveness of BMPs for controlling sediment impacts (Rashin *et al.*, 1999).

Other CMER steering committees have also sponsored BMP effectiveness studies. The Monitoring Advisory Group (MAG) initiated development of an effectiveness monitoring program (Schuett-Hames *et al.*, 1996). Several studies were subsequently conducted to evaluate the performance of Watershed Analysis prescriptions for riparian areas (Soicher, 1999a; Grizzel *et al.*, 2000) and unstable slopes (Soicher, 1999b). The Wildlife Steering Committee sponsored an ambitious study on the effectiveness of TFW riparian prescriptions for the protection of wildlife (O'Connell *et al.*, 2000). Projects to develop methods for effectiveness monitoring were also funded during this period (e.g., Pentec Environmental, Inc., 1991; Cupp *et al.*, 1999). Experience gained from these studies is being used to develop the effectiveness monitoring program for the newly established FPRs. With several millions of dollars in federal funding to support research on salmon, CMER is now developing an ambitious research and monitoring program for the new rules. One of the key areas that CMER will focus on is non-fish-bearing headwater streams and their functions and impacts on receiving waters.

Like many other states, Washington is also interested in trend monitoring to determine long-term integrated responses to the forest practice rules. Washington began a trend monitoring program in 1989 that ended soon afterward when funding and interest waned. The effort was scaled back and revived in 1992. Modest data gathering efforts continued until the present (principally conducted by Native American tribes). Recently, a Monitoring Design Team has been developing a more durable trend program design and a draft of this program will soon be released.

2.11. Wyoming

Wyoming has 11 million acres of forests, second only to Nevada for lowest total in the west, and 83% of the forest is in public ownership. Harvest levels are very low. Wyoming has voluntary BMPs developed by the Wyoming State Forestry Division. In 2000/2001 a field audit based on the interdisciplinary team approach used in Montana was conducted on 12 timber harvest sites (Lee, 2002). Audit sites were biased toward those that had potential water quality problems or highly erodable conditions, including those in close proximity to running water or containing wetland and riparian drainage. The findings are that:

> . . . most sales had one instance where the application or effectiveness of the BMP was inadequate. Overall, these departures were minor and did not cause erosion or deliver sediment to a waterway. On average, audited sales were found to meet or exceed the standard set forth in the BMP handbook on 91.4% of the total application points, and 93.3% of the total effectiveness points.

Practices commonly found to need improvement included construction of cross drainage, slash placement on skid trails (to divert and slow water), rolling dips for haul roads, construction of energy dissipaters, spacing of erosion control features, and SMZ designation.

3. Synthesis

A variety of NPS control programs are used in the west, some regulatory and others voluntary. In order to assess program effectiveness, most western states have invested in monitoring and testing of BMP implementation rates, the effectiveness of BMPs, or both. Overall, these studies show high rates of BMP implementation and the general effectiveness of state BMPs in protecting water quality. An example is Montana. Over a 10-year period, audit reports show that BMP implementation has increased from 78 to 96% and water quality impacts have decreased. Still, there is unlimited skepticism about the effectiveness of forest nonpoint source control programs and limited assessment resources. For example, a National Public Radio commentary from the Executive Director, Montana Trout Unlimited, is critical of the Montana audit results:

> The audits routinely show BMPs are being used and that they are probably effective. But there's a catch. The audits are after-the-fact, snapshots-in-time estimates of whether practices affecting, say, road drainage or construction, were effective on small portions of randomly selected timber sales. The audits are subjective. The estimates [are] intuitive. Cause and effect is not measured. Scientific rigor is absent. Moreover, the audits occur during summer, when conditions are dry and vegetation leafed out, complicating guesses on how effective BMPs were during wetter periods. Has the timber industry made strides with BMPs? Unequivocally, yes. Can it do more to improve the balance between producing wood fiber and protecting the environment? Absolutely. Will that happen? It would be nice.

In Oregon, with the oldest of the silvicultural nonpoint source control programs, the Pacific Rivers Council has filed a lawsuit against the Board of Forestry (*Pacific Rivers Council et al. vs. James Brown*), alleging that the rules result in take of coho salmon in violation of the federal Endangered Species Act. Regionwide there are efforts to increase regulation of harvesting near small, non-fish-bearing streams, and certain practices like clearcutting and the use of silvicultural chemicals are an anathema to many, thus precipitating public referendums.

This level of skepticism about the results of BMP audits and monitoring may be why states like Oregon, Washington, and California (where skepticism is the greatest) spend substantial funds and time developing protocols for rigorous, scientifically defensible assessments of BMP effectiveness and implementation. There are also redundant assessment approaches used in these states, from basic inspection statistics, enforcement data, interdisciplinary team reviews, and survey studies to more detailed research projects.

It is unlikely that any single state can support all the assessment studies needed to evaluate the effectiveness of state BMPs and implementation rates. Instead, the aggregate regional results must be used. States like Montana, Idaho, and Wyoming can say that they have surveyed BMP compliance and effectiveness and can track trends, but these audit assessments are somewhat subjective. Extensive inspection or enforcement records provide for statewide coverage and trends in Oregon, Washington, and California but are, again, somewhat subjective. Detailed watershed studies in California (Caspar Creek), Idaho (Mica Creek), Washington (Watershed Analysis), and soon in Oregon (Hinkle Creek) allow for rigorous and scientifically defensible testing of the state BMP package, but just for one watershed and one weather pattern. Detailed tests of riparian rules in Oregon, Montana, and Washington or the chemical rules in Washington and Oregon allow for a broader test of specific rules and adjustment of those rules, but these studies say nothing about the effectiveness of other rules. Quantitative evaluations of every possible

TABLE II

Summary of state silviculture NPS control programs showing states with BMPs, forest practice rules, BMP implementation rates, and presence and type of effectiveness studies

State	BMPs	FP rules	Impl. rate	Effectiveness
Arizona	Federal and tribal guidelines	No	Not applicable	No
California	Yes	Yes	92%	*Study*/survey
Colorado	Yes	No	No data	Trend
Idaho	Yes	Yes	92%	*Study*/survey
Montana	Yes	Yes	96%	Survey
Nevada	Yes	Yes	100%	NA
New Mexico	Yes	Yes	75%	Planned
Oregon	Yes	Yes	96%	*Study*/survey
Utah	Yes	No	No data	*Study*/survey
Washington	Yes	Yes	No data	*Study*/survey
Wyoming	Yes	No	91%	Survey

rule permutation is a daunting challenge. For example, there are an estimated 50 unique combinations of riparian prescriptions under Washington's new forest practice rules (Schuett-Hames and Conrad, 2002). Each assessment approach has its advantages and disadvantages, but put together regionally, we can say with confidence that BMPs are being implemented at a high rate, they are generally effective, and for some practices, particularly road sediment abatement BMPs, we have the regionwide data to prove it. Some uncertainty to this conclusion is created by the continuing evolution of water quality goals. For example, landslides used to be viewed as uniformly detrimental to water quality and fish habitat. Now landslides are seen as essential to maintaining stream functions and the debate focuses on the timing, size, and numbers of landslides affected by forest management.

A westwide assessment of silvicultural BMP implementation can be made from the rates reported by individual states (Table II). Adjusted for the acres of forestland in each state (USDAFS 2002) and using the so-called 'imputation method' of the United States census (estimated residents in nonreporting households based on average of residents in nearby households) for Colorado, Utah, and Washington, we calculate that the westwide BMP implementation rate is 94%. The trend data from Idaho and Montana indicate that this rate is increasing, although it will be difficult to make further significant gains. BMP implementation data can be especially useful in targeting specific practices that are underapplied.

All states except Arizona and Nevada report some effectiveness monitoring or plans to conduct effectiveness monitoring. These efforts continue to evolve from

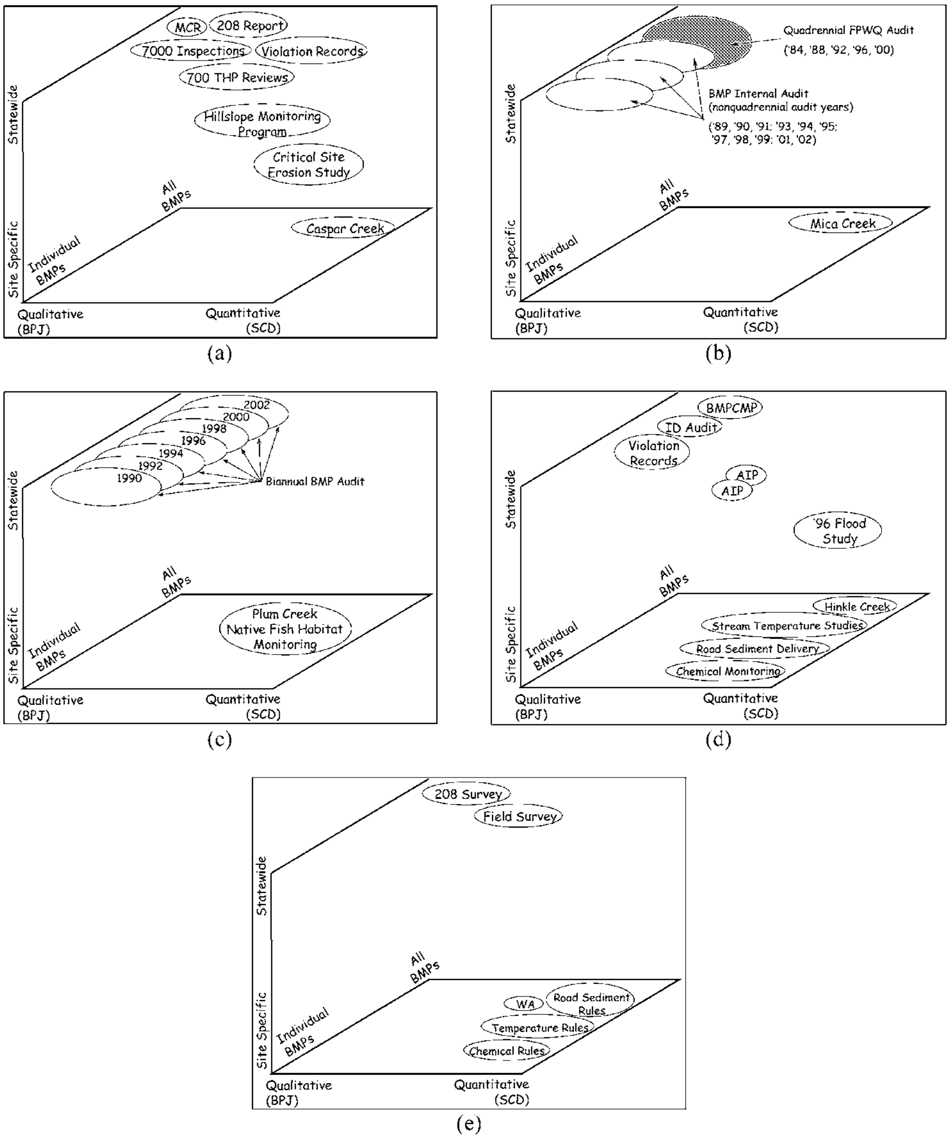

Figure 2. A dimensional depiction of the rigor (Best Professional Judgment [BPJ] or Scientifically Credible Data [SCD]), scope (individual BMP or all BMPs), and scale of area coverage (site specific or statewide) for effectiveness and implementation assessments carried out in the five key Western states of (a) California, (b) Idaho, (c) Montana, (d) Oregon, and (e) Washington.

qualitative assessments to rigorous and scientifically defensible tests of individual practice effectiveness. One way to look at how states are evaluating effectiveness is to depict the effectiveness studies in terms of assessment rigor, BMP coverage, and geographic coverage. Effectiveness assessments can range from qualitative, best professional judgment to scientifically defensible, with adequate controls to account for natural background response. Assessments can be focused on one or just a few individual practices or assess all the state rules or BMPs. Assessments can be isolated on single watersheds where more rigorous controls can be utilized or they can be carried out statewide across many different ecoregions. Figure 2 provides a qualitative three dimensional depiction of the various state assessments in these terms both for BMP effectiveness and implementation. It is the efficient mix of these approaches that provides the most return on investment in state progam assessments.

While assessments universally find BMPs effective in reducing impacts from forest activities, the performance standards and expectations for BMPs continue to change. There is widely recognized drift in assessments with increasing scrutiny about what is acceptable implementation and what is effective. Similarly, forest practice rules and BMPs continue to change, particularly for the West Coast states. This fluid combination of changing expectations and changing rules necessitates ongoing testing of effectiveness. This also means that states need to frame their monitoring and research projects to measure fundamental watershed responses to a continuum of management practices that can be applied universally to the region (e.g., minimum buffer widths needed to protect stream temperatures). When regulations are changed, these baseline studies would continue to provide relevant information.

In a monitoring strategy document for Washington, Schuett-Hames *et al.* (1996) noted that monitoring of aquatic resource trends was important because protection and restoration of aquatic habitat and species are the fundamental management objectives. Too often we hear of the progress by point source programs to improve water quality without having data to demonstrate positive trends for nonpoint source pollution control efforts. The plans for trend monitoring in Washington, monitoring in managed watersheds in Colorado, stream habitat condition inventories in Oregon, and the ongoing Caspar Creek Study in California, represent the first efforts to develop that trend data.

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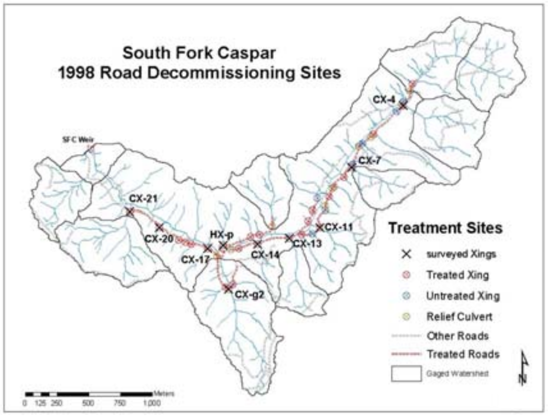
Erosional Costs of Riparian Road Decommissioning in the Caspar Creek Experimental Watershed

Elizabeth Keppeler
Redwood Sciences Laboratory, USDA Forest Service, Fort Bragg, California
Pete Cafferata
CALFIRE, Sacramento, California

Study Site: Jackson Demonstration State Forest Northern California Coast



Management History

•Redwood Douglas fir forest originally clearcut circa 1870 and yarded with oxen and splash dam

•Streamflow and sediment yields measured continuously by mainstem weir since 1962

•Riparian road construction initiated 1967

•2nd growth harvested (selection) and tractor yarded 1971-73.

•4.6 km of 1967 road decommissioned in 1998. Numerous upslope roads and skid trails remain untreated.

Above: CX-4 before and after the 44-yr peakflow of March-99. Left: CX-7 and below: CX-13 after the same storm.

Treatments

26 stream crossing excavations:

- Excavated to depth of original channel
- Side slopes < 50%
- Jute netting within 30 m of channel
- Conifer planting at 3 m spacing

Cross-draining (all road segments):

- 5% grade
- Side slopes < 50%
- Inlet > 0.15 m
- Ditch not obliterated

Out sloping (upper 2 km only):

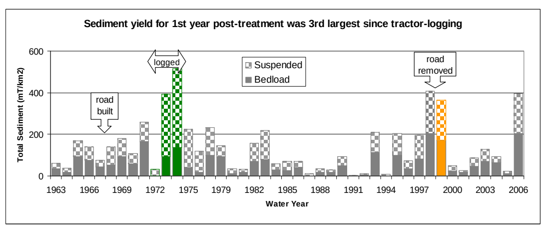
- 10% grade
- Ditch and berm obliteration
- Conifer planting at 3 m spacing

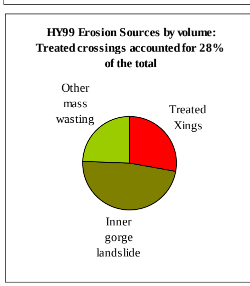
Erosion Measurements

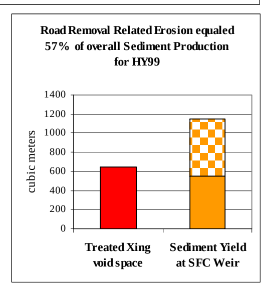
➢Following decommissioning, 10 restored crossings were benchmarked and surveyed to establish a reference longitudinal profile and 3-5 cross-sections, At one site a full topographic survey was made. Surveys were repeated after one and 3-4 wintering periods.

➢After the first winter (HY99), gully incision and mass-wasting were measured along all treated road segments. These measurements were repeated after 3 wintering periods at all sites where erosion was evident or previously documented, and again after 8 wintering periods at those sites where further downcutting was evident.

South Fork Caspar Sediment







See also: http://www.fs.fed.us/psw/topics/water/caspar/pubs/Rd600DecomNote.pdf

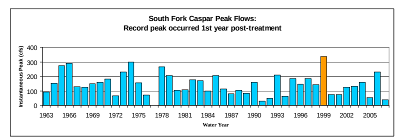
Results

➢All treated crossings downcut during the first winter.

➢Eroded volumes varied from 1 to 191 m^3 per site and totaled 651 m^3 at 34 sites after 1 winter. After 3 winters this volume had increased 17% to 759 m^3 (~4% of the excavated volume).

➢Just 4 sites accounted for half of the measured erosion. 3 of these continue to erode after 8 winters.

➢Erosion was negligible along the outsloped road and at most cross-drain locations.



Conclusions and Recommendations

➢Gully incision along the decommissioned roads accounted for approximately 1/3 of the total inventoried erosion volume and about 1/2 of the annual sediment load in the South Fork Caspar Experimental Watershed during the first post-treatment winter.

➢Mean erosion volumes measured at the treated crossing sites in this project following one and three over-wintering periods were 24.6 m^3 (32 yd^3) and 27.4 m^3 (36 yd^3), respectively.

➢Operators/inspectors should ensure crossings are excavated to original channel grade and side slopes are reclined to < 50% to prevent slumping.

➢Newly excavated crossings with significant drainage areas should be armored with appropriately sized boulder rip-rap or grade control structures to reduce post-treatment incision.

CALIFORNIA FORESTRY NOTE

State of California
The Resources Agency
California Department of Forestry & Fire Protection

P.O. Box 944246
Sacramento, CA 94244-2460
Phone: 916-653-7209
Web: www.fire.ca.gov

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STATE FOREST ROAD 600: A RIPARIAN ROAD DECOMMISSIONING CASE STUDY IN JACKSON DEMONSTRATION STATE FOREST

Elizabeth T. Keppeler[1], Peter H. Cafferata[2], and William T. Baxter[3]

[1] Hydrologist, USDA Forest Service, Pacific Southwest Research Station, Fort Bragg.
[2] Forest Hydrologist, California Department of Forestry and Fire Protection, Sacramento.
[3] Fire Captain, California Department of Forestry and Fire Protection, Willits (formerly Forester II, Jackson Demonstration State Forest).

ABSTRACT

Road decommissioning work has been studied in the South Fork Caspar Creek experimental watershed since 1998, when a 4.6 km (2.8 mi) segment of Forest Road 600 was decommissioned. A total of 26 watercourse crossings and eight cross-drain relief culverts were removed, while an additional eight minor crossings remained untreated. A detailed time study documented costs associated with the different treatments implemented at these sites. Gully measurements were made after one and three over-wintering periods. Additional measurements consisted of a longitudinal profile with three to five cross-sections at nine benchmarked sites and a detailed topographic survey at a tenth crossing where the road crossed the main stem of the South Fork. Surveying work was completed at these sites after one and four winter periods. Mean erosion volumes measured at the treated crossing sites following one and three over-wintering periods were 24.6 m^3 (32 yd^3) and 27.4 m^3 (36 yd^3), respectively. Erosion volumes were mainly created after the first winter, with a 17% increase following three over-wintering periods. Only three decommissioned crossings continue to erode after eight winters. After three winters, gully erosion equated to four percent of the total volume of fill material removed at the stream sites. Approximately 50% of the total eroded volume measured was produced by only three of the decommissioned crossings, which is consistent with results from past studies, where most of the erosion volume is produced by a small percentage of the excavated crossings. Gullied stream crossings along the decommissioned roads accounted for nearly one third of the total inventoried erosion volume and 57% of the sediment load in the South Fork Caspar Experimental Watershed during the first post-treatment winter. The erosional costs associated with road decommissioning in this study were significantly greater than anticipated during project planning. Detailed pre-project survey work, operator skill, and diligent project inspection are critical to ensure proper excavation at treated crossing sites. In addition, boulder armoring of major crossings may help reduce post-treatment gullying.

INTRODUCTION AND LITERATURE REVIEW

While forest roads in general are known to be a major anthropomorphic cause of sedimentation in forest streams in the western United States (Megahan and Kidd 1972; Reid and Dunne 1984; Furniss and others 1991; Luce and Black 1999; MacDonald and others 2004), roads located within riparian zones are especially prone to sediment delivery to stream channels (WFPB 1997). Several studies in diverse geologic settings have concluded that roads located within 60 m (200 ft) of a stream channel deliver considerably more sediment than those located more than this distance. Rice and others (1979) described roads within 60 m of the stream channel as delivering sediment to stream channels in the South Fork Caspar Creek watershed, where the study described in this paper took place. Ketcheson and Megahan (1996) reported that sediment flow from most cross-drains extends less than 60 m in the Idaho batholith. More recently, Coe (2006) reported that sediment travel distance from forest roads was generally less than 40 m (130 ft) in the central Sierra Nevada.

Road decommissioning (abandonment)[4] near streams is a practice that has been used extensively in northwestern California to reduce long-term road sediment delivery, thereby lessening impacts to sensitive aquatic resources such as listed

[4] California Forest Practice Rules define “abandonment of roads” as procedures that permanently close a road in a manner that prevents erosion, maintains hillslope stability, and re-establishes natural drainage patterns (CAL FIRE 2007).

anadromous fish species (Harris and others 2006). Weaver and Hagans (1994) state that proactive road abandonment (i.e., closure or road decommissioning) is a method of closing a road so that regular maintenance is no longer needed and future erosion is largely prevented. Criteria that are commonly used to identify roads to proactively decommission include: (1) roads in close proximity to fish-bearing streams, (2) roads located in unstable inner gorge areas, and (3) roads with excessive amounts of perched fill (CDF 2002). Treatments include removing culverts and reestablishing channels to their original grade and channel configuration. Road prisms at watercourse crossings are pulled back to a stable slope configuration and the regraded channel may be armored to prevent downcutting or erosion of the old fill material.

An on-going program of road decommissioning and upgrade work throughout a forest ownership to remove existing and potential erosion sites and reduce long term sediment production is widely accepted as a valid approach to improve aquatic habitat conditions (Klein 2003, PWA 2005a, Luce and others 2001, Madej 2001, Switalski and others 2004). In addition to benefits from this type of road work, however, there are also short-term impacts due to channel adjustments following crossing removal, as documented in previous studies (Klein 1987, Bloom 1998, Madej 2001, Brown 2002, Klein 2003, PWA 2005a, PWA 2005b, Foltz and Yanosek 2005, Harris and others 2006). Results from three past studies are briefly described below.

Madej (2001) studied logging roads in the Redwood Creek watershed in Humboldt County. She reported that although road removal treatments do not completely eliminate erosion associated with forest roads, they substantially reduce sediment yields from closed logging roads. On average, treated roads contributed about one-fourth the sediment produced from untreated roads. Twenty percent of the excavated stream crossings accounted for 73% of the post-treatment erosion from crossings. For 207 crossings that had been decommissioned over a period of 17 years from 1980 to 1997, an average of 50 m^3 (65 yd^3) of sediment per crossing was reported. Almost 80% of the treated road reaches had no detectible erosion following a 12-year recurrence interval storm. Madej (2001) concluded that by eliminating the risk of stream diversions and culvert failures, road removal treatments significantly reduce long-term sediment production from retired logging roads.

In another study in Humboldt County, Klein (2003) conducted a monitoring project to determine volumes of erosion following road removal at excavated crossings and impacts to water quality in the upper Mattole River basin. The Sanctuary Forest, Inc. is implementing an erosion control and prevention program in this watershed to reduce long-term sediment yield, with the focus on decommissioning unneeded forest roads that pose sedimentation risks. Erosional void dimensions were measured at 18 excavated crossings. Both channel scour and bank slumps were documented for each crossing. Most of the erosion was found in the excavated channel areas, but erosion was also documented above crossings where culverts had been located. An average of

12 m^3 (15.5 yd^3) per crossing of post-excavation sediment was reported following one over-wintering period. Approximately 20% of the excavated crossings produced roughly half the total sediment volume. The average post-treatment sediment delivery measured in this study was about 14% of the estimated pre-treatment sediment delivery potential. Klein stated that if it is assumed that the longer term volume of sediment delivery at excavations is twice that of the first-year volume (similar to that reported by Madej 2001), then post-treatment sediment delivery may approach 28% of pre-treatment sediment delivery potential.

PWA (2005a) recently reported that erosion at excavated stream crossings was the principal source of post-decommissioning sediment delivery from treated roads in the Elk River watershed in Humboldt County. About 90% of post-decommissioning erosion and sediment delivery volumes originated at excavated stream crossings. Similar to the earlier studies, a few crossings produced the majority of sediment. As in the upper Mattole River watershed study, approximately 20 percent of crossings produced about 50 percent of the delivered sediment. The estimated average erosion at 52 decommissioned crossings was approximately 13 m^3 (17 yd^3) following two, four, and seven over-wintering periods. PWA (2005a) reported that post-decommissioning erosion from excavated crossings is minimized by excavating stable, low gradient sideslopes and by completely excavating erodible fill that was placed in the channel when the crossing was constructed.

In general, the results of past studies on road decommissioning work show that: (1) road treatments can reduce the long-term sediment production from abandoned and upgraded roads, (2) excavated crossings will be the major short-term source of sediment input to stream channels following road decommissioning work, (3) post-treatment sediment delivery will likely be approximately 20% or less than pre-treatment sediment delivery potential at excavated crossings, and (4) most of the sediment input at excavated crossings can be expected to occur during the first few winters following treatment.

SITE DESCRIPTION

The study site is a 4.6 km (2.8 mi) road network, including portions of Forest Road 600 and spur roads 602, 603, 604, and 606, located within the South Fork Caspar Creek experimental watershed on Jackson Demonstration State Forest (JDSF) (figure 1). Caspar Creek is a small coastal stream draining approximately 21.7 km^2 (5,360 acres) of predominately coast redwood and Douglas-fir forest that is approximately 140 years in age. The watershed is underlain by the Franciscan Complex, composed of well-consolidated sedimentary sandstone (Cafferata and Spittler 1998). Caspar Creek flows from an elevation of 320 m (1050 ft) to the Pacific Ocean, a distance of 13 km (8 mi), and supports anadromous fisheries of coho salmon and steelhead trout along most of this length (Nakamoto 1998).

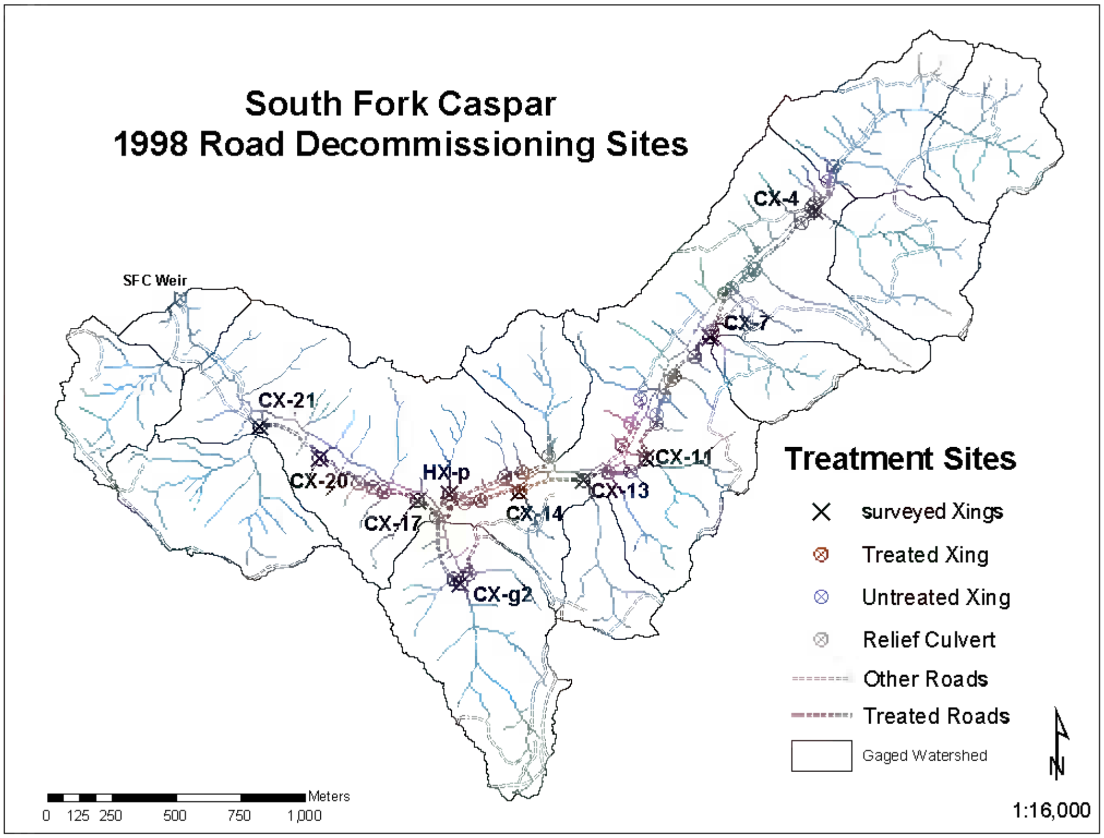

Figure 1. South Fork Caspar Creek Experimental Watershed, Mendocino County, CA.

The South Fork of Caspar Creek is a data rich environment. Streamflow at the South Fork weir has been gauged since 1962 (Henry 1998). Measurements of suspended sediment transport and bedload deposition have been ongoing since that date, as well. Since 1996, continuous measurements of instream turbidity have been recorded (Lewis and Eads 2001). Comprehensive summaries of sediment yields from both the South and North Forks of Caspar Creek have been completed (Lewis 1998, Lewis and others 2001, Keppeler and others 2003, Rice and others 2004). Changes in peak stream discharges associated with timber operations in the South Fork were documented by Ziemer (1981) and Wright and others (1990), and in the North Fork by Ziemer (1998).

The South Fork Caspar Creek road system was constructed during the summer of 1967 and expanded during the 1971-73 selection harvest of the watershed in order to facilitate tractor yarding (Krammes and Burns 1973, Rice and others 1979). Road construction and logging were designed according to the Caspar Creek Experimental Watershed study plan developed to quantify the impacts of these treatments on streamflow, sedimentation, and aquatic habitat. As such, the timber harvest and road system location, design, and construction were consistent with the management objectives and standards of the era (Krammes and Burns 1973). Road 600, the main haul road, was built within 61 m (200 ft) of the perennial stream. During construction, coarse woody debris, soil, and rock were deposited in the channel. Tractors operated in the streambed to build bridge crossings and landings, and to remove construction-related debris (Krammes and Burns 1973, Burns 1970).

Road 600 was used extensively for yarding and hauling activities between 1971 and 1973. Subsequently, the road was utilized year-round for post-harvest management, research access, and recreation until approximately 1994, when seasonal closures were implemented. During the 1980's and early 1990's, preventative maintenance was limited to annual grading, infrequent spot-rocking, and replacement of failed culverts. Spur roads 602-606 were largely ignored and unused since the mid-1970s.

By the mid-1990s, erosion incidents related to these roads were increasingly frequent. In 1994, a detailed landslide survey of the South Fork Caspar Creek watershed documented 10 significant features estimated to have occurred within the last five years. Nine were related to the road and skid trail system. In 1995, two additional failures occurred as a result of deteriorated steel culverts and displaced 434 m^3 (568 yd^3) of sediment, routing most of the material directly to the perennial stream channel. During the 1997-1998 El Niño storm season, five large road-related landslides occurred in the South Fork watershed, displacing 1,675 m^3 (2,190 yd^3) of sediment. Two additional landslides occurred, displacing 568 m^3 (743 yd^3) of material, but these were not related to the road system built in 1967 (Cafferata and Spittler 1998).

METHODS

Decommissioning Treatment, Timing, and Costs

Jackson Demonstration State Forest contracted for the decommissioning of 4.6 km (2.8 mi) of South Fork Caspar road segments in 1998 with an addendum to a timber sale agreement. Contract specifications required that stream crossings be excavated to the depth of the original channel, with side bank slopes not to exceed 50%. Jute netting was required to be installed for erosion control within 30 m (100 ft) of the well-defined channel area. Additionally, the contract specified that conifers were to be planted at a 3 m by 3 m (10 ft) spacing within the area covered by jute netting (figure 2).

Along the upper 2 km (1.2 mi) of Road 600, the contract required outsloping at a grade of 10% and berm obliteration to improve runoff dispersion. The contract further stated that the inboard ditch along this outsloped road segment was to be packed with soil to prevent flow concentration and conifers were to be planted along the road segment at 3.65 m (12 ft) spacing. Cross-road drains (i.e., waterbars) were required for all decommissioned road segments at an approximate spacing of 30 m (100 ft) and were to be installed with a grade of 5%,

Figure 2. Excavated crossing CX-21 with jute netting on side slopes, November 1998.

a width of 0.6 m (2 ft), an inlet depth of at least 0.15 m (6 in), and side bank slopes of less than 50%.

The project was implemented between August 6, 1998 and September 9, 1998, with a total cost of $32,495. There were 214 hours of excavator work, 75 hours of D-8 tractor work, 6 hours of D-6 tractor work, and 80 additional laborer hours. Stream crossing removal accounted for 47% of the total cost. A total of 17,900 m^3 (23,410 yd^3) of fill was removed from designated stream crossings, at a cost of \$0.85/m^3 (\$0.65/yd^3). Total outsloping costs were $4,465 or $2.15/m ($0.66/linear foot). Cross-drain construction ($1.68/m or $0.51/linear foot) and waterbarring ($0.45/m or $0.14/linear foot) accounted for the balance of the project expenses.

Erosion Measurements

To evaluate the erosional consequences of the road decommissioning treatment, measurements were made at a total of 42 road features: 26 excavated stream crossings, 8 excavated ditch relief culverts, and 8 untreated (minor missed) crossings where erosion or diversion problems were evident. Ten restored stream crossings were benchmarked prior to the arrival of the first winter rains. At nine of these sites, a longitudinal profile and several cross-sections were surveyed. A topographic survey was made at the tenth benchmarked feature, CX-4 (the mainstem crossing at the upper end of the treated segment of Road 600). Pre-winter photos were also taken at each of these ten sites. In spring of 1999, the longitudinal profiles, cross-sections, and the topographic survey were repeated. Longitudinal profiles and cross-sections were repeated at five of these sites in the summer of 2002. Change in cross-sectional area was calculated using the WinXSPRO computer software program (Hardy and others 2005). The topographic survey of site CX-4 was repeated in late 2001.

Additionally, after the first winter (1998-1999), gully erosion was documented at 32 of 34 sites by measuring the average width and depth of each gully at one meter increments along the length of the feature. The mean of these cross-sectional measurements was then multiplied by the length of the gully to determine the volume of each feature. These measurements were repeated in October 2001.[5] Photographs were taken a second time at established photo points during these remeasurements. A separate contract compliance survey was completed in November 2002. Finally, gully measurements were made a third time in 2006 at selected sites where fresh scour was visible.

RESULTS

After one winter, evidence of channel downcutting, gully erosion, and mass wasting was apparent (figure 3). Gully erosion measured at 32 sites totaled 651 m^3 (851 yd^3), with approximately half of this erosion occurring at just four sites--an eroded volume approximating four percent of the total fill removed (651 m^3/17,900 m^3). Erosion was negligible along the outsloped road surface and at most cross-drain locations.

Figure 3. Treated crossing CX-7 eroded severely and has yet to stabilize. In 2006, a debris flow deposit filled much of the void.

[5] This re-measurement included six additional sites not formally inventoried in 1999.

Mean erosion measured following the first winter at 25 decommissioned stream crossings was 24.6 m^3 (32 yd^3).[6] At 17 of the sites, gully erosion scoured 10 to 50 m^3 (13 to 65 yd^3) of sediment from the newly constructed channel crossings. New gullies of greater than 50 m^3 (65 yd^3) were created at three sites. At the main crossing (CX-4) at the top of treated Road 600, stream scour produced a 152 m^3 (199 yd^3) gully (figure 4). This excavated crossing on the mainstem of the South Fork is located within residual sediment aggradation from a historic splash dam built in the 1860's.[7] Thus, this site was prone to extreme post-treatment downcutting during the first winter. During the summer of 1999, stabilization was attempted with the placement of boulders to armor the headcut and large redwood logs and stumps within the gully to dissipate energy.

Erosion estimates from the surveyed cross-sections and topographic survey yielded similar eroded volume estimates as obtained with the gully survey work (table 1). Total erosion volumes for the gully survey and the cross-section survey for the same ten crossings after one over-wintering period were 451 m^3 (539 yd^3) and 421 m^3 (550 yd^3), respectively. Along the 10 surveyed longitudinal profiles, one channel incised as much as 2 m (7 ft), but most incised only 0.3 to 1 m (1 to 3 ft) (figure 5).

Following two additional over-wintering periods, most gullied crossings continued to downcut and widen at a decreased rate. However, gully size decreased at ten sites where channels aggraded due to revegetation and, in a few cases, the recruitment of new large wood. The total eroded volume from all the inventoried features increased from 651 m^3 to 759 m^3 (993 yd^3), an increase of 17%. Mean erosion following the three winter periods for the 26 decommissioned stream crossings increased to 27.4 m^3 (36 yd^3), an increase of about 11%. All but three of the crossing sites had less than 50 m^3 (65 yd^3) of erosion, the average reported by Madej (2001) in a comprehensive assessment of 207 crossings excavated between 1980 and 1997. The three crossings with the highest erosion rates accounted for 50% of the total erosion measured after three winters.

For the six crossings where the cross-sections were remeasured a second time (2002) and the topographic survey repeated (2001), the total eroded volume increased from 343 m^3 (449 yd^3) to 419 m^3 (548 yd^3), a change from June 1999 to summer 2002 (three additional over-wintering periods) of approximately 22%. The third topographic survey of site CX-4 indicates another 138 m^3 (181 yd^3) of volume loss within the crossing treatment zone, but this is largely due to re-entry impacts when heavy equipment was used in November 1999 to install the rock armoring and place logs and stumps in the gully. Additionally, an active seep has compromised the right bank.

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[6] Data is missing for one decommissioned stream crossing.
[7] Splash dam logging operations in the Caspar Creek watershed are described in Napolitano (1996) and Napolitano and others (1989).

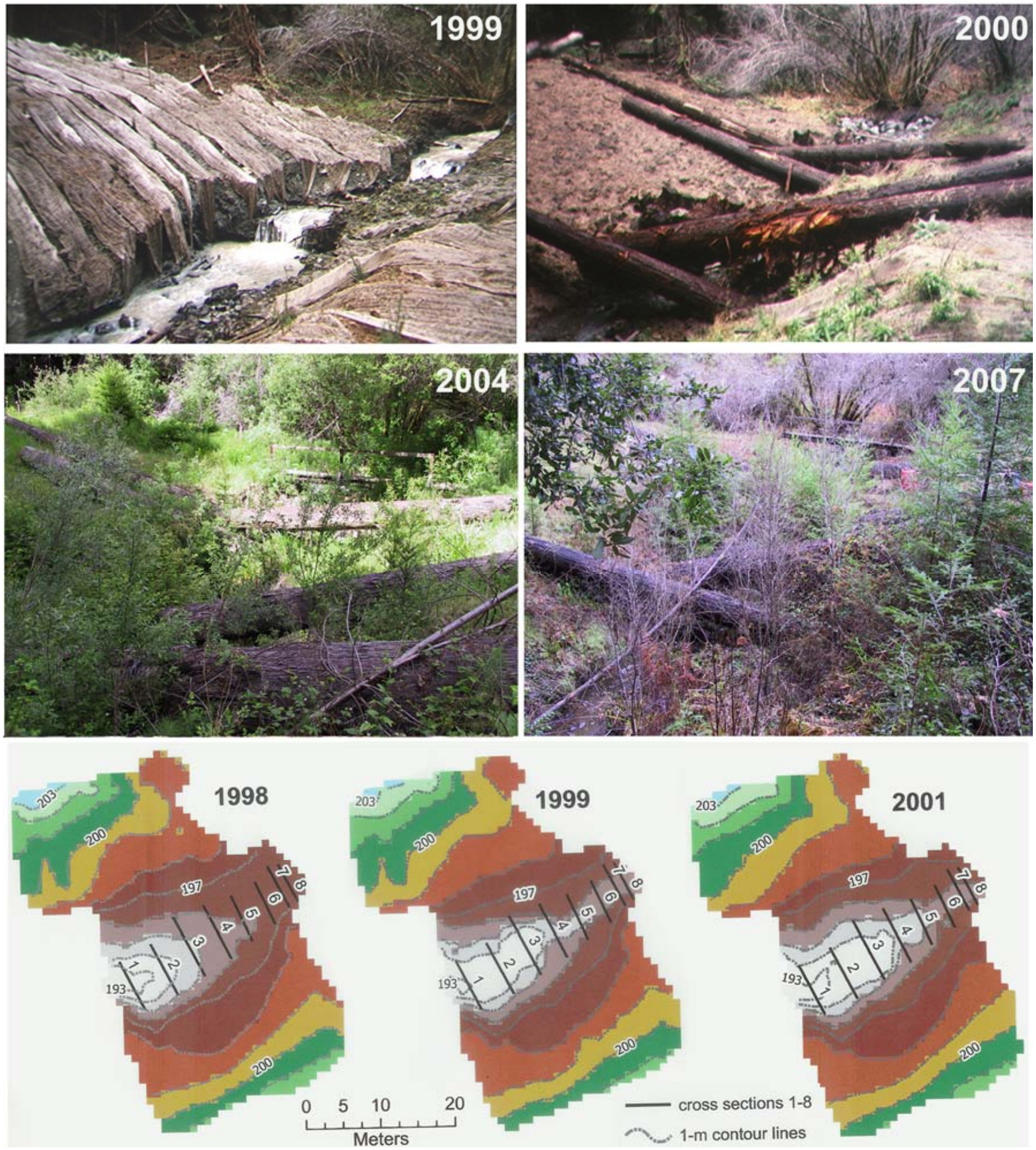

Figure 4. Photographs show channel adjustments and revegetation occurring between 1999 and 2007 at the large watercourse crossing (CX-4) on road 600. Surveyed grid elevations indicate almost 2 m (7 ft) of downcutting. Although further headcutting was halted by the boulder armoring done in 1999 and the placed redwood stumps have re-rooted, channel widening due to bank sloughing has continued.

Table 1. Erosion data for features evaluated along treated road segments (TX = treated crossings, UX = untreated crossings, R = excavated ditch relief culverts, and m = missing measurement).

Road	Feature		Volume		Length		Change	Surveyed X-Sections		
No.	ID	Type	Jun-99 (m^3)	Oct-01 (m^3)	Jun-99 (m)	Oct-01 (m)	1999-2001 (%)	Eroded Volume (m^3) 1998-99	1999-2002	Total
600	**CX-4**	TX	151.5	191.0	32	32	26%	93.9	37.6	131.5
600	**CX-7**	TX	86.2	99.2	41	42	15%	82.1	9.2	91.3
600	**CX-21**	TX	56.1	62.8	43	43	12%	69.9	2.8	72.7
600	**CX-11**	TX	32.9	34.9	33	32	6%	42.5	8.7	51.2
600	**CX-13**	TX	30.1	31.6	36	36	5%	31.6	-0.5	31.1
600	CX-5	TX	24.0	30.1	22	21	25%			
603	**CX-G2**	TX	29.9	28.6	23	23	-4%	35.5		
603	HX-un4	TX	18.7	23.7	33.5	33	27%			
600	CX-12	TX	19.9	23.4	33	35	18%			
600	**CX-14**	TX	20.1	22.0	37	37	9%	23.3	17.9	41.2
600	CX-18	TX	23.1	21.5	26	24	-7%			
603	X-un3	TX	17.9	18.6	22.5	22.5	4%			
600	**CX-20**	TX	15.6	17.5	27	27	12%	16.4		
602	**HX-p**	TX	17.8	17.2	32	32	-3%	12.1		
600	**CX-17**	TX	11.1	13.0	25	25	17%	13.3		
600	X-un6	UX	9.4	12.4	23.5	24	32%			
602	HX-602s	TX	7.3	12.1	28	28	65%			
600	X-un2	TX	12.3	11.4	31	31	-7%			
600	CX-9	TX	9.5	11.2	20	19	19%			
602	HX-606t	TX	9.0	8.9	18	18	-1%			
606	HX-606d	TX	11.1	8.7	15.5	15	-22%			
604	X-604y	TX	m	8.3	m	19				
600	X-z	UX	5.6	6.7	9	21	18%			
600	X-un1	UX	8.1	6.3	18	18	-23%			
600	X-ff	UX	m	5.1	m	17				
600	CX-10A	TX	1.8	5.1	5	17	191%			
606	CR-606d2	R	7.0	5.0	9.5	9	-29%			
600	CX-15	TX	2.7	3.8	14	14	38%			
604	X-604-e2	TX	2.6	3.7	17.5	17.5	42%			
600	CR-10	R	1.5	3.2	10	10	112%			
600	CX-19	TX	2.0	3.2	14	14	57%			
600	X-un8	UX	m	2.7	m	30				
600	X-un7	UX	m	2.0	m	16				
600	CR-un5	R	4.3	2.0	12	5	-55%			
600	CX-8	TX	1.3	1.1	25	21	-10%			
600	CR-6	R	0.9	0.9	7	7	0%			
603	CR-603-g1	R	m	0.7		10.7				
600	CR-16	R	0.0	0.0	15	15				
602	CR-602-f1	R	0.0	0.0	m	m				
606	CR-606c	R	0.0	0.0	m	m				
604	X-604-E1	UX	0.0	0.0	m	m				
606	X-606-a	UX	0.0	0.0	m	m				
	Totals	**42**	**651**	**759**	**758**	**861**	**17%**	**421**	**22%**	

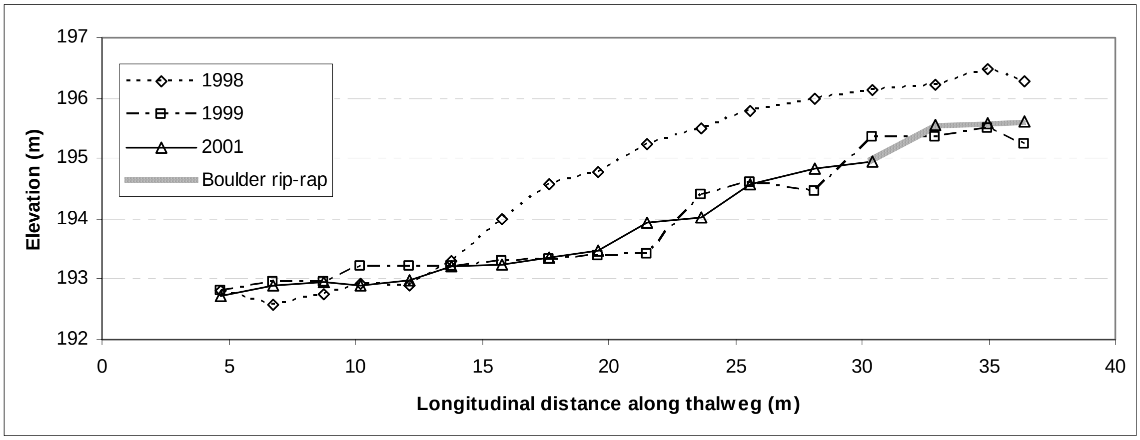

Figure 5. Surveyed longitudinal profile of the thalweg at crossing CX-4.

Subsequent observations from 2003 to 2006 indicate that the majority of crossing sites have stabilized with the exception of the two largest erosion sites—CX-4 (the main crossing at the top of Road 600) and site CX-7, and a mid-sized gully at site CX-G2. Each of these locations had special circumstances that interfered with successful and complete excavation. The latter crossing was the first significant excavation attempted in the project and was not fully excavated. As of 2006, these sites had continued to widen due to progressive bank failures. Site CX-4 enlarged by 17 m^3 (22 yd^3), or 9%. Crossing CX-7 experienced a net increase of 10 m^3 (13 yd^3), or 10%, as a result of enhanced erosion, even with partial in-filling from a large upslope debris flow. CX-G2 enlarged by 5 m^3 (6.5 yd^3), or 17%.

A November 2002 inspection evaluated project compliance with contract specifications for cross-drain placement, road surface outsloping, and stream crossing excavations. Incomplete excavation was noted at 12 crossing sites. Bank slopes exceeded the contract specification of 50% at three sites. At crossing CX-7, an exemption to the bank slope requirement had been negotiated in the field with the contractor due to the excessive excavation that would have been necessary to satisfy this specification. Other than these deviations, only minor variances were observed. The estimate of total fill volume removed for this project, 17,900 m^3 (23,400 yd^3), exceeded the pre-project estimate by 70% due to the inherent difficulties of making these estimates in heavily vegetated terrain and, in part, to the lack of training in this assessment skill. High levels of conifer mortality were noted for the planted seedlings in the retired roadbed, a result of poor soil conditions in the old roadbed and, to a lesser extent, red alder competition.

DISCUSSION

The first post-treatment winter (hydrologic year 1999) began in typical fashion. Rain events during December 1998 through February 1999 produced eight moderate storm peaks, with only one event having a return period of greater than one year. Rainfall totals for February and March were well above normal, resulting in annual precipitation 17% greater than the annual mean. The wet spring culminated in a major storm peak on March 24, 1999 with a discharge of 22.6 L/s/ha (338 cfs). This event had an estimated 44-year recurrence interval at the South Fork Caspar Creek weir, the highest flow in the 45-year record. A strong stressing storm of this magnitude is capable of testing the effectiveness of forest practices (Tuttle 1995), such as those implemented at the excavated crossing sites. Field observations suggest that the bulk of the treated crossing channel adjustments occurred during this extreme event. However, early season observations and photo records indicate that channel adjustments had initiated prior to this major spring storm. While a recent report prepared for the California Department of Fish and Game (CDFG) evaluating the erosional consequences of road decommissioning at 449 northern California sites treated between 1998-2003 did not detect a strong correlation between rainfall and post-treatment erosion (PWA 2005b), strong stressing storms occurring soon after treatment clearly contribute to severe down-cutting.

Long term comprehensive measurements of sediment production and erosion in the Caspar Creek experimental watersheds afford a unique insight into the consequences of road decommissioning on the sediment budget at a watershed scale. At the South Fork Caspar weir (SFC), continuous in-stream turbidity measurements are correlated with sediment concentrations from automated pumped water samples to determine event-based and annual suspended sediment yields (Lewis and Eads 2001). During the March 1999 storm event, recorded turbidity exceeded 2,000 NTU (the maximum value for the turbidity sensor). The SFC sediment load estimate for this storm event is 523 mT (123.4 mT/km^2) and 807 mT (190.3 mT/km^2) for the hydrologic year.[8] This annual load equates to an estimated volume of 602 m^3 (788 yd^3) using a bulk density of 1.34. Sediment accumulation at the South Fork weir debris basin measured an additional 547 m^3 (715 yd^3), the third largest annual accumulation in the 44-year record (1963-2006), exceeded only in 1998 and 2006. Thus, total South Fork Caspar sediment yield for 1999 was 1149 m^3 (1,503 yd^3), with erosion at the decommissioned crossings equivalent to 57% of this total. Sediment yields in 1998 and 1999 were similar to the peak yields measured in the mid-1970s when tractor logging occurred in the basin (figure 6).

Evidence of increased sediment production in the South Fork is documented in both sediment loads since 1997 and changes in mean bed elevation since 2000. From 1998 to 2003 sediment loads exceeded 1990 to 1997 loads by 36%. Suspended loads systematically exceeded the pre-1998 relationship during large storms (Keppeler and Lewis, in review). Channel cross-sections along the South Fork mainstem show a decrease in mean bed elevation from 2000-2006 of 0.04 m (0.13 ft) equating to roughly 522 m^3 (683 yd^3) of bed degradation over the

[8] The English units are: 807 mT = 890 t; 190.3 mT/km^2 = 544 t/mi^2. Long-term average annual sediment yield at SFC is approximately 137.5 mT/km^2 (393 t/mi^2).

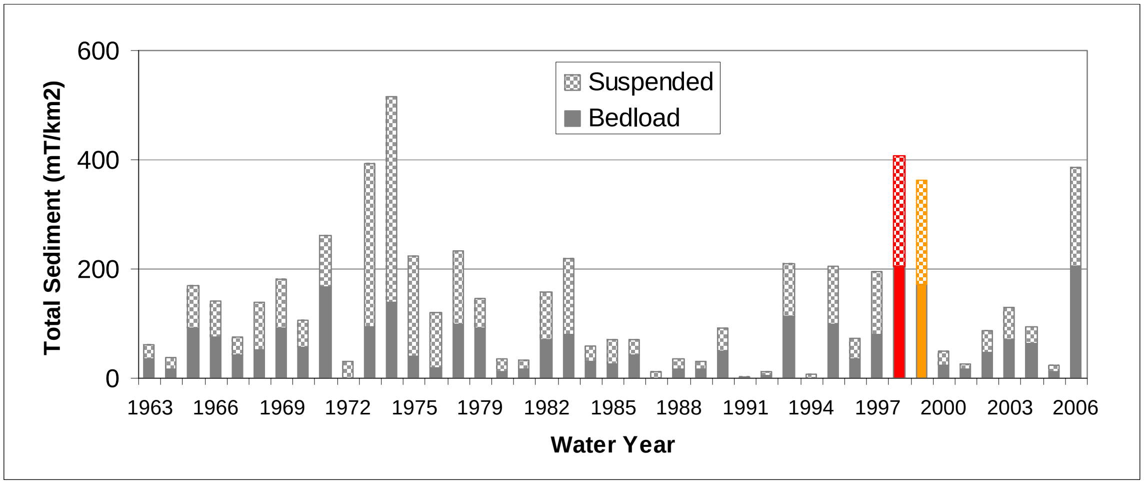

Figure 6. Total annual sediment yield for the South Fork Caspar Creek watershed 1963-2006. High yields from 1973-1975 reflect tractor logging impacts in the South Fork watershed (Rice and others 1979). High sediment yields in water year 1998 (shown in red) resulted from numerous landslides; high sediment yields in water year 1999 (shown in orange) resulted from road decommissioning work and landslide material which continued to be transported downstream. (2006 suspended load estimate is preliminary).

3160 m (2 mi) study reach. Although mainstem V* values, a measurement of fine sediments in pools, have been trending downward since data collection was initiated in 1992, a small increase occurred from 1999 and 2004 before declining again in 2005 and 2006 (S. Hilton, USFS-PSW, Arcata, unpublished data). These data suggest that much of the sediment from the decommissioned crossings, numerous landslides and other forms of mass wasting during 1998, and a large inner gorge debris slide in 1999, was effectively transported down the steep tributary channels and redeposited in the lower-gradient mainstem channel to await further mobilization during high flows. In 2006, sediment accumulation in the SFC debris basin totaled 649 m^3 (849 yd^3) and the preliminary sediment yield estimate was the highest since 1998, suggesting that the large storms in the winter of 2005/2006 mobilized substantial stored sediment.[9]

Depth-integrated samples collected above and below three treated crossings (CX-7, CX-13, and CX-21) during storm events in hydrologic years 2004-2006 suggest sediment concentrations below these crossings remain elevated. They averaged 165% of the concentrations measured at the stream gaging stations above these road crossing sites.

Decommissioned road crossings produced a substantial component of erosion measured in the SFC watershed during 1999. Field personnel document all erosion features displacing greater than 7.6 m^3 (10 yd^3) of material in an annual

[9] The December 28, 2005 storm produced an instantaneous peak discharge of 15.4 L/s/ha, which was estimated to have a return interval of eight years in the South Fork Caspar Creek watershed. The 2006 suspended load estimate is preliminary.

ground-based inventory of the Caspar watersheds (Keppeler and others 2003). Gully erosion (exceeding 7.6 m^3) along the decommissioned roads accounted for 28% (564 m^3 or 738 yd^3) of the annual erosion (2,026 m^3 or 2,650 yd^3) measured in the South Fork Caspar Creek 1999 inventory. About half of the remaining erosion volume resulted from a single re-activated inner-gorge debris slide. The rest of the erosion was the result of mass wasting along the untreated skid trail and road system developed in the early 1970s for the second-growth harvest. Inventoried erosion in 1999 was almost two times higher than the total annual sediment yield for that year, indicating that much of the hillslope material did not reach the SFC weir.

Longitudinal profiles show that most of the channel adjustments occurred on the downstream portions of the excavated crossings (figure 5). Treated roads were located at the break in slope above the inner gorge, making it difficult for the equipment operator and JDSF contract administrator to determine the appropriate target gradient. As in many road crossing excavations, excavation of fill was incomplete at many of the sites (PWA 2005b).

In general, crossings with larger contributing areas experienced the most erosion. Drainage area above a crossing explains 80% of the observed variation in erosion at the 10 sites where the more intensive survey methods were utilized. Crossings with longer affected lengths also experienced greater erosion, but excavated volume was not well-correlated with post-treatment erosion. Although Madej (2001) found that a surrogate for stream power (expressed as drainage area × channel gradient) and volume excavated were the best predictors of post-treatment crossing erosion, the Caspar study did not include channel gradient measurements.

Not all the stream crossings within the decommissioned road segments were treated. Eight crossing sites were either missed in the original project planning inventory or were overlooked by equipment operators. These sites were either small ephemeral channels or skid trails functioning as minor channels. Downcutting was evident at six of these locations, but averaged less than 6 m^3 (8 yd^3) per site. The other two sites experienced only minor rilling as a result of continued flow diversion onto the treated road segment where outsloping was not specified. Equipment access to these sites is no longer feasible, thus any additional rehabilitation efforts are limited to work that can be completed by hand crews. Fortunately, none of these sites appear to present a significant erosion hazard.

Both the outsloped and the cross-drained portions of the treated roads support ample herbaceous cover. The outsloped segments, where the road rock was disturbed, revegetated more readily. Little evidence of fill-slope sloughing has been observed post-treatment. The jute netting application does not appear to have provided significant benefit for erosion control. In some places, JDSF staff foresters observed that it has inhibited revegetation. The jute netting may have reduced sheet erosion, but given the amount of gully erosion that occurred at these sites, sheet erosion was likely insignificant in terms of total erosion.

One unforeseen consequence of the road decommissioning was the development of an entrenched foot trail by both recreational and research use. The trail has required additional erosion control measures to mitigate rilling.

CONCLUSIONS

- Mean erosion volumes measured at the treated crossing sites in this project following one and three over-wintering periods were 24.6 m^3 (32 yd^3) and 27.4 m^3 (36 yd^3), respectively. Average erosion at all 34 project crossings (including those untreated/missed) was 22 m^3 (30 yd^3). These values are within the range of those reported in the literature (11.5 m^3 [15 yd^3] to 50 m^3 [65 yd^3] per crossing).
- Gullied crossings along the decommissioned roads accounted for approximately one third of the total inventoried erosion volume and about half of the annual sediment load in the South Fork Caspar Experimental Watershed during the first post-treatment winter.
- Erosion voids were mainly created during the first winter, with only a 15-22% increase following three to four additional over-wintering periods. Three crossings continue to erode after eight winters.
- Only three of the decommissioned crossings produced about 50% of the total eroded volume measured. This is generally consistent with results from past studies, where a small percentage of decommissioned crossings account for most of the documented erosion volumes.
- After three winters, measured erosion at 34 excavated crossings and relief culvert sites totaled only four percent of the excavated volume of fill.
- The erosional costs associated with road decommissioning in this study were significantly greater than anticipated during project planning.

RECOMMENDATIONS

The main recommendations from this study for future crossing excavation work are:

- More careful determination of appropriate channel excavation depths should be made by experienced field personnel.
- Diligent inspection by contract administrators during field work is required to ensure that these excavation depths are reached at the treated crossing sites and that streambanks are sloped back from the channel to prevent slumping.
- Newly excavated channel bottoms at the larger crossings with significant contributing watershed areas should be armored with appropriately sized rip-rap, other types of large roughness elements, or grade control structures to prevent channel incision (Castro 2003).

- Beneficial practices along treated road segments include ripping and outsloping the road surface, and cross-drain installation to reduce the likelihood that missed crossings will become diversion problems. This treatment is especially important if the inside ditch in not obliterated. Also, ripping the road surface enhances revegetation and prevents new diversion problems associated with post-treatment recreational trail use.
- Cost savings may be achieved by: (1) permitting D8-sized crawler tractors to initiate fill removal until the top of the culvert is reached, rather than requiring this work to be completed by an excavator, and (2) allowing the tractor to push excavated fill material to the nearest stable location, rather than requiring end-hauling of all excavated material.
- Thorough evaluation of potential restoration needs in areas accessible only via a road system designated for decommissioning should be performed prior to finalizing treatment plans. A comprehensive watershed assessment is advised.

One approach to adequately accomplish pre-project work is to use the field survey procedures developed by Pacific Watershed Associates (PWA) in Chapter 10, Upslope Erosion Inventory and Sediment Control Guidance, California Salmonid Stream Habitat Restoration Manual (CDFG 2006). Their approaches were in part utilized for a similar road decommissioning project for JDSF Road 630, located in the Middle Fork Caspar Creek watershed, during the fall of 2005.[10] A detailed field study of channel adjustments following excavation work at four of the largest crossing sites is in progress, with field data collection scheduled to occur until 2007 or 2008. Preliminary observations after one winter show that on average the maximum channel incision is 0.6 to 1 m (2-3 ft) (J. Bawcom, CGS, Willits, personal communication). One crossing did show considerable incision, however, with a total eroded volume of 98 m^3 (128 yd^3).

It will likely be more than a decade before the effectiveness of these road treatments can be fully evaluated in terms of reduction of long-term erosion in the South Fork Caspar Creek watershed. Evidence from 2006 suggests that the treated roads are relatively small sources of new erosion, but the remaining skid trail and road system still poses risks in this watershed. Continuing research efforts in the Caspar Creek watersheds will investigate the implications of additional watershed restoration techniques, as well as the hydrologic consequences of additional timber harvest operations.

[10] The CDFG (2006) methodology was used as a guide. Excavation work was completed that was economically feasible with California Department of Fish and Game SB 271 grant funds available for decommissioning Road 630.

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Arnold Schwarzenegger

Governor

State of California

Mike Chrisman

Secretary for Resources

The Resources Agency

Ruben Grijalva

Director

California Department of Forestry and Fire Protection

California Department of Forestry & Fire Protection
P.O. Box 944246
Sacramento, CA 94244-2460

SEDIMENT STORAGE AND TRANSPORT IN THE SOUTH FORK NOYO RIVER WATERSHED, JACKSON DEMONSTRATION STATE FOREST

By:

Rich D. Koehler and Keith I. Kelson
WILLIAM LETTIS & ASSOCIATES, INC.
1777 Botelho Dr., Ste. 262
Walnut Creek, CA 94596

And

Graham Matthews
GRAHAM MATTHEWS & ASSOCIATES
P.O. Box 1516
Weaverville, CA 96093

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California Department of Forestry
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Resource Management
P.O. Box 944246
Sacramento, CA 94244-2460

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State of California

Mary D. Nichols
Secretary for Resources
The Resources Agency

Andrea E. Tuttle, Director
California Department of Forestry
and Fire Protection

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P.O. Box 944246
Sacramento, CA 94244-2460

By:

Rich D. Koehler and Keith I. Kelson

WILLIAM LETTIS & ASSOCIATES, INC.
1777 Botelho Dr., Ste. 262
Walnut Creek, CA 94596

And

Graham Matthews

GRAHAM MATTHEWS & ASSOCIATES
P.O. Box 1516
Weaverville, CA 96093

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EXECUTIVE SUMMARY

The South Fork Noyo River (SFNR) watershed in northern coastal California 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. Historically, large populations of anadromous fish reproduced in the river. However, drastically declining fish populations over the past several decades has raised concerns over the cumulative impacts of sediment on water quality, fish habitat, and the aquatic environment. In 1999, the U.S. Environmental Protection Agency established a Total Maximum Daily Load (TMDL) for the SFNR, and determined sediment loading allocations aimed at improving water quality criteria for sediment. The EPA acknowledged that the office-based sediment budget assessments used in the TMDL were incompatable with field geomorphic relations. Prior to this study, very little data existed on sediment storage volumes and transport rates in the SFNR.

The overall goal of this assessment was to use field mapping and data collection techniques to assess long- and short-term sediment storage and transport within the SFNR. Specific objectives of this investigation were to collect baseline data on the volume of sediment stored and transported within the SFNR watershed over the past approximately 110 years and to collect present-day stream flow and sediment transport data from the main stem SFNR and its major tributaries. This effort provides better data for calculating the sediment budget of the watershed and contributes to the evaluation of how forest management practices have affected the past and present distribution of sediment within the basin.

In this study, we performed detailed geologic mapping and surveying to quantify the volumes of sediment associated with pre-historic terraces, historic terraces, and the active channel along four stream reaches. We also collected reconnaissance-level data along three stream reaches in the South Fork Noyo River watershed. These stream reaches were selected from different portions of the watershed in order to detect spatial variability in the locations and amounts of stored sediment and to assess long-term sediment transport. Additionally, we assessed the present-day hydrology and sediment transport within the major sub-watershed areas in the SFNR watershed by establishing ten streamflow and suspended-sediment sampling locations. Data collected at these sampling stations were used to develop relations between discharge, suspended sediment load, suspended sediment concentration, turbidity, and other hydrologic parameters. Total suspended sediment loads calculated for each sampling station are used to assess present-day sediment transport through the watershed.

The total volume of post-logging sediment (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 beneath 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.

Present-day suspended sediment loads computed for each sampling station ranged from 14 to 684 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 of the SFNR and Kass Creek. The sediment source for this increase in suspended sediment transport is the large amount of sediment stored in the active channel along this reach.

This research shows that sediment trapped in long-term storage along the SFNR channel is transported downstream in high-discharge events. This sediment increases the overall suspended sediment load and can lead to an overestimation of the sediment generated by upslope management practices. The data produced in this study can be used in the future to monitor sediment transport through the SFNR watershed and to assess the recovery of the SFNR channel from past logging sediment inputs.

We recommend that future sediment transport studies designed to assess the sediment contribution from upslope forest management include an assessment of in-channel storage and transport. A clear understanding of the distinction between these two sediment sources is necessary to properly evaluate sediment budget analyses.

INTRODUCTION

The South Fork Noyo River (SFNR) 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 (Figure 1). The majority of the SFNR watershed is owned and operated by the California Department of Forestry and Fire Protection (CDF) as the Jackson Demonstration State Forest, and is managed for timber production and recreation. Widespread clearcut logging in the basin during the early 20th century removed most of the old-growth redwood trees and resulted in the addition of large volumes of sediment to the South Fork Noyo River and its tributaries. Historically, large populations of anadromous fish reproduced in the river. However, drastically declining fish populations over the past several decades have raised concerns over the cumulative impacts of sediment on water quality, fish habitat, and the aquatic environment.

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 as adopted by the State of California North Coast Regional Water Quality Control Board. Sedimentation was determined to be impacting the cold-water fishery, including the migration, spawning, reproduction, and early development of coho salmon and steelhead trout (EPA, 1999). In 1999, the Environmental Protection Agency (EPA) established the Noyo River Total Maximun Daily Load (TMDL) for sediment and identified sediment loading allocations aimed at improving water quality criteria for sediment. The EPA acknowledges incompatibilities between field geomorphic relations and office-based sediment source analyses (EPA, 1999; Mathews, 1999). In particular, large uncertainties exist in the data currently available on sediment transport and storage. The amount of sediment that is stored in the system for various lengths of time strongly influences the assessment of short-term sediment budgets. Thus, quantifying reasonable ranges of sediment transport and storage volume are critical to understanding the sediment budget within the SFNR watershed and to evaluating the long-term cumulative impacts of sediment within the SFNR ecological system.

The primary objectives of this research, therefore, are to collect basic data on volumes of sediment stored and transported within the SFNR watershed over the past approximately 110 years and to collect present -day stream flow and sediment transport data from the main stem SFNR and its major tributaries. By evaluating the watershed over this time period (the duration of management influence), these data provide information on long- and short-term storage and transport within the SFNR watershed. We use this information to evaluate how forest management practices have affected the past and present distribution of sediment within the basin. The results of this research address the uncertainties in sediment budget analysis and provide a broader base for understanding long-term watershed processes in the South Fork Noyo watershed and other watersheds throughout northwestern California.

BACKGROUND

The majority of the South Fork Noyo River watershed is characterized by narrow, deeply-incised valleys and steep mountainous terrain (Figure 1). However, subdued, low relief topography dominates the headwater region. The watershed is bordered by Riley Ridge on the northeast, Three Chop Ridge on the east, and a northwest-trending ridge occupied by state Highway 20 on the southwest. The SFNR flows in a generally northwesterly direction from its headwaters to the confluence with the main Noyo River and meanders among fluvial terraces along the valley floor for much of its length. Short, relatively straight, parallel tributaries drain the slopes southwest of the SFNR and long, dendritic drainage networks are typical on the northeastern slopes. Parlin Creek and the North Fork of the SFNR are the two main tributaries to SFNR in the study area (Figure 1). These two streams drain in a northwesterly direction from their headwaters but bend to the southwest to join the SFNR.

Logging history of the SFNR basin

The South Fork Noyo River, like most Mendocino County watersheds, experienced a varied history of land-use practice over the past approximately 110 years. These land uses influenced the sediment transport processes, and thus the entire ecological system, within the watershed. The SFNR watershed is unique in Mendocino County because major logging operations on hillslopes did not begin until 1904, almost 50 years later than most other watersheds on the coast. River log drives were performed in the basin prior to 1904, however, these logs were cut primarily from river terrace areas and not hillslopes (Marc Jameson, personal communication, 2001). During the early "old-growth" logging era, unregulated clear-cut logging methods were used, in which logs were yarded by oxen teams over skid trails and stockpiled at landing areas near stream channels. Some landings were located within stream channels, which resulted in modification of natural stream courses. The history of the "old-growth" logging era in SFNR is documented by Wurm (1986) and is summarized below.

The Caspar Lumber Company acquired property within the South Fork Noyo River watershed in 1893 and began excavation of a tunnel that would provide a railway connection from the South Fork Noyo River watershed to the existing railway in the Hare Creek drainage by way of Bunker Gulch (Figure 2). This railway connection into the South Fork Noyo basin allowed Caspar Lumber Company to transport cut logs out of the basin to their mill in Caspar. The 1000-foot-long tunnel was completed in 1903 and by 1904 a railroad grade was constructed to Camp One in the vicinity of the confluence of the North Fork of the SFNR and the SFNR. This railroad grade was constructed using fill material blasted from steep slopes east of the Bunker Gulch tunnel (Figure 3a). Camp One became the field headquarters of Caspar Lumber Company in the SFNR watershed and the junction for all logging rail lines to the north and east (Figure 3b). The majority of old-growth redwood groves were clearcut and yarded to the train cars by ox-and-bull yarder teams. In 1915, steam donkey yarders replaced the ox-and-bull yarder method. These logging techniques resulted in nearly complete destruction of stream channel morphology and likely made surface soils highly susceptible to erosion (Figure 4).

Small rail lines were constructed up virtually every significant tributary in the SFNR watershed, and the main railway extended up the main channel following the progression of logging operations (Figure 2). Along the North Fork of the South Fork Noyo River the tracks reached Camp 15 by 1923 and the logging was completed in 1927. Along the SFNR, the tracks reached Camp 5 at Parlin Creek in 1912 and Camp 19 at the headwaters in 1929. The rail line extended over the Dunlop Pass trestle in 1937, leaving the South Fork Noyo watershed. By 1946, the majority of the old-growth redwood logging was completed and all of the branch rail lines had been removed, leaving only the main line tracks.

During the late 1940's and 1950's, a second phase of intense logging began in the SFNR watershed that involved "second-growth" forests as well as residual old-growth forests. During this time, there was little or no regulation of management practices, silviculture, size of timber harvest units, or road construction. The majority of the old railroad grades were converted to haul roads, and spur roads were constructed on steep slopes and adjacent to stream channels. Side-casting of waste material was common. Logs were yarded to landings by tractors across steep slopes and in stream channels, which likely loosened hillslope surface soils and promoted erosion of channel sediments. Over time, hillslope surface erosion and landslides involving saturated side-cast material resulted in sediment contributions to the SFNR and its tributaries.

The passage of the Z'berg-Nejedly Forest Practice Act in 1973 dramatically changed timber management practices in California. The new guidelines provided for buffer zones to protect watercourses and inner gorge areas from harvest activity as well as higher standards for road construction and harvest techniques. Modern second growth-logging in the SFNR watershed is governed by the Forest Practice Rules. Although management practices conducted following the Forest Practice Act have contributed to a decrease in the rate of sediment delivery to channels in the SFNR, large volumes of sediment within the SFNR basin continue to affect the ecology of the watershed (EPA, 1999).

Logging Influences on Fish Habitat

Timber harvest practices have been associated with a number of hydrologic and geomorphic processes, including increased rates of surface erosion from forest roads (Lewis, 1998; Duncan et al., 1987; Ried and Dunne, 1984), and increased frequency of landslide occurrence (O'Loughlin and Ziemer, 1982; Rood, 1984; Swanston and Swanson, 1976). Accelerated erosion can have positive and negative effects on anadromous fish habitat. Positive effects include formation of new habitats for spawning, rearing, and overwintering as a result of the addition of coarse gravel to the channel (Swanston, 1991). The introduction of large woody debris from channel margins can increase cover, provide long-term storage for sediment, and create diverse aquatic habitat conditions (Napolitano, 1998). Negative effects of accelerated erosion include filling of pools, scouring of riffles, blockage of fish access, disturbing side-channel rearing areas, and siltation of spawning gravels (Swanston, 1991). The magnitude of these effects is dependent on the frequency and intensity of erosional events, as well as the sediment processing capabilities of a particular stream. The stream adjusts to these alterations downstream as well as upstream of local erosional events. As a general rule, larger streams and rivers adjust to erosional perturbations faster than smaller streams (Swanston, 1991).

Brown et al. (1994) provide anecdotal information on the presence of large populations of coho salmon and steelhead in the Noyo River watershed during the early 20th century. Limited data from stream surveys conducted by the California Department of Fish and Game (DFG) in the 1950's and 1960's suggest that coho salmon and steelhead both were present in SFNR, Parlin Creek, and the North Fork of the SFNR. Low numbers of coho salmon and steelhead were identified by DFG in the SFNR watershed in the 1980's and early 1990's (DFG, 1995a and b). In-migrant fish trap data collected by DFG since 1963 at its egg-taking station at Camp One on SFNR provides substantial data supporting the decline of anadromous fish in the basin. For example, the average number of returning coho to this hatchery-influenced system prior to the drought of 1977 were 2,819, 2,669, and 2,132 for each of the three respective coho salmon reproductive populations. The numbers of returning coho subsequent to the 1993 drought represent a decline of 93%, 60%, and 27% of the pre-1977 numbers for each of the three respective coho salmon reproductive populations (A. Grass pers. comm., in: EPA, 1999). For the 1998-99 season, the egg-taking station on SFNR reported only 5 returning males and 11 returning females (EPA, 1999). In contrast to this data, hundreds of coho salmon have been observed spawning downstream of the egg taking station in drought years (Marc Jameson, personal communication, 2001), and thus data from the egg taking station may not be indicative of salmonid population abundance for the entire basin.

DFG (1995a and 1995b) provides data on anadromous fish habitat such as, percent fine sediment within channel cobbles (embeddedness) in pool tailouts, percent of pools deeper than three feet, pool frequency, and shelter rating for Parlin Creek and SFNR. These data indicate that coho may have difficulty digging redds in a majority of the pool tail-outs because of high embeddedness. These data also suggest that infrequent deep pools, backwater pools, and low amounts of large woody debris may be limiting coho rearing and overwintering success. For our study, this is significant because the transport and storage of sediment directly influences the distribution of these fish habitat parameters.

Significance

Recently, the Noyo River watershed was placed on the 1998 Section 303(d) list by the State of California as required by the Clean Water Act. The listing was the result of water quality problems related to sedimentation and prompted the development of the Noyo River Total Maximum Daily Load (TMDL)(EPA, 1999). The TMDL outlined sediment loading allocations that, when implemented, are expected to result in improved water quality criteria for sediment. As part of the TMDL development, the recent Level One watershed analysis for the SFNR watershed provided important initial data on sediment inputs, outputs, and net storage (Matthews, 1999). However, this desktop (office-based) analysis also demonstrates that the uncertainties in evaluating these sediment parameters may be quite large. For example, the available data yielded the conclusion that the sediment input to the system is approximately 40% less than the sediment output. This estimate contradicts the geomorphic evidence of active aggradation directly downstream of the confluence between the SFNR and the main stem of the Noyo River. The incompatibility between field relations and desktop calculations is, in part, a result of large uncertainties in the data currently available on sediment input and storage. In particular, the volume of sediment eroded from roads and skid trails is poorly constrained, and the volume eroded from channel banks is unknown. The uncertainties in these volumes may be quite large, on the order of 50% to 100% or more. Quantifying reasonable ranges of sediment input from and storage in these sources is critical to understanding the sediment transport within the SFNR watershed, and thus to evaluating the long-term impacts of sediment transport within the SFNR ecological system. In addition, Graham Matthews and Associates (Matthews, 1999) and the U.S. Environmental Protection Agency (EPA, 1999) note that the discrepancy between inputs and outputs in the SFNR watershed may be a result of time lags from sediment delivery to transport through the system. In other words, the amount of sediment that is stored in the system for various lengths of time may strongly influence the assessment of short-term sediment budgets.

Based on our past experience within Mendocino County (Louisiana-Pacific Corp., 1998, EPA, 1998, Matthews, 1999), it is critical that there is a clear understanding of the background sedimentation processes in order to ensure accurate sediment budget analysis. Field-based data on sediment storage is often absent from standard sediment budget analyses. Understanding the long-term impacts of logging on sediment transport and storage is necessary to evaluate the sediment processing capabilities of forested coastal basins.

This study, therefore, was designed to evaluate the volume of sediment existing in streamside terraces, debris dams, and stream channels and to investigate the rates and processes of sediment transport through the SFNR watershed. By evaluating the SFNR watershed over the past approximately 110 years (the duration of timber operations), this report evaluates long-term sediment storage and transport within the basin and provides better constrained data for calculating the sediment budget of the watershed. These data are critical for assessing long-term cumulative impacts of sediment on the stream channel environment and for accurately evaluating the sediment budget of the SFNR watershed. Understanding sedimentation is important for evaluating watershed management plans and determining impacts on the watershed ecological system. The data presented in this report provides a broader base for understanding long-term watershed processes and thus impacts of various logging practices over time. These findings may also be directly applicable to other watersheds throughout northwestern California. In particular, this report addresses whether there is long-term sediment storage in the SFNR or if the system is efficiently transporting logging-induced sediment to the mainstem Noyo River.

APPROACH AND METHODS

Sediment storage component

Developing an understanding of a fluvial geomorphic framework is necessary to assessing long-term cumulative impacts of sedimentation related to logging practices. We assessed the historic and current influences on channel morphology by conducting both office-based and field data collection. This effort included meeting with CDF personnel familiar with the watershed, reviewing archival information, and performing detailed geomorphic field mapping along selected reaches. In a previous investigation of sediment storage in the Garcia River watershed (Louisiana-Pacific Corporation, 1998), we show that significant volumes of sediment accumulated at the mouths of major tributary channels. Based on this, we selected two stream reaches located at the mouths of major tributary basins that have been subjected to various degrees of upstream management activity. We then selected a stream reach on a tributary upstream of a major confluence and a stream reach on the main SFNR downstream from a major confluence. These stream reaches were selected from different portions of the watershed in order to detect spatial variability in sediment volume that may be related to different management practices occurring throughout the watershed. The stream reaches also were selected to compare sediment storage in upstream locations vs. downstream locations for long-term sediment transport analysis.

The locations of the four stream reaches for detailed study are shown on Figure 5. First, the areas located at the confluence of the SFNR and Parlin Creek (Area A) and the confluence of SFNR and the North Fork of the SFNR (Area B) were selected because these two tributaries are the largest within the SFNR watershed. Area A includes the site of Camp 5, and Area B includes the site of Camp 1 (see also Figures 2, 3 and 4). Second, an area along the North Fork of the SFNR (Area C) was selected in order to assess the sediment storage characteristics along this major tributary upstream from the SFNR confluence. This site includes the site of Camp 8 (Figure 2). Lastly, we selected a reach at the downstream end of SFNR in the Jackson State Demonstration Forest (Area D) in order to evaluate sediment volume at the forest boundary (Figure 5).

Within the selected study reaches, we developed detailed geomorphic maps of current channel conditions showing the locations of fluvial terraces, gravel bars, channels, bankfull channel margins, and detailed cross-sections. We identified three distinct geologic map units, including deposits associated with pre-historic terraces, historic terraces, and the active channel. Deposits associated with the active channel include deposits in the low-flow or summer channel, and gravel bars that are inundated during winter floods. Detailed study reaches were mapped, described and photographed in the field. For field mapping, a string line painted at 25 foot intervals was pulled tight along a straight line of sight in the channel thalweg and tied off on tree branches. The compass bearing of the string line was plotted on the field map. The distance from the line to the edge of each map unit was measured directly perpendicular to the string and also plotted on the field map. Channel and terrace storage thickness measurements were made with a survey rod and recorded in a field notebook. Detailed topographic cross sections were surveyed in each stream reach with a laser level and survey rod. Cross sections were located in areas where all of the described terraces are present and were used to calculate terrace sediment storage volume, to calibrate field mapping, and to assess volumes of sediment removed from the site since initial historic deposition. Information contained on the maps and cross sections provide a record of baseline channel conditions from which the effects of future timber management activities can be monitored.

The field geologic maps were imported into an ArcView Geographic Information System (GIS), and used to calculate the area of all of the mapped deposits. These data were combined with field thickness estimates to estimate the sediment volume associated with each deposit. Mapped deposits were sorted by origin and then cumulative terrace and channel storage volume for each stream reach was calculated as a sum of individual terrace and stream data. Thickness is the limiting measurement in the accuracy of this technique. For this study, the thickness of an individual terrace deposit was assumed to be the distance from the deepest scour in the active channel to the top of the terrace surface. Field evidence used to determine 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. Where this information was not available (i.e., sediment deposited across the channel with no observable channel or buried logs), a channel deposit thickness of one foot was assumed. For historic terraces and gravel bars, the thickness was calculated as the measured height of the terrace plus the thickness of the adjacent channel deposit. This method assumes a rectangular channel shape and does not account for an irregular buried bedrock surface.

In addition to assessing sediment storage volumes in the detailed stream reaches, sediment volume was quantified in channel reaches outside of the detailed stream reaches. In particular, we measured sediment storage volume between Areas A and B (herein designated Area G) and between Areas B and D (Area E) on the SFNR, and between Areas B and C (Area F) on the North Fork of the SFNR (Figure 5). For these areas, sediment storage volume was estimated by measuring length, width, and thickness values with pace and tape measuring techniques. For active channel deposits and historic terrace deposits, surface area was determined by approximating the shape of the surface as a rectangle. The volume of large, continuous pre-historic terraces was calculated by averaging width and thickness of the deposit and measuring the length on the map. Thickness measurement techniques used in reconnaissance reaches were the same as the techniques used in the detailed reaches. The uncertainties associated with both the detailed mapping and reconnaissance mapping technique are discussed later in this report.

<u>Streamflow and sediment transport component</u>

The flow of water is the driving force controlling the transport of sediment in fluvial systems. The timing, rate, duration, and frequency of these flows are important characteristics that must be understood to develop a process-based understanding of channel morphology and change. We assessed the present-day hydrology and sediment transport within the major sub-watershed areas in the SFNR watershed by establishing