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PART A - APPENDIX A: BED-MATERIAL SAMPLES

PART A - APPENDIX B: BED-MATERIAL SAMPLE LOCATIONS IN FOCUS AREAS

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PART A - ATTACHMENT A: FIELD REPORT, FIELD ASSESSMENT OF UNDERWATER CAMERA PILOT TEST FOR SEDIMENT GRAIN SIZE DISTRIBUTION

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fluvial Geomorphology Modeling Study (6.6)

Part A - Appendix A
Bed-material Samples

Initial Study Report

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

Tetra Tech

June 2014

Table A-1: Surface and subsurface samples collected in 2013.

Surface and subsurface samples collected in the Lower River								
PRM	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
29.1	13.7	25.0	45.4	54.1	0.4	10.0	38.1	44.4
33.1	17.1	30.1	52.9	58.7	1.2	9.8	29.6	37.1
35.3	11.7	21.2	37.6	44.6	0.3	4.4	28.1	34.3
39.0	17.6	39.2	65.3	75.7	0.7	17.3	48.3	58.6
41.1	23.6	41.4	62.9	73.4	0.5	16.9	48.7	58.3
43.3	13.6	35.0	61.5	72.3	1.1	18.2	54.8	66.7
45.0	18.5	34.5	56.4	61.5	1.0	15.2	51.1	61.3
47.0	16.8	31.2	55.9	62.8	0.6	12.3	38.4	46.2
52.2	17.6	34.0	53.4	59.3	0.4	11.5	29.4	34.9
55.2	12.4	23.0	41.7	48.0	0.5	14.6	32.3	38.4
59.2	16.6	33.0	62.4	74.0	0.7	15.6	40.8	49.6
63.4	17.0	30.3	58.0	60.7	1.1	13.0	45.8	56.0
67.9	16.8	34.1	68.6	80.3	0.6	15.9	54.5	68.9
72.6	16.2	36.9	70.7	82.1	0.9	14.8	47.1	60.7
75.2	15.2	28.2	51.0	58.2	0.6	18.3	58.1	71.9
79.1	16.7	33.1	67.5	77.6	0.4	18.3	61.4	73.2
83.0	16.3	30.0	57.5	66.8	1.2	22.2	72.0	84.0
87.0	13.5	28.7	62.7	75.1	0.4	20.9	74.8	92.0
91.5	18.2	35.4	79.0	94.0	1.1	16.5	53.8	69.3
95.5	25.1	50.1	82.4	89.5	0.7	12.5	54.2	70.6
99.0	18.0	41.8	76.4	86.9	0.6	17.7	64.4	78.8
101.8	15.8	41.8	110.7	135.5	2.9	34.6	105.2	122.7
99.0	23.5	44.6	80.5	88.5				

Table A-1 (cont.): Surface and subsurface samples collected in 2013.

Surface and subsurface samples in the Middle River								
PRM	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
103.9	23.7	45.6	78.8	87.0	0.4	22.6	60.0	73.2
104.8	22.4	40.1	78.3	90.8	1.3	22.3	93.4	121.3
105.5	21.8	42.3	82.9	96.4	1.6	29.3	95.7	113.8
106.5	37.4	72.0	119.5	131.4	3.9	43.6	134.1	177.4
108.7	21.1	38.1	83.6	112.0	1.7	32.4	105.7	123.4
111.0	34.3	70.9	132.2	160.1	3.0	35.0	106.0	139.6
113.5	35.7	76.3	119.7	131.0	1.4	50.8	111.6	129.8
114.5	18.6	46.9	101.7	116.8	1.8	23.2	80.4	95.7
114.8	23.5	53.7	117.9	134.0	2.1	29.6	87.3	108.7
115.5	19.0	49.0	105.4	120.0	1.1	25.2	71.5	88.8
116.3	34.5	66.4	119.3	136.0	4.7	51.8	130.4	147.1
118.2	33.6	64.2	114.0	129.5	1.7	30.5	92.7	116.0
121.2	25.5	52.3	102.1	115.9	1.6	24.7	84.0	102.4
123.6	28.6	54.0	115.5	135.9	1.1	28.1	94.5	114.0
125.2	31.5	72.6	124.1	142.5	1.3	21.3	66.7	78.0
126.6	22.5	54.7	119.3	138.4	1.3	35.7	125.9	144.4
128.0	24.1	48.9	93.1	109.7	1.7	33.9	85.1	98.9
129.0	27.3	51.2	84.2	95.2	0.9	35.0	103.0	119.0
129.8	42.2	78.0	135.5	160.7	2.2	42.2	117.5	140.5
131.2	29.2	61.1	115.9	132.0	0.8	26.1	69.3	82.7
133.3	32.0	60.9	116.1	132.6	1.1	23.4	72.4	93.8
135.6	24.7	43.9	75.9	87.3	0.6	20.0	60.8	74.3
136.7	22.7	45.6	105.4	124.5	1.4	24.7	69.2	84.9
138.6	17.5	46.1	120.7	149.9	1.6	30.1	107.0	134.6
139.4	36.3	74.3	123.2	141.3	2.8	38.2	150.3	173.5
140.8	30.4	67.9	136.2	156.6	1.2	25.9	93.8	108.5
142.6	28.6	50.3	88.8	104.7	1.2	23.8	84.0	99.3
143.3	39.0	88.9	157.0	172.8	1.4	36.9	167.1	220.7
144.5	35.9	76.9	145.6	166.9	3.3	42.1	120.7	173.8
145.5	33.6	76.9	177.2	212.5	1.7	26.8	130.2	147.0
106.0	35.6	72.0	121.4	139.4				
107.2	18.0	61.9	119.1	136.4				
108.3	29.3	75.9	153.2	170.6				
115.4	33.5	80.3	136.0	156.3				
115.8	24.8	50.3	88.5	103.1				
115.9	20.9	65.5	133.6	151.8				
115.9	19.1	44.6	113.1	147.4				
138.6	15.3	43.9	118.6	141.8				
138.6	32.7	64.0	109.7	125.2				

Table A-1 (cont.) Surface and subsurface samples collected in 2013.

FA-104 (Whiskers Slough)								
PRM	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
104.0	18.8	33.5	54.3	58.6				
105.1	26.1	49.5	83.6	93.2				
105.1	26.2	51.4	96.1	109.7				
105.1	22.5	43.6	81.3	90.0				
105.2	21.7	39.5	75.0	86.0				
105.3	30.8	62.6	113.8	132.4	4.4	38.5	96.6	114.5
105.3	22.5	74.8	130.9	150.1				
105.5	56.5	90.0	138.4	157.7				
105.5	18.7	43.1	95.0	111.8	3.1	27.3	70.9	81.2
105.7	25.3	49.9	110.7	125.4				
105.8	36.1	61.6	114.7	132.9	0.6	29.9	79.6	100.3
106.0	35.6	72.0	121.4	139.4				
FA-113 (Oxbow I) and FA-115 (Slough 6A)								
PRM	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
113.7	41.2	79.4	154.0	184.9				
114.2	28.8	59.2	109.5	123.1	3.3	29.9	107.7	131.5
115.1	17.3	50.3	97.8	110.7				
115.4	33.5	80.3	136.0	156.3				
115.8	24.8	50.3	88.5	103.1				
115.9	20.9	65.5	133.6	151.8				
115.9	19.1	44.6	113.1	147.4				
116.0	20.3	39.5	64.0	78.5	1.9	33.7	138.0	152.4

Table A-1 (cont.): Surface and subsurface samples collected in 2013.

FA-128 (Slough 8A)								
PRM	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
128.2	14.8	35.4	81.3	102.7				
128.7	22.0	38.4	77.4	94.3				
128.7	19.7	48.4	102.5	121.1				
128.9	25.0	47.9	102.1	118.7	1.6	25.1	98.0	121.8
129.1	22.5	54.2	101.9	115.4				
129.4	26.3	65.6	123.6	151.8				
129.5	27.0	52.9	84.1	92.6				
129.6	43.3	92.1	141.8	157.1				
129.7	25.1	58.0	106.2	120.3				
129.8	42.2	78.0	135.5	160.7	2.2	42.2	117.5	140.5
FA-138 (Gold Creek)								
PRM	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
138.6	15.3	43.9	118.6	141.8				
138.6	32.7	64.0	109.7	125.2				
138.7	20.7	66.5	118.6	132.4				
138.7	33.3	95.1	174.3	226.3				
138.7	19.0	49.4	95.4	113.8				
139.0	35.1	80.5	126.1	151.3				
139.0	23.6	41.1	79.7	94.1				
139.1	14.4	65.8	115.4	132.9				
139.2	9.8	25.9	110.1	139.4				
139.3	56.1	135.8	222.4	242.0				
139.3	15.4	36.7	96.6	119.3				
139.4	36.7	74.5	128.0	146.7				
139.5	22.5	49.4	90.0	109.1	3.1	28.4	78.7	95.6
139.8	37.5	93.7	159.5	174.5				
140.0	18.5	43.6	87.5	105.6	1.0	16.2	58.2	76.6

Table A-1 (cont.): Surface and subsurface samples collected in 2013.

FA-141 (Indian River)								
PRM	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
141.9	24.8	64.0	118.9	138.1				
142.1	33.3	81.0	153.3	172.9				
142.2	25.3	82.6	160.7	187.2				
142.8	17.6	53.7	136.4	155.1				
142.8	26.2	58.6	95.4	107.3				
142.8	21.4	36.6	63.8	73.2				
142.9	24.0	49.6	82.0	89.9	1.4	28.7	83.2	113.1
143.0	30.8	86.2	144.0	166.9				
143.3	27.8	61.8	140.2	160.7				
FA-144 (Slough 8A)								
PRM	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
144.9	24.3	49.8	104.7	121.7	0.3	1.0	14.9	22.6
145.2	33.1	66.3	111.5	120.2	1.2	20.1	71.8	92.3
145.7	37.0	90.0	151.8	165.3	0.7	27.5	92.8	108.3
144.9	32.0	68.9	109.3	117.6				
144.9	30.8	72.5	151.2	175.2				
144.9	17.4	38.7	62.4	72.4				
144.9	17.4	56.9	154.2	202.4				
145.0	10.2	19.4	39.4	43.0				
145.0	53.0	127.2	193.8	216.6				
145.0	11.9	24.1	39.6	45.0				
145.1	6.8	18.4	39.1	43.0				
145.1	18.6	41.1	74.0	84.2				
145.5	52.9	88.9	142.4	161.8				
145.6	207.7	273.5	338.3	351.2				
145.6	25.5	46.3	84.1	104.7				

Table A-1 (cont.): Surface and subsurface samples collected in 2013.

Yentna River								
Sample	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
YN1	9.5	17.4	28.6	31.4	0.4	8.6	25.4	29.2
YN3	11.6	22.3	34.7	40.8	0.4	5.6	27.1	32.4

Chulitna River								
Sample	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
CH1	17.0	31.0	63.0	81.9	1.3	25.8	92.4	112.5
CH2	12.8	28.3	54.7	61.5	1.1	18.4	59.8	73.2
CH3	12.6	24.2	46.8	56.2	0.7	13.2	47.1	57.3
CH5	25.8	47.0	77.1	86.2	1.1	22.2	77.9	94.9
CH6	29.0	51.0	87.5	101.2	1.0	21.5	82.2	100.9

Talkeetna River								
Sample	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
TK1	20.8	44.1	82.3	95.1	1.7	27.2	114.7	137.5
TK2	11.7	20.4	49.4	59.9	0.7	16.7	54.9	65.8
TK3	13.9	24.4	44.6	53.9	0.5	21.8	59.1	70.4
TK4	14.6	39.5	76.5	87.9	2.7	28.6	71.0	79.6
TK5	10.8	27.6	69.2	82.4	0.7	19.5	64.7	86.4

Deshka River								
Sample	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
D1,PC-1	23.6	41.3	65.7	76.9	1.2	9.8	42.7	55.6
D2					0.2	0.4	0.9	1.3
D3,PC-2	23.7	36.7	51.8	56.4	1.3	17.7	33.4	35.1
D4					0.3	0.5	1.1	1.7
D5					0.4	0.9	2.6	4.5
D6					0.4	0.7	1.5	1.7
D7,PC-3	17.1	32.6	45.9	52.0	0.6	7.3	24.3	29.9
D8					0.3	0.6	0.9	1.2

Table A-1 (cont.): Surface and subsurface samples collected in 2013.

Trappers Creek								
Sample	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
TC5	24.7	40.9	64.0	74.9				
TC6	20.1	38.6	61.1	72.7				
TC7	33.0	52.7	83.6	92.9				
TC8	25.7	49.8	89.5	110.6				
TC10	16.6	29.3	51.5	59.8	9.9	32.0	70.6	78.5
TC11	30.3	44.5	71.7	82.2				
TC12	17.5	35.4	57.1	62.4				
Golder-13	16.0	27.4	43.7	51.1				

Whiskers Creek								
Sample	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
S1/S2	18.8	33.5	54.3	58.6	0.4	12.0	24.5	27.1

Unnamed Tributary PRM 113.7 (UNT113.7)								
Sample	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
UNT113.7	27.3	90.2	457.4	583.3	0.1	2.9	103.3	132.7

Slash Creek								
Sample	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
Slash					1.7	11.9	27.2	31.3

Gash Creek								
Sample	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
Gash	13.1	25.2	46.5	56.3	1.6	19.2	102.6	119.0

Table A-1 (cont.): Surface and subsurface samples collected in 2013.

Lane Creek								
Sample	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
Lane	24.7	56.7	116.3	143.4	2.6	31.1	117.2	152.6

Skull Creek								
Sample	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
Skull	23.4	68.5	223.2	311.9	2.1	22.7	80.2	115.9

Gold Creek								
Sample	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
Gold Ch.	31.5	84.8	177.4	212.5				
Gold Fan	28.2	56.5	100.5	114.7	1.6	21.1	59.4	72.8

Indian River								
Sample	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
Ind. Ch.	35.2	75.4	161.9	191.4				
Ind. Fan	17.5	37.6	71.1	83.2	0.6	19.1	48.9	60.0

Unnamed Tributary PRM 144.6 (UNT144.6)								
Sample	Surface Gradation (mm)				Subsurface Gradation (mm)			
	D_{16}	D_{50}	D_{84}	D_{90}	D_{16}	D_{50}	D_{84}	D_{90}
UNT144.6	27.1	83.2	178.5	224.7	2.3	23.7	58.9	77.0

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fluvial Geomorphology Modeling Study (6.6)

Part A - Appendix B
Bed-material Sample Locations in Focus Areas

Initial Study Report

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

Tetra Tech

June 2014

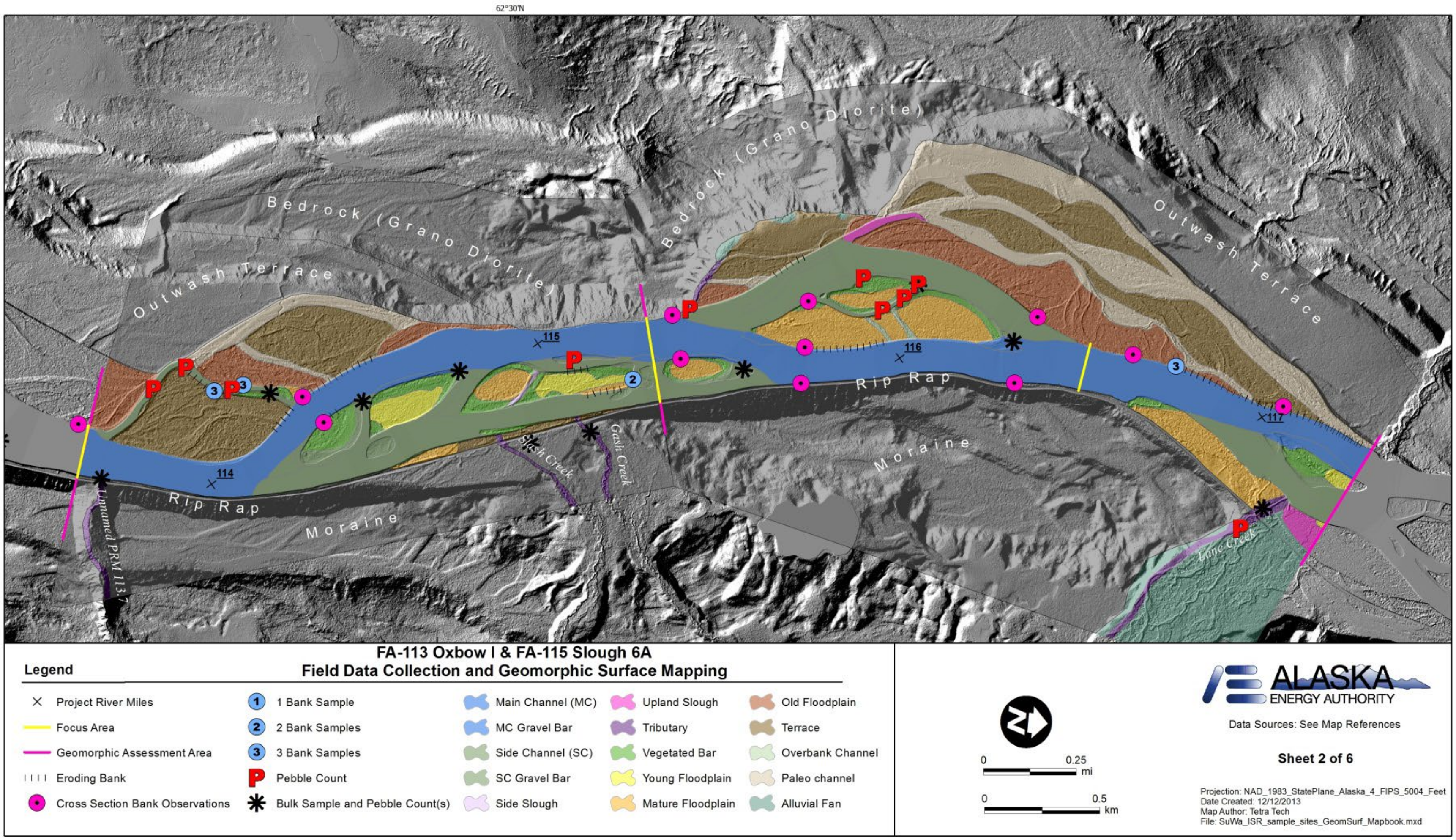

Figure B-1: Sediment samples and bank observations collected at FA-113 (Oxbow I) and FA-115 (Slough 6A)

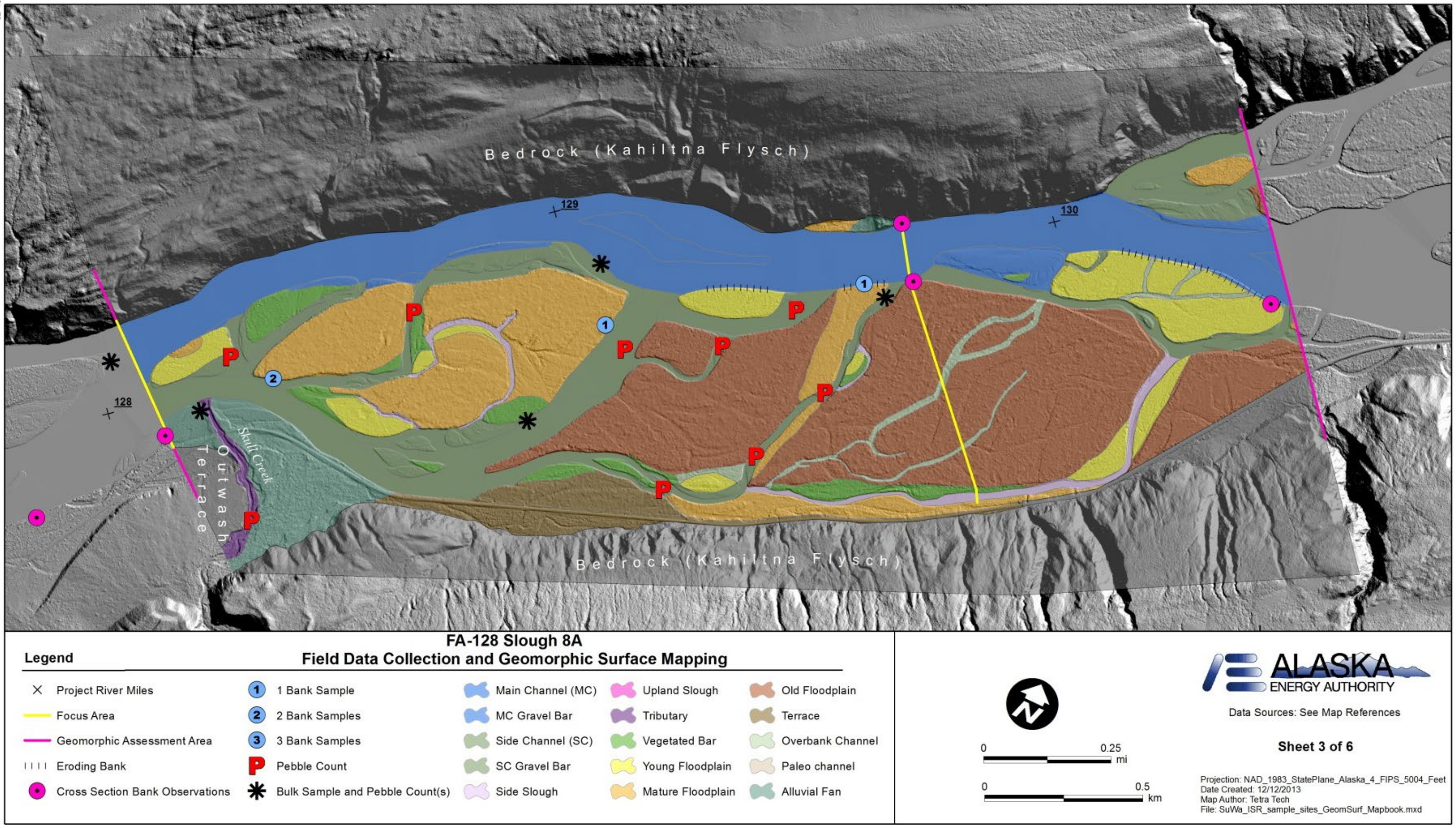

Figure B-2: Sediment samples and bank observations collected at FA-128 (Slough 8A).

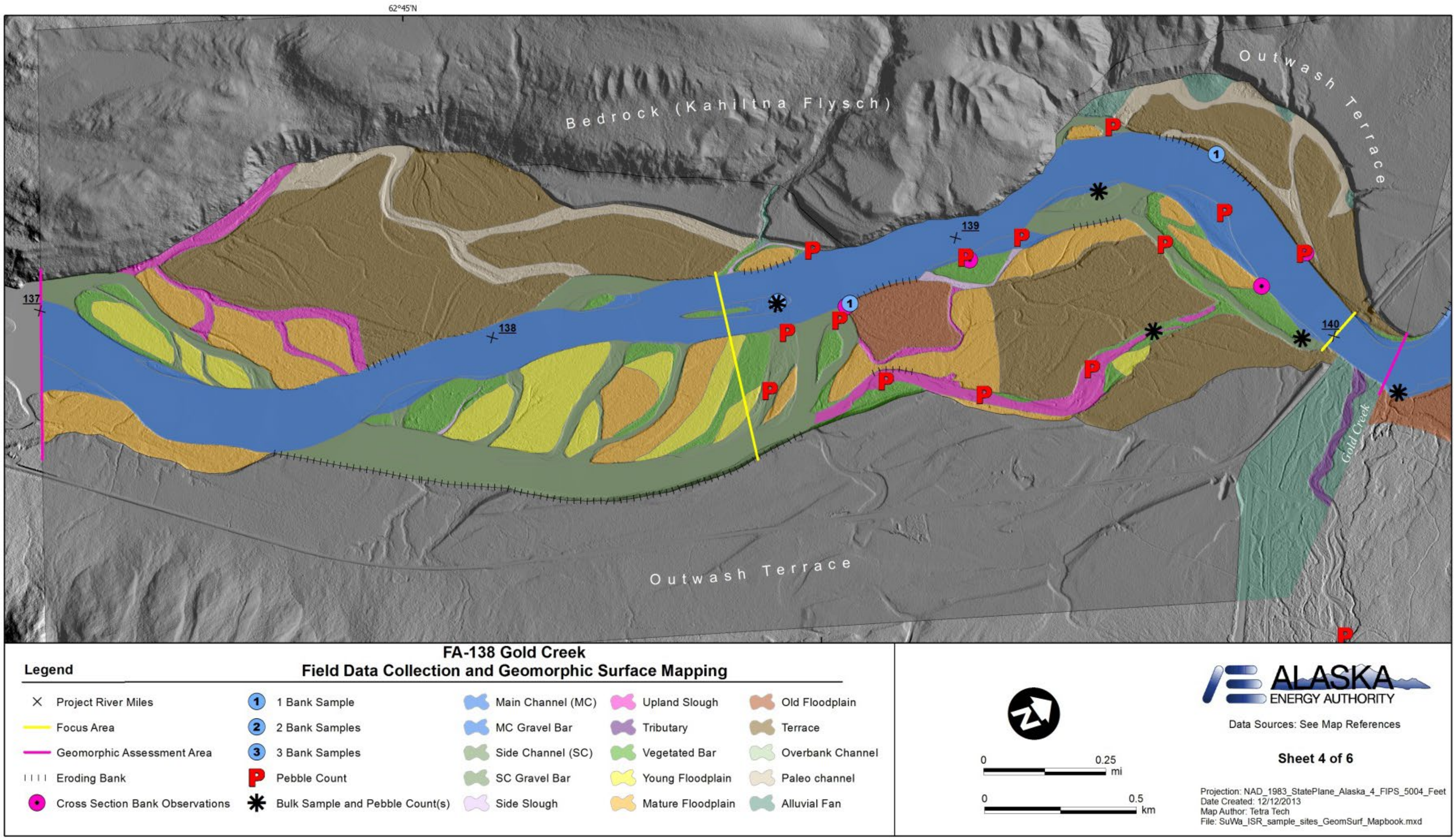

Figure B-3: Sediment samples and bank observations collected at FA-138 (Gold Creek).

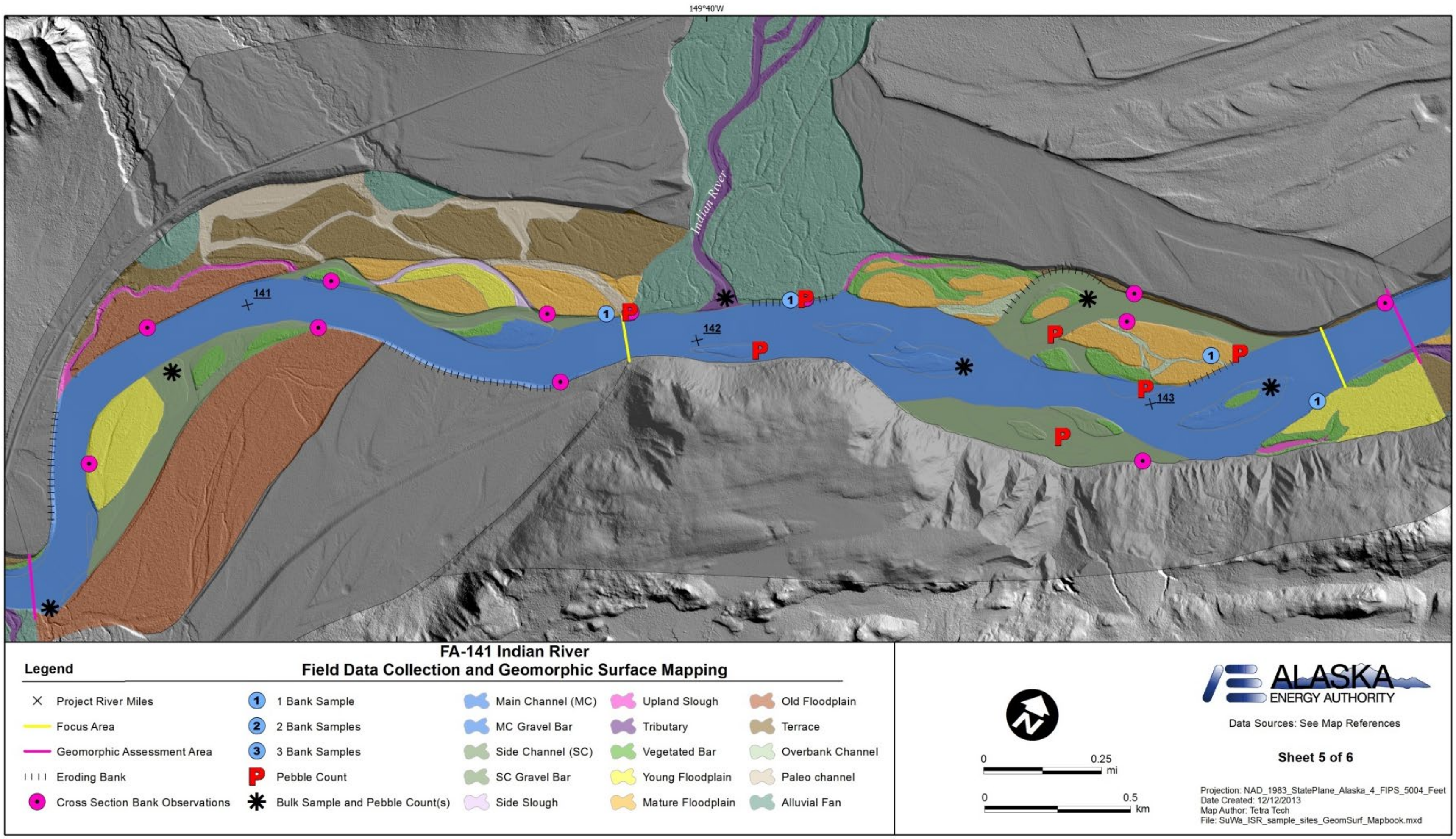

Figure B-4: Sediment samples and bank observations collected at FA-141 (Indian River).

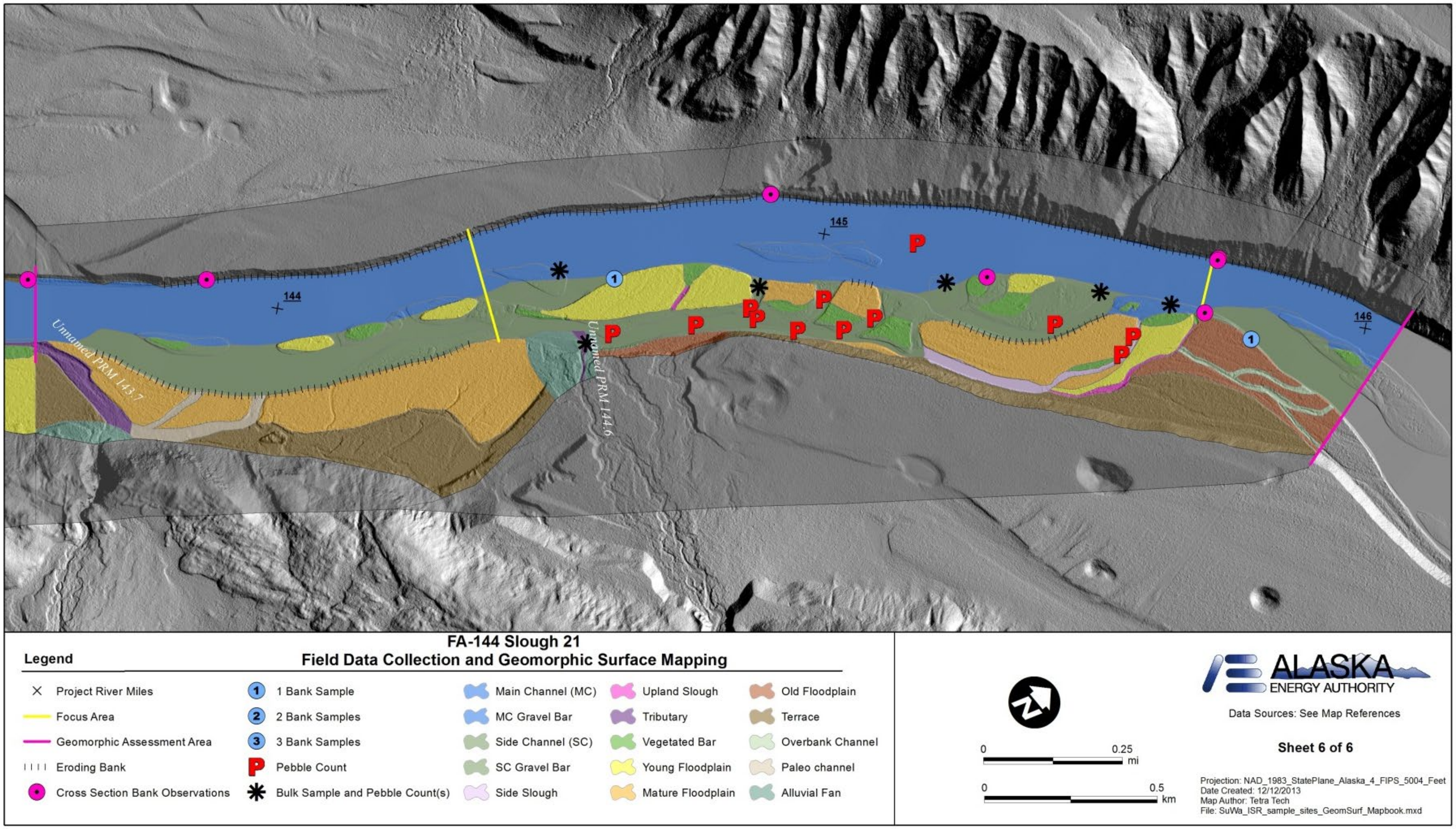

Figure B-5: Sediment samples and bank observations collected at FA-144 (Slough 21).

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fluvial Geomorphology Modeling Study (6.6)

Part A - Appendix C
Bank-material Samples

Initial Study Report

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June 2014

Table C-1: Bank material samples collected in 2013.

Susitna River - Outside of Focus Areas						
PRM	SAMPLE NAME	DATE SAMPLED	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	D_{90} (mm)
107.2	107.2	7/13/2013	0.05	0.14	0.34	0.40
109.5	109.5B	9/5/2013	0.00	0.00	0.13	0.18
109.5	109.5	9/5/2013	0.13	0.25	0.40	0.43
119.7	119.7	9/7/2013	0.09	0.19	0.36	0.42
123.6	123.6	9/7/2013	0.02	0.06	0.18	0.21
143.9	143.9	9/7/2013	0.23	0.54	9.66	11.68
Whiskers Slough						
PRM	SAMPLE NAME	DATE SAMPLED	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	D_{90} (mm)
104	Whiskers	7/13/2013	0.05	0.07	0.16	0.21
105	105.0-FA104	7/13/2013	0.02	0.05	0.10	0.11
105	105.0-FA104	9/23/2013	0.01	0.05	0.13	0.17
105	105.0-FA104	9/23/2013	0.13	0.25	0.41	0.44
105	105.0-FA104	9/23/2013	0.02	0.05	0.09	0.10
105	105.0-FA104	9/23/2013	0.05	0.07	0.12	0.13
105	105.0-FA104	9/23/2013	0.08	0.16	0.24	0.28
105	105.0-FA104	9/23/2013	0.06	0.09	0.20	0.24
105	105.0-FA104	9/23/2013	0.05	0.08	0.21	0.25
105	105.0-FA104	9/23/2013	0.06	0.13	0.22	0.24
105.3	105.3	9/5/2013	0.04	0.08	0.22	0.30
105.3	105.3	7/11/2013	0.00	0.07	0.16	0.20
105.5	105.5B	9/5/2013	0.19	4.14	11.19	12.79
105.5	105.5C	9/5/2013	0.08	0.15	0.22	0.23
105.7	105.7	9/5/2013	0.07	0.15	0.24	0.30
105.7	105.7	9/5/2013	0.02	0.06	0.35	10.08

Table C-1 (cont.): Bank material samples collected in 2013.

FA-113 (Oxbow I) and FA-115 (Slough 6A)						
PRM	SAMPLE NAME	DATE SAMPLED	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	D_{90} (mm)
114	114.0-FA113	9/23/2013	0.03	0.05	0.11	0.12
114	114.0-FA113	9/23/2013	0.03	0.06	0.12	0.16
114	114.0-FA113	9/23/2013	0.02	0.06	0.10	0.11
114	114.0-FA113	9/23/2013	<0.0625	0.14	0.40	1.00
114	114.0-FA113	9/23/2013	0.06	0.11	0.21	0.24
114	114.0-FA113	9/23/2013	0.06	0.11	0.19	0.22
114.3	114.3	9/5/2013	0.06	0.09	0.15	0.19
115.3	115.3	9/23/2013	0.07	0.17	0.34	0.40
115.3	115.3	9/23/2013	0.06	0.13	0.24	0.30
116	116.0B	9/5/2013	0.07	0.15	0.23	0.27
116.1	116.1	9/5/2013	0.06	0.13	0.22	0.25
116.5	116.5-FA115	9/23/2013	0.02	0.04	0.09	0.12
116.5	116.5-FA115	9/23/2013	0.06	0.10	0.19	0.21
116.5	116.5-FA115	9/23/2013	0.06	0.12	0.20	0.22
FA-128 (Slough 8A)						
PRM	SAMPLE NAME	DATE SAMPLED	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	D_{90} (mm)
128.3	128.3	9/7/2013	0.01	0.03	0.06	0.09
128.3	128.3	9/7/2013	0.13	0.25	0.42	0.46
128.8	128.8	9/24/2013	0.08	0.16	0.32	0.38
129.1	129.1	9/7/2013	0.00	0.08	0.17	0.21
129.5	129.5	9/7/2013	0.02	0.05	0.12	0.16
129.7	129.7	9/23/2013	0.06	0.22	0.41	0.45
129.7	129.7	9/23/2013	0.06	0.11	0.22	0.25
129.7	129.7	9/23/2013	0.06	0.09	0.18	0.21
FA-138 (Gold Creek)						
PRM	SAMPLE NAME	DATE SAMPLED	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	D_{90} (mm)
138.7	138.7	9/7/2013	0.00	0.15	0.33	0.40
138.7	138.7B	9/7/2013	0.00	0.15	0.32	0.43
139.5	139.5	9/7/2013	0.00	0.07	0.18	0.21
139.7	139.7-FA138	9/24/2013	0.05	0.06	0.13	0.20
139.7	139.7-FA138	9/24/2013	0.03	0.05	0.10	0.11
139.7	139.7-FA138	9/24/2013	0.06	0.13	0.25	0.33
139.7	139.7-FA138	9/24/2013	0.02	0.09	0.06	0.08
139.7	139.7-FA138	9/24/2013	0.02	0.04	0.09	0.11
139.7	139.7-FA138	9/24/2013	0.08	0.15	0.23	0.24
139.8	139.8	9/24/2013	0.00	0.15	0.30	0.37

Table C-1 (cont.): Bank material samples collected in 2013.

FA-144 (Slough 8A)						
PRM	SAMPLE NAME	DATE SAMPLED	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	D_{90} (mm)
141.9	141.9	9/7/2013	0.01	0.05	0.12	0.19
142.2	142.2	9/7/2013	0.00	0.11	0.22	0.25
142.2	142.2B	9/7/2013	0.00	0.09	0.22	0.25
143	143	9/7/2013	0.05	0.08	0.19	0.23
143.1	143.1	9/7/2013	0.00	0.13	0.25	0.33
Side Channel 21						
PRM	SAMPLE NAME	DATE SAMPLED	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	D_{90} (mm)
145.6	FA-144	9/24/2013	0.06	0.12	0.21	0.23
145.6	FA-144	9/24/2013	0.06	0.13	0.23	0.27
145.7	145.7	9/24/2013	0.00	0.07	0.17	0.21
145.7	145.7	9/7/2013	0.13	0.25	0.43	0.48
145.7	145.7	9/7/2013	0.06	0.12	0.24	0.31
145.7	145.7	9/7/2013	0.06	0.16	0.37	0.47

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fluvial Geomorphology Modeling Study (6.6)

Part A - Appendix D
Water Surface Measurements

Initial Study Report

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June 2014

Table D-1: Water-surface elevation measurements collected by the Geomorphology (ISR 6.5) and Geomorphology Modeling Studies (ISR 6.6).

PRM	Pin	Pin Northing (ft)	Pin Easting (ft)	WSE (NAVD88)	WSE Survey Date	Discharge at Gold Creek (cfs)
103.5	LB_Pin	3053462.315	1616351.824	359.52	9/9/2013 @ 1730	29,700
104.8	Other	3058639.170	1612251.651	370.21	8/25/2013 @ 1600	28,400
104.9	Other	3059009.466	1612649.670	370.78	8/25/2013 @ 1451	28,600
105.1	Other	3060286.346	1612864.130	372.44	8/25/2013 @1354	28,700
105.2	Other	3060806.854	1613080.214	373.28	8/25/2013 @ 1250	29,200
105.3	LB_Pin	3060974.969	1613866.992	373.40	7/9/2013 @ 1000	24,000
105.3	Other	3061368.227	1613032.788	374.69	8/24/2013 @ 1130	36,700
105.3	LB_Pin	3060974.969	1613866.992	373.99	9/3/2013 @ 1615	27,200
105.4	Other	3061624.440	1612663.093	374.30	8/25/2013 @ 1007	30,500
105.4	Other	3061624.440	1612663.093	374.13	9/9/2013 @ 1625	30,000
105.5	Other	3062342.432	1613063.138	374.91	8/25/2013 @ 1129	29,700
106.1	RB_Pin	3064242.192	1616119.292	381.10	8/24/2013 @ 1200	36,600
106.6	LB_Pin	3065986.101	1617908.279	384.97	8/24/2013 @ 1310	36,600
106.6	RB_Pin	3066273.675	1617211.504	384.38	9/9/2013 @ 1610	30,000
107.8	RB_Pin	3071897.814	1618807.244	393.54	8/24/2013 @ 1330	36,600
107.8	RB_Pin	3071897.814	1618807.244	392.95	9/9/2013 @1550	30,100
108.3	LB_Pin	3074398.958	1619971.981	399.26	8/24/2013 @ 1415	36,400
109.0	LB_Pin	3077833.055	1618672.464	405.28	8/24/2013 @ 1445	36,400
109.0	RB_Pin	3077716.055	1618018.016	404.74	9/9/2013 @ 1520	30,200
110.5	LB_Pin	3085407.446	1618004.383	418.82	8/24/2013 @ 1530	36,300
111.9	RB_Pin	3092118.979	1620308.696	430.63	8/24/2013 @ 1600	36,300
111.9	RB_Pin	3092118.979	1620308.696	430.00	9/9/2013 @ 1140	30,700
112.5	RB_Pin	3095033.777	1621936.319	435.30	8/24/2013 @ 1620	36,200
113.6	RB_Pin	3100370.703	1623703.698	446.08	8/23/2013 @ 1355	40,600
113.6	RB_Pin	3100370.703	1623703.698	445.04	9/9/2013 @ 1110	30,900
114.4	RB_Pin	3103491.710	1622951.785	451.60	8/23/2013 @ 1315	40,500
114.4	RB_Pin	3103491.710	1622951.785	456.21	9/9/2013 @ 1100	31,000
115.4	Dog_Leg_Pin	3108579.159	1621187.253	460.43	8/23/2013 @ 1300	40,500
115.4	LB_Pin	3108765.954	1621793.555	460.03	8/23/2013 @ 1145	40,400
115.4	RB_Pin	3108569.687	1621187.879	459.38	9/9/2013 @ 1035	31,000

Table D-1 (cont.): Water-surface elevation measurements collected by the Geomorphology (ISR 6.5) and Geomorphology Modeling Studies (ISR 6.6).

PRM	Pin	Pin Northing (ft)	Pin Easting (ft)	WSE (NAVD88)	WSE Survey Date	Discharge at Gold Creek (cfs)
115.7	Dog_Leg_Pin	3110475.421	1620770.197	462.35	8/23/2013 @ 1120	40,200
116.3	LB_Pin	3113516.628	1621594.369	469.43	8/23/2013 @ 1506	40,400
116.3	RB_Pin	3113736.499	1620621.118	469.67	8/23/2013 @ 1045	39,900
116.3	LB_Pin	3113516.628	1621594.369	468.24	9/9/2013 @ 1003	31,100
116.6	RB_Pin	3115145.649	1620995.623	470.42	8/23/2013 @ 1010	39,800
117.1	RB_Pin	3117352.341	1621488.799	475.41	8/23/2013 @ 1515	40,400
117.1	RB_Pin	3117352.341	1621488.799	474.28	9/8/2013 @ 1630	32,500
118.4	LB_Pin	3123706.224	1624208.984	487.76	8/23/2013 @ 1605	40,200
118.9	LB_Pin	3126235.338	1625321.284	490.68	9/8/2013 @ 1610	32,500
119.9	RB_Pin	3129429.847	1629093.353	497.93	8/23/2013 @ 1630	40,100
119.9	LB_Pin	3129045.488	1629566.328	496.99	9/8/2013 @ 1605	32,500
120.7	RB_Pin	3133547.765	1630498.382	503.82	9/8/2013 @ 1555	32,500
122.6	RB_Pin	3141727.588	1634640.521	519.14	9/8/2013 @ 1530	32,400
124.1	RB_Pin	3148383.906	1638149.862	531.29	9/8/2013 @ 1515	32,400
125.8	LB_Pin	3154402.166	1643976.499	545.42	9/8/2013 @ 1455	32,400
126.8	LB_Pin	3159156.026	1646564.734	553.23	9/8/2013 @ 1425	32,300
127.8	LB_Pin	3162143.793	1649915.520	562.26	8/21/2013 @ 1150	36,600
128.1	LB_Pin	3163495.224	1650734.327	565.55	8/21/2013 @ 1115	35,900
128.1	LB_Pin	3163495.224	1650734.327	565.21	9/8/2013 @ 1430	32,300
129.7	RB_Pin	3168864.095	1656594.787	580.33	8/20/2013 @ 1640	24,500
129.7	LB_Pin	3168378.786	1656974.669	581.37	8/21/2013 @ 1330	39,900
129.7	RB_Pin	3168864.095	1656594.787	581.73	8/21/2013 @ 1310	39,400
129.7	LB_Pin	3168378.786	1656974.669	580.88	9/8/2013 @ 1415	32,300
130.5	LB_Pin	3169822.521	1660403.410	595.92	8/20/2013 @ 1700	24,500
134.3	RB_Pin	3184640.903	1673313.952	628.48	9/8/2013 @ 1248	32,200
135.0	LB_Pin	3185473.412	1676708.764	635.53	9/8/2013 @ 1230	32,200
138.1	RB_Pin	3196613.421	1686630.975	670.83	9/8/2013 @ 1100	32,000
138.7	LB_Pin	3199533.507	1688525.301	677.51	8/15/2013 @ 0900	19,900
138.7	LB_Pin	3199533.507	1688525.301	679.31	8/21/2013 @ 1550	41,900
138.7	LB_Pin	3199533.507	1688525.301	678.95	9/8/2013 @ 1037	32,000

Table D-1 (cont.): Water-surface elevation measurements collected by the Geomorphology (ISR 6.5) and Geomorphology Modeling Studies (ISR 6.6).

PRM	Pin	Pin Northing (ft)	Pin Easting (ft)	WSE (NAVD88)	WSE Survey Date	Discharge at Gold Creek (cfs)
139.0	LB_Pin	3200920.692	1688839.744	678.37	8/16/2013 @ 1130	18,000
139.0	LB_Pin	3200920.692	1688839.744	681.53	8/21/2013 @ 1610	42,000
139.0	LB_Pin	3200920.692	1688839.744	680.43	9/8/2013 @ 1020	31,100
139.8	Dog_Leg_Pin	3203388.958	1690821.304	689.33	8/16/2013 @ 1345	17,700
139.8	RB_Pin	3203984.702	1690785.288	688.86	8/16/2013 @ 1445	17,600
139.8	RB_Pin	3203984.702	1690785.288	690.95	9/8/2013 @ 1000	31,900
140.5	LB_Pin	3205629.217	1692258.386	699.71	8/22/2013 @ 1710	43,600
140.5	LB_Pin	3205629.217	1692258.386	698.39	9/8/2013 @ 1300	32,200
141.1	RB_Pin	3208677.460	1693777.652	707.25	8/22/2013 @ 1645	43,800
141.1	RB_Pin	3208677.460	1693777.652	705.79	9/8/2013 @ 1240	32,200
141.5	RB_Pin	3219748.343	1708265.646	749.57	8/18/2013 @ 1230	16,900
141.7	RB_Pin	3209430.538	1696118.562	713.17	8/22/2013 @ 1615	43,900
141.9	RB_Pin	3209866.077	1696950.795	714.43	8/22/2013 @ 1545	43,800
142.2	RB_Pin	3210882.272	1698644.550	717.71	8/22/2013 @ 1515	44,000
142.2	RB_Pin	3210882.272	1698644.550	716.31	9/8/2013 @ 1225	32,200
143.0	RB_Pin	3212571.431	1701930.180	725.35	8/14/2013 @ 1150	19,200
143.5	RB_Pin	3213734.934	1704503.335	733.61	8/22/2013 @ 1430	44,100
143.5	RB_Pin	3213734.934	1704503.335	732.26	9/8/2013 @ 1145	32,100
143.9	RB_Pin	3215061.646	1705563.100	737.19	9/8/2013 @ 1130	32,200
144.3	RB_Pin	3216799.534	1706618.157	742.32	9/8/2013 @ 1105	32,000
144.9	RB_Pin	3219750.597	1708267.930	751.35	9/8/2013 @ 1045	32,100
145.7	RB_Pin	3222696.907	1711399.435	758.79	8/18/2013 @ 1400	16,800
145.7	LB_Pin	3222273.719	1711724.521	762.92	8/22/2013 @ 1100	45,600
145.7	RB_Pin	3222696.907	1711399.435	762.88	8/22/2013 @ 1115	45,600
145.7	RB_Pin	3222696.907	1711399.435	761.25	9/8/2013 @ 1020	32,000

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fluvial Geomorphology Modeling below Watana Dam Study (6.6)

Part A - Appendix E
Evaluation of 50-Year Simulation Period, Pacific Decadal Oscillation, and Selection of Representative Annual Hydrographs

Initial Study Report

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

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Prepared by

Tetra Tech

June 2014

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LIST OF ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

Abbreviation	Definition
1-D	One dimensional
2-D	Two Dimensional
AEA	Alaska Energy Authority
cfs	cubic feet per second
FA(s)	Focus Area(s)
FGM	Fluvial Geomorphology Modeling
FSP	Final Study Plan
JISAO	Joint Institute for the Study of Atmosphere and Ocean
NWFSC	Northwest Fisheries Science Center
OS	Operational Scenario
PDO	Pacific Decadal Oscillation
PRM	Project River Mile
TM	Technical Memorandum
USGS	U.S. Geological Survey

1. INTRODUCTION

The RSP Section 6.6.4.2.2.1 (AEA, 2012) indicates that the approach for developing hydrologic input to the fluvial geomorphology models is:

> It is currently envisioned that a 50-year, continuous period of record that represents the length of the FERC licensing period will be used for the 1-D modeling, and shorter modeling periods will be used for the 2-D model due to computational limitations. The 50-year period will be divided into three points in time to provide comparison: year-0, year-25, and year-50. As previously indicated, the 1-D model will be applied to address the analysis of reach-scale issues and the 2-D model to address local-scale issues.
>
> The shorter periods for the 2-D model will include specific years or portions of annual hydrographs for selected years of wet, average, and dry hydrologic conditions and warm and cold Pacific Decadal Oscillation (PDO) phases. Therefore, up to six annual hydrologic conditions will be considered. (The inclusion of the warm and cold PDO phases was requested by NOAA-NMFS and USFWS in the May 31, 2012, study requests; the rationale for the request was discussed at the June 14, 2012 Water Resources TWG meeting and it was agreed that the PDO phases would be included in the suite of representative annual hydrologic conditions.) Other scenarios might include rapid release of flows from an ice jam or larger flood events that are not contained in the period of the hydrologic record chosen for simulation.

The USGS (2012) has provided an extended hydrologic record for 11 gage locations within the Susitna River Basin for a period of 61 years. This information will be used as the hydrologic record for analysis of existing stream flow characteristics and will also provide the flows to be used by the Reservoir Operations Study (Engineering) and the Open-water Flow Routing Model (FSP Section 8.5.4.3) to generate flow conditions in the Middle and Lower Susitna River Segments for the with-Project conditions. Subsets of the 61 year record need to be selected to construct a 50-year continuous flow record for the 1-D reach-scale modeling and individual representative years for the 2-D Focus Area modeling.

The Fluvial Geomorphology Modeling Approach Technical Memorandum (Tetra Tech, Inc. 2013h) provides detail on this approach for using the 50-year continuous simulation to address reach-scale conditions throughout the study area, using representative annual hydrologic conditions to address local-scale conditions in the FAs, and the integration of reach-scale and local-scale modeling. Neither the FSP nor the FGM Approach TM identify the 50 years that will comprise the continuous flow record nor the individual years that will represent dry, average and wet conditions with warm and cool PDO.

2. STUDY OBJECTIVES

The objective of this appendix is to document the selection of the hydrologic conditions that are to be used in the 1-D and 2-D fluvial geomorphology modeling. The specific objectives include:

- Identify the 50 years that will be used for reach-scale modeling out of the 61 available years from the USGS streamflow record extension study
- Identify candidate years from the 50 years for up to 6 representative dry, average and wet conditions including warm and cool PDO
- From the candidate years, recommend representative years for fluvial geomorphology modeling in the Focus Areas

3. STUDY AREA

The study area for the Fluvial Geomorphology Modeling below Watana Dam is the portion of the Susitna River from Watana Dam (PRM 188) downstream to Susitna Station Gage (PRM 30). The bed evolution modeling approach calls for the application of a 1-D bed evolution model to predict the geomorphic response of the Susitna River to the Project for the entire study area (excluding Devils Canyon). Reach-scale bed evolution morphology modeling will be performed within these limits to include portions of the Chulitna and Talkeetna Rivers.

To provide a higher level of detail and to model physical processes not adequately represented in a 1-D bed evolution model, 2-D bed evolution and hydraulic models will be applied in Focus Areas. Locations of the Focus Areas are described in Technical Memorandum: Adjustments to Middle River Focus Areas (R2 2013).

4. METHODS AND VARIANCES IN 2013

4.1. Overview

As described in the introduction, there are 61 years of available data from the flow extension study (USGS 2012). As the reach-scale modeling will be performed as a 50-year flow simulation, a subset of the available data was selected. The overall approach to selecting the 50 individual years was to include the most suitable years for sediment transport modeling and maintain the overall flow characteristics of the more complete record; i.e. that the hydrographs include the temporal and spatial variability of the overall system. Therefore, the 50 years should include the least amount of synthesized flow along the mainstem Susitna River and major tributaries (Chulitna, Talkeetna and Yentna Rivers).

The Focus Area modeling will not be performed for the entire 50-year flow record due to the limitations of performing long-term simulations with 2-D sediment transport models. The 2-D sediment transport models will be run for representative hydrographs for open water conditions using existing conditions geometry as an initial condition and updated conditions for years 25 and 50 (Tetra Tech 2013h). The representative hydrographs will consider dry, average and wet conditions including warm and cool PDO. This selection considers both flow volumes and short-term high flows to include the range of geomorphically significant flows for potentially erosional and depositional processes.

4.1.1. Existing Information and Need for Additional Information

The primary information required for selection of the hydrologic conditions is the 61 year series of flow data available from the record extension study (USGS 2012). Because the emphasis of the Focus Area modeling and detailed habitat analyses are in the Middle River Segment, the USGS Susitna River gage at Gold Creek (gage no. 15292000) was used for this analysis. This gage also has the longest period of record (56 years) of the 61 years from 1950 to 2010 included in the flow extension study. The data included mean-daily discharges (measured and synthesized). From these data a variety of results can be calculated, including mean annual flows, seasonal and monthly average flows, minimum, median, maximum, and other daily flow statistics.

The other information includes data representing Pacific Decadal Oscillation (PDO). PDO is a climate index based on sea surface temperatures in the North Pacific (Mantua et al. 1977). According to the Northwest Fisheries Science Center (NOAA 2013), PDO has warm and cool phases that depend on the direction of winter winds in the North Pacific. Winter winds from the north lead to cooler conditions and winds from the southwest result in warmer conditions. Monthly values of standardized PDO index are available from 1990 to present at the Joint Institute for the Study of Atmosphere and Ocean website (JISAO 2013).

4.1.2. Methods

4.1.2.1. Selection of 50-year Flow Series

The first step in the selection process was to eliminate years where flows were synthesized at the Gold Creek gage from another gage. This left 56 years of actual gage measurements. Because the overall study extends throughout the Susitna River Basin, other candidates for eliminating 6 additional years were periods when few other gages were in operation. This maintains the largest amount of actual gage measurements used for this fluvial geomorphology modeling in basin and the highest degree of natural inter-basin variability in the flow record.

After the 50-years were selected, flow duration curves were compared for the 50-years versus the 61 year complete record to determine if the subset differed significantly from the full time series. This comparison was also made for the Maximum Load Following – Operational Scenario 1 flow series to consider potential operational effects. If appreciable differences were detected then alternative years would be considered.

4.1.2.2. Candidate Years for Dry, Average and Wet Conditions

The method for selecting candidate dry, average and wet condition years followed these steps.

1. Group the individual 50 years by warm and cool PDO index. This grouping was done by water year PDO index and repeated for PDO "regime," where longer periods are grouped. The grouping for regime is consistent with NOAA (2013).

2. Rank the entire 50 years and warm and cool PDO subsets from lowest runoff volume to highest by water year and by open water months (May – September). The rankings included the open water because this period includes high flow periods that will be simulated in the fluvial geomorphology modeling.
3. Identify candidate years for representative dry, average and wet conditions. Because the objective is to select representative years, the two highest and lowest ranked years were not included as candidates. Excluding the two lowest ranked (dry) and highest ranked (wet) years, the lower, middle and upper 25 percent years (12) in the ranking were selected as candidates.
4. Dry and average years from an average annual (or open water) ranking that included extreme flood flow periods were also excluded because they were deemed as not representative.
5. Four candidate years were then identified with two each from cool and warm PDO conditions.
6. The hydrographs and annual flow duration curves were compared for the four candidate years for each condition.

Because up to 6 representative hydrologic years will be used for the Focus Area 2-D morphology modeling, the overall flow variables were compared to evaluate whether PDO would produce a geomorphic response in the Susitna River. Neal et al. (2002) compared streamflow for cool PDO (1947-1976) to warm PDO (1977-1988) for six streams in southeast Alaska (Juneau and south). They found no significant difference in mean annual flows but higher winter flows for warm PDO and higher summer flows for cool PDO. Brabets and Walvoord (2009) compared streamflow at 16 Yukon Basin gages. Using Wilcoxon Rank Sum test they found statistically significant ($p<0.10$) lower winter and April flows for cool PDO (1944-1975) versus warm PDO (1976-2005) at 15 of the gages. Considering May through September months individually (16 gages x 5 months = 80 comparisons) they showed 69 without a statistically significant difference, 6 with increased flow for warm PDO and 5 with decreased flow for warm PDO.

Following the method used by Brabets and Walvoord (2009) Wilcoxon Rank Sum tests were conducted on a range of flow variables that can be computed from the gage record. As with the Yukon Basin study, the variables included were annual, seasonal, and monthly flows as well as extreme flows and other statistics. If the flows are not shown to be statistically different during open water conditions (as with the Yukon Basin study), then the representative years can be selected without regard to PDO.

4.1.3. Study Products

The study products are the selected years that comprise the 50-year flow record for the 1-D reach-scale morphology model and the recommended dry, average and wet years for 2-D local-scale morphology modeling for the Focus Areas.

4.1.4. Variances from Study Plan

The study plan was implemented with no variances.

5. RESULTS

5.1. Selection of 50-Year Flow Series

Figure 5.1 shows the 11 gages included in the flow extension study (USGS 2012). Black indicates actual gage measurements and the colors represent the index stations used to develop flow series for other gages when no record exists. For example, light blue and orange indicate periods when the Talkeetna or Gold Creek gages were used as index stations. Eliminating water years 1997 through 2001 leaves 56 years of measured flows at Gold Creek and eliminates a 5 year period when all the flows except Talkeetna are synthesized.

1950 through 1957 is another period when one gage (Gold Creek) is used to synthesize the flows at the 10 remaining gages. Therefore, these 8 years were considered as candidates for excluding the 6 remaining years. However, during review of the individual year hydrographs, long periods of constant flow were found for 1954 and 1956 record at Gold Creek. The flow extension study (USGS 2012) indicates that these two years plus 1958 and 1961-1963 include "likely estimated flow." The hydrographs for these 6 years are shown in Figure 5.2. There are multiple periods ranging from weeks to approximately 1 month where flow is constant for each of these years. To avoid using this unrealistic flow series, these 6 years were eliminated, bringing the number of remaining flow years in the extended record to 50.

Although it may be somewhat unrealistic to use the 61 years as a basis of comparison, flow duration curves for the 61- and 50-year flow series were compared to determine if they are reasonably consistent. The flow duration curves include pre-project as well as Maximum Load Following OS-1 conditions. As there are only very slight differences between the sets of curves, the recommended 50-year flow series includes water years 1950-1953, 1955, 1957, 1959-1960, 1964-1996, and 2002-2010. Open water simulations will generally include the May through September portions of these years, though specific start and end dates will be identified for each year.

5.2. Candidate Years for Dry, Average and Wet Conditions

The first step in selecting candidate dry, average and wet years was to group the 50 years into cool and wet PDO. There does not appear to be an agreed upon method for making this discrimination. 1977 is the commonly used start of a warm PDO regime. PDO regime is a long-term condition where the warm or cool dominates, and years with the opposite index area included in the dominant category. The NWFSC website (NOAA 2013) uses 1977 as the start of a warm regime but indicates recent shorter regimes of cool from 1998-2002, warm from 2003-2007, and cool from 2008-2012. Another difference is the months used for accumulating PDO index. Mantua et al. and Neal et al. use PDO index summed for the November through March period (year assigned by water year) and the NWFSC website uses May through September. Brabets and Walvoord correlated the PDO index calculated for a water year to flow of that water year.

Figures 5.4 through 5.6 show PDO indices based on winter, summer, and water year values. These plots also show long-term PDO regimes and the more recent short periods. The water year values and the long-term regimes were used to group years into warm and cool. Based on water year PDO indices, there were 27 cool and 23 warm years and based on the long-term PDO regime there were 25 years of each condition in the 50-year period.

Figures 5.7 shows the individual years ranked from lowest to highest flow based on annual flow volume. Figure 5.8 is a similar plot using average flows during the approximate open water period of May through September. Figure 5.9 shows maximum daily flows from each water year. The solid and hatched red bars are warm PDO index and blue bars indicate cool PDO index. The candidate dry, average and wet years are shown with hatching, each with two from warm and cool PDOs based on the water year discrimination. Had the discrimination been made by long-term PDO regime, each of the years would be categorized the same except for 1970, which falls into a cool regime. The candidate years were selected excluding the two highest and lowest ranked years and excluding dry or average years with extreme flood flows. For example, 1973 is a dry year with the 6th lowest mean annual flow but has a mean daily flow exceeding 50,000 cfs and an instantaneous peak of 54,100 cfs indicating nearly a 5-year flood. This is considered as non-representative of dry years. 1964 is an average year that is considered as non-representative. Its mean annual flow is ranked at 24 of 50 but has mean daily flows in excess of 80,000 cfs and an instantaneous peak of 90,700 cfs, which is between a 50- and 100-year flood.

The maximum daily flow (Figure 5.9) shows greater scatter among the candidate years for the three flow categories. This shows the variability of the extreme conditions and illustrates the difficulty in representing a range of conditions within selected years. From Figure 5.9, it appears that 1978, 1983, and 1980 may not be good choices for dry, average and wet year, respectively.

5.2.1. Candidate Dry Years

Figure 5.10 shows four candidate dry years and Figure 5.11 shows the flow duration curves for these years. 1974 was excluded as non-representative because it included a 1-week period in May with flows exceeding 30,000 cfs, the remaining summer period mostly below 20,000 cfs and late August flows down to 8,100 cfs. The geomorphically relevant flows are greater than 10,000 cfs and probably greater than 20,000 cfs as the critical discharge for bed mobilization at Gold Creek is approximately 25,000 cfs (Tetra Tech 2013c). Four hydrographs are very similar with flows generally between 10,000 and 30,000 cfs for the summer period. For three of the four years have mean-daily flows that briefly exceed 30,000 cfs and instantaneous peaks that range from 33,000 to nearly 36,000 cfs. The 1.25 year flow is 35,000, which would be exceeded in about 75 percent of years. The flow duration curves above 10,000 cfs are also very similar for the four years; however, the low flow portion below 4,000 cfs is much higher for 1978 as a result of higher winter flows.

5.2.2. Candidate Average Years

Figures 5.12 and 5.13 show the annual hydrographs and flow duration curves for candidate average years. Flows are generally between 10,000 and 40,000 cfs over the summer period. The flow duration curve shows more variability for flows between 10,000 and 20,000 cfs and more consistency for flows greater than 20,000 cfs. June and July are generally greater than 20,000 cfs for these average years. Peak instantaneous flows range between 37,000 and 42,000 cfs. As 43,700 is the 2-year flood peak, these discharges are expected to be exceeded approximately 50 percent of years.

5.2.3. Candidate Wet Years

Figures 5.14 and 5.15 show the wet year annual hydrographs and flow duration curves. These years have higher range of flows and include periods of flood flows. June through August are nearly all greater than 20,000 cfs. High flows occur anytime June through August. The two cool years show very different timing in peak flows: May and June for 1972 and August for 1967. The four years have consistent flow duration curves for flows greater than 10,000 cfs. Instantaneous peak flows are 51,000 cfs for 1980 (< 5 yr), 64,900 for 1981 (~ 10 yr), 80,700 and 82,600 for 1967 and 1972 (both > 20 yr and < 50 yr).

5.2.4. Comparison of Dry, Average and Wet Flow Duration Curves

Figure 5.16 shows all flow duration curves grouped by dry, average and wet conditions and Table 5.1 is a summary of time flows are equaled or exceeded. Below 10,000 cfs there is considerable overlap among all the curves. Dry and average years tend to segregate for flows greater than 15,000 cfs. Although average years trend lower than wet years, they do not fully segregate until flows exceed 30,000 cfs at about 5 percent exceedance. Table 5.1 shows the range of time flows are exceeded for each of the hydrologic conditions. Below 10,000 cfs the differences are not very distinguishable because of overlapping ranges in time exceeded. To provide additional detail the portions of the flow duration curves are plotted for flows greater than 10,000 cfs in Figure 5.17. Above 20,000 cfs there is very little overlap in the ranges of time exceeded. Therefore, the geomorphic response should be quite different for the three hydrologic conditions based on the fact that sediment transport increases dramatically at the higher flow rates.

5.2.5. Consideration of Warm and Cool PDO

Visual comparison of the representative annual hydrographs (Figures 5.10, 5.12 and 5.14) raises the question of whether PDO has a discernible impact on the summer flows relevant to geomorphic processes of erosion and sediment transport as each condition has two warm and two cool hydrographs. Brabets and Walvoord (2009) of applied the Wilcoxon Rank Sum test to evaluate whether warm and cool PDO flows in the Yukon basin may be from different populations. They compared flows computed for mean annual, winter (January through March), April through September monthly, and fall recession (October through December) periods. At 15 of 16 gage sites winter and April flows were higher for warm PDO ($p = 0.10$), though no trend was evident for May through September. "p" is the percent chance of making an incorrect choice when selecting the alternative hypothesis, which in this instance is that the flows are different based on warm and cool PDO index. Six of the 16 gages showed higher flows for the fall recession for warm PDO.

For this study, the Wilcoxon Rank Sum test was applied to the Gold Creek gage data with PDO determined by water year value and by the long-term regimes. The subsamples exceeded 20 in each case. Ott and Longnecker (2010) indicate that when subsamples exceed 10, then the rank sum (T) approximates the normal distribution and the standard normal variable (z) statistic can be used. Tables 5.2 and 5.3 show the results of this comparison. In addition to mean annual flow, summer (May-Sept.) and winter (Oct.-April) conditions, monthly conditions, and a range of flow exceedance values were used. The monthly conditions were used to discern whether any open water periods show significant difference based on PDO.

Similar to the findings of the Yukon Basin study, none of the Gold Creek summer flow conditions are significantly different between warm and cool PDO, even including extreme high and low flows. The other similarity to the Yukon Basin study is that all but one of the months show higher winter flows for warm PDO at p=.05 (or at p=0.10) and October is borderline at p=0.11. The results are similar whether PDO is divided by annual value or long-term regime. The average winter flows appear to increase by 20 to 40 percent based on PDO, but the amounts are generally less than 500 cfs.

5.2.6. Initial Recommendations for Dry, Average and Wet Years

Based on the comparisons of hydrographs, flow duration curves and the statistical comparisons it does not appear that differentiating by PDO produces geomorphically discernible conditions. Therefore, we recommend selecting one each of dry, average and wet years. Any of the four years for each category appears to be a good candidate to use as representative and the geomorphic response is expected to be similar. Reviewing the flow duration curves for each year, 1950 is recommended for dry, 1985 for average, and 1981 for wet. The flow duration curves for these years are summarized in Table 5.4 and the annual hydrographs and flow duration curves are shown in Figures 5.18 and 5.19 for comparison.

6. DISCUSSION

6.1. Selection of 50-Year Flow Series

The 50 initially selected years for the 1-D reach-scale morphological modeling includes years with the most actual gage data by eliminating likely estimated data at Gold Creek and eliminating as much of the remaining synthesized data as possible. The final selected 50 year flow record (series of years) will be used for open water modeling of the Middle and Lower Susitna River Segments including tributaries.

6.2. Candidate Years for Dry, Average and Wet Conditions

The candidate dry, average and wet years have been identified cool and warm PDO and an initial recommendation has been made to use 1950, 1985 and 1981 as the representative dry, average and wet years, respectively. Analysis presented in this document suggests that for open water conditions (May through September) PDO does not affect the selection as there are no discernible differences. Although there are statistically significant differences in October through April flows, these flows are not going to be used for open water modeling of the focus areas. There may be a need to consider PDO differences for winter modeling and potentially for habitat analyses. This analysis can serve as a starting point for these considerations.

6.3. Final Selection Process and Coordination

The final selection of the 50-year flow series and the representative dry, average and wet years will be coordinated with the other study components and presented to the TWG for feedback. Although it is unlikely that any one year can be fully representative of the many aspects of flow, from the perspective of sediment transport and geomorphic response, other year from the candidate years are likely also suitable. Therefore, should some other study component identify an aspect of these years that is relevant to the selection, the geomorphology modeling would probably be able to accommodate a different selection.

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8. TABLES

Table 5.1 Summary of flow duration curves for dry, average and wet years for the Susitna River at Gold Creek.

Discharge, cfs	Percent time equaled or exceeded		
	Dry Years	Average Years	Wet Years
5,000	39-48	42-50	42-51
10,000	33-35	33-44	37-40
15,000	22-27	26-36	27-33
20,000	12-14	18-23	21-29
25,000	0-6	7-16	14-20
30,000	0-1	2-7	5-12
35,000	0	0.3-4	3-9
40,000	0	0	2-6
50,000	0	0	0-2
60,000	0	0	0-0.7

Table 5.2 Wilcoxon Rank Sum Test for annual PDO for the Susitna River at Gold Creek.

Period	Mean flow for period (cfs)			Diff. %	Z (Stand. Normal) Z_{crit} = 1.96 □.05	p
	Cool	Warm	Difference			
	N = 27	N = 23	(Warm-Cool)			
Water Year	9574	9724	151	2	0.127	0.90
May-Sept.	19755	19477	-277	-1	-0.827	0.41
Oct.-April	2226	2686	460	21	**2.988**	0.00
October	5825	6905	1079	19	1.625	0.11
November	2429	2956	527	22	**2.414**	0.02
December	1703	2047	343	20	**2.735**	0.01
January	1437	1740	304	21	**2.852**	0.01
February	1272	1601	329	26	**2.920**	0.01
March	1186	1458	272	23	**2.725**	0.01
April	1624	1975	352	22	**3.037**	0.00
May	13485	14383	899	7	0.613	0.54
June	27010	24457	-2552	-9	-1.353	0.18
July	22837	24470	1633	7	1.119	0.27
August	21462	20487	-975	-5	-0.847	0.40
September	14029	13558	-471	-3	-0.477	0.64
Maximum	46952	39687	-7265	-15	-1.265	0.21
90% (May-Sept.)	30876	29167	-1709	-6	-1.119	0.27
75% (May-Sept.)	24726	24665	-61	0	-0.243	0.81
50% (May-Sept.)	19670	19561	-110	-1	-0.516	0.61
25% (May-Sept.)	13913	14109	196	1	0.088	0.93
10% (May-Sept.)	8080	8933	853	11	0.866	0.39
Min. (May-Sept)	3493	4236	743	21	1.334	0.19
Min. (annual)	1139	1385	246	22	**2.504**	0.02

Note: Bold indicates statistically significant difference.

Table 5.3 Wilcoxon Rank Sum Test for PDO regime for the Susitna River at Gold Creek.

Period	Mean flow for period (cfs)			Diff. %	Z (Stand. Normal) Z_{crit} = 1.96 □=.0	p
	Cool	Warm	Difference			
	N = 25	N = 25	(Warm-Cool)			
Water Year	9347	9939	592	6	1.310	0.20
May-Sept.	19388	19866	477	2	0.068	0.95
Oct.-April	2100	2775	675	32	**4.414**	0.00
October	5445	7198	1753	32	**3.095**	0.00
November	2362	2981	619	26	**2.639**	0.01
December	1660	2062	402	24	**2.978**	0.00
January	1376	1777	401	29	**3.609**	0.00
February	1196	1652	456	38	**4.153**	0.00
March	1094	1528	433	40	**4.366**	0.00
April	1468	2104	636	43	**4.249**	0.00
May	13204	14593	1389	11	0.883	0.38
June	26157	25513	-644	-2	-0.126	0.90
July	22829	24348	1519	7	1.154	0.25
August	21113	20914	-199	-1	-0.417	0.68
September	13673	13951	278	2	-0.184	0.85
Maximum	46500	40720	-5780	-12	-0.776	0.44
90% (May-Sept.)	30561	29619	-942	-3	-0.553	0.58
75% (May-Sept.)	24254	25142	888	4	0.728	0.47
50% (May-Sept.)	19212	20028	816	4	0.805	0.42
25% (May-Sept.)	13726	14281	554	4	0.243	0.81
10% (May-Sept.)	7695	9249	1553	20	1.329	0.19
Min. (May-Sept)	3355	4315	960	29	1.407	0.17
Min. (annual)	1048	1456	408	39	**4.176**	0.00

Note: Bold indicates statistically significant difference.

Table 5.4 Summary of flow duration curves for dry, average and wet years, Susitna River at Gold Creek.

Discharge, cfs	Percent time equaled or exceeded		
	1950 (dry)	1985 (avg.)	1981 (wet)
5,000	43	42	50
10,000	33	36	40
15,000	27	30	33
20,000	14	23	21
25,000	3	12	16
30,000	0.8	5	12
35,000	0	3	9
40,000	0	0	6
50,000	0	0	2
60,000	0	0	0.1

9. FIGURES

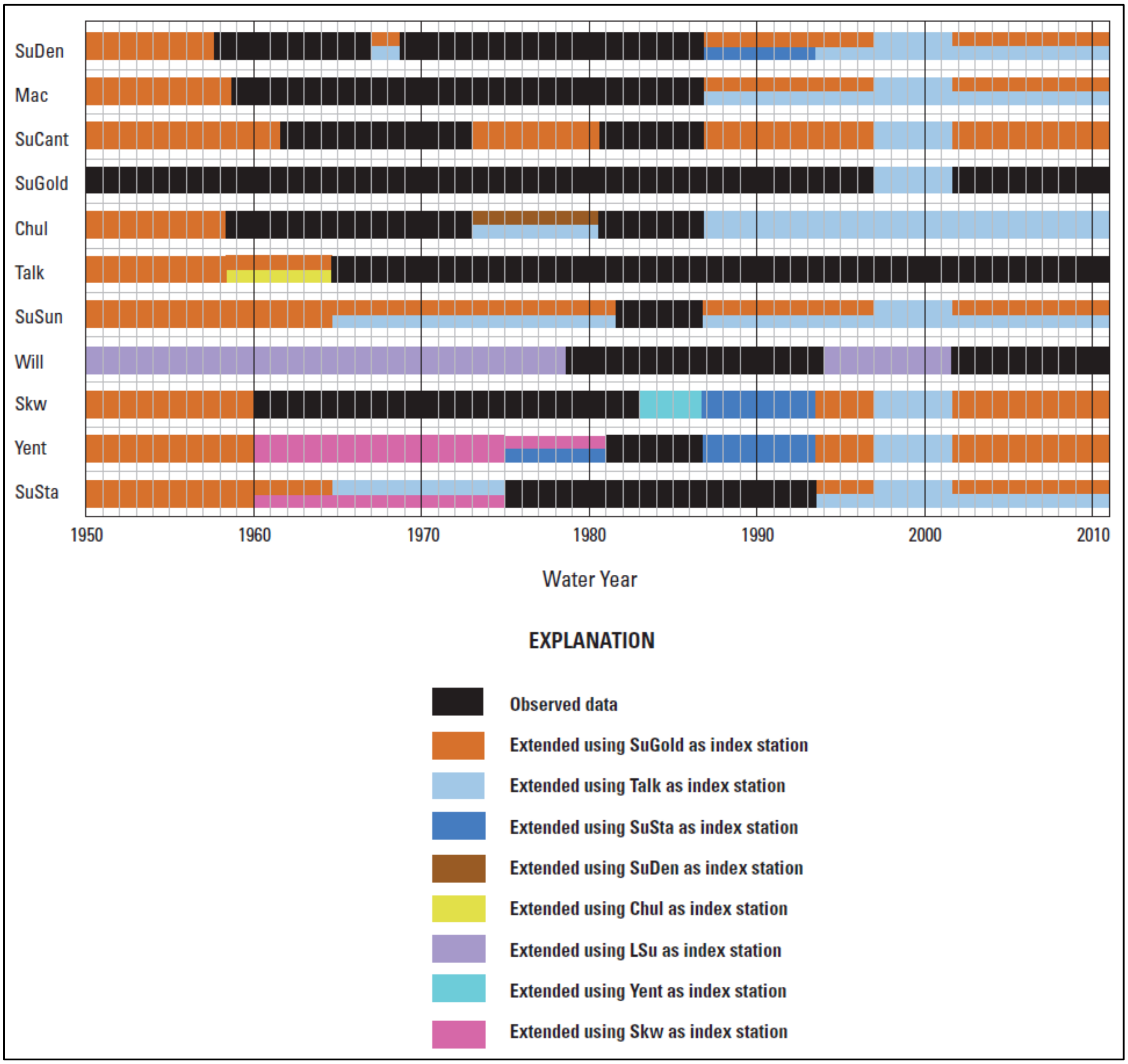

Figure 5.1 Observed data and index station from streamflow record extension study (USGS, 2012)

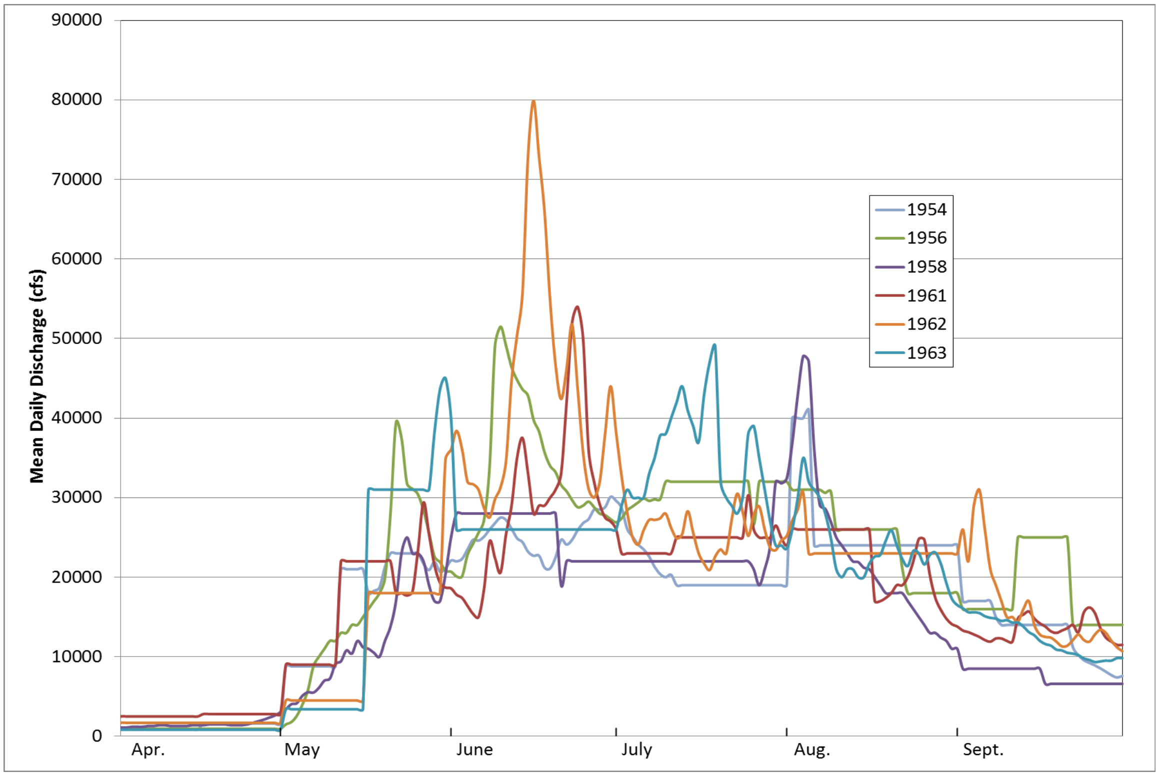

Figure 5.2 Susitna River Gold Creek Gage with likely estimated flows.

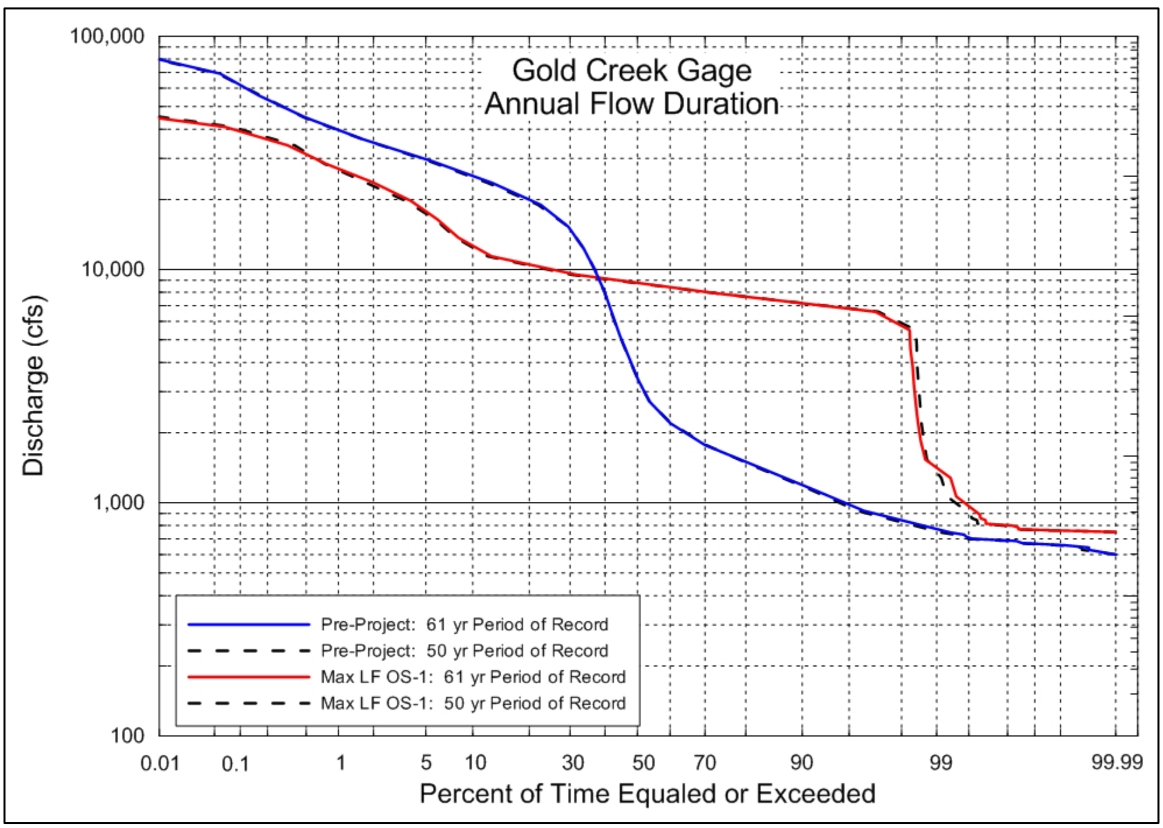

Figure 5.3 Flow duration curves for 50 and 61 year periods of record.

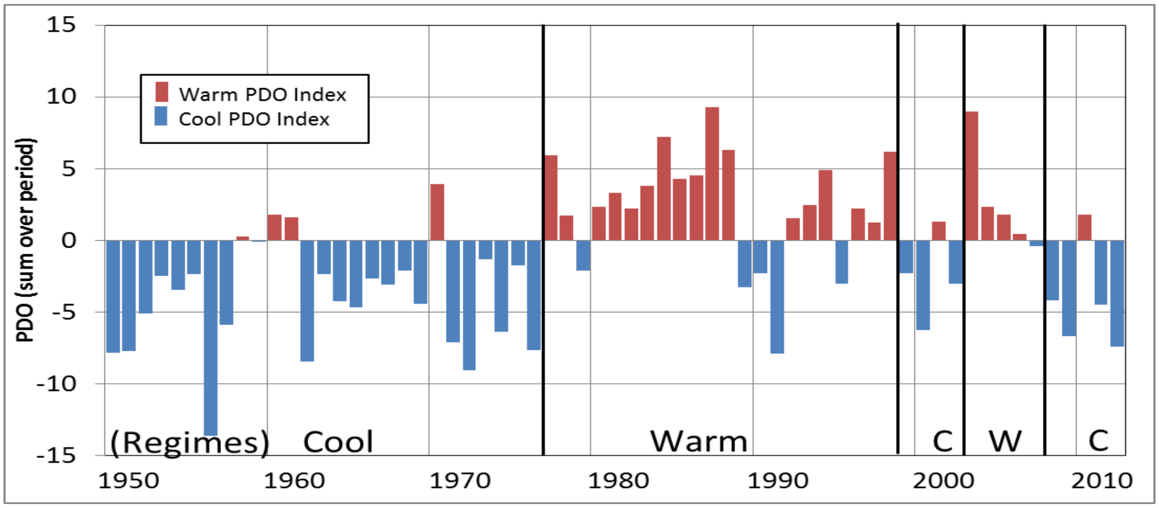

Figure 5.4 PDO index (November – March).

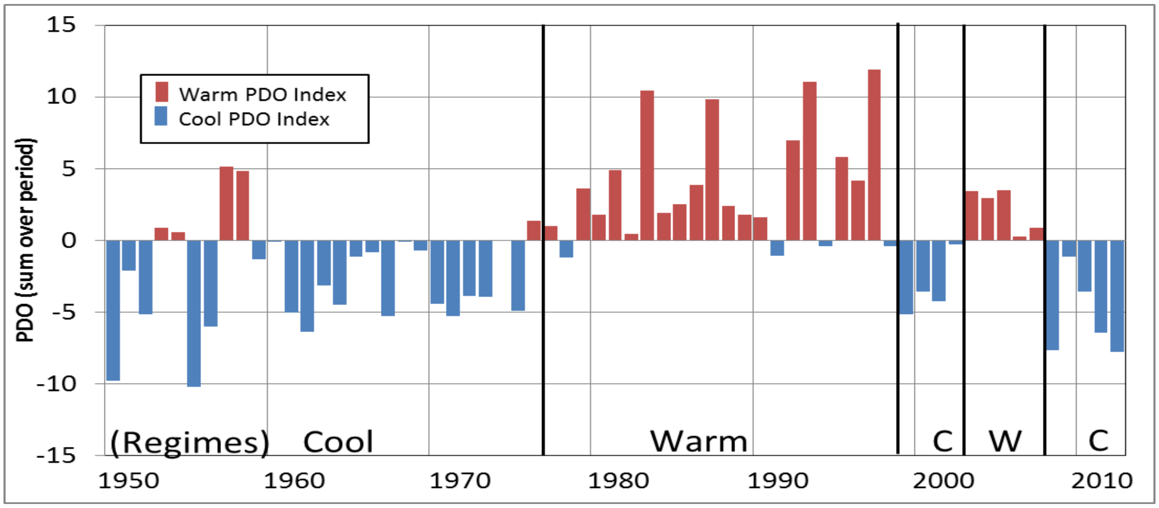

Figure 5.5 PDO index (May – September).

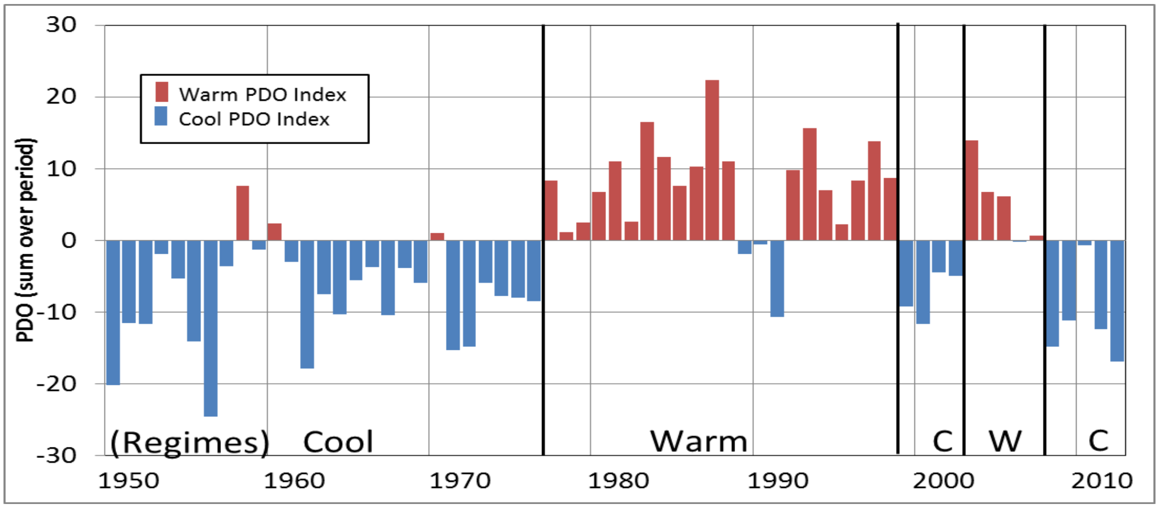

Figure 5.6 PDO index (Water Year).

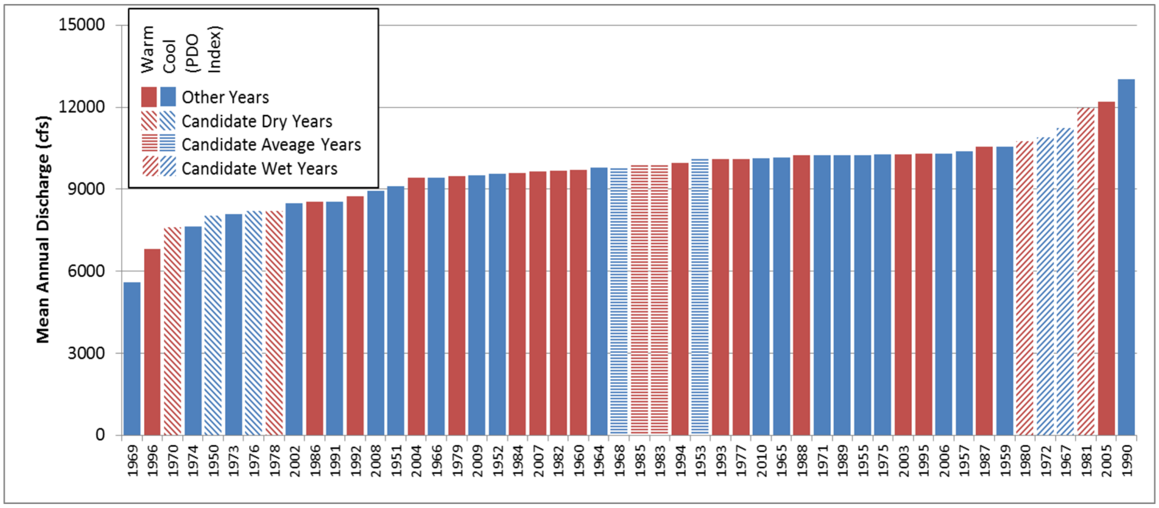

Figure 5.7 Ranked mean annual flows for 50-year record.

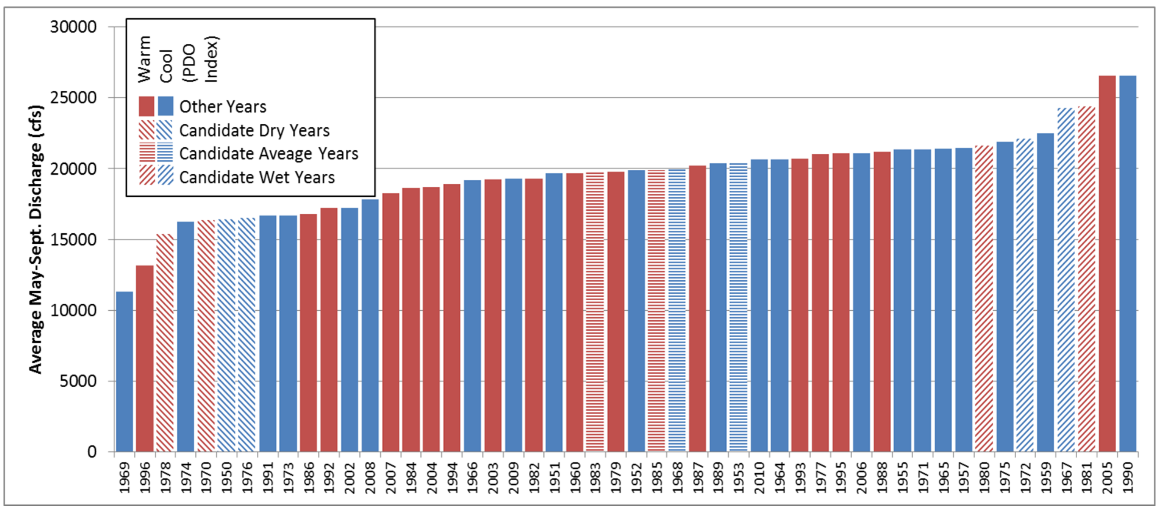

Figure 5.8 Ranked average flows for May through September for 50-year record.

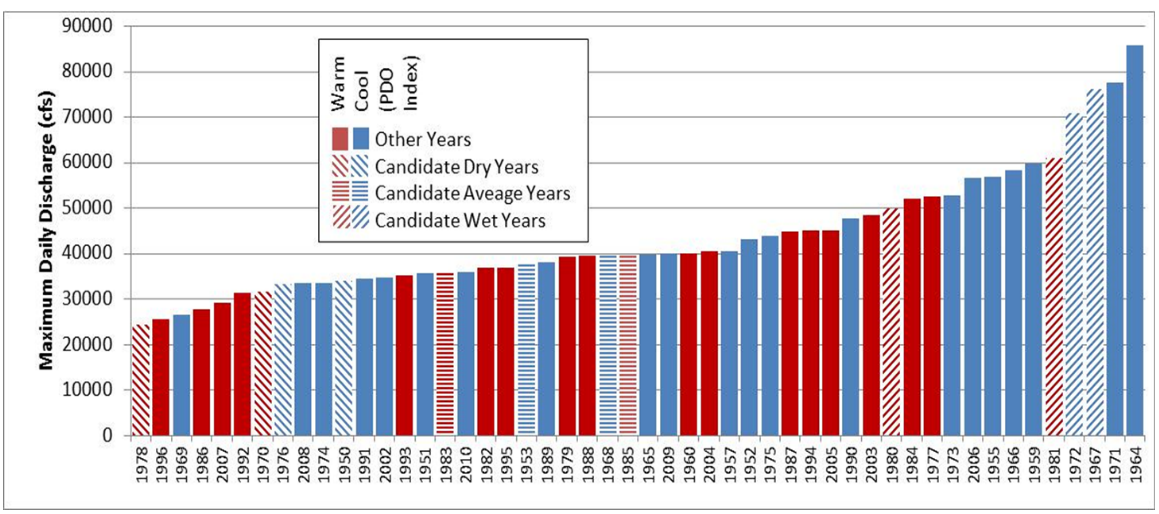

Figure 5.9 Ranked maximum daily flows for 50-year record.

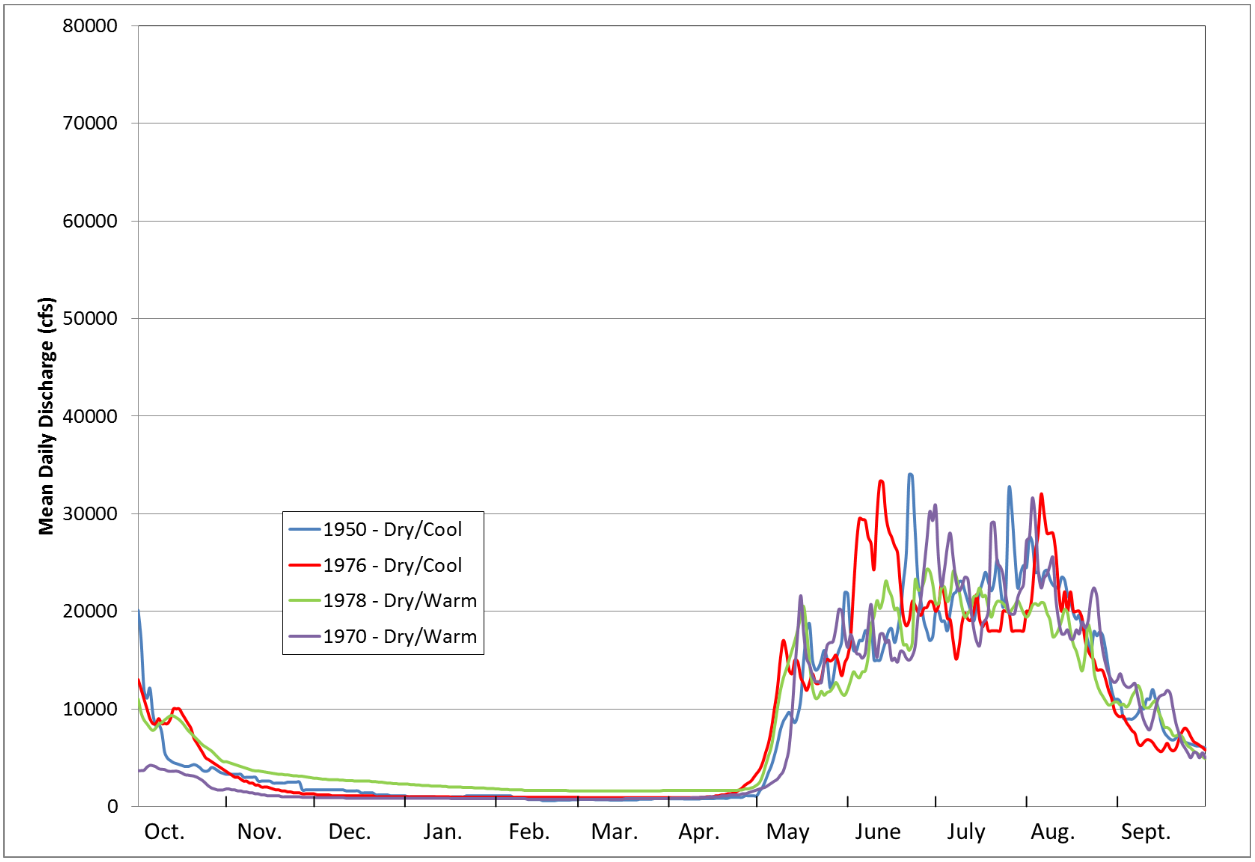

Figure 5.10 Candidate dry years annual hydrographs.

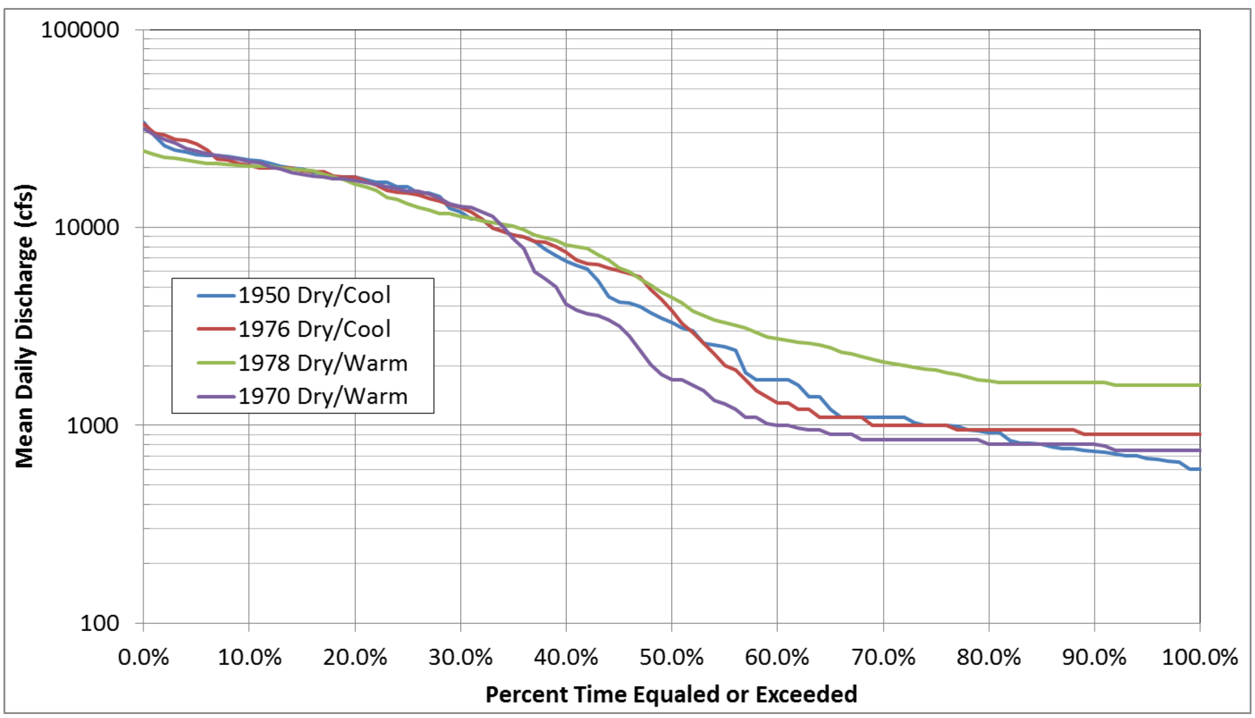

Figure 5.11 Candidate dry years flow duration curves.

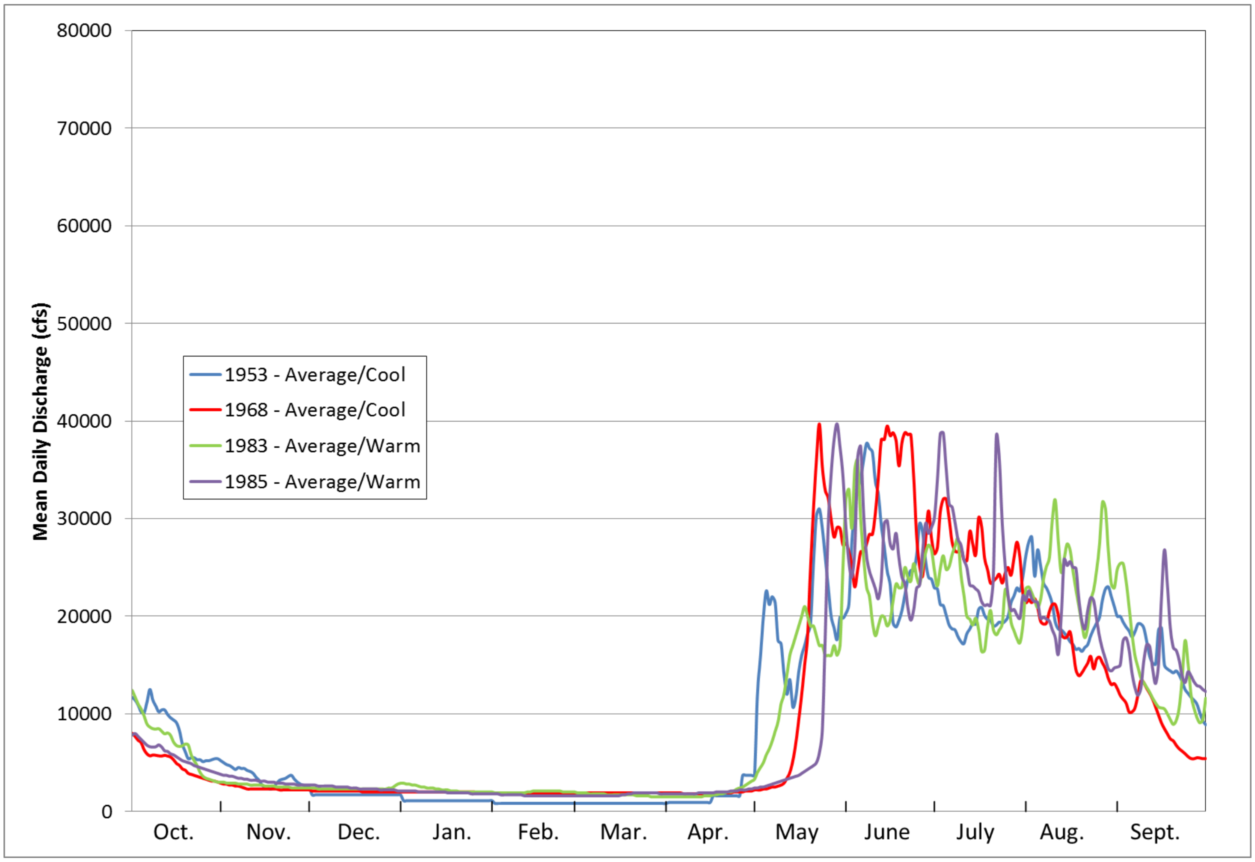

Figure 5.12 Candidate average years annual hydrographs.

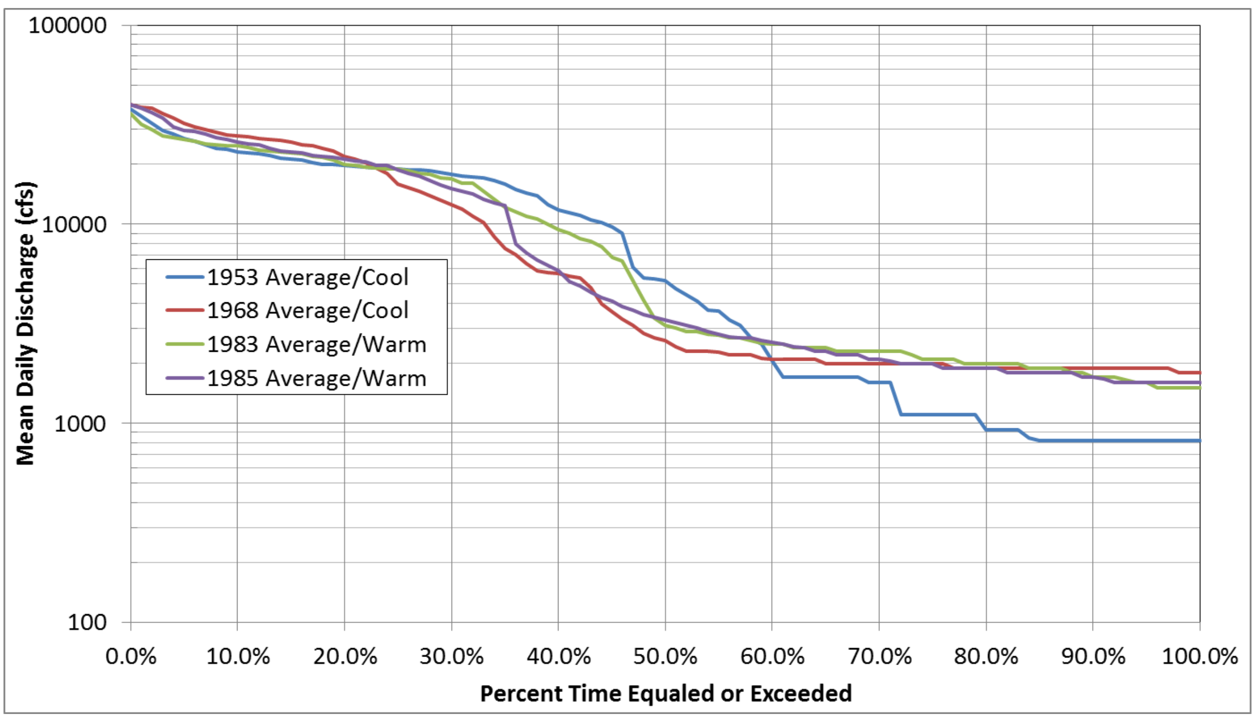

Figure 5.13 Candidate average years flow duration curves.

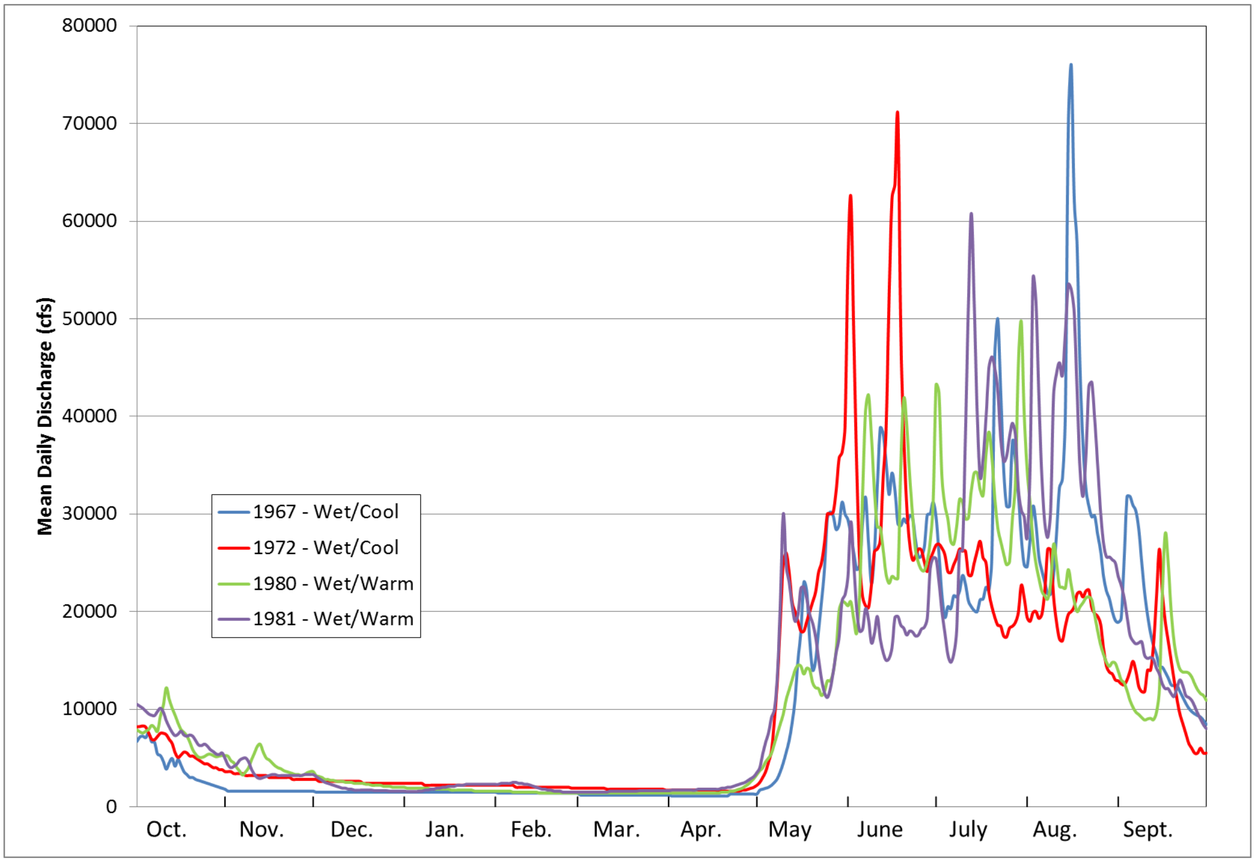

Figure 5.14 Candidate wet years annual hydrographs.

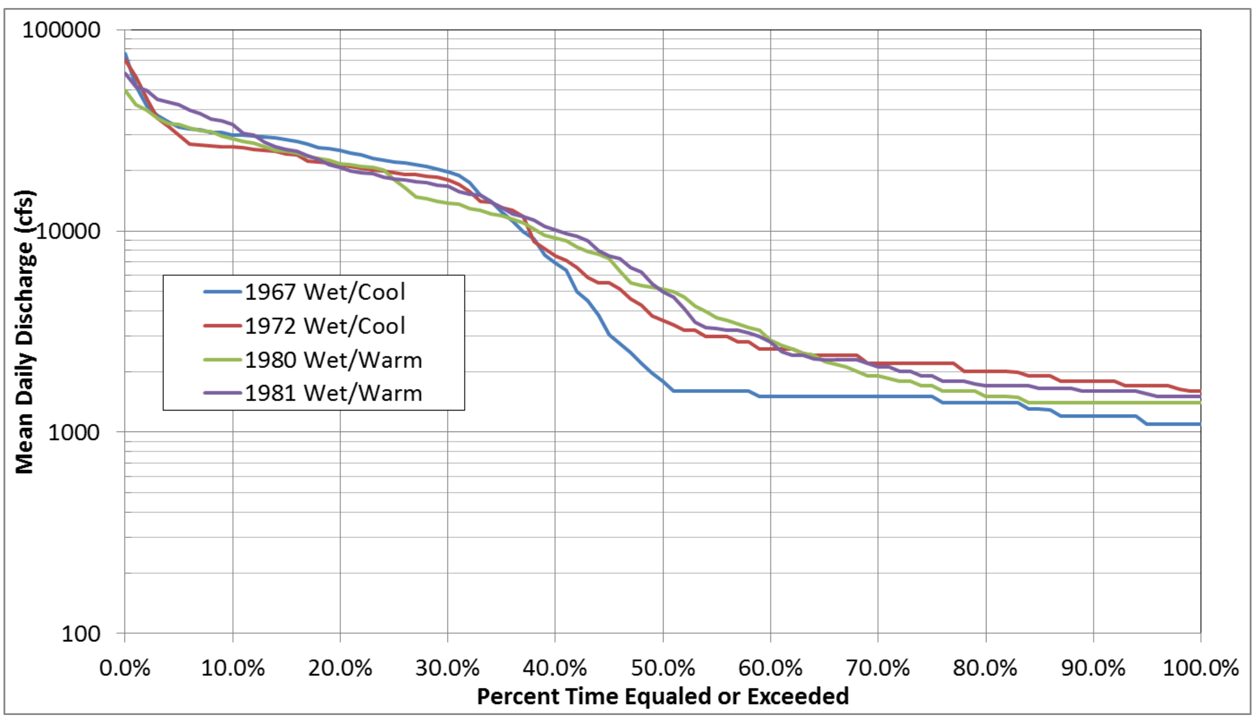

Figure 5.15 Candidate wet years flow duration curves.

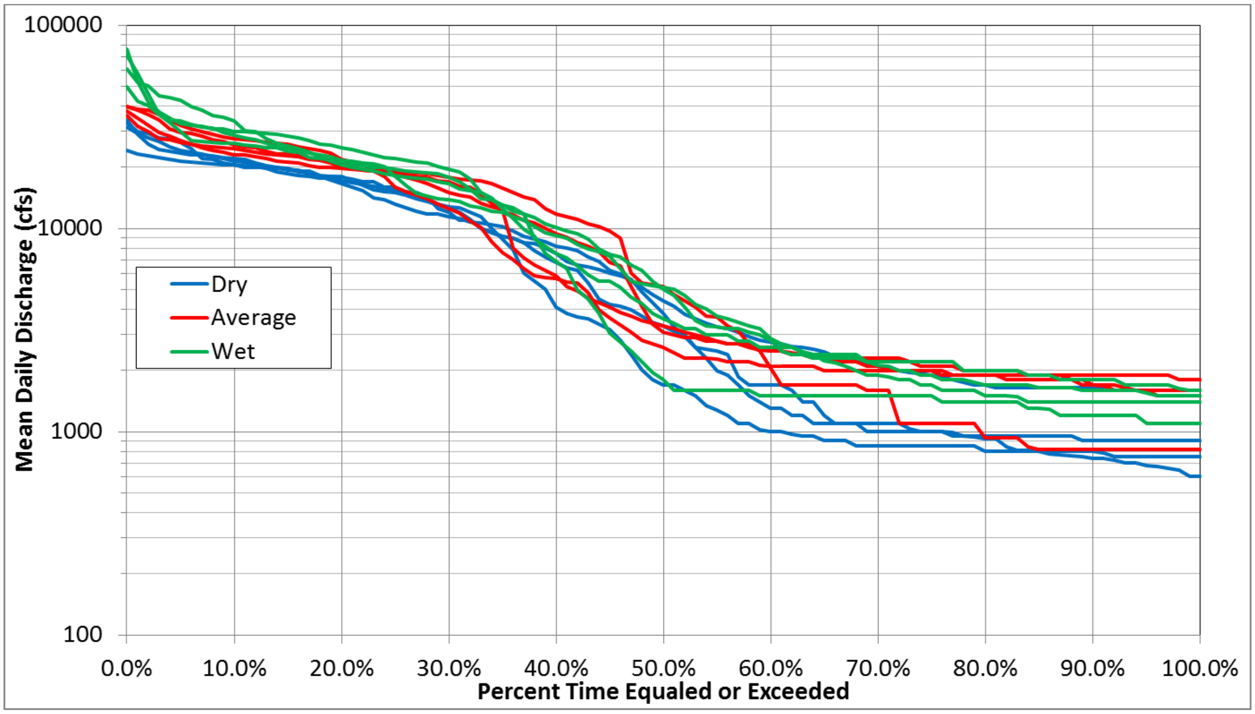

Figure 5.16 Candidate dry, average, and wet years flow duration curves.

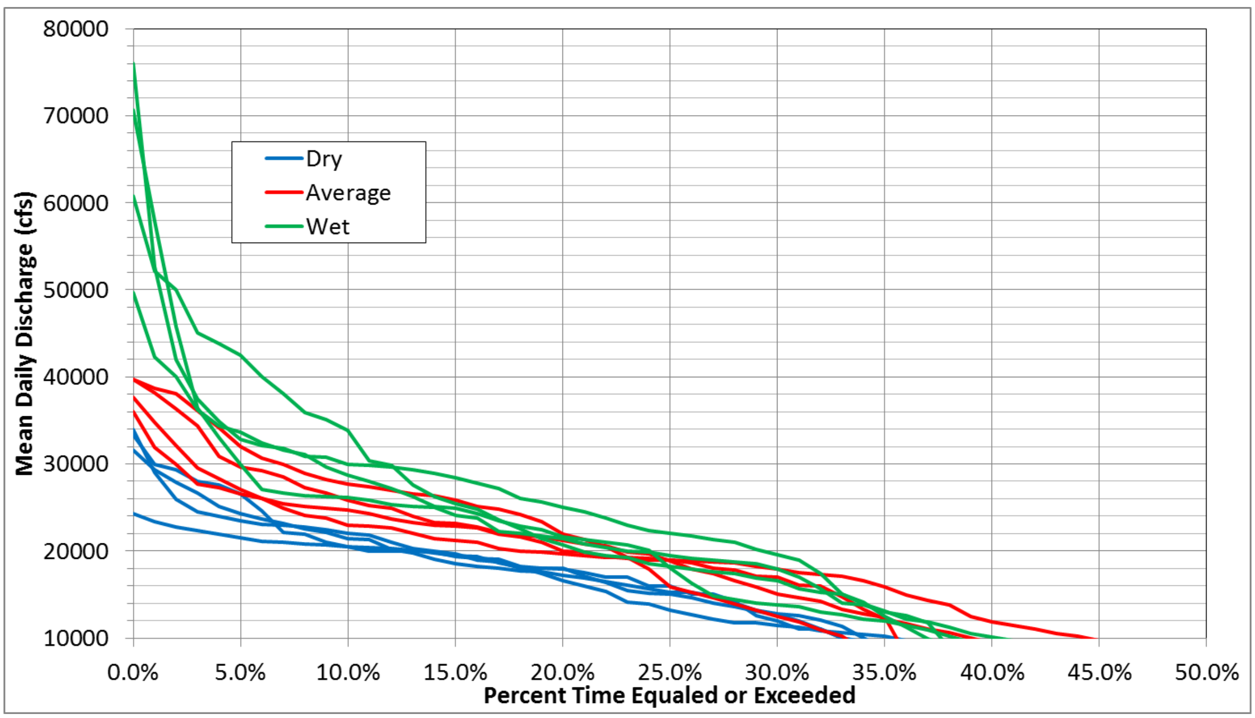

Figure 5.17 Candidate dry, average, and wet years flow duration curves for flows exceeding 10,000 cfs.

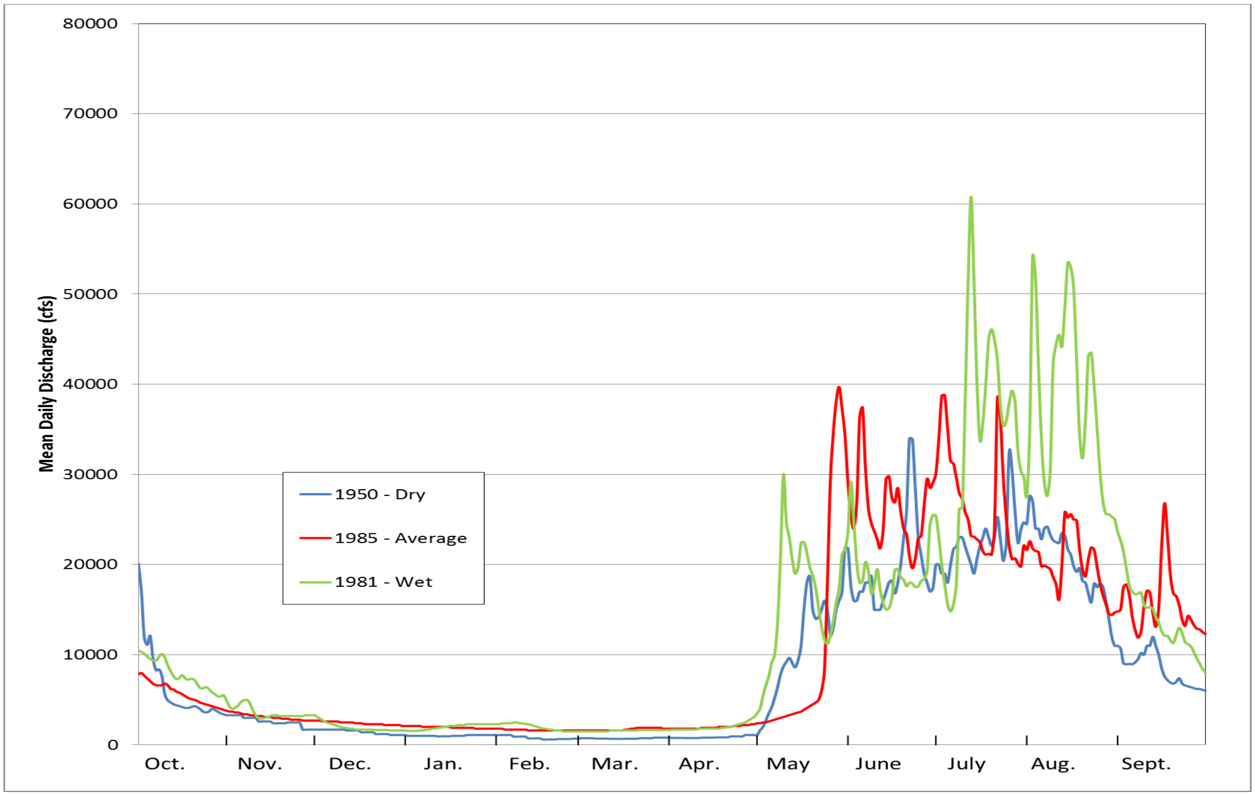

Figure 5.18 Recommended dry, average and wet representative years annual hydrographs.

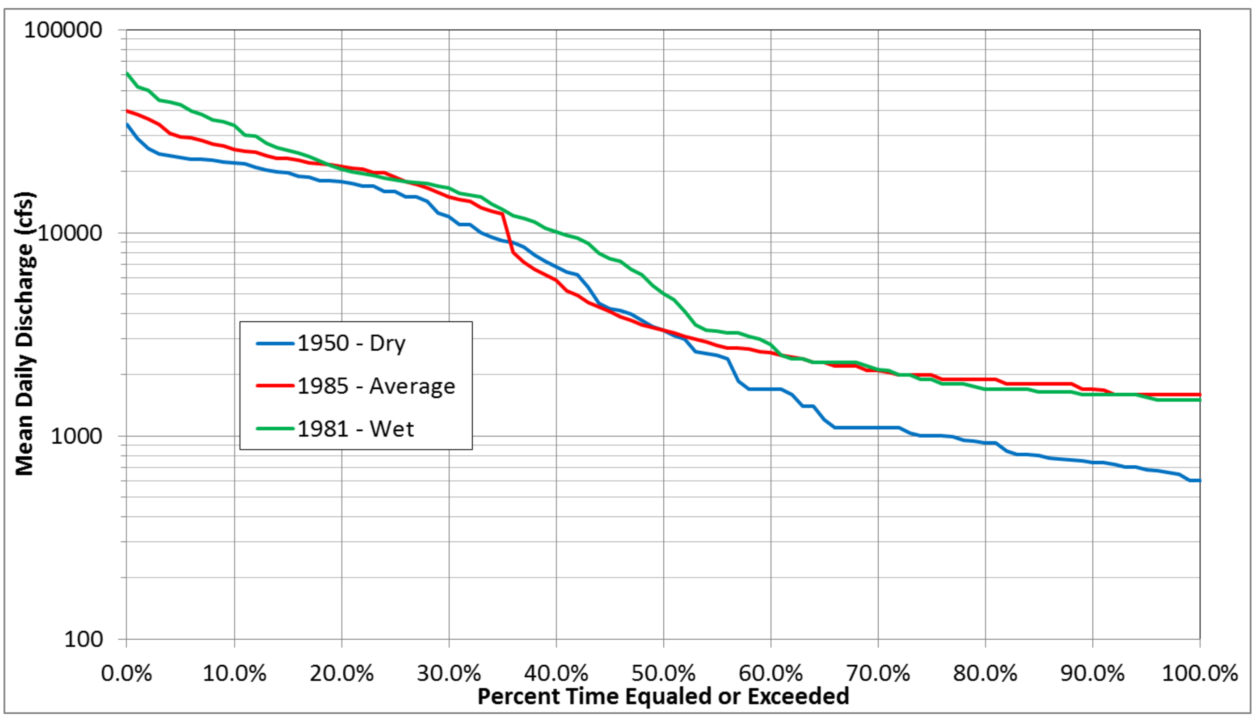

Figure 5.19 Recommended dry, average and wet representative years flow duration curves.

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fluvial Geomorphology Modeling Study (6.6)

Part A - Attachment A
Field Report - Field Assessment of Underwater Camera Pilot Test for Sediment Grain Size Distribution

Initial Study Report

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

Tetra Tech

June 2014

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EXECUTIVE SUMMARY

Tetra Tech performed a field assessment in March 2013 of the use of underwater cameras during the ice-covered period to acquire images of the Susitna River main channel bed material for the purpose of quantifying grain size distribution as part of the Susitna-Watana Hydroelectric Project. During the open-water period, turbidity is high due to flow originating from glacial melt and reduces visibility below the level needed for the use of cameras. Additionally, high flow and associated stage during the open-water period eliminates the possibility to use shallow water or dry pebble counts in deeper portions of the channel. Therefore, the field assessment work was conducted during the ice-covered period with the anticipation of increased water clarity due to associated reduced glacial inflow and turbidity during the winter months. The field testing was coordinated with winter study efforts conducted by other consultants working on the project to ensure multidisciplinary interaction and leverage field safety, labor, and logistical planning across study efforts. The field assessment was performed by lowering underwater cameras through holes drilled through ice covering the river at two test sites, Whiskers Slough (Project River Mile 105) and the discharge transect ESS40 (Project River Mile 107).

The goals of this effort were: (1) to determine if collecting images for bed material size distribution through ice is feasible and (2) to test various equipment for underwater bed material image acquisition and determine equipment and methods to apply to future full-scale studies. The various equipment tested included four cameras, three light sources for scene illumination, and two parallel mounted lasers with a constant spacing of 4 inches to provide a reference of scale in the acquired images. The equipment was generally tested for its ability to perform in cold weather environments, and different setups were compared for the quality of images obtained.

Field testing determined that use of underwater cameras to obtain images of bed material for determining gradation is feasible during the ice-covered period. The GoPro and AquaVu cameras both performed well. The GoPro is considered slightly better than the AquaVu for this field application because the color image obtained by the GoPro camera provided enhanced edge and shape detection compared to the black and white image obtained by the AquaVu. Also, the AquaVu camera required the use of a laptop for recording images. The Wide-I and SplashCam cameras are not recommended for use in full-scale studies due to poor image resolution and inconsistent operation.

Although it is possible to obtain bed material images that can be used to determine gradation during the ice-covered period, the estimated cost for a full-scale application of this method is considerably more expensive than the costs of traditional pebble counts on dry land or from open-water period images acquired from boats. Careful consideration of sample locations and frequencies should be made prior to specification of full-scale application to reduce over sampling and focus on locations where samples are unattainable during the open-water period using traditional methods.

1. INTRODUCTION

This Field Report summarizes the field assessment in March 2013 of underwater camera use and acquisition of bed material imagery for the purpose of quantifying main channel grain size distribution as part of the Susitna-Watana Hydroelectric Project. This field testing, performed by Tetra Tech, was coordinated with winter study efforts conducted by R2 Consultants and GW Scientific to ensure multidisciplinary interaction and leverage field safety, labor, and logistical planning across study efforts. This effort was undertaken to determine the feasibility of sampling main channel bed material during the ice-covered period (October through April) utilizing underwater photography and in areas that are too deep or too turbid to allow for physical collection of samples and sieve analysis, or traditional visual pebble count techniques (e.g., Wolman pebble count). During the open-water period (May through September), the same basic equipment could be used, except the water is typically too turbid to collect the images. If water clarity was sufficient during an open-water period, the equipment would be deployed from a boat or used by staff on foot in shallow water rather than through holes in the ice. Two study sites near Talkeetna, Alaska, were used for the ice-covered period testing: Whiskers Slough (Project River Mile 105) and ESS40 (Project River Mile 107), which is a transect location upstream of Whiskers Creek used for discharge measurement.

During the majority of the open-water period, the Susitna River is turbid due to inflow of glacial origin (U.S. Geological Survey [USGS] 1987) rendering the collection of bed material images by underwater photography impractical. However, the turbidity is quite low and visibility much higher during the ice-covered period when the glacial melt contribution to flow ceases. Previous turbidity measurements near Talkeetna (Harza-Ebasco Susitna Joint Venture 1986) indicated values during the middle of the open-water period can be over 100 times larger (480 Nephelometric Turbidity Units [NTU] on July 21, 1985) than near the start of the ice-covered period (4 NTU on October 10, 1985). The lowest values (less than 10 NTU) that were measured in October 1985 corroborate anecdotal information that a narrow window of visibility is present in late September and early October prior to ice-up of the Susitna River when temperatures in the upper watershed greatly reduce glacial melt contribution and the turbidity level falls (M. Wood, pers. comm., 2013). The differences in water clarity between the open-water period and ice-covered period are illustrated in Figure 1-1 and Figure 1-2, respectively.

Figure 1-1. Photograph taken July 22, 2012, during temperature logging, illustrating high turbidity and low visibility for Susitna River during the open-water period.

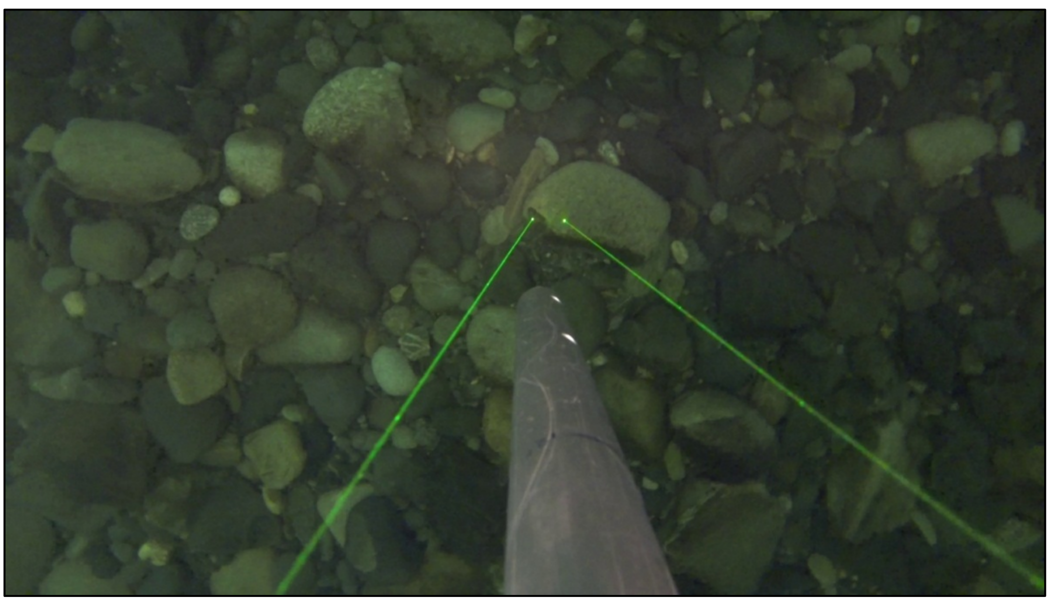

Figure 1-2. Photograph taken on March 21, 2013, below 3.8 feet of ice and approximately 6.5 feet above the streambed, illustrating low turbidity and high visibility for Susitna River during the ice-covered period.

2. METHODS

A safety orientation with initial coordination between the Tetra Tech, R2 Consultants, and GW Scientific staff was conducted on March 19, 2013, prior to performing field work on ice. This information was provided by GW Scientific staff and included orientation to travel routes and equipment previously staged at Whiskers Slough, such as warm-up tents.

The field assessment of underwater camera equipment for acquiring images of main channel bed material was conducted over two days, on March 20 and 21, 2013. Study sites (Figure 2-1) at Whiskers Slough, near Project River Mile 105, and ESS40, near Project River Mile 107, were utilized for the field testing on March 20 and March 21, respectively. Initial testing at Whiskers Slough allowed field staff to try the equipment first before exposing it to high main channel Susitna River water velocities and deeper depths, and to evaluate initial field use issues for the equipment and procedures prior to testing at ESS40. Testing at ESS40 used the same mounting and setup adjustments that were determined from testing at Whiskers Slough.

The work was coordinated with other studies to ensure multidisciplinary interaction and increase understanding of how comprehensive synoptic datasets can potentially be supported and obtained during future field efforts. Additionally, coordination between field efforts assisted with the labor needed to perform pilot testing, including safety orientation, and the setup and maintenance of travel routes and previously staged equipment.

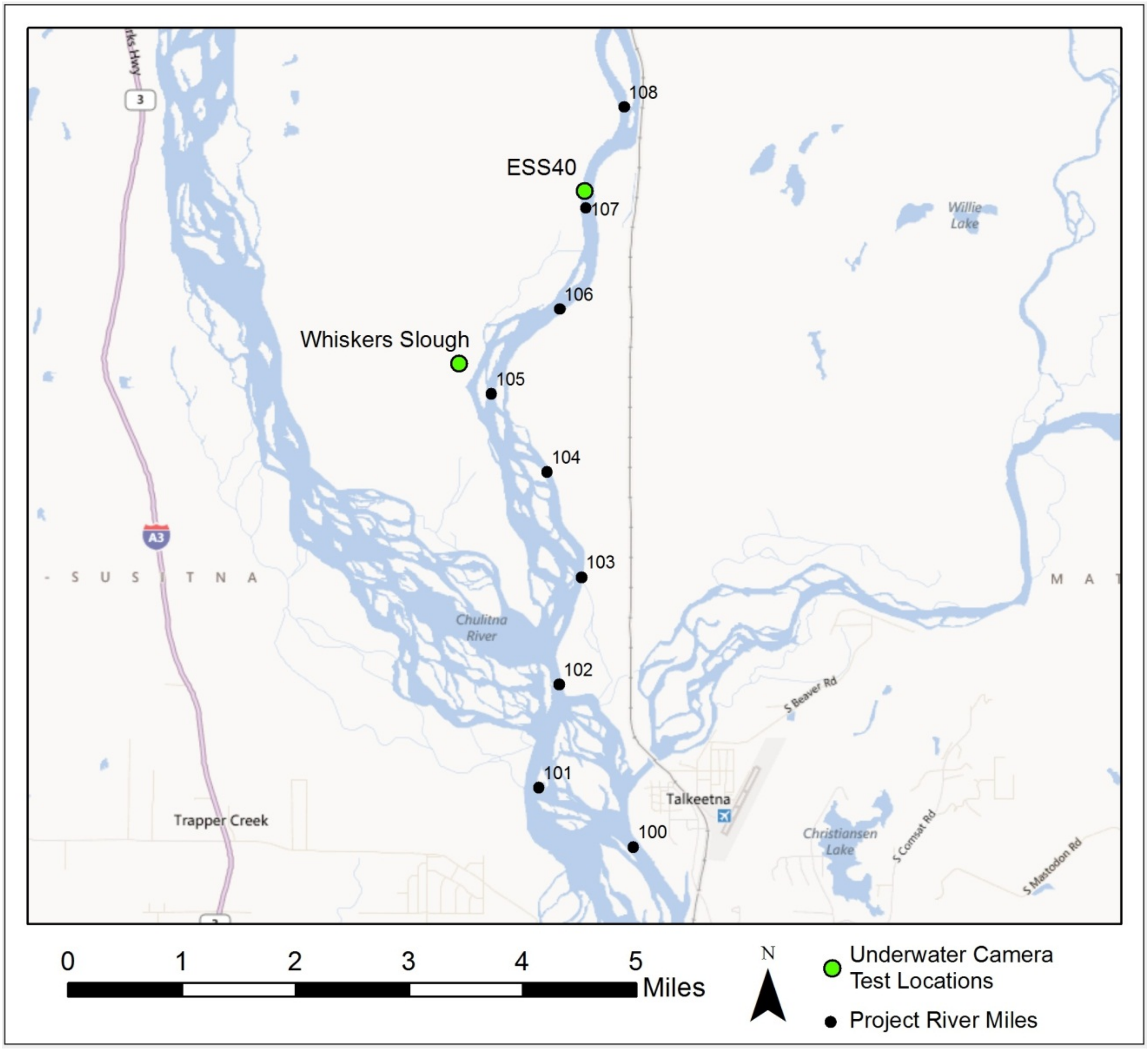

Figure 2-1. Underwater camera test locations for March 19-21, 2013, field pilot testing.

2.1. Goals and Information Sought

The goals of this effort were: (1) to determine if collecting images for bed material size distribution through ice is feasible and (2) to test various equipment for underwater bed material image acquisition and determine equipment and methods to apply to future full-scale studies.

Answers to several questions were sought through performance of this field testing, including:

- Will bed material be visible in the acquired images at a level allowing for ranges of grain size to be distinguished?
- Will frazil ice, turbidity, or other moving material interfere with the acquisition of images?
- How can artificial light be used to increase scene illumination for improved image quality?
- What camera equipment performs best?

- How much time is required to collect sample images at a site?
- Are main channel water velocities too high for securing camera equipment to pole in order to lower to the equipment to the bed?
- What additional challenges of working with underwater camera equipment in winter conditions are identified?

2.2. Field Test Equipment

The equipment tested included four different cameras, three different lights, and two parallel mounted lasers with a spacing of 4 inches for scaling of objects captured in the photographs (Table 2-1).

Table 2-1. Equipment tested for underwater images of streambed material.

Type of Equipment	Equipment Specifics	Purpose of Equipment
Camera	GoPro Hero3 Black Edition (GoPro) video camera	Image acquisition
Camera	SplashCam Deep Blue Pro (SplashCam) underwater video camera	Image acquisition
Camera	Deep Sea Power & Light Wide-I SeaCam (Wide-I) black and white video camera	Image acquisition
Camera	AquaVu black and white video camera with lights (supplied by GW Scientific)	Image acquisition and scene illumination
Lasers	Deep Sea Power & Light SeaLaser 100 two green lasers parallel mounted with a spacing of 4 inches	Scaling of objects in images
Light	Princeton Tec scuba flashlights, two parallel mounted	Scene illumination
Light	Brinkman Q-Beam Starfire II underwater fishing light	Scene illumination
Computer	Panasonic Toughbook laptop	Recording of images from SplashCam, Wide-I, and AquaVu

The camera equipment varied in terms of power sources, and acquisition and storage of images. The GoPro has an internal rechargeable battery and microSD memory card slot. An additional battery can be used with the GoPro to extend the operation of the camera. The additional battery was used for field testing and provided sufficient power for the duration of field testing at each site. However, cold weather is generally known to reduce the operational time of batteries and replacement batteries should be considered for field work of extended camera use. The AquaVu camera, Brinkman Q-Beam Starfire II underwater fishing light, and external 12-volt batteries were provided for field testing by GW Scientific. The Wide-I, SplashCam, and AquaVu cameras do not have internal storage for recorded images and required an external recording device and connection cables. A Panasonic Toughbook laptop was used to record the images from these three cameras with the installed software Roxio VHS to DVD 3. The AquaVu camera had an internal battery, and the SplashCam and Wide-I were powered with an external 12-volt Sun Xtender battery, although cables can be configured to connect to the 12-volt outlet on a snowmachine for power supply. The lasers and Brinkman Q-Beam Starfire II underwater fishing light were also powered using an external 12-volt battery. The Princeton Tec scuba flashlights each had internal power from AA batteries.

The AquaVu camera has an LED light ring around the lens to provide scene illumination. These lights were used with the GoPro mounted on the opposite side of the pole to provide a third light source for testing. The AquaVu camera was also equipped with a water temperature sensor. However, this temperature sensor was not calibrated during the field assessment and the values presented on the images are erroneous.

Marshalltown aluminum push button handle sections, typically used for concrete finishing work, were utilized to deploy equipment through holes in the ice. Four 6-foot-long sections of handle were used to provide a 24-foot-long pole to reach the stream bed, allow for adequate grip, and prevent the pole from being lowered below the surface or below ice and snow that may be encountered. The handle sections were hollow tubes with an outside diameter of 1.375 inches and a wall thickness of 0.063 inch. The equipment was mounted on the lowest pole section nearest the streambed at a set distance from the end of the pole (Figure 2-2) in order to determine the elevation above the stream bed in each photograph.

Both 8-inch and 10-inch power ice augers were used to bore holes through ice at the two sites, Whiskers Slough and ESS40. Four test holes were attempted at Whiskers Slough and three test holes were attempted at ESS40. Test holes were created with the objective to obtain varying ice and snow cover thicknesses to evaluate the impacts to scene illumination. Also, each test hole required at least 3 feet of water to allow for submergence of the equipment below the bottom of the hole, and equipment had to be at least 1 foot above the stream bed. The criterion of 1 foot above the stream bed was determined from personal communication with the GoPro technical support staff (S. Garretson, pers. comm., 2013) in regards to the minimum focal length for the GoPro camera and to allow for a wider field of view of bed material to be captured in the images.

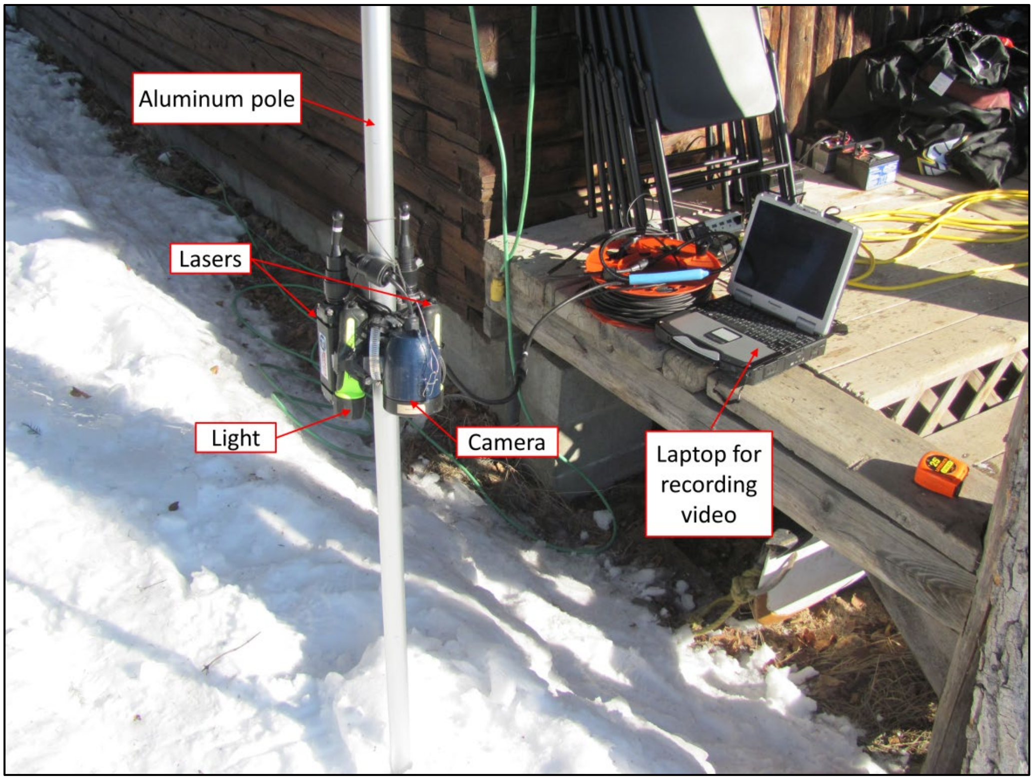

Figure 2-2. Equipment setup on expandable aluminum pole.

3. RESULTS

The results of the underwater camera testing are presented as images obtained from each of the two test sites, Whiskers Slough and ESS40, and for each equipment combination that successfully acquired images. The GoPro and AquaVu cameras were used successfully to acquire images. The Wide-I, however, did not function at either test site, and the SplashCam worked at Whiskers Slough but did not function at ESS40. A summary of the various equipment setups that were tested at each site is presented in Table 3-1. Images and specifics are presented for each test site in this section.

Table 3-1. Summary of equipment setup evaluated at each test site.[1]

Site	Camera Type	Camera Mode	Light Type	Image Quality (Good, Fair, Poor)	Figure Number
Whiskers Slough	Wide-I	-[2]	-[2]	-[2]	-[2]
	GoPro	0.5 second time lapse	None	Poor	Figure 3-3
	GoPro	0.5 second time lapse	Princeton	Fair	Figure 3-4
	GoPro	Video	Princeton	Good	Figure 3-5
	SplashCam	Video	Princeton	Poor	Figure 3-6
ESS40	Wide-I	-[2]	-[2]	-[2]	-[2]
	SplashCam	-[2]	-[2]	-[2]	-[2]
	AquaVu	Video	Princeton and AquaVu	Fair	Figure 3-8
	GoPro	Video	Princeton and AquaVu	Good	Figure 3-9
	AquaVu	Video	AquaVu	Good	Figure 3-10
	GoPro	Video	AquaVu	Good	Figure 3-11
	AquaVu	Video	Brinkman	Good	Figure 3-12
	GoPro	Video	Brinkman	Good	Figure 3-13
	AquaVu	Video	None	Good	Figure 3-14
	GoPro	Video	None	Good	Figure 3-15

1. Lasers were used for each test setup for scaling of objects in the image.
2. Wide-I did not transmit images to the laptop for recording at the field test sites, and it could not be determined if this issue was due to video or power cables, cable connections, the camera, or cold weather conditions. SplashCam did transmit images at Whiskers Slough, but did not transmit images to the laptop for recording at the ESS40 field test site. It also could not be determined if this issue was due to video or power cables, cable connections, the camera, or cold weather conditions. Test images were transmitted during initial camera setup testing at Tetra Tech's office on March 14, 2013, and again at GW Scientific's office on March 19, 2013.

3.1. Field Testing at Whiskers Slough Site

The Whiskers Slough site (Project River Mile 105) is composed of several stream features, four of which include "Whiskers" in their name: Whiskers Creek, Whiskers Slough, Whiskers West Side Channel, and Whiskers East Side Channel. Conditions at the Whiskers Slough site on March 20, 2013, were sunny and the ice was transparent, providing visibility to the bottom from above the ice (Figure 3-1). Average air temperature during equipment testing at the Whiskers Slough site was approximately 25°F and determined from the hourly observation data from the nearest Natural Resources Conservation Service (NRCS) SNOTEL site (Site ID 967). Average water temperatures during equipment testing were estimated as 32.8°F based on observations at the USGS station for the Susitna River at Sunshine (Site ID 15292780).

Initial testing at Whiskers Slough allowed field staff to try the equipment first before exposing it to high main channel Susitna River water velocities and deeper depths, and to evaluate initial field use issues for the equipment and procedures prior to testing at ESS40. Camera equipment was mounted on the aluminum pole approximately 2 feet from the end of the pole. A 10-inch ice auger was used to cut a hole for accessing the water for camera testing (Figure 3-2). Four test holes were initially created at the Whiskers Slough site to investigate locations with varying ice and snow thicknesses and a minimum 3 feet of water. One hole each was created at the mouth of Whiskers Creek, near the mouth of Whiskers Slough, in Whiskers West Side Channel upstream of the downstream-most junction with Whiskers Slough, and within Whiskers Slough upstream of the junction with Whiskers Creek. Of the four locations evaluated, only the location at the mouth of Whiskers Creek provided adequate water depth for equipment testing. The water depth at this hole was 5.75 feet, and ice thickness was approximately 6 inches. No freeboard (distance between the ice and water surfaces) was observed.

Figure 3-1. Transparent ice at Whiskers Slough on March 20, 2013, provides good visibility of stream bed.

Figure 3-2. Lowering camera equipment through hole in ice at the mouth of Whiskers Creek.

The Wide-I camera did not transmit images to the laptop for recording at the Whiskers Slough field test site, and it could not be determined if this issue was due to video or power cables, cable connections, the camera, or cold weather conditions. Consequently, images are not presented or evaluated for this camera.

The GoPro camera was tested in three modes each using the lasers. The first mode was without the use of the lights, with the camera was set to acquire time lapse images every 0.5 second (Figure 3-3).

Figure 3-3. GoPro image from Whiskers Slough without lights or lasers, and using time lapse setting of 0.5 second between images.

The second mode used the Princeton Tec scuba flashlights and lasers with a time lapse setting of 0.5 second (Figure 3-4).

A folding scale was attached to a second aluminum pole and placed within the field of view for the purpose of visualizing the image resolution and edge distortion from the wide angle lens. The scale would not be used for a larger area application of underwater imagery because unfolding the scale requires hand access below the bottom of the ice. This requires ice that is thin enough and water shallow enough to access the scale, which is less likely to occur for the majority of the potential main channel sample locations.

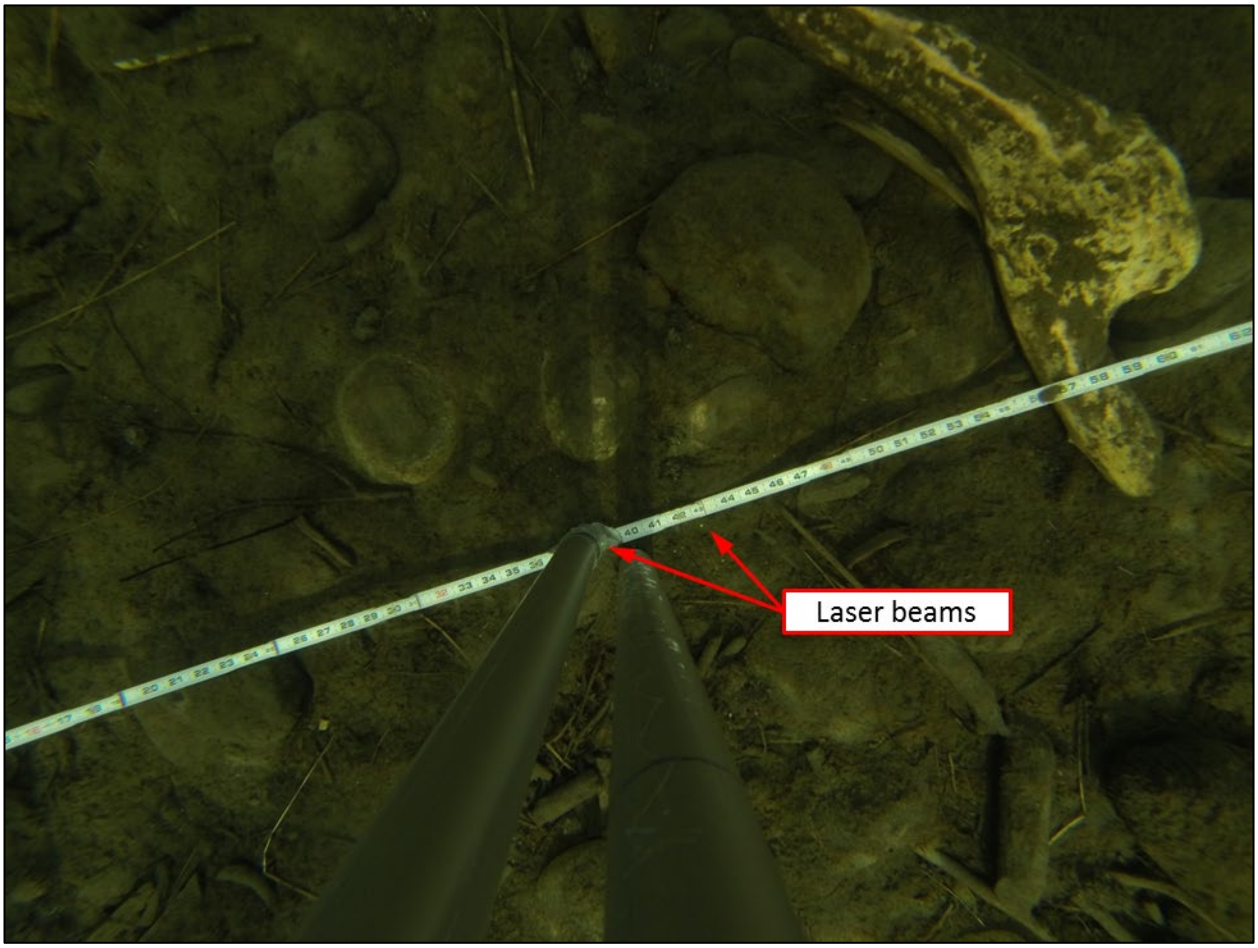

Figure 3-4. GoPro image from Whiskers Slough with lights, lasers, scale, and a time lapse setting of 0.5 second between images.

The third mode used the Princeton Tec scuba flashlights, lasers, and scale, but with the camera set to video mode (Figure 3-5).

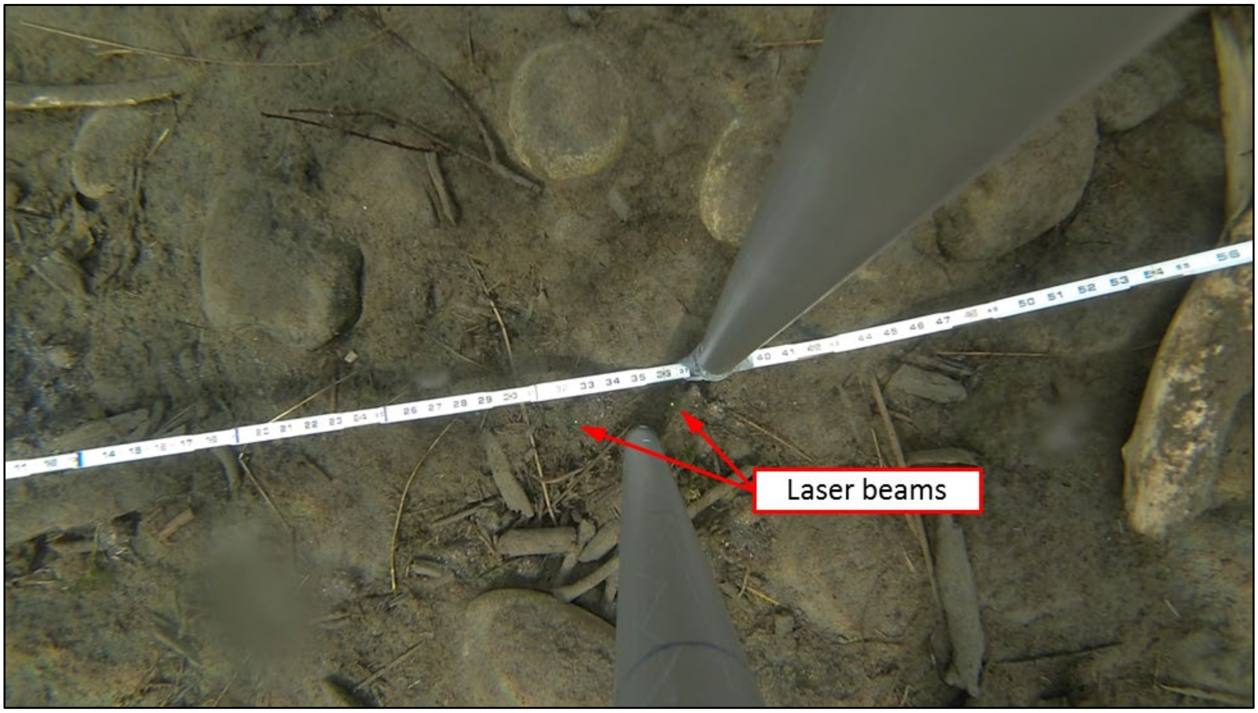

Figure 3-5. GoPro image from Whiskers Slough with lights, lasers, and scale in video mode.

The SplashCam was tested with the Princeton Tec scuba flashlights, lasers, and scale in the field of view (Figure 3-6). Video was recorded using Roxio VHS to DVD 3 installed on a Panasonic Toughbook laptop.

Figure 3-6. SplashCam image from Whiskers Slough with lights, lasers, and scale. Lasers are not visible due to poor image resolution.

3.2. Field Testing at ESS40

The purpose of full-scale application of this equipment was to obtain main channel bed images to determine grain size distributions that could not be obtained otherwise or during other times of the year due to high flow and turbidity. The discharge sampling transect ESS40 (Project River Mile 107) provided a location with main channel access to test the equipment performance with deeper water, thicker ice and snow cover, and higher water velocities. Testing at ESS40 was performed after the initial mounting and setup adjustments were determined from testing at the Whiskers Slough field site.

Conditions at ESS40 on March 21, 2013, were sunny to partly sunny and the ice was covered with varying snow depths. Average air temperature during equipment testing at ESS40 was approximately 24°F (NRCS SNOTEL Site ID 967). Average water temperatures during equipment testing were estimated as 32.8°F (USGS Site ID 15292780). Camera equipment was mounted on the aluminum pole approximately 1.5 feet from the end of the pole. An 8-inch ice auger was used to cut holes for accessing the water for camera testing. Three test holes were created before a hole was located with more than 3 feet of water to provide submergence of the equipment and at least 1 foot between the camera and bed material for the GoPro minimum focal length. Water depth at the hole was 10.4 feet, the ice thickness was approximately 3.8 feet, and 0.2 inch of freeboard was observed. Very little snow cover and frazil ice was observed at the hole used for camera testing (Figure 3-7). Higher velocities were apparent upon initial submergence of the equipment at ESS40 with the force of the flow on the equipment and pole felt above the ice. However, the force was not too large that the equipment could not be kept vertical, and inserted and removed through the ice hole.

Figure 3-7. Lowering camera equipment through hole in ice at ESS40.

Both the Wide-I and SplashCam cameras did not transmit images to the laptop for recording at the ESS40 field test site, and it could not be determined if this issue was due to video or power cables, cable connections, the camera, or cold weather conditions. Consequently, images are not presented or evaluated for these cameras.

The AquaVu and GoPro cameras were simultaneously mounted on the aluminum pole to ensure similar conditions for each test. The folding scale was not used at ESS40 since ice thickness prevented it from being deployed down the hole and the swift current may have caused the scale to become separated from the pole. During actual full-scale implementation of field sampling using underwater camera methods, the folding scale would not be utilized due to anticipated ice thickness preventing field personnel from being able to unfold the scale below the ice. The cameras were tested in video mode using lasers and four separate light setups.

The first light setup used both the AquaVu's integrated lights and the Princeton Tec scuba flashlights (Figure 3-8 and Figure 3-9). As previously noted, the water temperature values measured by the AquaVu camera and imprinted on the acquired images are not accurate.

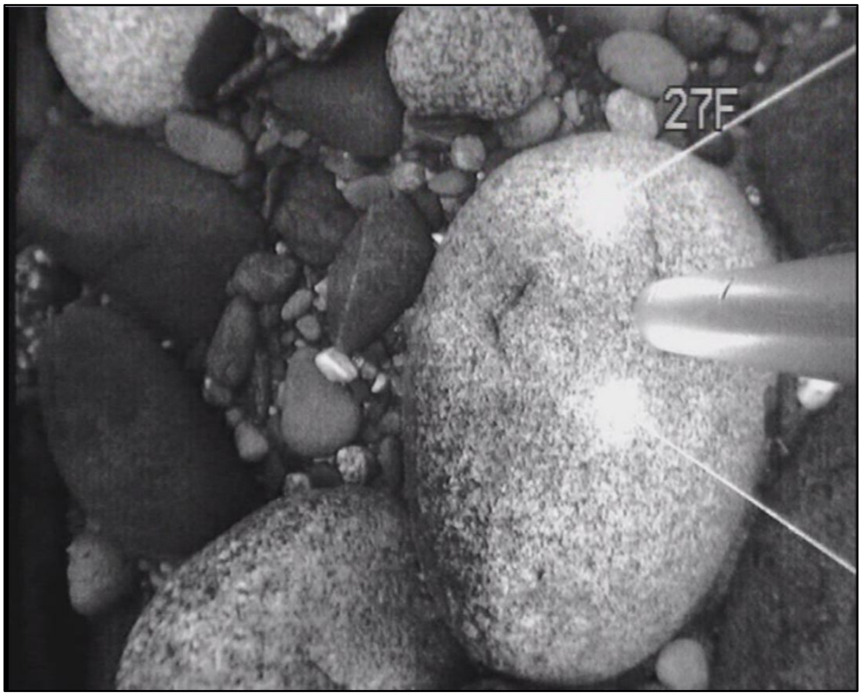

Figure 3-8. AquaVu image from ESS40 using lasers and both the AquaVu integrated lights and Princeton Tec scuba flashlights. (Note: The temperature sensor was not calibrated and values are erroneous.)

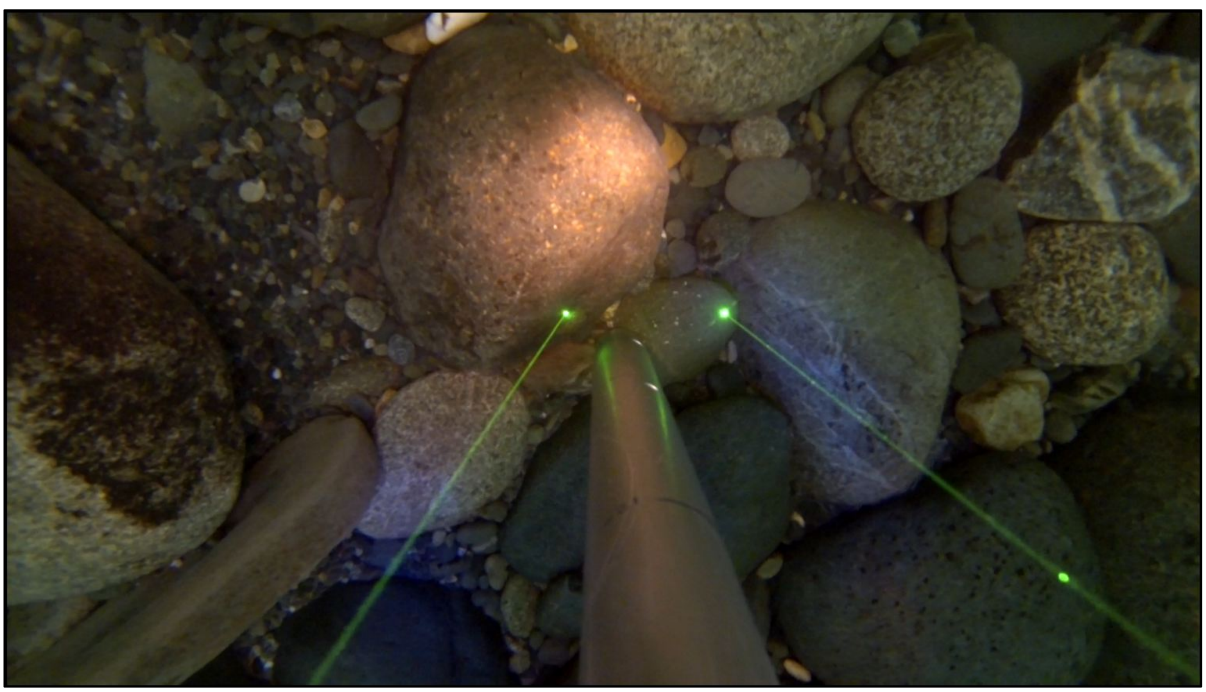

Figure 3-9. GoPro image from ESS40 using lasers and both the AquaVu integrated lights and Princeton Tec scuba flashlights.

The second light setup used only the AquaVu's integrated lights for both the AquaVu and GoPro images acquired (Figure 3-10 and Figure 3-11).

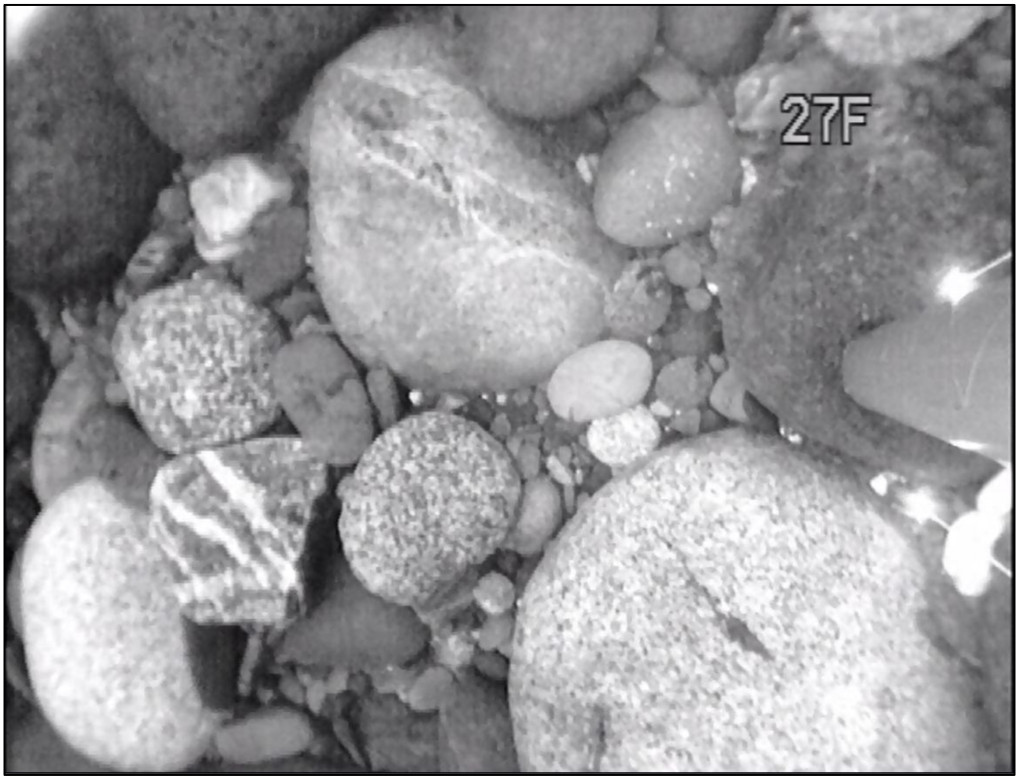

Figure 3-10. AquaVu image from ESS40 with lasers and the AquaVu integrated lights. (Note: The temperature sensor was not calibrated and values are erroneous.)

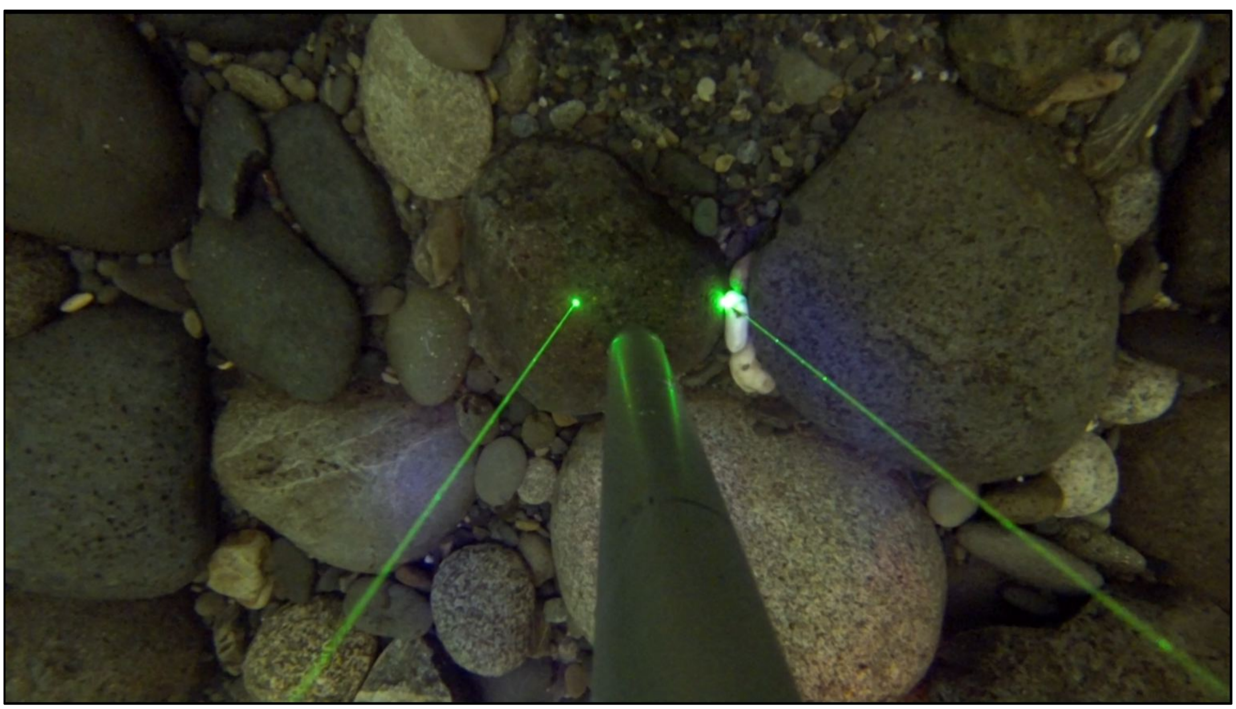

Figure 3-11. GoPro image from ESS40 with lasers and the AquaVu integrated lights.

The third light setup used the Brinkman Q-Beam Starfire II underwater fishing light for both the AquaVu and GoPro images acquired (Figure 3-12 and Figure 3-13).

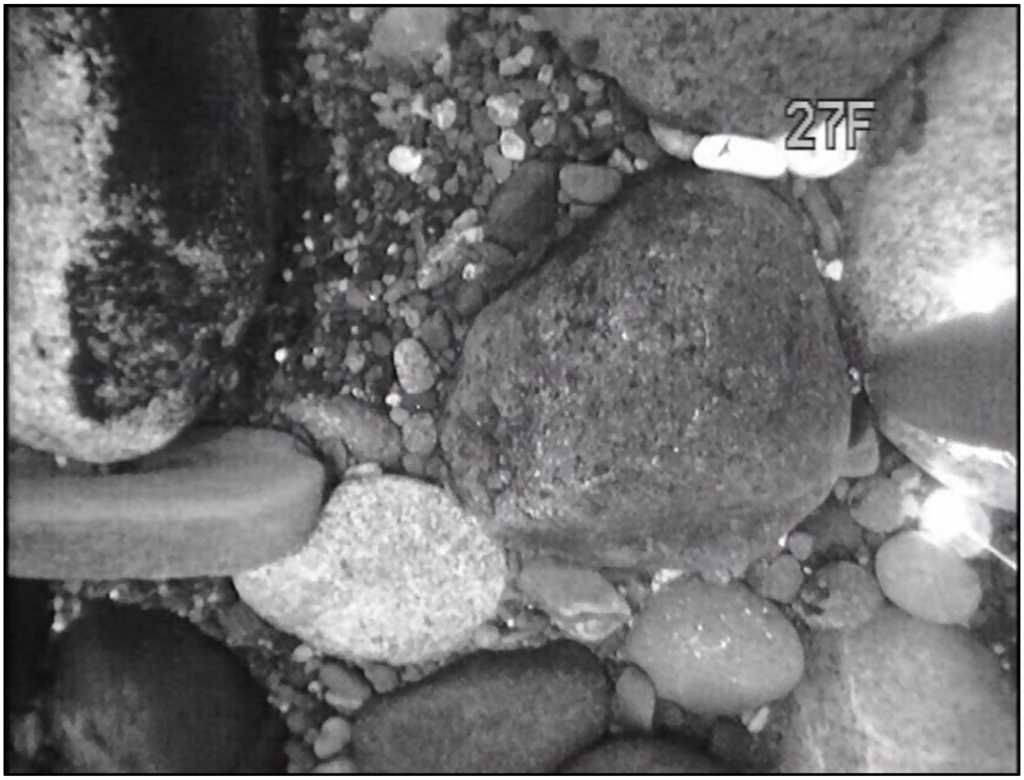

Figure 3-12. AquaVu image from ESS40 with lasers and the Brinkman Q-Beam Starfire II underwater fishing light. (Note: The temperature sensor was not calibrated and values are erroneous.)

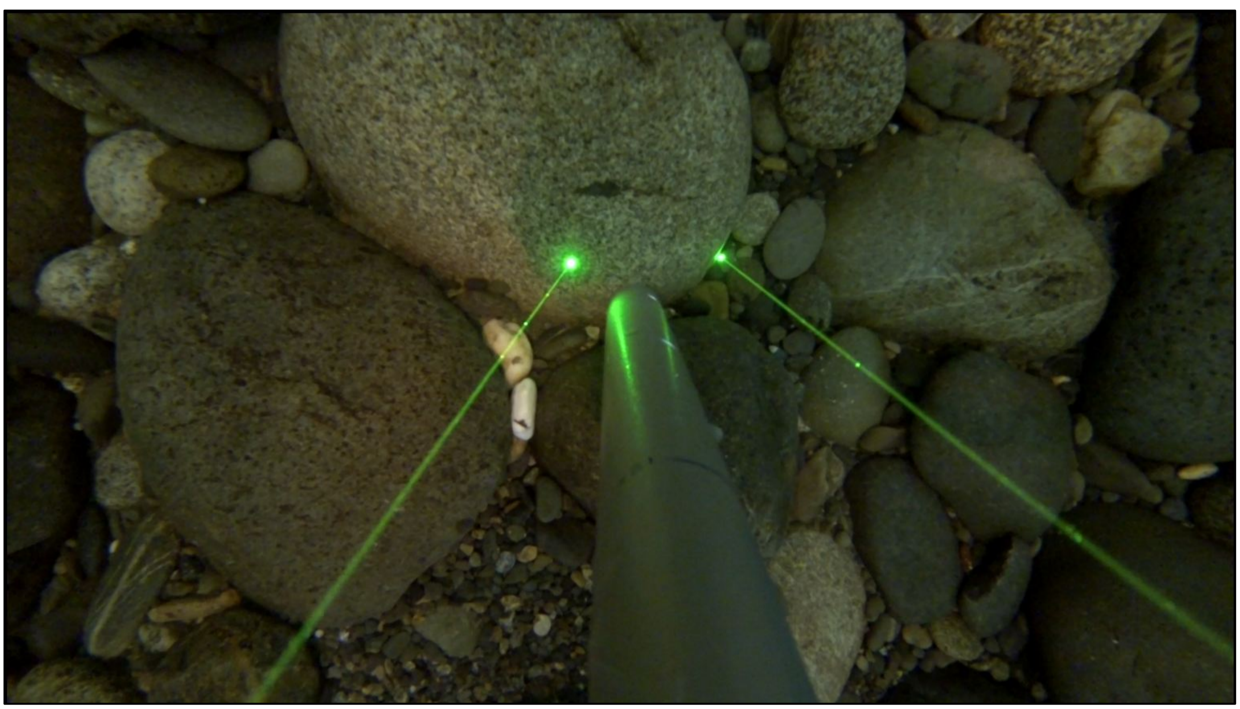

Figure 3-13. GoPro image from ESS40 with lasers and the Brinkman Q-Beam Starfire II underwater fishing light.

The fourth setup tested was without the use of lights for both the AquaVu and GoPro images acquired (Figure 3-14 and Figure 3-15).

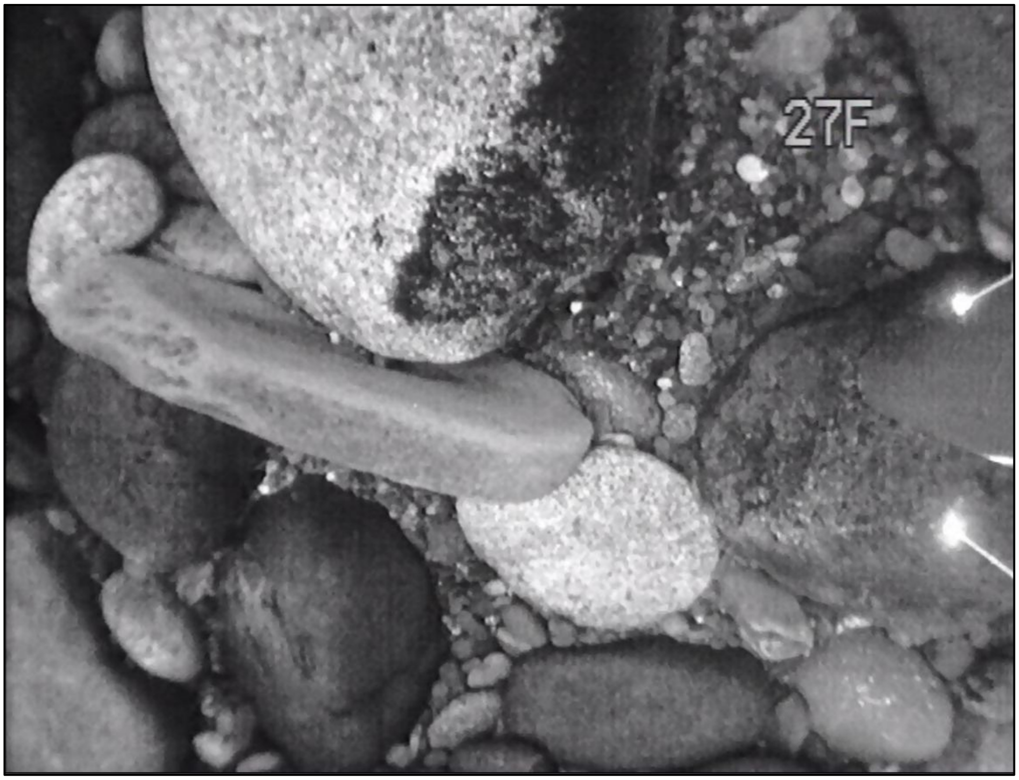

Figure 3-14. AquaVu image from ESS40 with lasers and without lights. (Note: The temperature sensor was not calibrated and values are erroneous.)

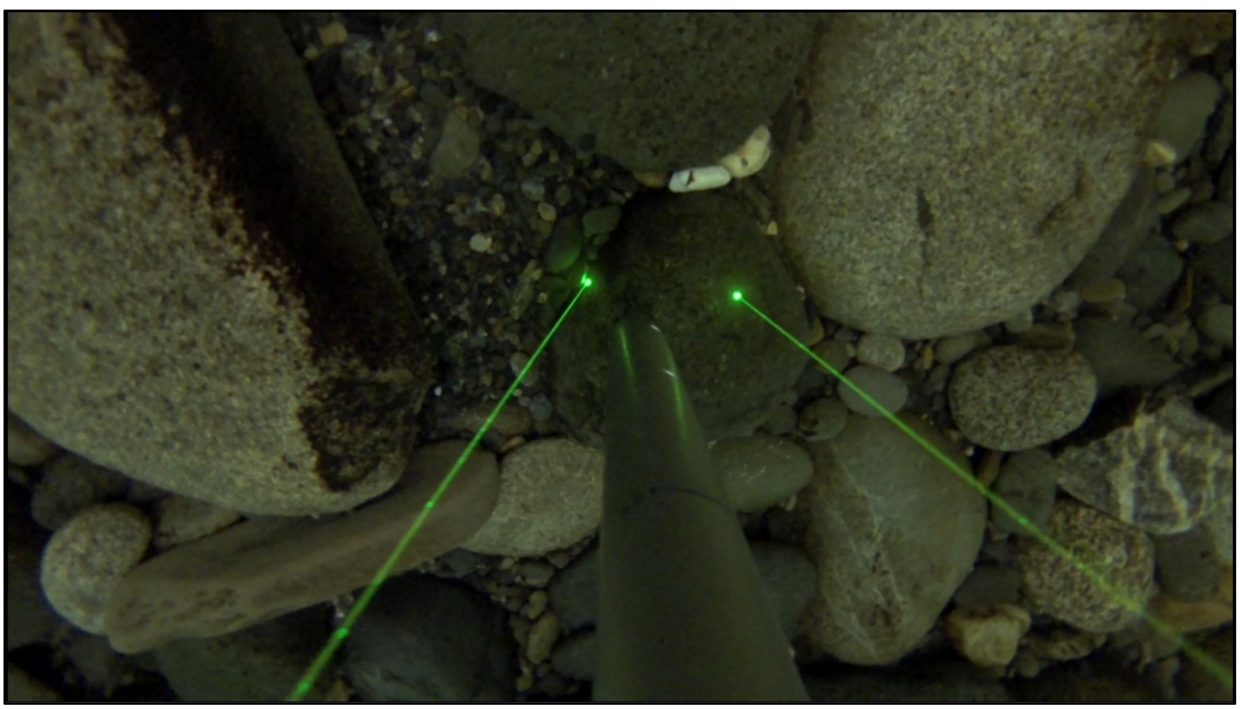

Figure 3-15. GoPro image from ESS40 with lasers and without lights.

The GoPro camera was also tested without the use of lights and by setting the camera to acquire time lapse images every 0.5 second; however, the amount of light under the ice was not sufficient for the shutter speed of the time lapse image setting. The resulting images were completely dark and could not be lightened to view objects.

4. SUMMARY AND RECOMMENDATIONS FOR FULL-SCALE STUDIES

Tetra Tech tested underwater camera equipment in the field at Whiskers Slough on March 20, 2013, and ESS40 on March 21, 2013, for the purpose of acquiring stream bed images to determine stream bed gradation. The acquired images allow the tested cameras and lights to be evaluated for future full-scale studies, which achieved the two goals of the field study. The overall results of this field assessment conclude that underwater cameras are feasible and can be applied for future full-scale studies to determine stream bed gradations of the main channel on the Susitna River during the ice-covered period. However, a full-scale study should consider the trade-off between the levels of effort for dry land/wading and boat survey methods during the open-water period and for the ice-covered method described in this field report. Sample locations and frequencies should be prioritized such that the focus for the ice-covered method is limited to those locations unattainable during the open-water period.

Water clarity was high at both the Whiskers Slough and ESS40 test sites, and turbidity was not an issue. Frazil ice and moving material did not interfere with the acquisition of bed images. The water velocities experienced during testing were not too high for securing camera equipment to the pole, or for inserting and removing the pole. Specific equipment results and other considerations for full-scale studies learned during the field testing are documented here.

4.1. Equipment Evaluation

Generally, the GoPro and AquaVu cameras both functioned well at ESS40 in video mode, and the GoPro worked well at Whiskers Slough in both video and time lapse modes. Bed material was visible in the acquired images at a level that allows for ranges of grain size to be distinguished. The color images acquired from the GoPro camera provide better edge detection than the black and white images from the AquaVu camera. Adjacent bed materials can have similar colors or have varying color, which may make it difficult to determine individual rocks from black and white images. Some models of AquaVu cameras do provide color images; however, the model tested at ESS40 provided black and white images only.

The Wide-I camera did not function during the field testing at either location, and the SplashCam did not function at ESS40 and produced poor image resolution at Whiskers Slough. Therefore, the Wide-I and SplashCam are not recommended for future use during full-scale studies.

The use of different underwater lights had little to no impact on the AquaVu black and white images, but they did provide increased brightness for the GoPro color images. However, it is difficult to determine which light source is most beneficial for full-scale studies since sufficient ambient light was available at both ESS40 and Whiskers Slough for acquisition of video images. The lights are relatively inexpensive, with the Princeton Tec scuba lights costing about $40 each and the Brinkman underwater fishing lights costing about $20 each. It is recommended that light sources be considered for full-scale studies that may take place with less ambient light due to winter months with less daylight time or under thicker ice and snow cover.

The lasers help to determine scale between the points where they appear in the image, and distortion should be much less near the center of the image than toward the edges. The lasers were powered by a 12-volt battery and are recommended for use during future full-scale studies.

4.2. Additional Considerations for Full-Scale Study

Performing future full-scale underwater image sampling in association with other field efforts, such as discharge sampling along transects, will allow for sharing of labor to drill ice holes and increase comprehensiveness of collected datasets for the Susitna-Watana Hydroelectric Project. In order to determine the bed gradation, approximately 100 individual rocks would need to be sampled on the order of 0.5 inch and larger. Approximately 40 rocks can be identified within this size class by visual inspection of the images acquired at ESS40 (Section 3.2), and discharge measurements are typically taken at intervals of 20 to 50 feet along a transect, which is usually completed in one day of field work (R. Beebee, pers. comm., 2013). Not all discharge measurement locations along a transect would require sampling to obtain a composite bed material sample of the main channel. Since the underwater camera equipment would be placed down the same holes drilled for discharge measurement, a single transect for gradation can also be obtained within one day of field work. Discharge transects should provide sufficient ice holes to obtain an adequate number of images from which to determine the stream bed gradation. Additional transects beyond those used for discharge measurements would also need to be sampled to provide representative conditions for each geomorphic reach.

Equipment selected for full-scale studies that require ice-augered holes must fit through the hole easily. A cone, such as a dog collar cone, could be used on top of the equipment to help guide the equipment back out of the hole and prevent it from becoming hung up on the underside of the ice. Both 10-inch and 8-inch augers were tested with the equipment and produced adequately sized holes for the equipment. The staff of GW Scientific recommended making sure the equipment used could fit through 8-inch auger holes to increase the efficiency and number of holes that could be drilled. The 10-inch auger holes require more effort to drill and clear since the column of ice that needs to be lifted during clearing is over 50 percent larger.

Further investigation should be performed to determine the amount of barrel distortion observed in the wide angle lens. Taking photographs of a grid with a known spacing could also be used to calibrate the distortion and provide control points to correct the images in post-processing software. This process would be similar to that used in remote sensing to georectify images. Traditional georectification of images involves stretching and warping them to align with maps or other spatial data, such as surveyed ground control points in a Geographic Information System (GIS). Taking photographs with the underwater cameras at known distances away from the end of the pole and oriented vertically above a grid placed on the ground would provide a quasi-ground control point dataset. The optimal elevation above the bed may also be determined for the quasi-ground control point datasets that incorporates a field of view large enough to capture a high percentage of bed material needed to determine the gradation. The establishment of the quasi-ground control point datasets should be performed in the office prior to full-scale study implementation.

Automatic post-processing of images to determine streambed grain size distributions from photographs may be possible for full-scale implementation. These automated methods follow the description of Strom et al. (2010) and are implemented in the Federal Highway Administration (FHWA) Hydraulic Toolbox Version 4.0.0 (2012). The basic use relies on knowing the dimensions represented by each image pixel, converting images to black and white and further filtering to remove effects caused by color variations, and assigning background pixel values so that individual objects can be determined. Each software feature of the implemented method in the FHWA Hydraulic Toolbox is not fully documented (FHWA 2012) and potential problems are cited, including shadows and color/texture variations. These methods will be explored for efficient application to the larger quantity of images that are anticipated to be acquired during a full-scale study.

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